Master's thesis

NTNU
Norwegian University of Science and Technology
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Department of Engineering Cybernetics

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Curbing inflation - A control systems approach

Master's thesis in Cybernetics and Robotics
Supervisor: Trond Andresen
May 2023

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Preface

This master's thesis is written at the Department of Engineering Cybernetics at the Norwegian University of Science and Technology (NTNU) in Trondheim. This is the final thesis and the culmination of a 5-year-master's degree. In this regard I would like to thank family and friends for their continued support, especially Audun, Eirik and Anders for putting up with my rambling and our discussions both on and off topic.

This thesis has given me the possibility to transfer the tools and concepts a five-year cybernetics degree has equipped me with to a field which I, before beginning this period, knew little about. This work has sparked an interest in the dynamics of social systems and economics that I think will last a lifetime.

The foundation for this thesis has been laid by Trond Andresen, and I want to thank him for the discussions, his insight and the multiple cups of home brewed tea he provided from his role as my supervisor.

This thesis has been written without assistance from ChatGPT or other similar AI-chatbots.

Abstract

A stable economy is crucial for efficient allocation of resources, high-employment and welfare in the world today. Instabilities in global politics and climate leads to rapid changes in production and supply chains. It is therefore necessary with an economic system equipped to handle these scenarios. Recently the COVID-19 recession and the following energy shortage have created an inflation problem in the western world. This thesis discusses current methods for inflation control, mostly the use of policy rate setting by a central bank, through control theory. New ways of curbing inflation through fiscal policy with taxes and transaction fees are presented. To evaluate the effects of these, a stock-flow model with a central bank, commercial banks and a real economy is built. To understand the effects of the inflation controlling actions a dynamic model of price formation has also been developed and added to the economy model. The results from simulations with policy rate shows how an economy given time can be forced into a stable growth rate, but that this might also lead to times of recession. The results of control through tax and transaction fees show that fiscal policies are effective in situations where the economy is subject to an external price shock. The conclusion from the research and results shown in this thesis is that the economy is too complex a system to be controlled by policy rate alone and that the addition of alternative control inputs, like dynamic tax rates, could increase effectiveness of control whilst also maintaining the welfare of the population.

Sammendrag

En stabil økonomi er avgjørende for effektiv allokering av ressurser, høy sysselsetting og velferd i verden i dag. Ustabilitet i global politikk og klima fører til raske endringer i produksjon og endringer i leverandørkjeder. Det er derfor nødvendig med et økonomisk system rustet til å håndtere disse scenarioene. Nylig har resesjonen med COVID-19 og den følgende energimangelen skapt et inflasjonsproblem i den vestlige verden. Denne oppgaven diskuterer nåværende metoder for inflasjonskontroll, for det meste bruk av styringsrentesetting av en sentralbank, fra et reguleringsteknisk perspektiv. Nye måter å dempe inflasjonen på gjennom finanspolitikk med skatter og transaksjonsgebyrer presenteres, og for å evaluere effektene av disse bygges det opp en stock-flow-modell med sentralbank, kommersielle banker og en realøkonomi. For å forstå effektene av inflasjonskontrollerende handlinger er det også utviklet en dynamisk modell for prisdannelse og lagt til makroøkonomimodellen. Resultatene fra simuleringer med styringsrente viser hvordan en økonomi gitt tid kan tvinges til en stabil vekstrate, men at dette kan føre til resesjon i større eller mindre grad. Resultatene av kontroll gjennom skatt og transaksjonsgebyrer viser at finanspolitikken er effektiv i situasjoner der økonomien er utsatt for et eksternt prissjokk. Konklusjonen fra forskningen og resultatene vist i denne oppgaven er at makroøkonomien er et for komplisert system til å skulle kontrolleres av styringsrenten alene, og at ekstra pådrag, som dynamiske skattesatser, kan øke effektiviteten av kontrollen samtidig som velferden til befolkningen opprettholdes.

Table of Contents

List of Figures

1 Introduction

Background

> *"Only two of my predecessors have come in person to call upon Congress for a declaration of war, and I shall not do that. But I say to you with all sincerity that our inflation, our public enemy number one, will, unless whipped, destroy our country, our homes, our liberties, our property, and finally our national pride, as surely as any well-armed wartime enemy."*
>
> -Gerald Ford

Gerald Fords "WIN" campaign of 1974 might be considered one of the biggest government public relations blunders ever[1], but his thoughts on the impacts of an unstable economy has withstood the test of time.

A stable economy is crucial for efficient allocation of resources, high-employment and welfare in the world today. Instabilities in global politics and climate leads to rapid changes in production and changes in supply chains. It is therefore necessary with an economic system equipped to handle these scenarios. Recently the COVID-19 recession and the following energy shortage have created an inflation problem in the western world.

Through the emergence of control theory, other fields have experienced enormous progress using the tools and principles developed. Incredible achievements have come from this. Everything from the industrial revolution to self-driving cars and a robot on Mars[2] have been aided by control theory. This thesis aims to use these tools and principles from control theory on the economic system to analyze the current system for inflation control and develop new methods based on the analysis.

To analyze the different control systems, a model of the economy is developed based on the stock-flow modeling framework created by Trond Andresen, where the system consists of nodes that are interconnected through differential equations.

The thesis will be structured as follows. Chapter 2 will include the theoretical foundation of the thesis, starting with economic history and causes of inflation. It will then move into the current models and methods used for control, and finally discuss alternative approaches and dynamic modelling of the economy. Chapter 3

[1] CRUTSINGER, MARTIN (2006-12-28). "Ford's WIN Buttons Remembered". The Washington Post. ISSN 0190-8286.

[2] Quattrocchi et al., 2022

will describe the implemented model and setup of the scenarios that are to be simulated. Chapter 4 displays the results from the scenarios, which are then discussed in chapter 5. To end the thesis, chapter 6 contains conclusion and suggestions for further work on the topic.

Goals of the thesis

- Analyze current inflation control through control theory
- Develop and discuss alternative methods for inflation control
- Develop a model of inflation and use this to test both current and alternative ways of curbing inflation

2 Theory and background

2.1 Inflation

Inflation is the term used in economics to describe the increasing price level on goods and services over a specific period of time. To measure inflation, economists typically use the Consumer Price Index ("CPI"), which tracks the average prices of a basket of goods and services consumed by households. The inflation rate [%/y] is calculated as the percentage change in the CPI over a given period of time, normally a year(y). It is important to note that if the price of a small amount of goods increase this is not what economists call inflation, which is a weighted average [Davidsen, 1997].

The "best" rate of inflation is widely considered to be a low and stable rate, typically in the range of 2% per year. The reasoning behind having a low and stable inflation rate opposed to no inflation (0%) is that it is seen as a balance between price stability and economic growth.

Stable prices make it easier for both consumers and businesses to plan for and predict the future, thereby making investments easier.

When we describe inflation there are terms used related to both the cause and the speed or rate of inflation.

Inflation of different speeds are categorized in the following way

- Moderate inflation (<10%)
- Strong inflation (10% to 1000%)
- Hyper inflation (>1000%)

Moderate inflation, if stable, is seen as manageable and an environment suited for running a business. It is when the inflation becomes strong that it can have large negative consequence on the economy of a country, and in the worst case of hyper inflation this can be disastrous [Davidsen, 1997]. An example of this happened in Zimbabwe 2007-2009 with peak inflation of 89.7 sextillion percent in a year, leading to a switch to US Dollars [Hankea and Kwok, 2009].

2.1.1 Causes of inflation

The causes of inflation are not universally agreed upon, and there is a conflict between monetarist and Keynesian economists. Monetarist believe that inflation in the short run can be effected by surges in supply and demand, but in the long run it is only affected by the money-supply [Greenspan, 2004].

Keynesian economists are sceptical towards the mechanisms of the market in the short run and emphasise that prices, wages and interest rates are sticky and that the resulting effects of this will impact the long run [Davidsen, 1997].

In Keynesian economics the causes of inflation are based on the triangle method which sees inflation as a function of the following components [Gordon, 1988].

- Demand-pull inflation
- Cost-push inflation
- Built-in inflation

Demand-pull inflation

Demand-pull inflation is the result of increased demand for goods and services. This can be the result of higher spending from households because of increased income, an increasing population or a shock to the economy in the form of government spending. All these result in an increase of demand, and if the demand for a good goes up it generally means that you can increase the price.

Cost-push inflation

This type of inflation occurs when the prices of raw materials go up. As a consequence, firms that have increased costs must choose between increasing their prices or decreasing profit margins. Cost-push inflation can be a result of Demand-pull or anything that increases the cost of production, e.g. import tariffs from the government. The increase in prices may lead to reduced demand for the given goods, which creates a negative feedback loop.

Built-in inflation

In an inflation-environment, workers constantly experience increasing prices, which then in turn lead to higher wage demands. This creates a self-sustaining cycle pushing the price level upwards.

2.2 Economic history

Modern economics started with Adam Smiths(1723-1790) work and his piece, "The Wealth of Nations".

Later, many economists have contributed to the field of macroeconomics, both by further developing the existing theories, and sometimes by introducing new ideas that directly contradict the current leading theories.

The greatest economists of modern economics are Adam Smith, David Ricardo(1772-1823), Alfred Marshall(1842-1924) and John Maynard Keynes(1883-1946) [Ogg, 2022].

Keynes, often called "the giant economist"[1], is the origin of Keynesian economics also called Keynesianism.

Keynes was alive during the great depression and his work, "The General Theory of Employment, Interest and Money", was developed during this time. His theories argue that aggregate demand, which is the sum of spending by households, business and the government, is the most important driving factor in the economy. Keynes also argued that the market was not self-balancing and that government intervention would be necessary to counter times of recessions[Jahan et al., 2014]. Keynes is by many thought of as the the founder of the field of macroeconomics [Rodrigo, 2023]

The state's key ways of influencing the economy is through fiscal and monetary policies. Fiscal policies are done by the government, and monetary policies are done by the central bank(CB).

By the use of fiscal policies, governments can spend or collect money to influence the economy. This can be done through changes in taxation, or changes in government spending. Government spending to affect the economy became popular after the great depression using Keynes' theories and breaking with the previous laissez-faire approach popularized by Adam Smith.

[1] Keynes was 198cm tall [Ogg, 2022]

During times of recession a government wants to stimulate its populations spending. To do this, it can reduce the tax level on households and businesses, effectively giving the population more money to spend. The government can also pour money directly into the economy by for example starting infrastructure projects that create jobs like the Bonneville Dam under Franklin D. Roosevelt's administration and the New Deal [BANEL, 2017].

Monetary policy is what is done by the central bank to control the economy. This includes setting the interest rates or "printing" money.

2.2.1 Modern Monetary Theory

Traditionally the government and the CB have been separated by law. In Norway this is written in the Central Bank Act and states that the bank is owned by the central government, but shall not be instructed in the performance of its activities unless its by the King in Council[Norges-Bank, 2020]. This means that the CB is not allowed to lend money to the government. The reasoning behind this is to prevent that the CB is being used in short-term politics. Additionally, there is a fear that the governments being able to lend as much as they want could lead to hyper-inflation. This way of thinking is now being challenged by Modern Monetary Theory(MMT).

MMT is built around the fact that a country that issues its own currency, as for example the US, the UK, Japan and Norway, cannot go bankrupt as they can in theory "print" the amount of money that they owe at any given time[Kelton, 2020].

> *"the state has no source of money, other than the money people earn themselves. If the state wishes to spend more it can only do so by borrowing your savings or by taxing you more"*
>
> -Margaret Thatcher

This quote from Margaret Thatcher represents the traditional way of thinking about public spending, where the people fund the government through taxation or lending. This is now being turned on its head saying that the government is funding the people.

Stephanie Kelton is one of the primary advocates for MMT and her book "The Deficit Myth", which became a New York Times bestseller in 2020, explains the theory in depth.

> *It is true that a deficit is recorded on the government's books whenever it spends more than it taxes. But that's only half the story. MMT paints the rest of the picture using some simple accounting logic. Suppose the government spends $100 into the economy but collects just $90 in taxes. The difference is known as the government deficit. But there's another way to look at that difference. Uncle Sam's deficit creates a surplus for someone else. That's because the government's minus $10 is always matched by a plus $10 in some other part of the economy.*
>
> - Stephanie Kelton

With this way of looking at government budgets, overspending is still a possibility, but the warning sign for overspending is not a budget deficit, but inflation.

MMT is based around fiat money as opposed to something like the gold standard. Fiat money is money that is not backed by a commodity like gold, silver or wheat. This means that the money doesn't have use-value in itself other than what is given by for example the government.

Warren Mosler, the founder and one of the primary advocates for MMT, also called Mosler Economics, described how fiat money works in the following way. Imagine a person giving a speech in a room full of people. If the person picks up a piece of paper that could be considered as litter and then asks if anyone is willing to work for him for one hour to get this piece of paper, there is an overwhelming likelihood that no one will want to do it. But if he explains how there is a man with a gun stationed outside the door, and the only way to get out of the room is to have one of these pieces of paper, then everyone in the room will be willing to work to some degree for the previously worthless piece of paper. This is how modern money works, and taxes play the part of the man with the gun[Mosler, 2013].

In Norway, for example, a Norwegian needs NOK to pay his taxes, and if he doesn't, the Norwegian government and the judiciary system has the right to use force, for example incarceration, to make him. This creates a need for NOK and gives it its value.

From this example the point that Stephanie Kelton explains in her book becomes clear. The government can't collect its taxes before providing the population with the means to pay. The speaker must hand out the piece of paper before the man with the gun can collect it.

2.3 Current inflation control

In classical control theory there are two main principals of control, feed-forward control and feedback control.

The feed-forward controller measures the disturbances to the system and uses this to calculate the necessary response.

Feedback control is the type of control used today to control the inflation rate and is in its simplest form illustrated in Figure 2.1. The system in the illustration is then the economy. The controller aims to control the system towards the desired reference value and uses information gathered about the current output value to create an input to the system. This type of control can be, and is, used to control a variation of different processes, and is something that comes natural to humans in our everyday life. For example we use taste when we cook, touch when we regulate the temperature in the shower, or hearing to adjust the volume when we speak. All of these processes could be represented by a feedback-loop as shown below.

This basic feedback structure will be used as a basis for looking at the current inflation control.

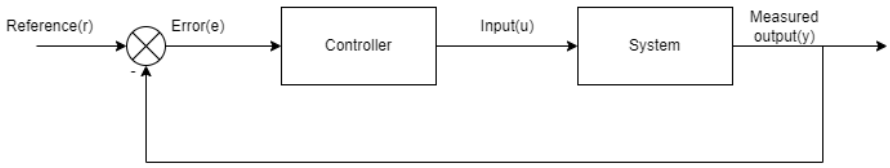


Figure 2.1: Feedback control block diagram

The Norwegian Central Bank(NCB) along with many other CBs, for example The Federal Reserve in the United States, has an outspoken goal of keeping inflation at a low and stable level. Most western countries have this target set at 2% inflation. This is one of the main tasks for NCB, keeping the financial and economic system stable[Norges-Bank, 2023c]. This goal is what creates the reference value for the control system.

The reasoning behind keeping the inflation rate at a stable 2% is that we want stability to create an economic environment where it is easy for business and households to predict and plan ahead, which becomes difficult in a fluctuating high-inflation environment.

The CBs seek to keep the inflation at 2% as opposed to 0% because a small inflation is thought to have positive impacts on the economy and it gives extra protection against deflation, which is thought to be more harmful to the economy. In a deflation environment, businesses and households may put off their spending, which could lead to further deflation and in the worst case a recession[Bank-of-England, 2023].

The NCB have two main instruments for controlling the economy; the policy rate and adding money to the system, “printing money”. In the feedback control system architecture, the NCB is the controller, and the interest rate is the input to the system.

2.3.1 NEMO

The Norwegian economy is a complex system affected by a multitude of factors. To predict how the economy will develop and how controlling actions will affect the system, NCB has developed a model called Norwegian Economy Model(NEMO). They began constructing the model in 2004 and the model has since then been under continuous development. It is emphasised from NCB that the model should be developed to be a decision making tool for monetary policies [Brubakk et al., 2009].

NEMO is a Dynamic Stochastic General Equilibrium (DSGE) model. The underlying rules for actors in the system are based on General Equilibrium Theory and microeconomic principals. All actors are assumed to act rational, i.e. households want to maximize consumption over the complete time period, and firms want to maximize profits. The model, when used to predict effects of shocks to the economy, assumes that the policy rate is set using either a simple rule (i.e. a Taylor rule), or by trying to minimize a loss function. The function that is to be minimized is not explicitly described in [Brubakk et al., 2009], but in a 2019 staff memo from NCB it is described. The function is a quadratic loss function of a weighted sum of the variables: Deviation from inflation reference, output, the level of the policy rate and changes in the policy rate[Kravik and Mimir, 2019].

This control method where the optimal future input values are constantly calculated based on the current state and knowledge of the system is very similar to what is called Model Predictive Control(MPC) in control theory [Seborg, 2011]. A generic block diagram of MPC is shown in Figure 2.2. A big advantage of this method of control is that future states are taken into account when regulating the present. This translated to the inflation control means that the model thinks about the future effects on the economy when calculating the current optimal input. A disadvantage to this control method is that an error or inaccuracy in the mathematical model will result in wrong calculation of optimal inputs and hence worse control.

DSGE models are as previously mentioned based on general equilibrium theory and microeconomic principals. These theories are not mutually agreed upon by all economists and are shown to be fallacious and only valid under strong unrealistic conditions by Steve Keen[Keen, 2011].

> *"PhD students, on the other hand, learn a class of models that goes by the grandiose – and utterly misleading – name of 'dynamic stochastic general equilibrium' (DSGE) models. Both IS-LM and DSGE models are derived from the microeconomic concepts that I have shown are fallacious in the preceding chapters. They differ only in how extreme their reliance is on microeconomic theory, and on the presumption that everything happens in equilibrium"*
>
> -Steve Keen

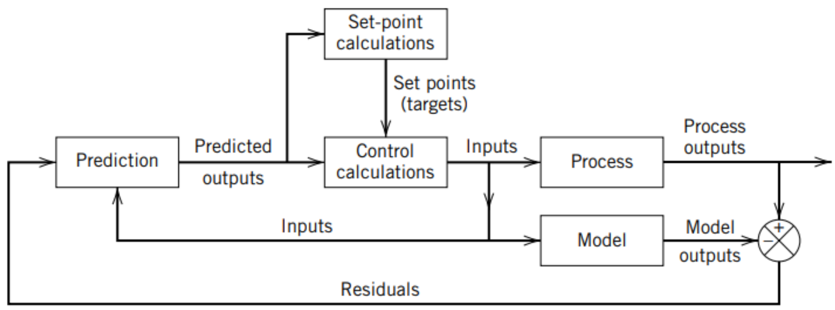


Figure 2.2: Model Predictive Control block diagram

Source: Seborg, 2011

NCB's illustration of how the model predicts the monetary policy transmission mechanism is shown in Figure 2.3. This figure resembles a causal diagram, which makes it easy to display causality within a system like the dynamics of social systems, or as in this case, macro economics. The causal diagram cannot be translated to a transfer function in contrast to a block diagram which is often used in the field of cybernetics.

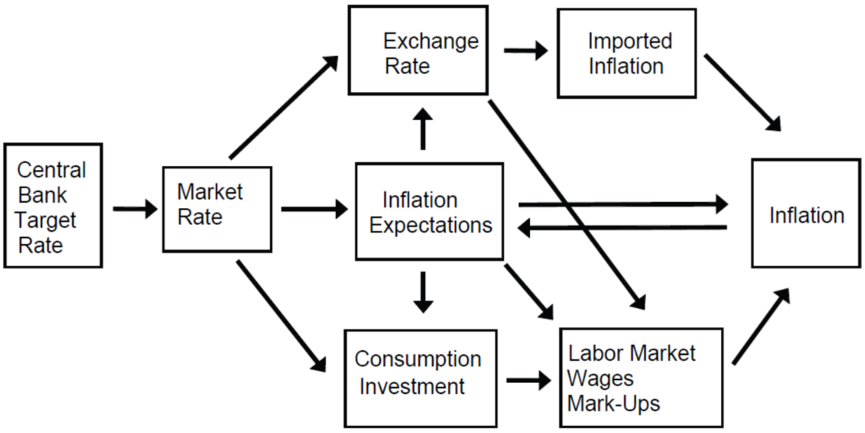


Figure 2.3: The monetary policy transmission mechanism

Source: Brubakk et al., 2009

The diagram in Figure 2.3 is missing information of whether the interactions are positive or negative between system parts. This information is crucial if one wishes to detect unstable parts of the system.

The "Inflation Expectations" part of the system represents the psychology aspect of the economy and can cause both positive and negative effects on the different parts of the system. To show a more manageable causal diagram, this part is therefore split up and altered to further elaborate on its impact. The resulting causal diagram is shown in Figure 2.4.

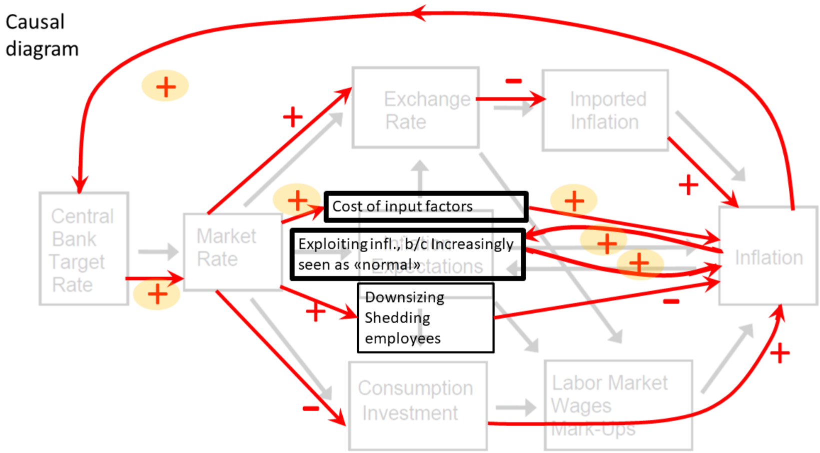


Figure 2.4: Causal diagram of monetary policy transmission mechanism

Source: Trond Andresen

In Figure 2.4 the controlling feedback from inflation to new policy rate is added to complete the system. From this new casual diagram it is clear that the system contains two positive feedback loops that pose a threat to the system stability. The inflation is regulated with higher policy rates which again drives up the market rate and cost of input factors increasing the cost-push inflation pressure.

In an environment with increased inflation, rising prices becomes normalised, giving firms the possibility to take advantage of this by raising prices more than the increased price of input factors, thus creating higher inflation and a positive feedback loop. This effect also occurs in the banking sector, where rising interest rates may lead to increased interest margins, as was the case the first quarter of 2023[SSB, 2023b]. This happens because the policy rate increases faster than the interest rate on deposits.

In Neoclassical economic theory, with perfect competition this form of exploitation of an inflation environment would not be possible, as a company increasing their margins would be priced out of the market.

In reality, the competition is not perfect and many factors play an important part in price setting.

2.3.2 The policy rate as a control mechanism

In the most basic terms, the rule is to increase the policy rate when inflation is too high, to try to lower aggregate demand and decrease investment to slow down the economy. When the opposite is the case and inflation is too low, the NCB lowers the policy rate to increase spending and investment in the economy.

The policy rate in theory affects inflation through three main channels according to the NCB; consumption and investment, inflation expectations and exchange rate[Norges-Bank, 2017].

By raising the policy rate, households, firms and municipalities have less money to spend after servicing their loans which in turn decreases their demand for goods and services. This weakens the businesses and make investment less desirable. This leads to lower production, higher unemployment and less increase in wages, and all of these factors may contribute to lower inflation.

In traditional economic theory the link between inflation and unemployment have been shown with a Phillips Curve as seen in Figure 2.5 with unemployment on the first axis and the inflation rate on the second axis. This illustration is now considered as old fashioned and too simplified, but still resides in certain economic textbooks.

Regardless of it being outdated, it shows how increasing unemployment is thought of as a way to combat inflation.

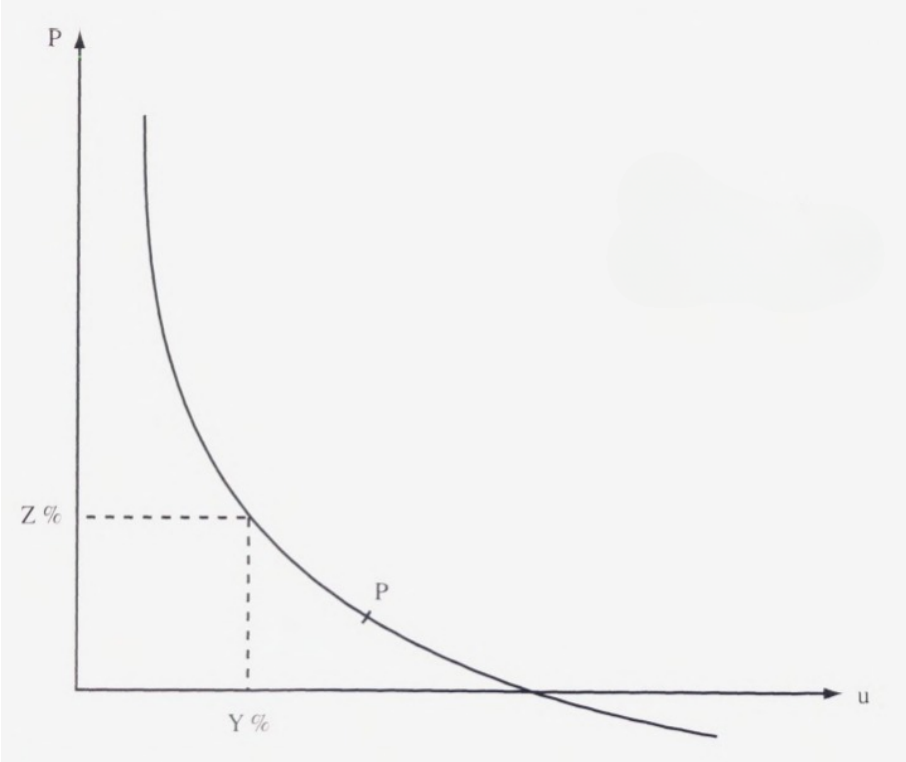


Figure 2.5: Phillips Curve

Source: Davidsen, 1997

The exchange rate is affected by the policy rate because a higher policy rate makes it more desirable for foreign investors to invest in the currency. This again increases the demand for the local currency and drives the price upwards. A stronger local currency means imported goods become relatively cheaper and inflation decreases.

The third channel is the most hazy and relies on the psychology in the market. The NCB explains that an increase in policy rate will lead to lower inflation expectations that in turn will lessen pressure on increased wages and prices. The expectations may also help increase the value of the local currency and have the same effects as described above. It should be noted that currency value is a complex mechanism that is affected by multiple factors, for example public sentiment also plays a huge role.

Constraints on the policy rate

The policy rate is a blunt gain that affects more than just inflation and must therefore be used with caution.

Because Norway is a small country with an open economy and free capital movement, it needs to adjust the policy rate in the same manner as its trading partners. This again reduces the range of motion for the NCB to set policy rates and makes achieving the monetary policy more complicated.

Norway has a unique situation where close to 95% of loans are floating interest loans. This stands in strong contrast to countries like the UK and the US where floating interest loans account for below 15% of all loans. Also, countries traditionally similar to Norway, Denmark and Sweden, only have 50-60% floating interest loans[Bjørnestad, 2020] [Haugland, 2022].

This puts NCB in a unique position where an increase in policy rate will have a much larger and faster impact on aggregate demand compared to countries with high degree of fixed interest loans. This again could create problems with currency value if other countries rapidly increase the policy rate and NCB can't increase to the same extent because the impact on the personal economy of Norwegian households would be to great.

The policy rate also has impact on income and wealth distribution in the population. The NCB suggests that a lower policy rate helps drive the price of assets upwards, thus leading to an increase in the wealth of those who are homeowners, or owners of other assets[Norges-Bank, 2021].

2.3.3 Critique of the policy rate as an actuator

The policy rate is acknowledged as the main instrument for control of the inflation rate, but it is not without critics.

The argument that an increased policy rate lessens disposable funds for households and that the unemployment increases suggest that it is the lower-income households, without capital and with a less secure work situation, that are the most affected by an increased policy rate. It is shown by Margrit Kennedy in her book "Interest and Inflation Free Money" that the bottom 80% of the population are net interest payers and the top 10% gains almost all the interest paid by the rest. This is shown in Figure 2.6. In this book she also points out the fact that interest is not only paid by those who borrow, but is a concealed part of almost everything we buy, depending on the labour vs capital cost of the goods or services. If this is the case, a positive feedback loop may occur, decreasing the inflation dampening effects of a higher policy rate.

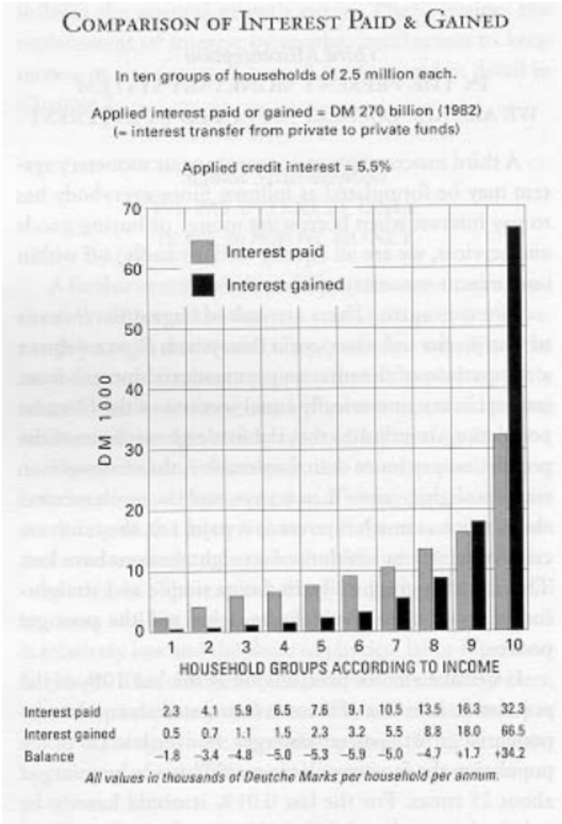


Figure 2.6: Comparison of interest paid and gained

Source: Kennedy, 1995

Warren Mosler has presented a list of critiques against the use of policy rate as an actuator.

The government is a net payer of interest which means that an increased policy rate means an increase in High Powered Money(HPM), which is money issued by the central bank, going to the commercial banks. This in itself is not necessarily an inflationary factor, but it does increase the banks Capital Adequacy ratio(CA) which gives the possibility of extending more loans. CA will be explained further in Section 2.4.2.

If the increased rates on loans doesn't scare off potential loan takers it could result in an increased amount of money in circulation. MMT suggests that this effect may lead to the policy rate having an opposite effect of the advertised drop in demand and accompanying decrease in prices.

MMT also points to the fact that interest can be seen as a basic income for those who have money, and thus increasing the differences in society.

The policy rates are included in forward pricing and thus an increase in interest automatically increases the price on certain goods[Mosler, 2022].

The way policy rate and interest affects the distribution of wealth in society is a complex issue that is not universally agreed upon. The typical stance is that a decrease in policy rates drives the price of assets upwards and benefits those who hold capital[Norges-Bank, 2021], but as previously mentioned, interest critics like Margrit Kennedy argues that the interest is a hidden redistributing mechanism in society from poor to rich[Kennedy, 1995].

> *"O believers, take not doubled and redoubled interest, and fear God so that you may prosper"* [1]
>
> -Surah Al 'Imran, verse 3:130 in the Qur'an.

Some studies show that this effect from the policy rate regulation, that favor the higher income households, has a dampening effect on the inflation rate impact because of the lower marginal propensity to consume. This means that a lower income household will increase its spending at a higher rate than a medium or high income household, given a raise in income[Kronick and Villarreal, 2019].

IMF have published studies that suggest monetary policies would have greater impact if inequality in society was being accounted for[Hansen et al., 2020]. This follows logically from the argument that a higher income household more easily can reduce its consumption when real income is lowered compared to a low income household that already only purchases necessities.

The policy rate resembles a flat taxation system and the results found on the impact of wealth distribution suggest that more control using fiscal policy and taxation could have a greater impact while at the same time decreasing inequality.

The recent post-Covid-19 monetary policies enacted by CBs in the western world has given new life to the debate on how inflation should be curbed both in Norway and internationally.

Jan Ludvig Andreassen, chief economist in Eika, was one of the earliest critics of the NCBs policy rate increases and points to several arguments for putting off further policy rate increases.

[1] Taking interest on loans are forbidden in Islam, because it is thought to be exploitative

"Norges Bank must look at causal relationships, why inflation is high and what is achieved by raising the interest rate now. Because it will not lead to cheaper wood from Finland, there will not be more Eastern European workers on the construction sites, it will not result in lower energy prices, because there is war. They don't run social policy and don't take income distribution into account, but they should. They choose not to do that, and I think that is a mistake."

-Jan Ludvig Andreassen[1]

He also emphasises that it is young people, who are economically vulnerable, that will take the hit, effectively giving them the double whammy of increased prices and an increase in interest cost [Andreassen, 2022].

In the same article, Marius Gonsholt Hov, chief economist of Handelsbanken, argues against Andreassen

"It is not an argument that we now have a lot of supply-side problems, and that Norges Bank should therefore not react to it. They can't fix the supply side, but if they are to avoid inflation getting stuck at too high levels, then they have to slow down demand, period."

- Marius Gonsholt Hov

He also refers to statements by counsel member at the CB of the USA, Christopher Waller, who expressed "I don't care what's causing inflation, it's too high, and it's my job to get it down" [Reuters, 2022]

After a series of rapid increases in policy rate from the NCB he is now encouraging patience and a slow down in increases [Hov, 2022]

Another critic of the CBs is former Treasury Secretary Lawrence Summers, who's now working as a Harvard University professor. He has criticized the US version of NEMO and stated that the " 'FRB-US economic model' is not really fit for purpose in terms of inflation." He also expresses concern with the delayed effect of a tightening policy "Given the lagged time periods it takes for Fed policy actions to take effect, there's some real disadvantages to delay in tightening policy" [Summers, 2022].

[1] These interviews were given in Norwegian and has been automatically translated using translation software

This delay from when inflation is measured to when new policy is enacted and then again to when results of the new policy can be seen is of special interest from a control systems perspective. This is often referred to as time delay, transport delay or dead time in control system theory. Time delays can have strong effects on the effectiveness of the controller, and may reduce stability and in the worst case cause increasing oscillations. Imagine if the speedometer of your car had a 5 second delay. This would cause a massive overshoot when accelerating up to the speed limit, followed by a massive undershoot when you stomp the brake because you realise that you are going too fast. This is of course an implausible example, but it shows the devastating effect delay can have on a control system.

Economic history supports this problem with time delay where "we find no instance in which a central bank-induced disinflation occurred without a recession.." and research suggests that the bigger the disinflationary measures are, the greater the following recession tend to be[Feroli et al., 2023].

Exchange rate

After the world globally abandoned the gold standard and representative money in 1971 the value of currencies have been determined by aggregate supply and demand. Some currencies, e.g. the Danish Krone is pegged against another currency, in this case the Euro, at a fixed rate. When fixing the rate the country gives up some of its possibility to influence the rate and through that the economy.

The factors that affect the value of a floating exchange rate currency are many and hard to predict. Traditionally a country's main tool for influencing its currency value is through the policy rate. An increased policy rate in theory attracts investors which again increases the demand for currency. A country's trade balance in theory also affects the value, where a country that exports more than it imports should get an appreciation of its currency due to the increased demand.

A problem with controlling currency value through interest rates is that it only works when all the other alternative currencies don't do the same. This is illustrated by the Norwegian Krone that have had a steady depreciation against the Euro and USD since the start of 2022 [DNB, 2023] even though the policy rate have steadily increased [Norges-Bank, 2023b] and the trade balance is at an all time high[Norges-Bank, 2023d].

This greatly affects the inflation rate in Norway as it is dependent on imported goods and greatly affected by ricing prices of these goods, also known as imported inflation.

The main way to combat this is to get an appreciation of the NOK effectively making all imported goods cheaper as shown in the upper part of Figure 2.4. The reason for the NOK going in the opposite direction is greatly debated by economists. Rune Østgård, author of "Fraudcoin - Thousand Years With Inflation as a Policy", have pointed to the mechanisms behind "The Norwegian Government Pension Fund Global", popularly called "The Oil Fund". The governments net profit in NOK is being transferred to the fund, which only contain foreign currency. This creates a massive need for exchanging NOK to foreign currency which again increases the supply of NOK [Østgård, 2023]. Others argue that turbulent times sends capital towards more safe havens, or that investors sense the age of oil is coming to an end, making investments in oil producing countries less attractive [Henmo and Åsnes, 2023].

Regardless of what is causing the fall in currency value the consequence is that the measures to combat inflation have not worked as foreseen, and therefore been sub optimal.

To enhance the control of the inflation rate it is critical to better the regulation of the currency value, and other tools may therefore be necessary.

In control systems theory a system is often referred to as Single-Input-Single-Output(SISO) or Multiple-input-Multiple-Output(MIMO). The control system for controlling inflation resembles a SIMO-system where there are several states that needs control but effectively only one input. Logically this makes perfect control improbable[1].

During the Bretton Woods conference in 1944 Keynes, representing the UK, proposed a system for the global economy where all international trade was done in a new currency "Bancor" issued by the The International Clearing Union (ICU). This system, which eventually lost to the US, would have a set of rules ensuring fair trade and aiming for growth and employment worldwide. Andresen put it this way in [Andresen, 2021]

> *I would describe Keynes' ICU/bancor proposal as a stabilizing control systems solution. His purpose was to ensure growth and employment in all countries with balanced trade between them, and avoid economic and financial polarization between countries. This resembles the way engineers approach the running of process plants, nuclear power stations and other complex dynamical systems. The main point is to ensure that*

[1] In control systems theory this is called Controllability, and a system is called controllable if with the available input the system can be forced to take any state within finite time. [Balchen et al., 2016]

they run stably, the second point is that they are run in an optimal way. Keynes had a deep understanding of stability and dynamics of economic systems.

A system designed in such a way would not automatically remove the problems of imported inflation but would ensure a more stable foreseeable economic environment.

To combat the depreciation of the NOK the government could use the "Oil Fund" to buy NOK instead of selling to limit the supply and hence, probably, increase the value.

Another way of avoiding depreciation, at least in the short term, is to encourage the large exporting firms to demand payment in NOK instead of USD. This will create the need for NOK globally and could increase the necessity of holding NOK for financial institutions globally, effectively expanding the network of nodes that trade in NOK. This trick was used by Vladimir Putin and the Russian Federation to stop the plummeting Ruble after entering into war with Ukraine [Nasr, 2022]. Such a measure could have a positive feedback effect through the psychological "Mere-exposure effect", which states that people tend to like or trust objects or people more with repeated exposure [Zajonc, 1968]. The currencies that people trust the most, so called "safe haven" currencies, typically USD, YEN and especially CHF become self fulfilling prophecies when capital is moved there because it is expected to be safe, effectively producing that exact outcome [Merton, 1948].

2.3.4 Alternative control input

The alternative to monetary control is fiscal control done by the government. The government can alter aggregate demand by changing the tax rates [The-World-Bank, 2022]. This, in contrast to the policy rate, enables the government to control which part of society is affected with higher accuracy. An example of how tax rate and inflation rate could be correlated is shown in Figure 2.7. This figure shows how the lowest income households get a small tax reduction in times with high inflation. The middle income households are the least affected by this solution, but the high income households get a steeper tax curve resulting in a higher tax in times with high inflation.

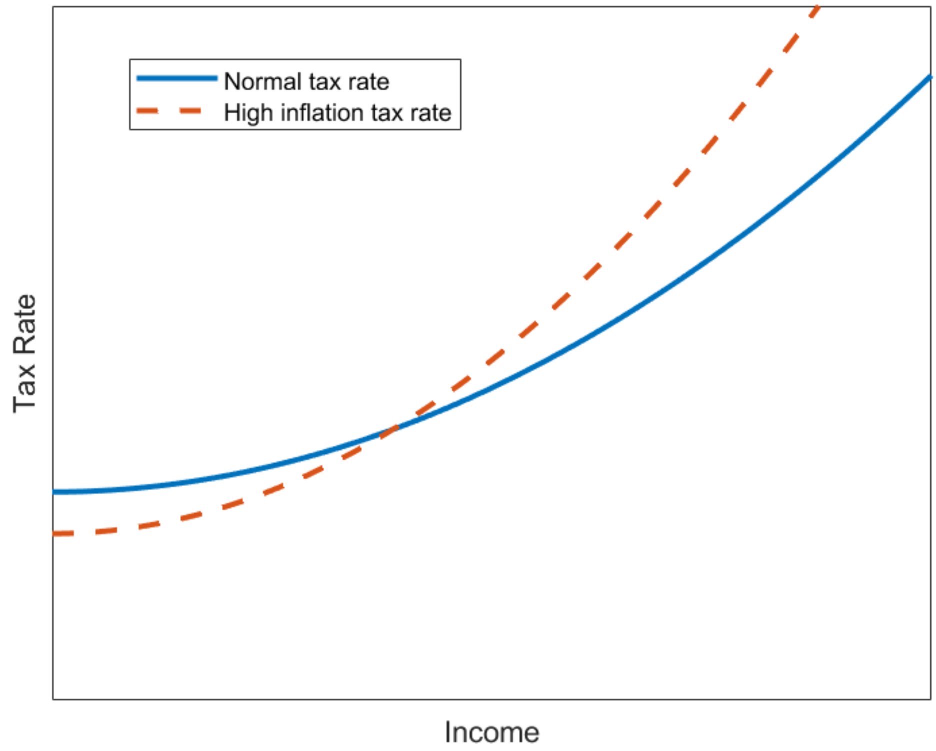


Figure 2.7: Conceptual inflation based tax rate

With digital tools available today, the tax curve could be automatically controlled and updated e.g each month. For an immediate effect, the predicted tax rates could be posted in news paper in a similar way to power prices [NRK, 2023]. The effect of this is psychological and would need to be tested out to see the effects. A possible downside to this dynamic tax rate could be that people not working steady hours shift their work time more towards times with low taxation which could be sub optimal for society.

The positive feedback loop through exploitation of ricing prices becoming normal seen in Figure 2.4 could also be damped by use of digital tools and social media. To reduce this positive feedback, strong competition in the market is necessary. This can easily be boosted by encouraging price sharing and discussion on social media holding suppliers accountable for their pricing.

2.4 Economic theories on inflation

2.4.1 Quantity Theory of Money

One of the most important theories developed by classical economists were the Quantity Theory of Money. In this equation, M x V, Money Supply[$] times velocity of money $[\frac{1}{y}]$, represents the total spending in the economy, which is equal to the total value of goods and services produced (P x Y), price times the level of output[Gordon, 1988].

$$MV = PY \tag{2.1}$$

This equation in itself is a truism and is like saying the amount of money i have spent equals the things i purchased times the price. To make it something more the economist added some assumptions on the behaviour of V and Y. V was assumed to be stable enough that it could be considered a constant, and Y tends to settle at full employment. This means that the rate of change for both V and Y equals zero and leads to (2.2)

$$\dot{P} = \dot{M}\frac{V}{Y} = \dot{M} \times constant^1 \tag{2.2}$$

This is the basic theory behind monetarism and means that the price level is only affected by the money supply, i.e. that the inflation rate is only affected by the rate of change in the money supply [Kelton, 2020].

> *"inflation is always and everywhere a monetary phenomenon"*
>
> -Milton Friedman

2.4.2 The Money Multiplier

The concept of The Money Multiplier is important in the National Banks' control of the money supply. In a simple model of the money supply(M), where we assume all money is held in bank deposits, the monetary base(HPM) consists of bank deposits(D) and bank reserves(R).

$$M = D \tag{2.3}$$

[1] This "dot notation" is commonly used in control system theory and represent the derivative with respect to time [Balchen et al., 2016].

$$HPM = R \tag{2.4}$$

Under normal circumstances, since this is how they make money, a bank is expected to loan out as much as it is capable of. To lessen the risks of banks going bankrupt and "runs on the bank" banks are usually bound by law to keep a certain percentage as liquidity. Traditionally this was called reserve requirement(RR) which meant the banks needed to keep a certain amount of deposits which could not be lent out. For simplicity lets say RR is 10%.

$$R = RR * D \tag{2.5}$$

The result of this is that if the National Bank inserts 100$ of new money or HPM into the economy this will increase the banks reserves by 100$, which the bank instantly will want to lend out to increase their earnings. When a loan of 100$ is given to a member of the public they immediately insert the money back into their bank as a deposit. This again gives the bank the ability to give new loans for the value of 90% of the deposited money. This effect can be described by the infinite geometric sum shown in Equation 2.6

$$\Delta M = \frac{\Delta HPM}{1-(1-RR)} = \frac{100}{1-(1-0.1)} = 1000 \tag{2.6}$$

Thus showing that the money supply increases by ten times the amount of new base money, or HPM.

$$HPM = R = RR * D = RR * M \implies M = \frac{HPM}{RR} \tag{2.7}$$

The old rules with RR have now been changed to a capital requirement expressed through the capital adequacy ratio(CA). A simplified version of how CA is calculated is seen below where A is the banks other financial assets associated with some risk, different assets will be associated with different risk and weighted thereafter, B are government bonds, R is the reserves and D is deposits. Since B and R are not associated with risk they appear only in the numerator. This simplified version only measures the total capital, excluding the special demands for Tier 1 capital, which is the book value of a banks stock plus retained earnings[Hummel, 2023].

$$CA = \frac{A+B+R-D}{A} \tag{2.8}$$

Banks are demanded by law to keep the CA or κ_0 above a certain level, and it is shown in [Andresen, 2018] that for the amount of money in circulation "the growth rate is inversely proportional to the minimum capital/asset ratio". The ratio established by the Bank for International Settlements (BIS) is 8%.

> *"And although there are a lot of Americans who understandably think that government money would be better spent going directly to families and businesses instead of banks – 'where's our bailout?' they ask – the truth is that a dollar of capital in a bank can actually result in eight or ten dollars of loans to families and businesses, a multiplier effect that can ultimately lead to a faster pace of economic growth."*
>
> -Barack Obama

The Money Multiplier makes for the possibility of new HPM added to the system having a much larger effect on money supply, as Obama emphasises here during the Subprime mortgage crisis(SMC). But the fact that the credit money grows endogenously also creates a problem which makes real control of the money supply hard or even impossible. Critique has been raised over whether the money multiplier is even real.

In his book "Debunking Economics" Steve Keen argues that the money multiplier is a mere myth. Two of his important points are as follows.

Firstly, the National Banks can't force the banks to issue new loans even if they lower the necessary CA or adds additional HPM into the system. An example of how you can lead a horse to water, but you can't make him drink can be seen by tracking the money multiplier effect after the SMC in the US Figure 2.8. This shows how the multiplier effect dropped drastically during the crisis making the effect of the new HPM injected lessen dramatically.

Secondly, the causality from deposits to loans seem to actually be the other way around.

> *"In the real world, banks extend credit, creating deposits in the process , and look for the reserves later."*
>
> -Alan Holmes, then Senior Vice President, Federal Reserve Bank of New York (1969).

This again further lessens the states control of the money supply[Keen, 2011].

Figure 2.8: 2000-2019 M1 Money Multiplier

Source: Federal Reserve Bank of St. Louis

2.4.3 The importance of velocity

The impact of the velocity of money is not a new discovery but the classical economists assumption that it is stable has made it a downplayed factor. The following was written already in 1885 by Karl Marx in his "Das Kaptial"

> *"Let the period of turnover be 5 weeks: the working period 4 weeks, the period of circulation 1 week. Then capital I is £2,000, consisting of £1,600 of constant capital and £400 of variable capital; capital II is £500, £400 of which are constant and £100 variable. In every working week a capital of £500 is invested. In a year of 50 weeks an annual product of 50 times 500, or £25,000, is manufactured. Capital I of £2,000, constantly employed in the working period, is therefore turned over $12\frac{1}{2}$ times. $12\frac{1}{2}$ times 2,000 makes £25,000. Of these £25,000 four-fifths, or £20,000, are constant capital laid out in means of production, and one-fifth, or £5,000 is variable capital laid out in wages. The total capital of £25,000 is thus turned over 25,000/2,500, or 10 times."*
>
> -Karl Marx

This is an extreme example but shows clearly how the "period of turnover", as he called it, or the velocity of money can make a limited amount of money finance several times its value over the course of a year [Marx and Engels, 1885].

2.4.4 Controlling the velocity of money

As previously stated the norm for attempts at controlling the inflation rate is by controlling M, but attempts at altering V has also occurred.

One example of this is the concept of demurrage of currency proposed by the German-Argentinian economist Silvio Gesell. The concept is that, contrary to what is the normal practise in our society, one must pay a negative interest rate i.e. a tax on storing money. The word "demurrage" comes from the shipping industry where this is a fee paid to the owner of a transport vessel if there is a delay in loading or offloading resulting in space being occupied and not able to create revenue. The idea is that money is only a means for transferring goods and services, and that holding excessive amounts "takes up space" hindering future transactions.

> *"Only money that goes out of date like a newspaper, rots like potatoes, rusts like iron, evaporates like ether, is capable of standing the test as an instrument for the exchange of potatoes, newspapers, iron and ether. For such money is not preferred to goods either by the purchaser or the seller. We then part with our goods for money only because we need the money as a means of exchange, not because we expect an advantage from possession of the money. So we must make money worse as a commodity if we wish to make it better as a medium of exchange."*
>
> -Silvio Gesell

Probably the most famous example of demurrage in practice was implemented by Michael Unterguggenberger, the mayor in the Austrian village of Wörgl during the great depression.

He was an educated man and had read Gesell's "the Natural Economic Order", and in these desperate times decided to give his ideas a try. A new currency was created called "Certified Compensation Bills" and used these to pay wages. The special thing about these bills were that the owner of a bill would at the end of the month need to buy a stamp from the post office, at the price of 1% of the original value, and glue it onto the bill for it to keep its value. This effectively means the bill would devalue at a rate of 1% per month. These new bills could at any time be swapped back to the original currency for a fee of 2%, and could also be used to pay taxes.

The results from this experiment was staggering. On average during the time of the experiment a total of 5500 Schillings worth of certificates were in circulation, and this was used to finance a total value of 2,5 million Schillings meaning the new currency circulated over at hundred times faster than the Schilling.

The experiment was actually so successful that more Austrian villages wanted to try the same, but this made the Austrian National Bank panic and it was forbidden[Migchels, 2012].

This shows how altering the money velocity, which is a behavioural factor, can be a control mechanism that works almost instantly in contrast to the money supply which is a stock and associated with a substantial time lag.

2.5 Transitioning to an electronic money system

With the continuous development of networking technology and smart phones, the use of electronic payments has skyrocketed. Norway is at the forefront of this development, being the country in the world closest to a cashless society with cash only counting for 2% of payments. This leads to new alternatives for the monetary system being explored by the CBs[McKinsey, 2023].

Starting in 2018, the NCB have investigated the possibility of Central Bank Digital Currency(CBDC), and the project is still ongoing.

CBDC is a digital form of currency that is issued and backed by a central bank, such as the Federal Reserve in the United States or the European Central Bank in the Eurozone. Unlike traditional fiat currency, which is physical cash and coins issued by central banks, CBDC is entirely digital and exists solely in electronic form.

CBDC can be designed in different ways, but generally, it is intended to operate like traditional currency, offering a reliable and secure means of payment and a store of value. CBDC can be used for transactions between individuals, businesses, and governments and can be transferred between accounts via digital channels[Norges-Bank, 2023a].

The transition to CBDC opens up the possibility for a range of advantages. In such a system all money in circulation could be HPM, meaning it is backed by the CB. This could result in only the owner of the banks taking the economic hit and eliminate the need for bailouts if a bank were to default. Such a system would also be able to eliminate theft and all transfers of money would be traceable, making tax evasion much harder. This is not directly connected to inflation control and will not be further discussed in this thesis.

Another possibility with CBDC is a system where every citizen could have a checking account at the CB as a part of their citizenship. This would increase the possibility of control by the CB. In such a system all money would reside in accounts at the CB and all payments, at least inside the country would be transfers between accounts at the CB. Such a system and how we might transition into such a system is discussed in [Brown, 2008], suggesting an increase of κ_0 until 100% is reached.

2.5.1 Demurrage with electronic money

Although the results from the Wörgl experiment are interesting it is hard to escape the fact that gathering all your notes each month and taking them to the post office to buy and glue a stamp to each one is a clear time thief and a disadvantage to this system. But with the introduction of electronic money (EM) this demurrage of money could be done digitally with simple programming by the CB, effectively negative interest on money in the checking accounts. In the opposite inflation case the interest could easily be altered to be positive which is the case that is normal in the present system.

2.5.2 Transactional fees

The concept of universal transactional fees is only possible in a system existing of only EM or else physical cash would have an advantage over the electronic money. As discussed [Andresen, 2018] both positive and negative fees on transactions are possible but in reality only a positive fee is possible as a negative fee would lead exploitation of the system by continuously transferring money between accounts and thus creating money. A fee on transactions between accounts would be similar to the Value Added Tax(VAT) but include all transactions, not only purchases of goods and services. This transaction fee could also be fast and easily regulated by the authorities.

2.6 Dynamic modelling of the macro economy

Traditionally the macro economy has been modelled using "comparative statistics" and models based on equilibrium theory, e.g NEMO, a DSGE-model. The macro economy is a complex system with a vast number of interconnected individuals with states that evolve through time and should therefore be described as a dynamic system.

The concept of modelling the economy using a network of interconnected nodes was developed by A.W. Phillips as early as the fifties [Phillips, 1954]. This way of modelling the economy was further enhanced by Trond Andresen [Andresen, 2000] and the principles developed there will be the foundation of the model presented in this thesis.

The most basic part of the economic system is e.g. a household, receiving wages once or maybe twice a month and then distributing this income as consumption spread out over the entire time period. These dynamics of a micro-agent in the economy can easiest be represented as a first order time lag, and the economic transfers can be abstracted to dynamic flows.

As explained in [Andresen, 2000] the economic sub-entities or nodes can be represented by a transfer function as seen in Equation 2.9. Here P is the output, and E is the input. This transfer function is equivalent to the linear first-order differential equation, Equation 2.10.

$$\frac{P}{E}(s) = \frac{1}{1 + T_p s} \tag{2.9}$$

$$T_p \dot{P}(t) = -P(t) + E(t) \tag{2.10}$$

This type of system can be explained as a buffer vessel as seen in Figure 2.9.The money flows can be thought of as a liquid where E is flowing into the vessel and P is flowing out of the vessel. The money stock(M), represented by the fluid level in the vessel, is changing with a rate equivalent to the flow into the vessel minus the flow out of the vessel.

$$\dot{M}(t) = -P(t) + E(t) \tag{2.11}$$

To get a step-response like the one in Figure 2.9 the flow out of the vessel must satisfy the condition set by Equation 2.12

$$P(t) = \frac{M(t)}{T_p} \tag{2.12}$$

As seen in Figure 2.9, following a unit step in input, the output will gradually slope towards the input level with the lag determined by the constant T_p. This "time lag" often referred to as the "time constant" is the time it takes for the output to reach $(1 - e^{-1})$ or approximately 63% of the final value.

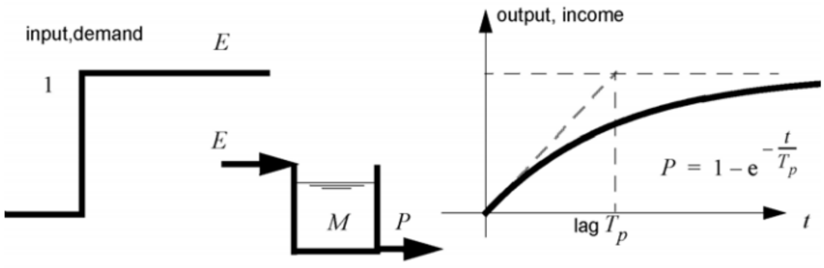


Figure 2.9: Step function and first-order time-lagged step response

Source: [Andresen, 2018]

2.6.1 The real economy

When we want to model the parts that make up the real economy(RE), the government, households and firms, we start with a first order time lag that represents a generic microeconomic agent as seen in Figure 2.10

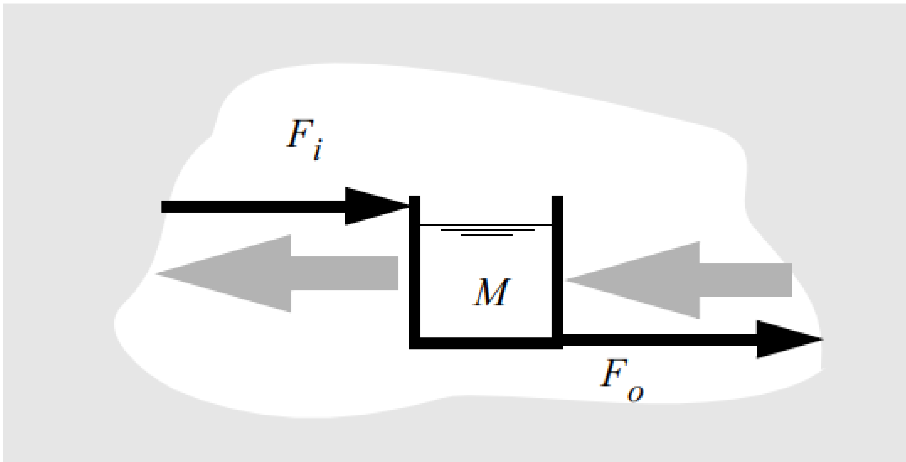


Figure 2.10: A generic microeconomic agent

Source: [Andresen, 2000]

M is the money stock of the agent and represents the need for a liquid buffer to cope with varying income and output flows(F). The time it takes for an instance of income to pass through to the output is labeled τ At equilibrium we have $F_i = F_o = F$ constant and M constant. This gives

$$M = F\tau \implies \tau = M/F \tag{2.13}$$

And from this it follows that the local velocity of money(v) is

$$v = \frac{1}{\tau} \tag{2.14}$$

This variable τ will represent an agents behaviour and could vary in time following changes in the economic environment, e.g. an uncertain environment may lead to a need for more safety leading to a higher liquidity preference and a larger τ, meaning the velocity decreases.

These microeconomic agents are thought to be connected and bundled together in sectors as shown in Figure 2.11 and the entire sector can be represented by a first-order time lag model. The time constant T of the bundled sector depends on the time constants of the internal agents and the outside outflow coefficient ρ, i.e. the part of an agents outgoing flow that escapes the sector. A larger time constant or a smaller outflow coefficient increases the aggregate time constant of the sector, this is shown in [Andresen, 2018]. If the sector was the sector of all firms these interconnections would represent firms buying from other firms, e.g. a bakery buying flour from a mill.

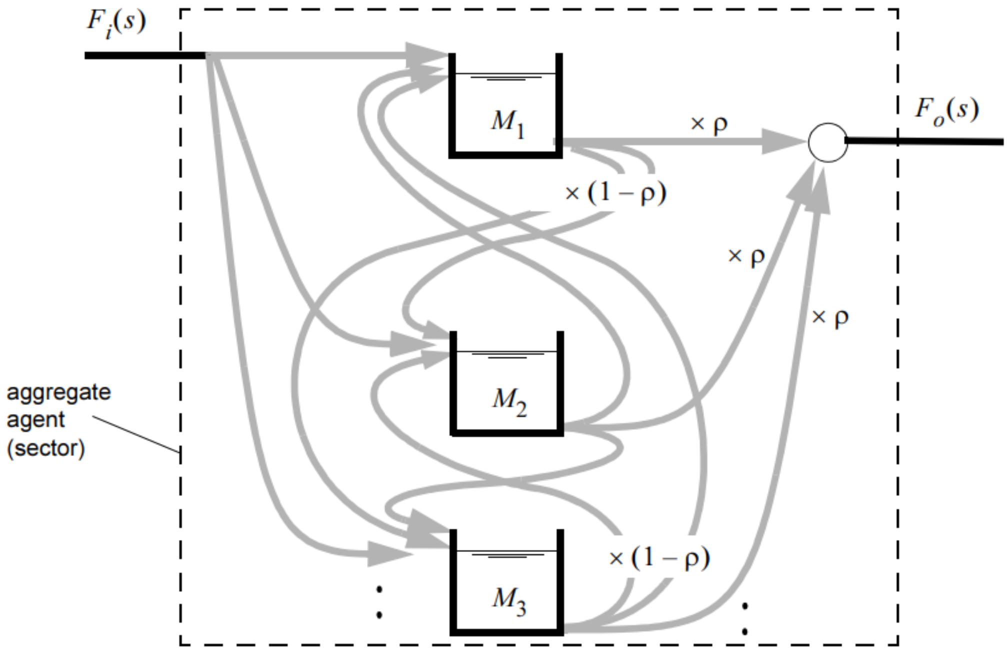


Figure 2.11: A flow network of microeconomic agents

Source: [Andresen, 2000]

Households and firms

Applying the methods introduced here we can create a model of a system with only households and firms. The block diagram representation of such a system can be seen in Figure 2.12. The household and firms sectors are bundled together and represented by an integrator, time constant and a negative feedback loop. This system is closed and only affected by the initial money stocks. The money flow from households to firms as consumption(C) and from firms to households as wages(W).

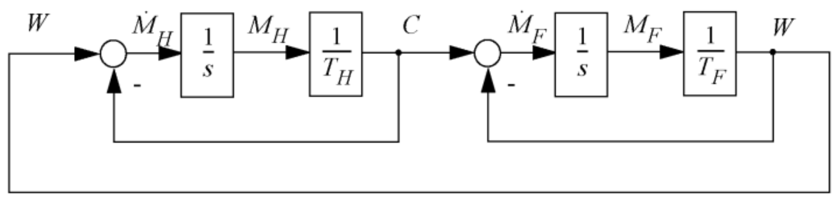


Figure 2.12: Elementary block diagram of firms and household

Source: [Andresen, 2018]

Including Government

To create a more realistic model a government sector needs to be added. This will inject money into the system through wages and consumption, and draw money out of the system through taxation. The government can be modelled in the traditional non MMT way were it only spends from the money it has already collected through taxes, but can also be an MMT government that has the ability to permanently destroy money collected through taxes, or inject new HPM. How this government affects the households and firms system is shown in Figure 2.13.

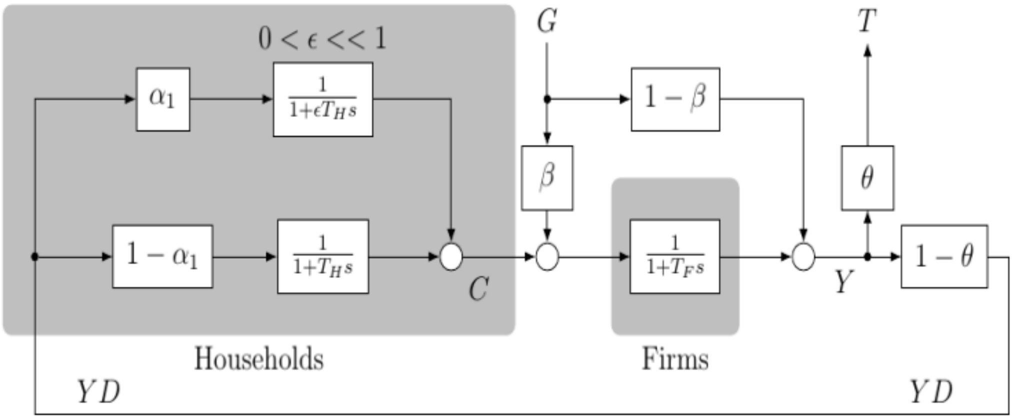


Figure 2.13: Block diagram of the real economy with a government sector

Source: [Andresen, 2018]

Capitalists

In our real economy model we also want to include capitalist behaviour. Capitalist receive the profits from firms that are left after paying taxes and wages. These profits are then either re-invested in the RE, used for creating new loans to RE or consumption, this is shown in Figure 2.14. Capitalists extending loans to the RE will be called non-bank financial institute(NBFI) The capitalist sector typically has a higher time constant than worker households.

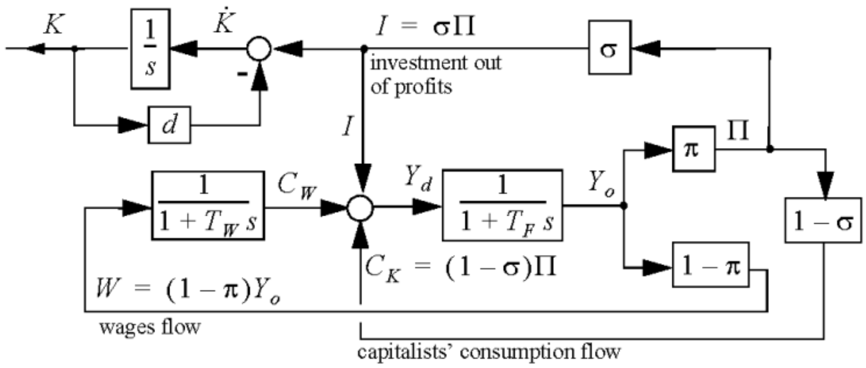


Figure 2.14: Block diagram of capitalist in the real economy

Source: [Andresen, 2018]

2.6.2 Banking System

The bank model used in this thesis will be based on assumption that the banks will always want to maximize their profits whilst obtaining the required capital-asset ratio κ_0

The model uses a Proportional Integral (PI) Controller to issue new loans when $1/\kappa_0$ is to low, increasing the debt and money supply in the system. A PI-controller generates a control input to steer the system towards a reference using the current measured error and the integrated error over the whole time-period. This PI-controller based bank model is seen in Figure 2.15

D = the bank's outstanding loans[\$]

M = deposit money [\$]

R = the bank's reserves at the Central Bank [\$]

K = the bank's capital [\$]

i_L = interest rate on loans given [1/y]

i_M = interest rate on deposit money [1/y]

λ = loss rate on loans [1/y]

r = loan repayment rate [1/y]

σ = share of net interest income that is left to the banks after expenses; $0 < \theta < 1$

F_{nl} = flow of new loans from the bank [\$/y]

κ_0 = required minimum capital-asset (C/A) ratio

κ = current actual C/A ratio

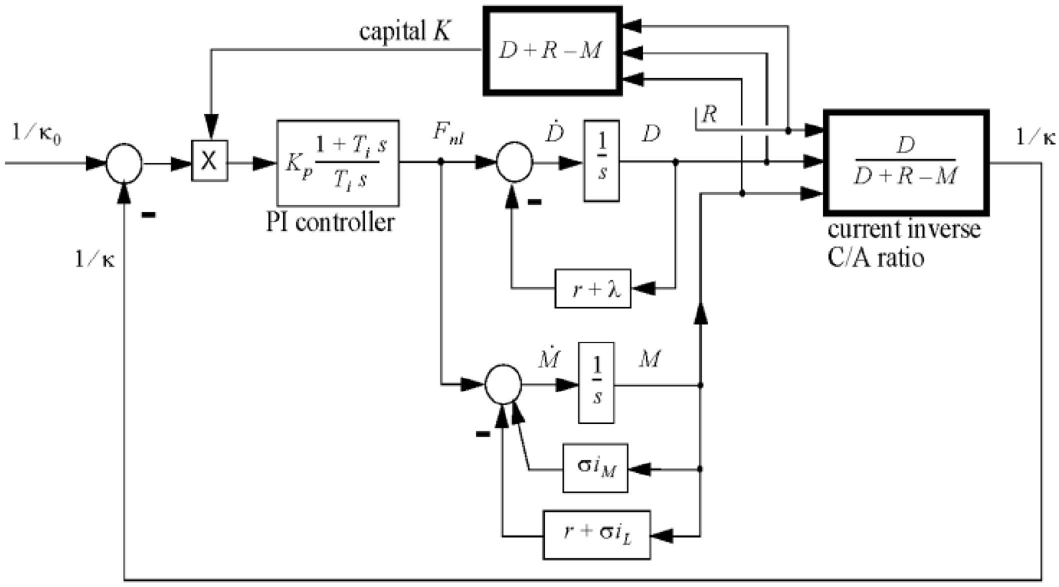


Figure 2.15: Block diagram of modern bank using a PI-regulator to reach required capital-asset ratio

Source: [Andresen, 2018]

Combined bank and real economy system

Combining the banking system with a real economy we get the system seen in Figure 2.16

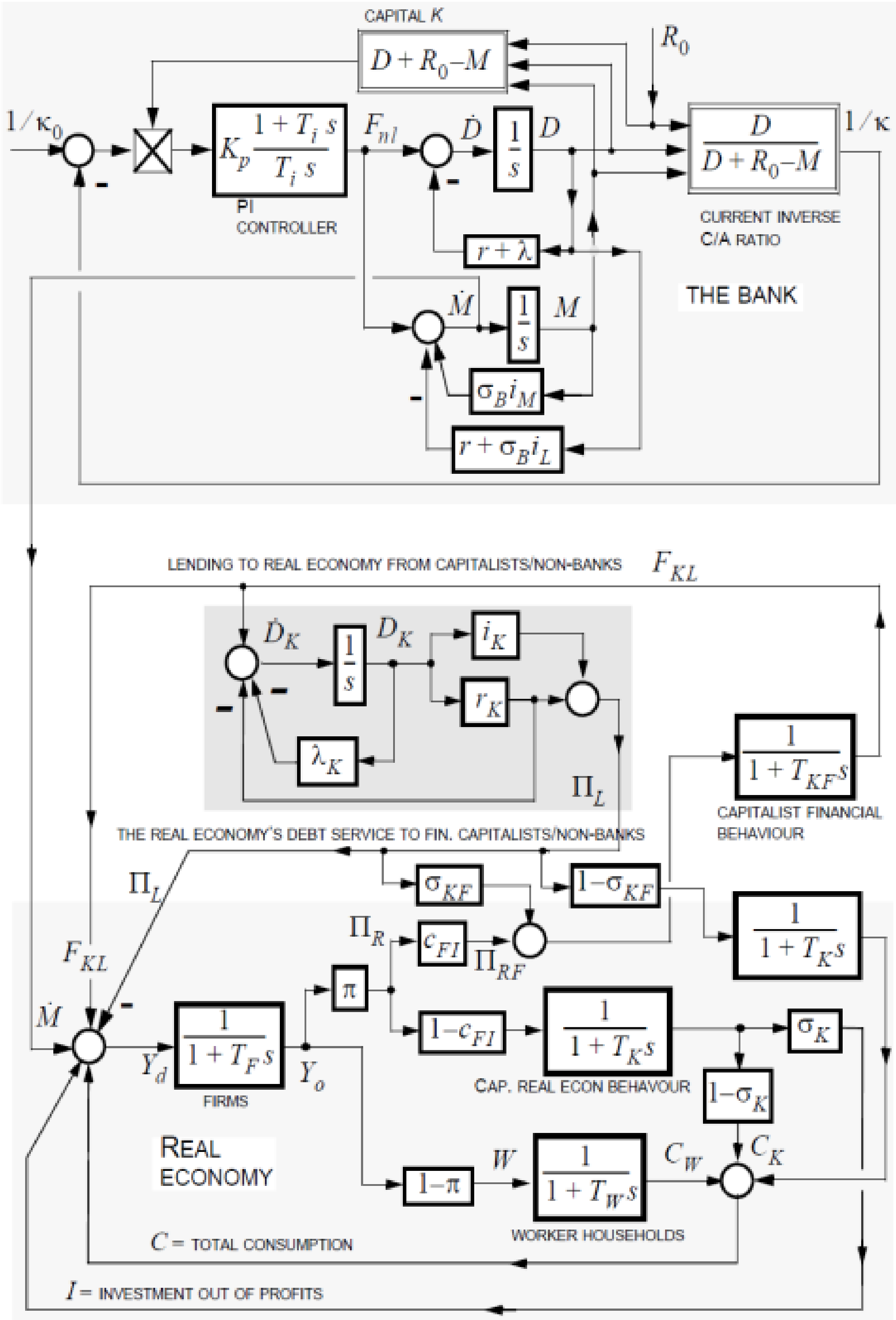


Figure 2.16: Block diagram of modern macroeconomic system

Source: [Andresen, 2018]

T_F = input-output time lag for the aggregate of non-financial firms (NFFs) [y]

T_K = time lag for spending and real-economic investment for the aggregate of NFF capitalists, out of real-economic profits [y]

T_{KF} = time lag for lending money from the aggregate of NFF capitalists[y]

T_W = time lag for the aggregate of workers/households [y]

$\dot{M}$ = net flow of Bank-created money to real economy [$]

F_{KL} = flow of new loans to real economy from NFF capitalists[$/y]

Y_d = aggregate demand for non-bank products and services [$/y]

Y_0 = aggregate real economy output [$/y]

D_K = NFF owners' financial assets[$]

i_K = interest rate on D_K [1/y]

λ_K = loss rate on D_K [1/y]

r_K = loan repayment rate on non-bank loans [1/y]

π = share of NFF output that capitalists receive; $0 < \pi < 1$

σ_K = share for real-economic investment; $0 < \sigma_K < 1$

σ_{KF} = share for capitalist lending; $0 < \sigma_{KF} < 1$

c_{FI} = "financialisation coefficient"; $0 < c_{FI} < 1$

Π_R = profits from Y_0 that capitalists receive [$/y]

Π_{RF} = profits from Y_0 that capitalist receive and allocate for lending [$/y]

Π_L = net interest income plus repayment for lending that capitalists receive [$/y]

3 Method

In this chapter we will present the model used for simulating the impacts of monetary and fiscal policies. Firstly a model of dynamic price formation will be developed. Secondly the model of the macro economy with a central bank, commercial banks and the real economy implemented in Simulink will be demonstrated. Simulink is a block diagram environment for Model-Based Design integrated with MATLAB. Lastly we will explain the different scenarios that are going to be simulated.

3.1 Dynamics of price formation

Price setting and modelling of price development is one of the most difficult formulation challenges in economic modelling [Sterman, 2000], but in order to see and measure the effects of controlling inputs on inflation such a model is necessary.

In his book “Business Dynamics”, Sterman outlines a generic way of setting the price of a commodity. Applying this way of thinking to the previously described “nodes and flows” way of modelling the economy, we can create a model that dynamically sets the price level(P). We here introduce widgets(wd) which we define as a generic measure of goods and services in the economy, i.e all the things that are bought. The word widget and concept of bundling all sorts of goods and services into this generic measure is borrowed from [Sterman, 2000].

We assume that the economy’s aggregate demand Y_d creates supply by the firms resulting in an outflow of produced widgets(Q_{wd}). The firms need time to alter their production to match demand, this is implemented as a first order time delay shown in Figure 3.1. The demand is given as a demand for widgets(Y_{wd}) and is found by dividing the aggregate demand by the current price level shown in Equation 3.1

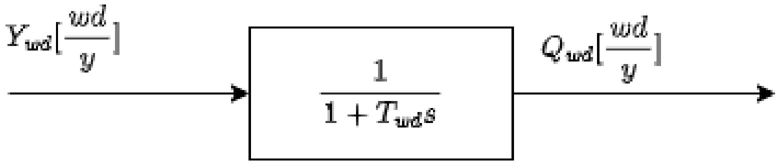


Figure 3.1: First order system representing production inertia

$$Y_{wd} = \frac{Y_d}{P} \tag{3.1}$$

The price level is a function of supply and demand as shown in the classical Quantity

Theory of Money repeated here with currently used notation. Here we use $\bar{P}$ as the reference price level, i.e the value that the price level is headed towards.

$$Y_d = MV = \bar{P}Q_{wd} \implies \bar{P} = \frac{Y_d}{Q_{wd}} \tag{3.2}$$

Prices in the economy have different inertia depending on what type of goods and services they are connected to, e.g a hair saloon might adjust their prices immediately if they sense demand is increasing, but other prices are contractual and might take years to respond to alterations in supply and demand. We have an interconnected system similar to the one seen in Figure 2.11 and the resulting time constant T_P is found as a time constant for the entire aggregate in the same way as earlier.

The resulting model for price formation is shown in Figure 3.2

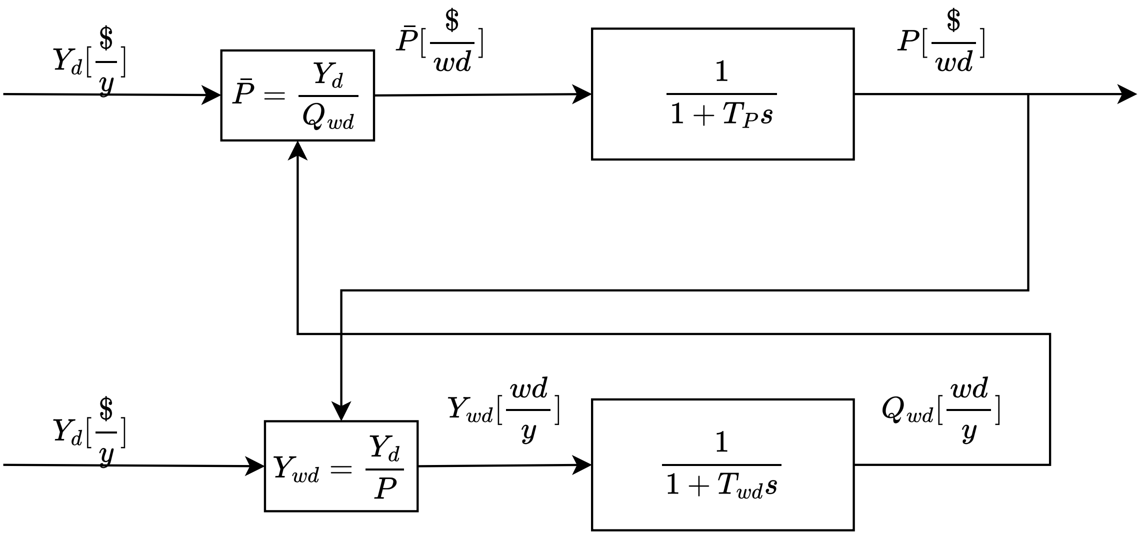


Figure 3.2: Block diagram of dynamic price formation

In this model all production is seen as local production within the country, i.e. there is no foreign sector. The reasoning behind this is that in a small country like Norway local aggregate demand is thought to have no affect on price level of foreign goods because

$$Y_d^{global} >> Y_d^{local} \tag{3.3}$$

The way to impact prices of foreign goods is therefore through the currency value which will not be modelled here.

3.2 Macroeconomic model

Overview

The implemented model consist of three main parts, the real economy, the commercial banks and the central bank. A simplified representation of how the system is interconnected is shown in Figure 3.3. The NBFI giving loans to the real economy is left out of the figure. The arrows connecting the boxes represent money flows.

The role of the central bank is to control the monetary policies. The dotted line shows how it sets the policy rate. The central bank can also inject new reserves into the system through the commercial banks, i.e "print money".

The commercial banks drive the creation of new money by giving loans to the RE and in return gets interest income from debt service.

The real economy as marked by the blue area is a circular economy showing how money flows flows between the government, households and firms sectors.

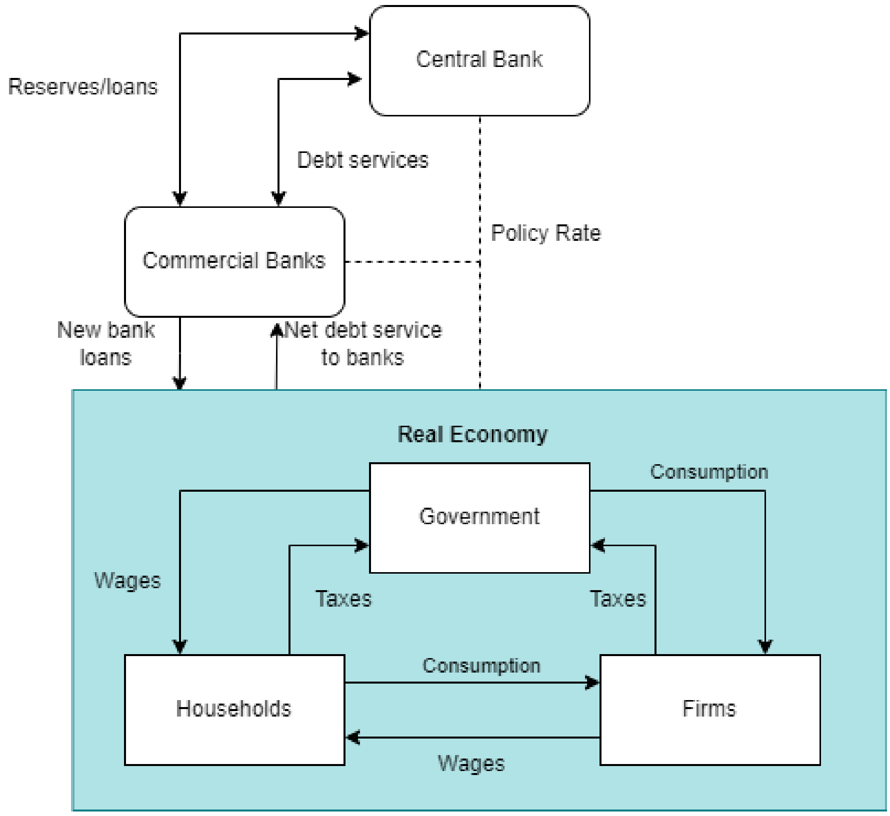


Figure 3.3: An overview of the modelled economy

3.2.1 The Central Bank

The CB implementation in Simulink is shown in Figure 3.4. The CB controls the policy rate, sets the κ_0 requirements and controls the injection of new reserves, i.e "printing of money".

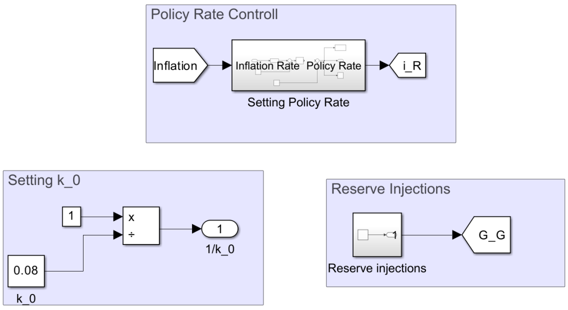


Figure 3.4: Central Bank implemented in Simulink

Parameters

$\dot{P}$ = Inflation rate. The rate of change in price level [1/y]

G_G = Government injection of reserves $\{0\}$ [$]

$\kappa_0 = \{0.8\}$

i_R = Policy rate, interest rate on reserves[1/y]

Model

The policy rate is set by a discrete PI-regulator as seen in Figure 3.5 The PI-regulator is discrete to mimic how the Central Bank sets the policy rate. This form of setting the policy rate is similar to using the simple Taylor Rule where the policy rate is increased if the inflation rate is to high and vice versa. The integral part of the regulator plays the part of the assumed equilibrium rate in the Taylor Rule. In this model we limit the policy rate to be positive.

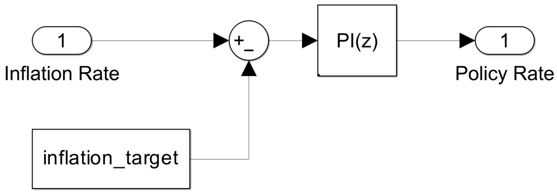


Figure 3.5: Central Bank setting policy rate using PI-regulator

3.2.2 Banks

The commercial banking sector implementation in Simulink is seen in Figure 3.6. The system includes CB reserves, debt and deposits and uses a PI-controller to issue loans without breaking the required CA ratio. Implemented similarly to that seen in Figure 2.16

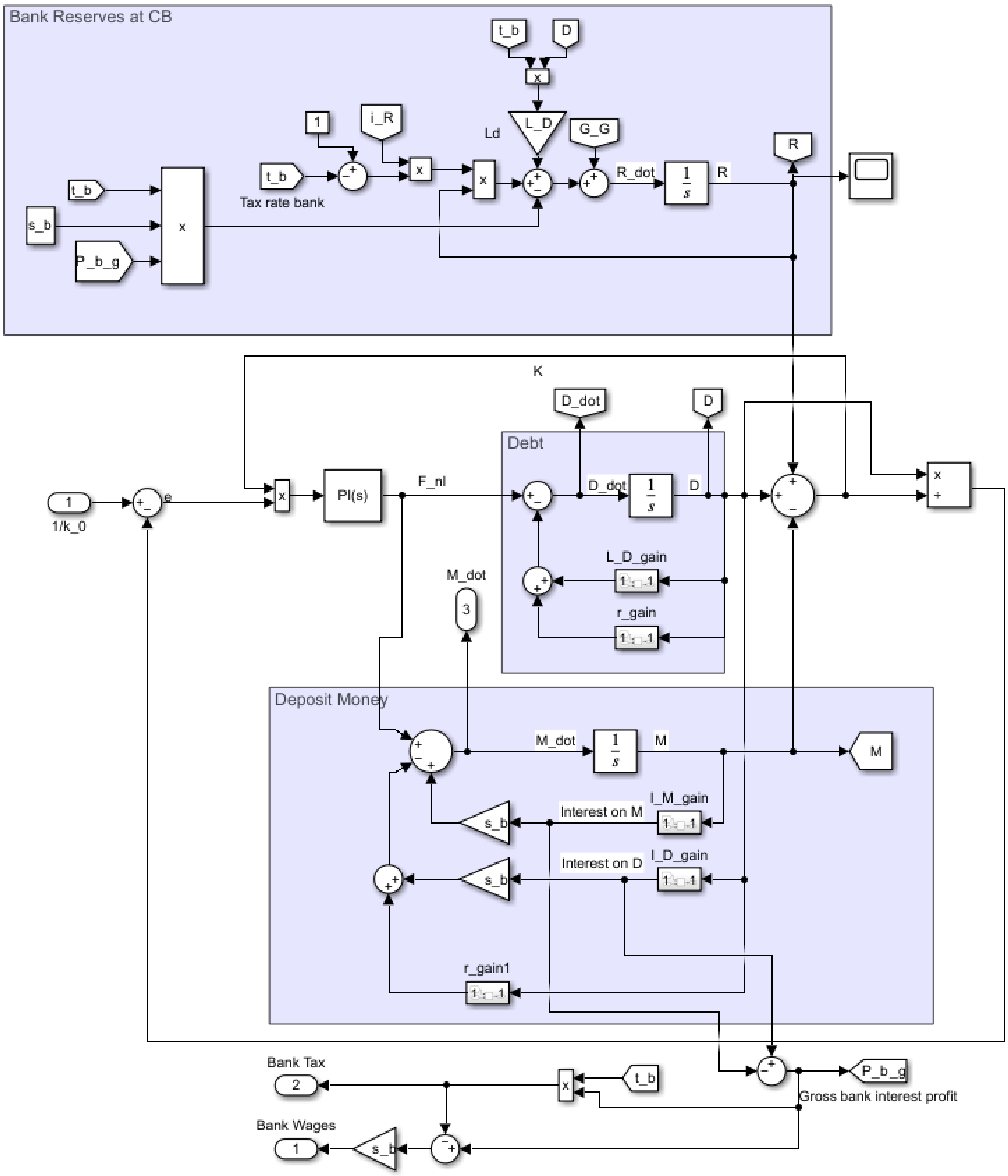


Figure 3.6: Commercial banking sector Simulink implementation

Parameters

s_b = profit share for banks {0.5}

t_b = tax rate for banks {1/3}[1/y]

L_D = Loss rate on bank debt [1/y]

r = repayment rate on bank loans {0.1} [1/y]

$$L_D = 0.001 + (i_R)0.05 \tag{3.4}$$

$$i_M = i_R + 0.01 \tag{3.5}$$

$$i_D = i_R + 0.025 \tag{3.6}$$

Model

Changes in debt(D) is a result of new loans issued, the amount of loans that has defaulted and the repayment of already issued loans. The flow of new loans(F_{nl}) can not go negative as this would in reality mean breaching the contract between lender and taker of loans and demanding the money back.

$$\dot{D} = F_{nl} - L_D D - rD \tag{3.7}$$

The deposited money(M) increase with new loans and interest payed on M, and decrease with repayment of debt and interest on debt.

$$\dot{M} = F_{nl} - rD - s_b i_D D + s_b i_M M \tag{3.8}$$

Taxes from the bank to the government is drawn from the reserves. The reserves increase with interest payment on money reserves.

$$\dot{R} = i_R(1 - t_b)R - s_b t_b(i_D D - i_M M) + t_b L_D D + G_G \tag{3.9}$$

3.2.3 The Real Economy

The real economy is implemented in Simulink with capitalist, firms households and government as seen in Figure 3.7. The parts not explicitly shown here can be seen in Appendix.

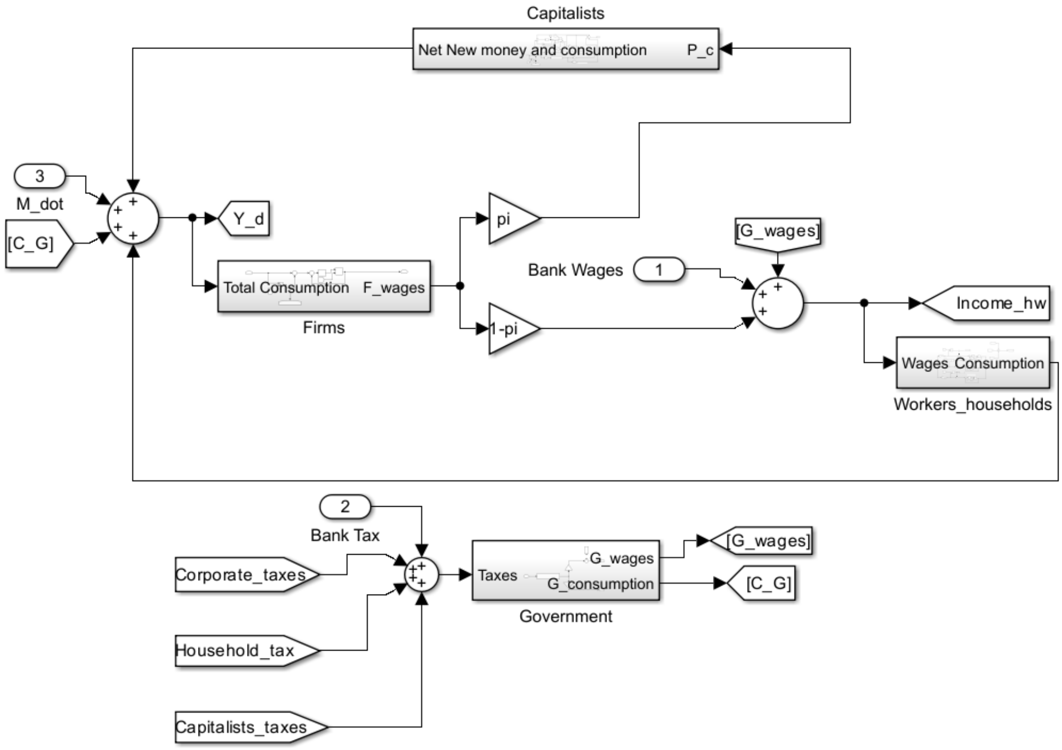


Figure 3.7: Simulink implementation of the Real Economy

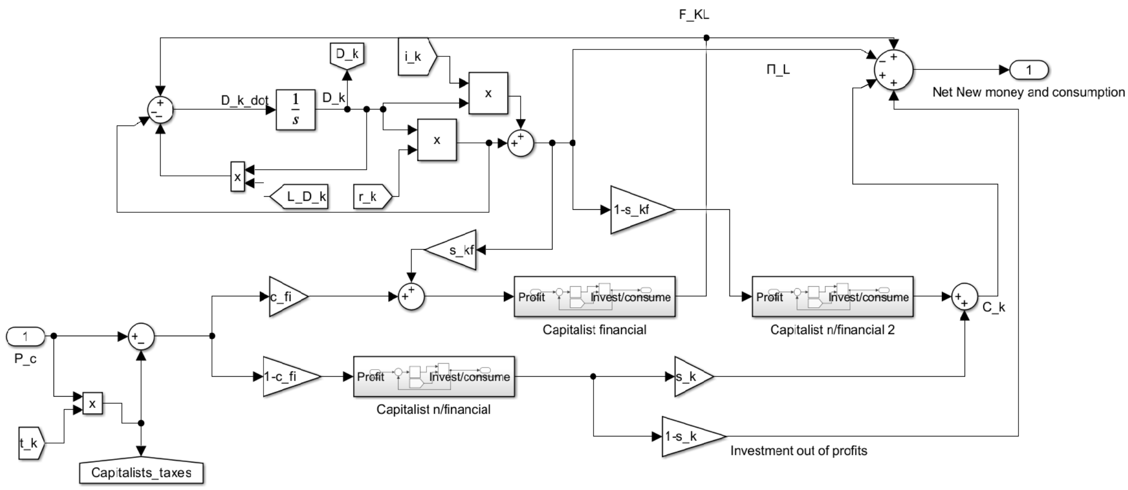


Figure 3.8: Capitalist part of The Real Economy implemented in Simulink

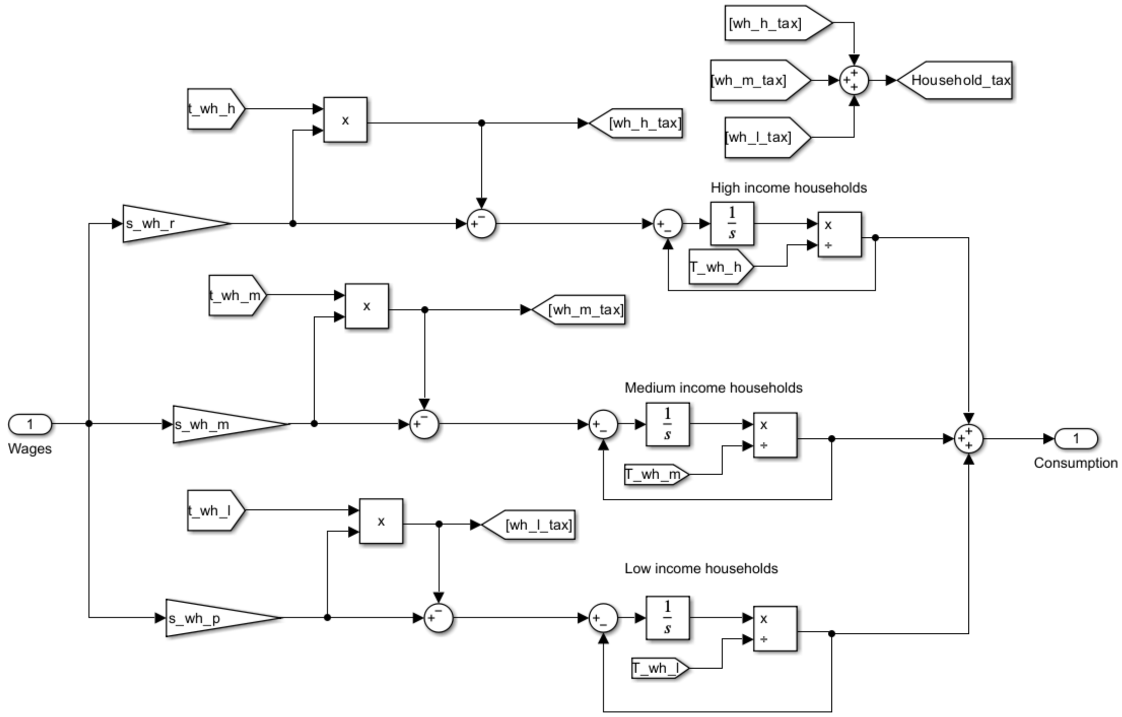


Figure 3.9: Households sector of the Real Economy in Simulink

Parameters

$\dot{M}$ = Change in deposit money(M)

Y_d = Aggregate demand [$/y]

pi=π= Part of NFF output that capitalist receive {0.2}

G_{wages} = Government wages, input to households from government [$/y]

C_G = Government consumption, input to firms from government [$/y]

T_F = Time constant for firms {0.5} [y]

T_{wh} = Time constant for worker households [y]

T_G = Time constant for government {1} [y]

T_k = Time constant for non financial capitalists [y]

t_f = Tax rate on firms {0.22} [1/y]

t_{wh}^h = Tax rate on high income households[1/y]

t_{wh}^m = Tax rate on medium income households[1/y]

t_{wh}^{l} = Tax rate on low income households[1/y]

s_{wh}^{h} = part of income that the high income third of the population receive{3/6}

s_{wh}^{m} = part of income that the medium income third of the population receive{2/6}

s_{wh}^{l} = part of income that the low income third of the population receive{1/6}

T_{kf} = Time constant for financial capitalists(NBFI) [y]

i_k = Interest on loans from capitalists$\{i_R + 0.045\}$ [1/y]

L_{D_k} = Loss rate on loans from capitalists, 2.5 times larger than L_D [1/y]

r_k = Repayment rate on loans from capitalists {0.1} [1/y]

s_{kf} = Share for capitalist lending {0.75}

s_k = Share for real-economic investment {0.25}

F_{KL} = Flow of new loans to RE from capitalist lending [$/y]

Π_L = net interest income plus repayment for lending that capitalists receive [$/y]

c_{fi} = "financialisation coefficient {0.2}

C_k = Consumption from capitalists [$/y]

μ = Time lagged loss rate on debt. A description of pessimism in society.

Model

The amount of money circulating in the RE is controlled through the bank sector and enters through the $\dot{M}$ variable. The growth rate is calculated as seen below.

The money velocity is controlled by the interconnected time constants of the capitalists, households, firms and government. Some of these are not constant and described by the the following equations.

A higher loss rate on loans will lead to a higher T_{kf} resulting in higher accumulation of money and decrease in money velocity.

$$T_{kf}(L_{D_k}) = 0.535(0.998 + 100L_{D_k})T_{kf0} \tag{3.10}$$

We use the μ variable to describe the level of optimism or pessimism in society.

It is simply the loss rate on debt lagged one year.

$$\mu = \frac{1}{1+s} L_D \tag{3.11}$$

A higher level of pessimism leads to larger time constants for both workers and capitalist lowering the velocity of money circulating the RE.

$$T_{wh}(\mu) = 0.83(0.998 + 100\mu)T_{wh0} \tag{3.12}$$

$$T_k(\mu) = 0.55(0.998 + 400\mu)T_{k0} \tag{3.13}$$

Alternative dynamic household time constant T_{wh}

We also implement the possibility of making small alterations in the time constants of households to explore how this affects the simulations. This alteration of time constants could be the result of e.g a transaction fee on all economic transfers set by the government.

This effect is hypothetical and will probably not be too large. Equation 3.15 shows how T_{wh} is altered by the transaction fee(F) and we set F equal to the deviation in inflation from the desired rate(I_e). Here T^*_{wh} is the normal time constant for working households.

$$F = I_e \tag{3.14}$$

$$T_{wh} = T^*_{wh} * (1 + F) \tag{3.15}$$

Alternative dynamic tax rates

The model has the possibility to set the tax rate on households constant, but also to implement a dynamic tax rate to simulate fiscal policies. In the case of no fiscal control the tax rates are given as in Equation 3.16.

$$t^h_{wh} = t^m_{wh} = t^l_{wh} = 0.33 \tag{3.16}$$

In the case with dynamic taxation the rates are set using the MATLAB code below. Here, the households sector has been split into three different sub sectors representing the richest third of the population, the poorest third of the population and the middle part as seen in Figure 3.9. The income distribution between these sectors are based on Norwegian income statistics [SSB, 2023a]. The two higher income thirds of the population will get a higher tax rate in high inflation situations, and the lowest income third will get a small tax reduction.

```
function tax_rate_h = fcn(inflation)
basic_tax=0.33;
inflation_ref=0.02;
inflation_error=inflation_ref-inflation;
tax_rate_h=basic_tax-(inflation_error*5);
if tax_rate_h<0.025
    tax_rate_h=0.025;
end
if tax_rate_h>0.5
    tax_rate_h=0.5;
end
```

```
function tax_rate_m = fcn(inflation)
basic_tax=0.25;
inflation_ref=0.02;
inflation_error=inflation_ref-inflation;
tax_rate_m=basic_tax-(inflation_error*2.5);
if tax_rate_m<0.02
    tax_rate_m=0.02;
end
if tax_rate_m>0.4
    tax_rate_m=0.4;
end
```

```
function tax_rate_l = fcn(inflation)
basic_tax=0.20;
inflation_ref=0.02;
inflation_error=inflation_ref-inflation;
tax_rate_l=basic_tax+(inflation_error);
if tax_rate_l<0
    tax_rate_l=0;
end
if tax_rate_l>0.2
    tax_rate_l=0.2;
end
```

When operating as an MMT regime the government has the opportunity to destroy the money they collect from the economy through taxes to limit the amount of money in circulation. It also has the possibility of injecting new money through increased government spending. This implementation can be seen in appendix,Figure A.2.

3.3 Simulation scenarios

Here follows an overview of all the simulation scenarios(SS) we want to simulate. All the simulations run over a time period of 300 years giving the model time to stabilize before a shock is inputted.

SS1A, no regulation

To establish a baseline we run a simulation with no monetary or fiscal regulation to control inflation, the policy rate is set constant at 0%.

- Constant 0% policy rate
- No fiscal control
- No monetary control

SS1B, no regulation, with supply shock

Same setup as in SS1A but with a 2 year supply shock inputted to the system after 153 years. The supply shock enters the system as a 5% decrease in widget production $Q_w d$.

- Constant 0% policy rate
- No fiscal control
- No monetary control
- 2 year supply shock after 153 years

SS1C, no regulation, with demand shock

Same setup as in SS1A but with a 5 year demand shock inputted to the system after 150 years. The demand shock enters as a 5% increase in aggregate demand Y_d.

- Constant 0% policy rate
- No fiscal control
- No monetary control
- 5 year demand shock after 150 years

SS2A, current system

The PI-regulator controlling the policy rate is connected and tries to regulate inflation towards a stable 2%. Only the policy rate is used as actuation, no fiscal policies.

- Monetary control
  - Policy rate used as actuator
- No fiscal control

SS2B, current system, with supply shock

The same setup as in SS2A but a 2 year supply shock is inputted to the system after 153 years.

- Monetary control
  - Policy rate used as actuator
- No fiscal control
- 2 year supply shock after 153 years

SS2C, current system with demand shock

The same setup as in SS2A but a demand shock is inputted to the system after 153 years. The supply shock enters the system as a 5% decrease in widget production $Q_w d$.

- Monetary control
  - Policy rate used as actuator

- No fiscal control
- 5 year demand shock after 153 years

SS3A, alternative control, with supply shock, normal government

The policy rate is again set to a constant 0%. The capital asset ratio κ_0 is set to a level that gives approximately 2% inflation when there is no disturbance. Dynamic tax rates and transaction fees are used as fiscal control. All incoming taxes are kept in the circulating economy.

- No monetary control
- Fiscal control
  - Dynamic tax rates
  - Dynamic transaction fee
- 2 year supply shock after 153 years

SS3B, alternative control, with demand shock, normal government

Same setup as SS3a but with no supply shock, and a 5 year demand shock after 150 years.

- No monetary control
- Fiscal control
  - Dynamic tax rates
  - Dynamic transaction fee
- 5 year demand shock after 150 years

SS3C, alternative control, with supply shock, MMT type government

Same setup as in SS3A but now with a government that can slightly reduce or increase spending unrelated to incoming tax.

- No monetary control

- Fiscal control
  - Dynamic tax rates
  - Dynamic transaction fee
  - Small alterations in government spending
- 2 year supply shock after 153 years

SS3D, alternative control, with demand shock, MMT type government

Same setup as in SS3C but with no supply shock, and a 5 year demand shock after 150 years.

- No monetary control
- Fiscal control
  - Dynamic tax rates
  - Dynamic transaction fee
  - Small alterations in government spending
- 5 year demand shock after 150 years

4 Results

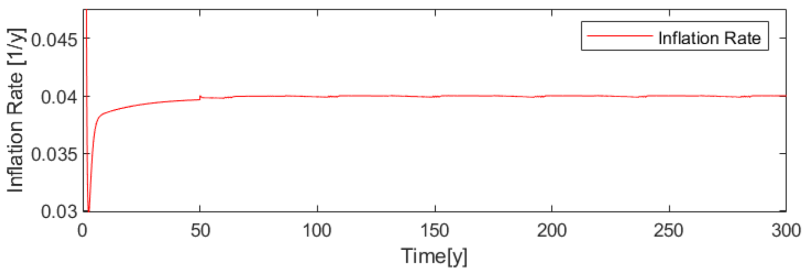
In this chapter the simulation results from the scenarios described in Section 3.3 will be presented and described. For each simulation scenario, the resulting inflation will be plotted along with the current control input i.e the policy rate or the dynamic tax rates. The simulations are divided into three main groups(SS1, SS2 and SS3) and all simulations within a group will be commented on collectively.

4.1 SS1 results

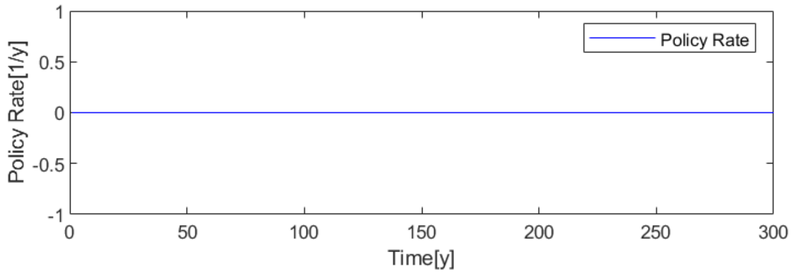
This is the baseline scenario and shows how the inflation acts with no active regulating input. Figure 4.1b shows that with a 0% constant policy rate the inflation rate stabilises at about 4%.

When injected with a supply shock as seen in Figure 4.2 the inflation sharply increases to above 7% before returning to 4% when supply returns to normal. Figure 4.3 shows inflation when the economy is experiencing a demand shock after 150 years. The sudden increase in demand initiates a spike in inflation with a max of just above 8%,then it settles towards 5% before the sudden drop in demand drops the inflation down to 0.8%.

SS1A



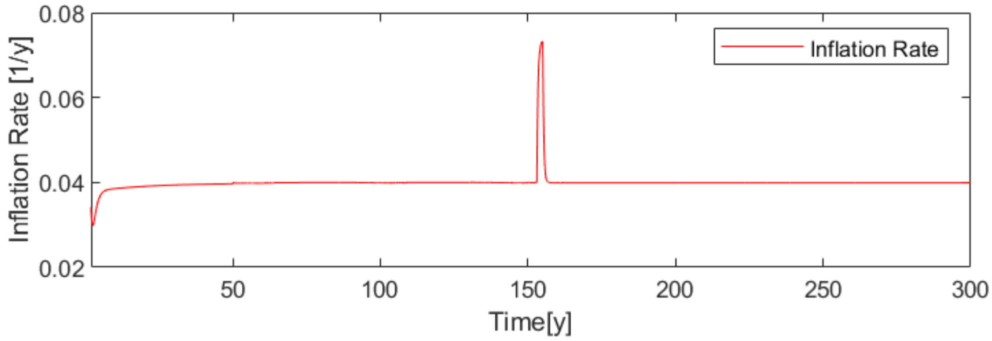
(a) Inflation rate from year 1 to year 300



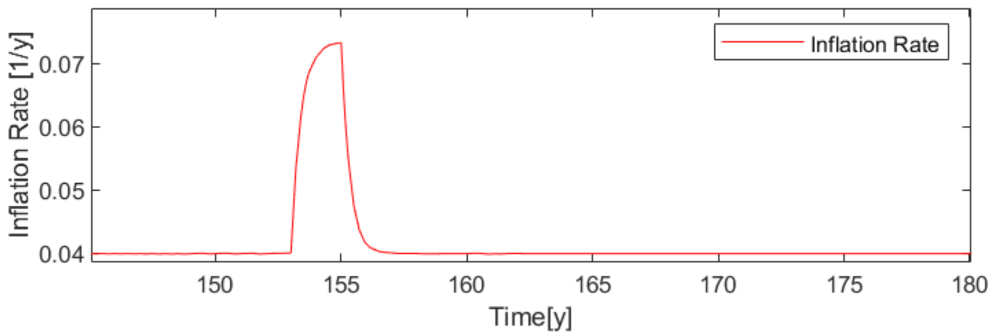
(b) Policy rate from year 1 to year 300

Figure 4.1: SS1A:Inflation rate with zero percent policy rate

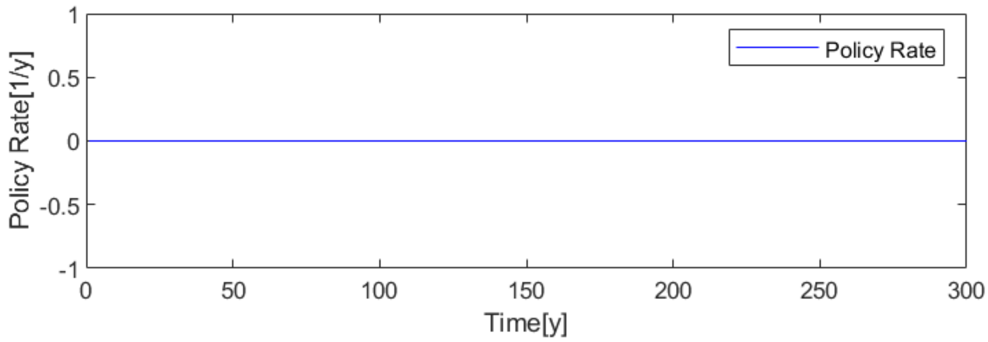
SS1B



(a) Inflation rate from year 1 to year 300



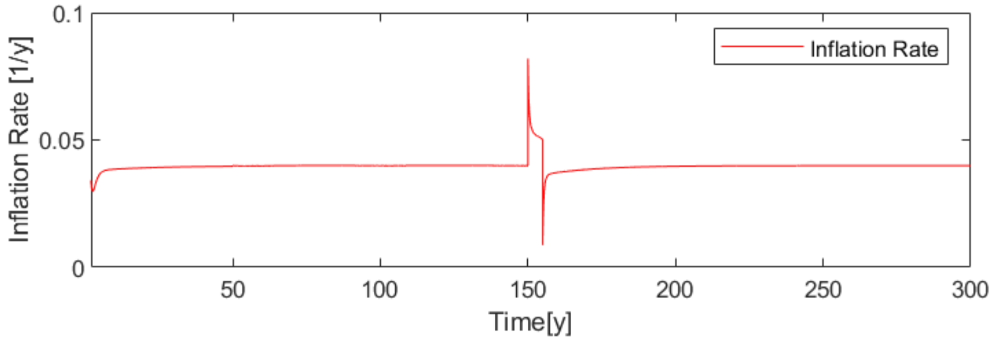
(b) Inflation rate from year 145 to year 180



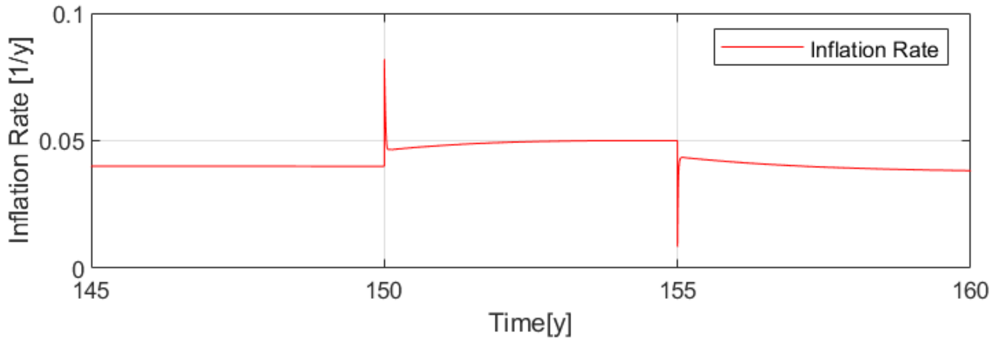
(c) Policy rate from year 1 to year 300

Figure 4.2: SS1B:Inflation rate with zero percent policy rate and supply shock

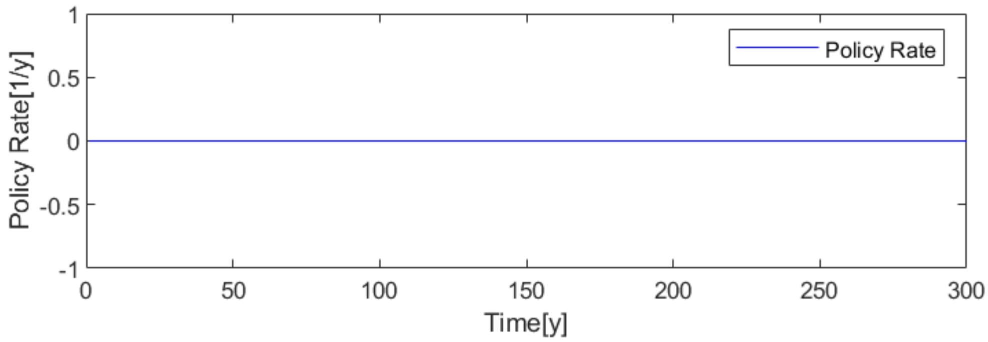
SS1C



(a) Inflation rate from year 1 to year 300



(b) Inflation rate from year 145 to year 160



(c) Policy rate from year 1 to year 300

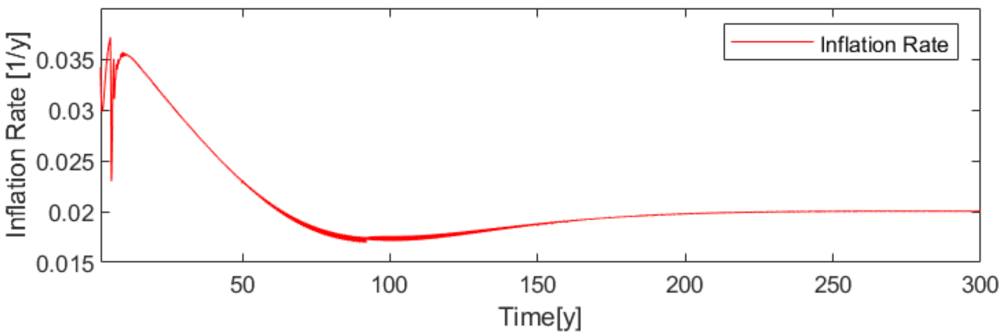
Figure 4.3: SS1C:Inflation rate with zero percent policy rate and demand shock

4.2 SS2 results

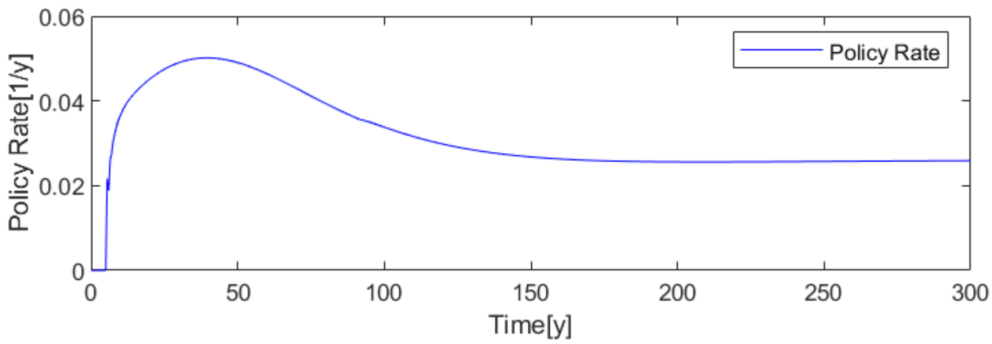
SS2 describes a scenario similar to the one used in at least most western countries where the policy rate is used as the only controlling input for curbing inflation. Figure 4.4 displays how an increase in policy rate dampens inflation and manages to stabilise the inflation rate, with a small undershoot, at the targeted 2% after approximately 150 years. This stabilised economy is subjected to a supply shock and the results are shown in Figure 4.5. The policy rate is increased to curb the inflation impact of the supply shortage resulting in an unstable inflation period maxing out at 4% and with a following maximum undershoot down to 1.1%. Policy Rate changes inflict sudden impacts on inflation creating a damped oscillating response.

The same system subjected to a demand shock is displayed in Figure 4.6. The spike in inflation leads to a rapidly increasing policy rate which reduces inflation to just above the desired 2% with small oscillations. When demand is restored to normal the system quickly recovers to 2% with low amplitude damped oscillations.

SS2A



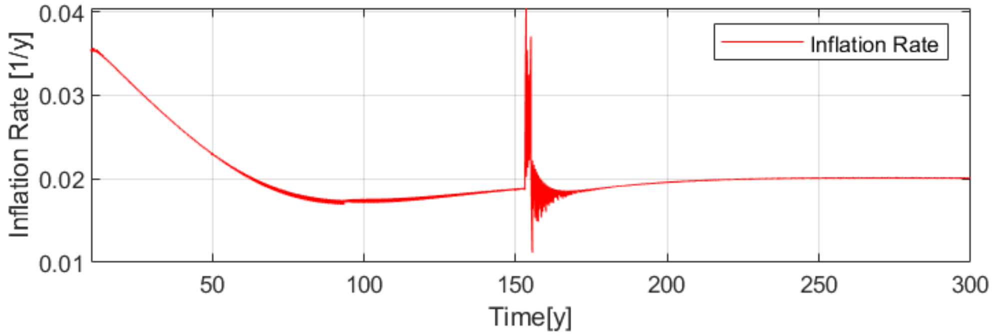
(a) Inflation rate from year 1 to year 300



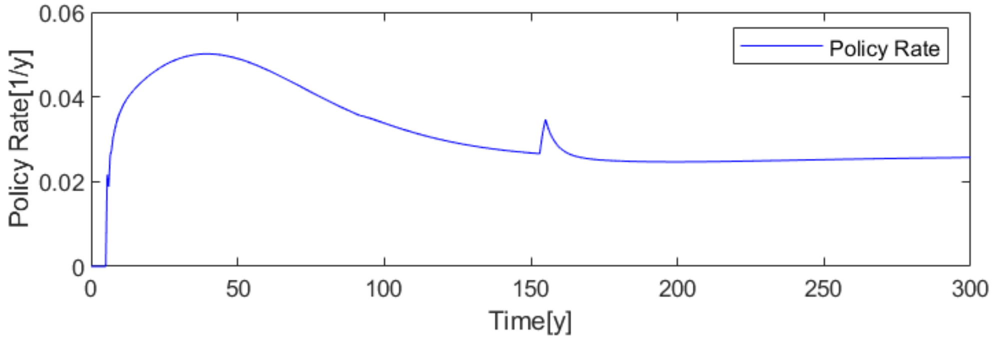
(b) Policy rate from year 1 to year 300

Figure 4.4: SS2A:Inflation rate and policy rate of economy controlled with interest rate

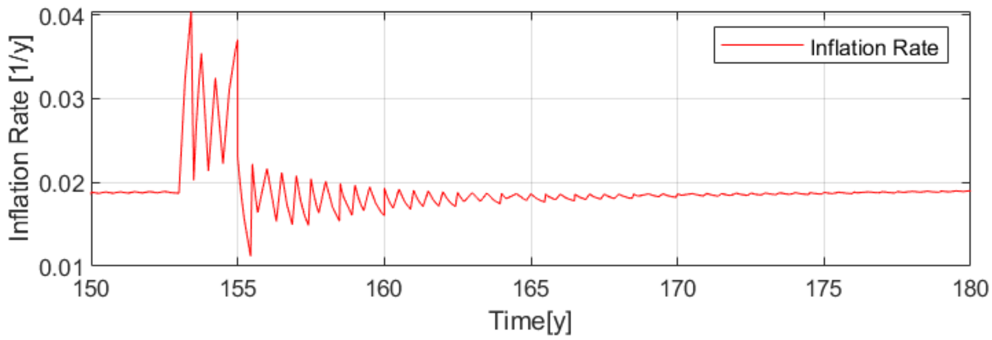
SS2B



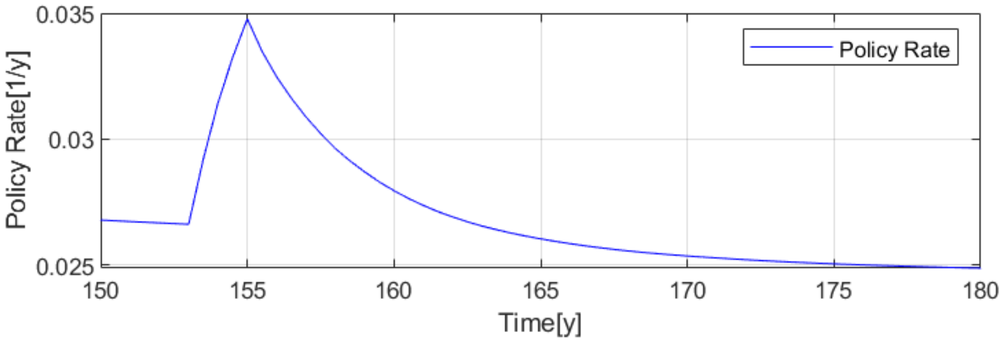
(a) Inflation rate from year 0 to year 300



(b) Policy rate from year 0 to year 300



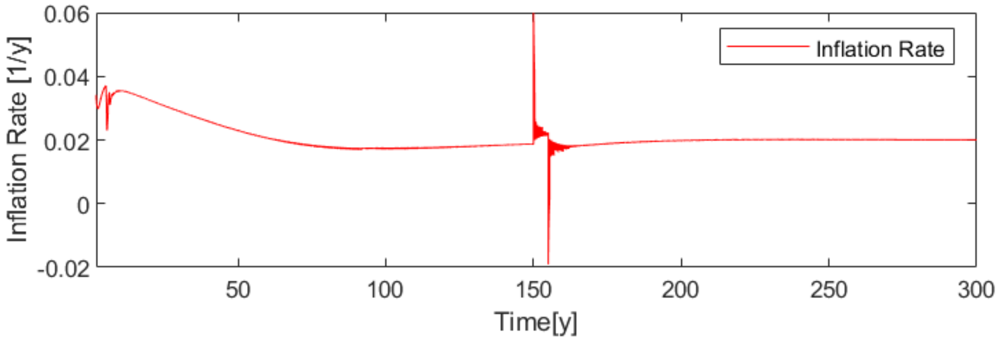
(c) Inflation rate from year 150 to year 180



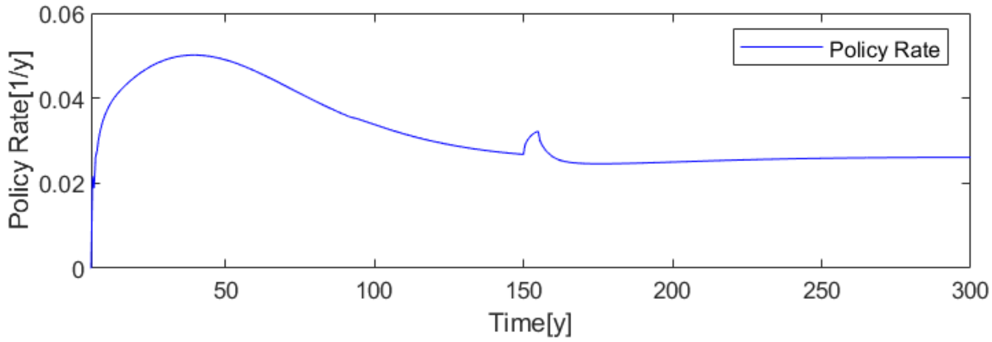
(d) Policy rate from year 150 to year 180

Figure 4.5: SS2B:Inflation rate and policy rate with a 2-year supply shock after 153 years

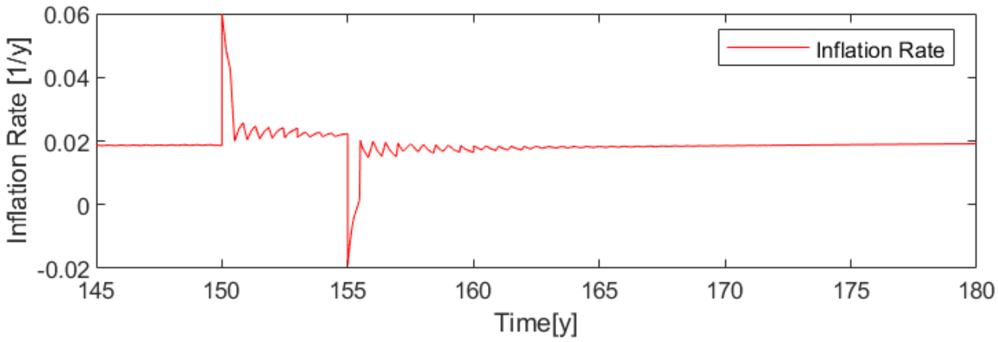
SS2C



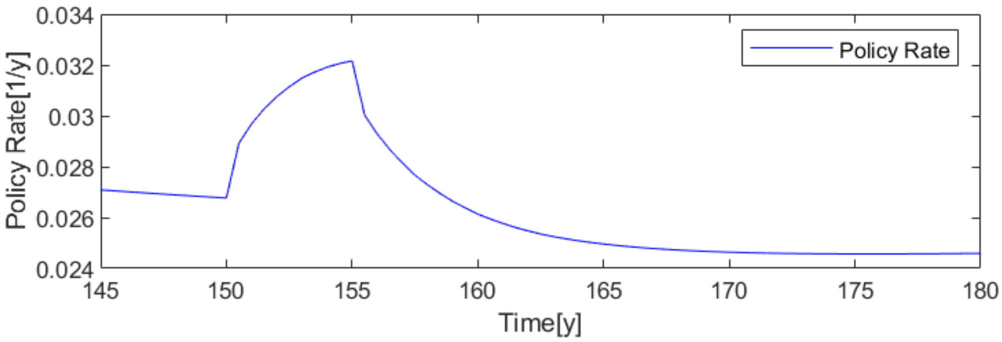
(a) Inflation rate from year 1 to year 300



(b) Policy rate from year 1 to year 300



(c) Inflation rate from year 145 to year 180



(d) Policy rate from year 135 to year 200

Figure 4.6: SS2C:Inflation rate and policy rate with a 5-year demand shock after 150 years

4.3 SS3

In this section all monetary control is turned off and only fiscal actuators are used. The κ_0 that gave stable approximately 2% inflation was $\kappa_0 = 0.19$. The system was again subjected to a supply shock and the resulting inflation and tax rates are shown in Figure 4.8. The supply shortage created an increase in inflation maxing out at just above 3.5% and no undershoot when returning to normal conditions. The tax increase on high and middle income households was just under 10% and 5%. Low income households got a small tax reduction of between 1-2%.

When subjected to a demand supply as seen in Figure 4.9 the inflation spiked at 6%, then stabilised towards 3% before a sudden decrease resulting in a short period of deflation of about 1%. To make it easier to read Figure 4.10 has been split into two different plots in the demand shock case due to the large spikes in tax rate.

The same two economic shock are again introduced to the system but now with an MMT type government that makes small changes to spending unrelated to the incoming taxes. In the case of the supply shock seen in Figure 4.11 not reintroducing the extra collected taxes into the economy results in a slightly more curbed inflation maxing out at just under 3%. The same is the case with the demand shock seen in Figure 4.12 where the peaks are limited to just below 4% and in the negative spike deflation is avoided resulting in a minimum inflation of just below 1%. The inflation in the 5 year period also stabilises at a slightly lower level at about 2.5%

The effect of an altered time constant is not easily seen from the figures displaying the total system response. The dynamics of a time constant altered by 2% can be seen below in Figure 4.7. The response is short lived and this type of regulation is only fitting for short term control.

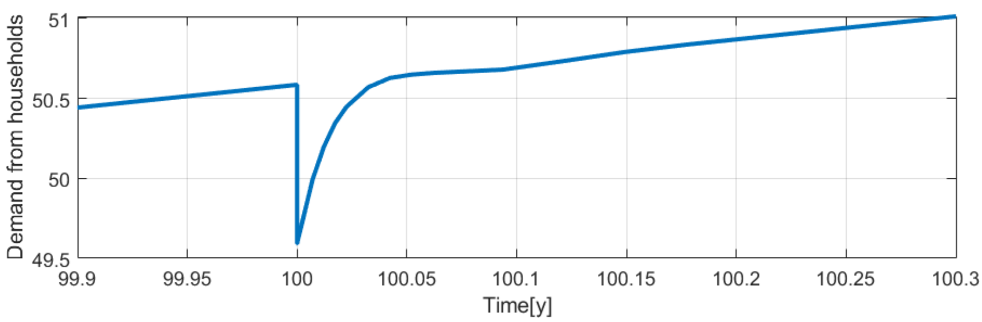
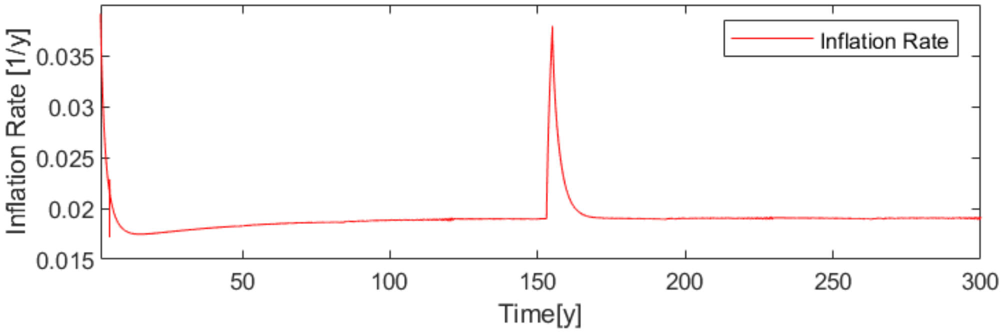
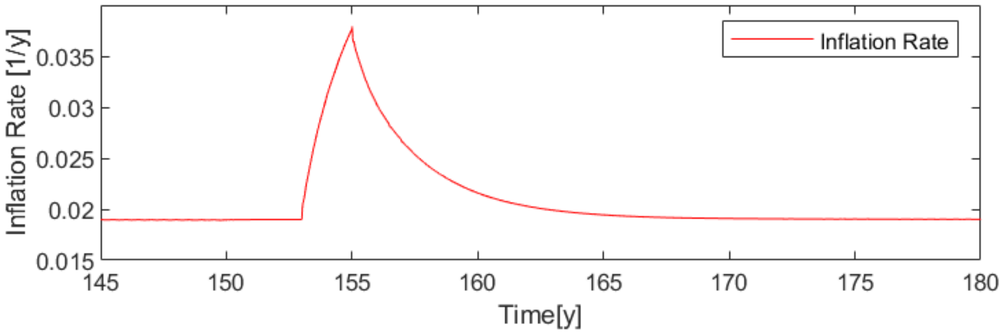


Figure 4.7: Effect of 2% household time constant increase on household demand

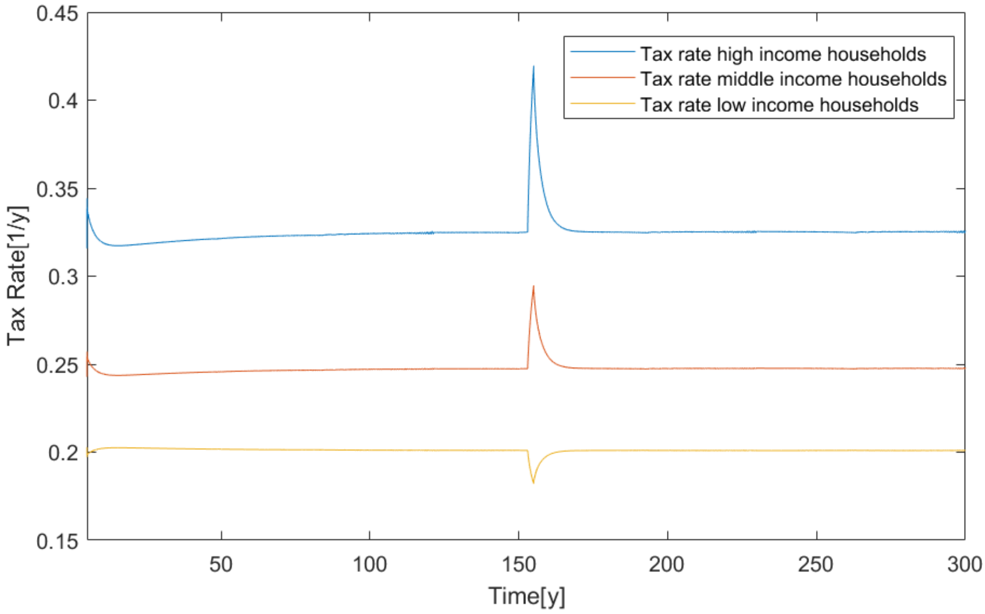
SS3A



(a) Inflation rate from year 1 to year 300



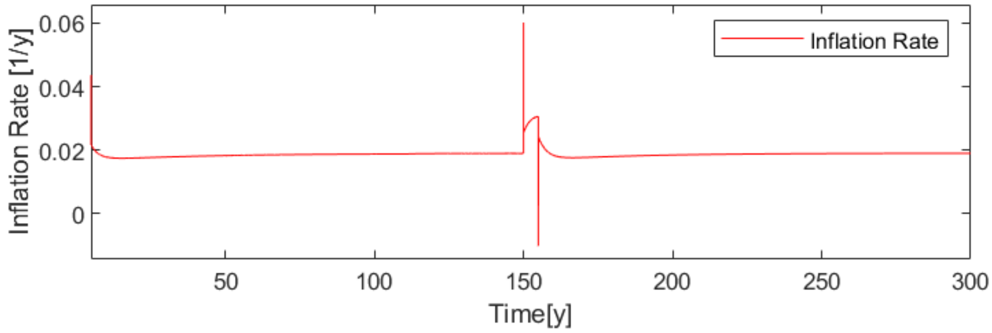
(b) Inflation rate from year 145 to year 180



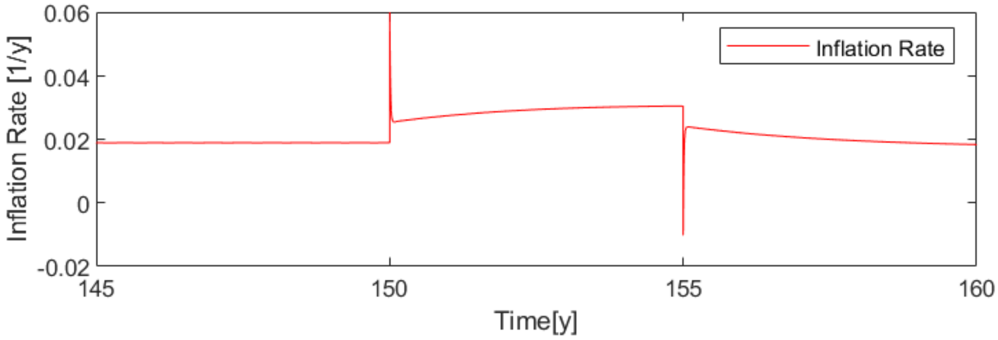
(c) Tax rates for households

Figure 4.8: SS3A:Inflation rate and tax rates for households with 2 year supply shock after 153 years

SS3B

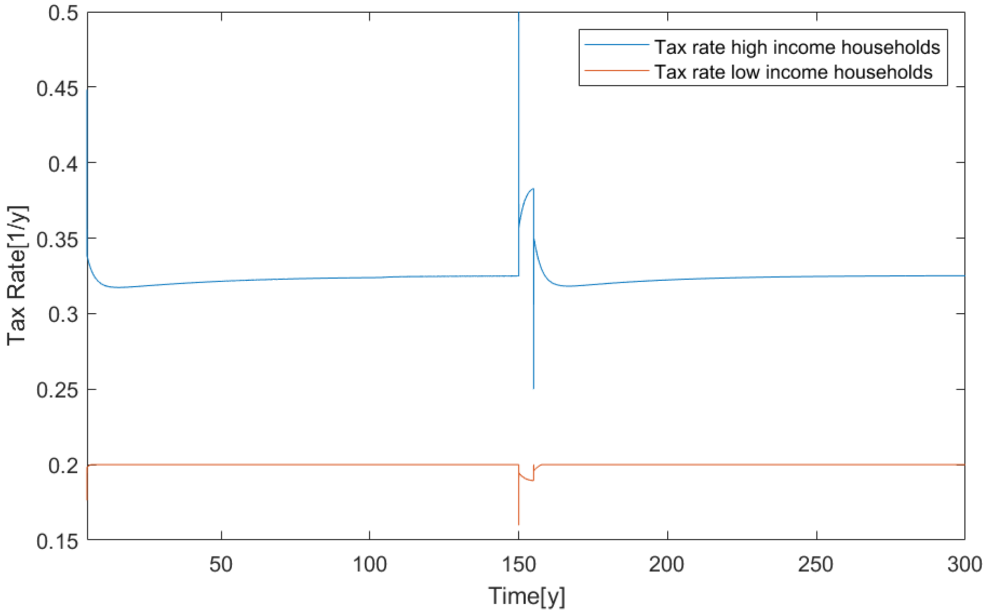


(a) Inflation rate from year 1 to year 300

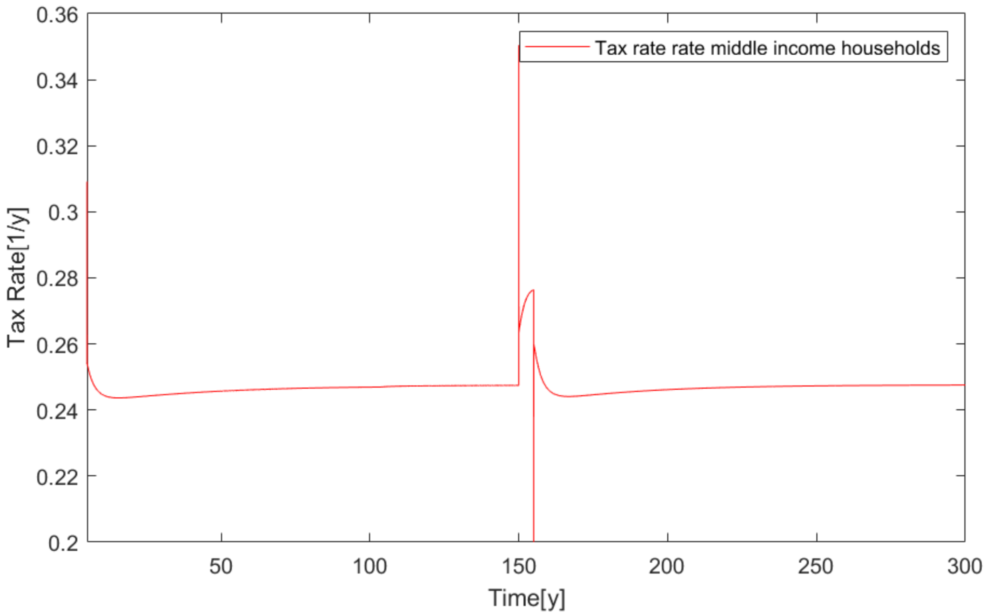


(b) Inflation rate from year 145 to year 180

Figure 4.9: SS3B:Inflation rate with 5 year demand shock after 150 years



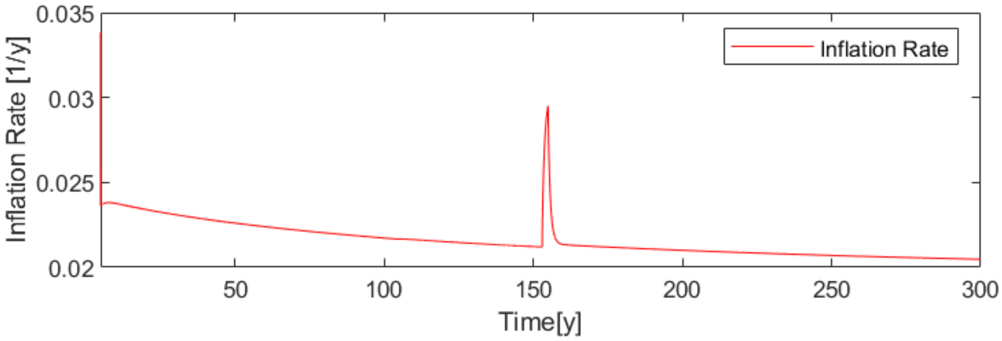
(a) Tax rates for households low and high income



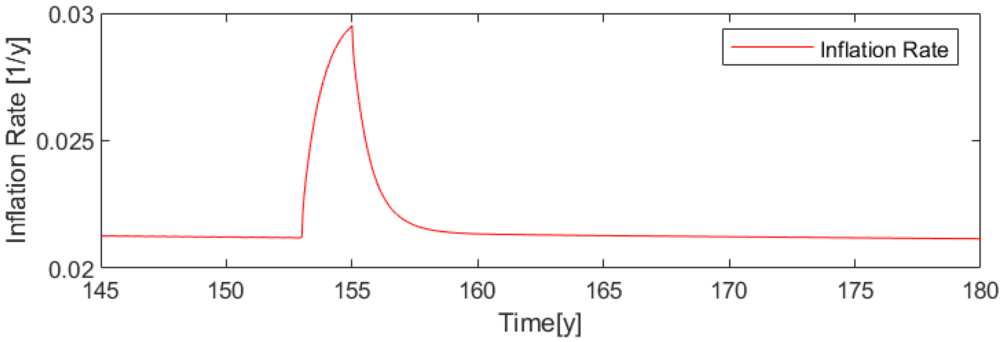
(b) Tax rates for households middle income

Figure 4.10: SS3B:Tax rates for households with 5 year demand shock after 150 years

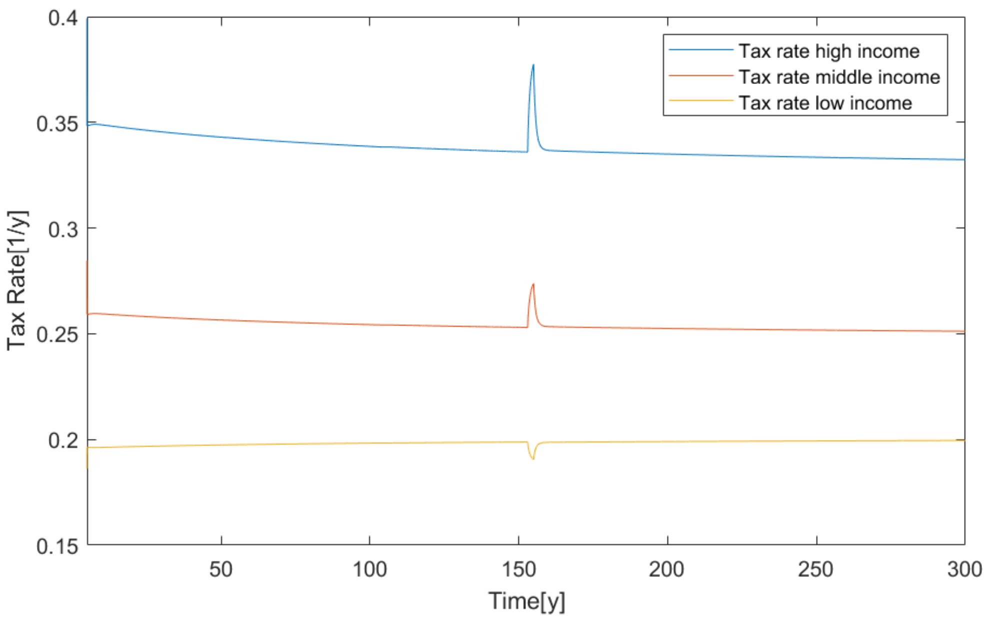
SS3C



(a) Inflation rate from year 1 to year 300



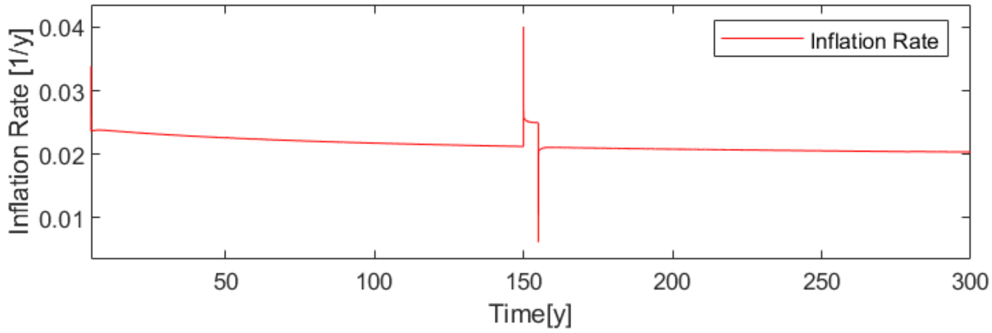
(b) Inflation rate from year 145 to year 180



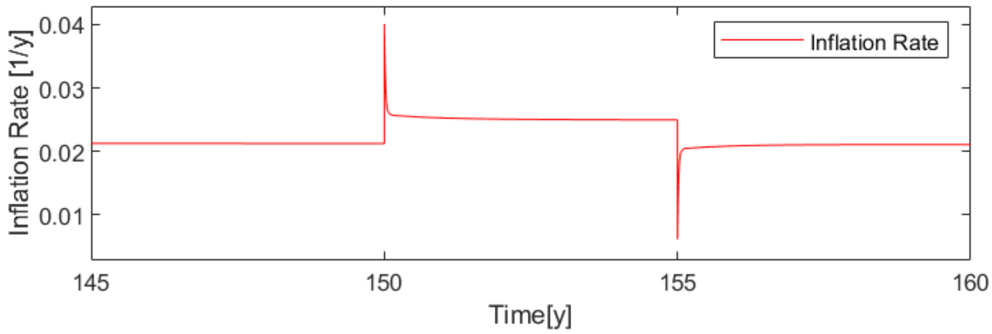
(c) Tax rates for households

Figure 4.11: SS3C:Inflation rate and tax rates for households with 2 year supply shock after 153 years

SS3D

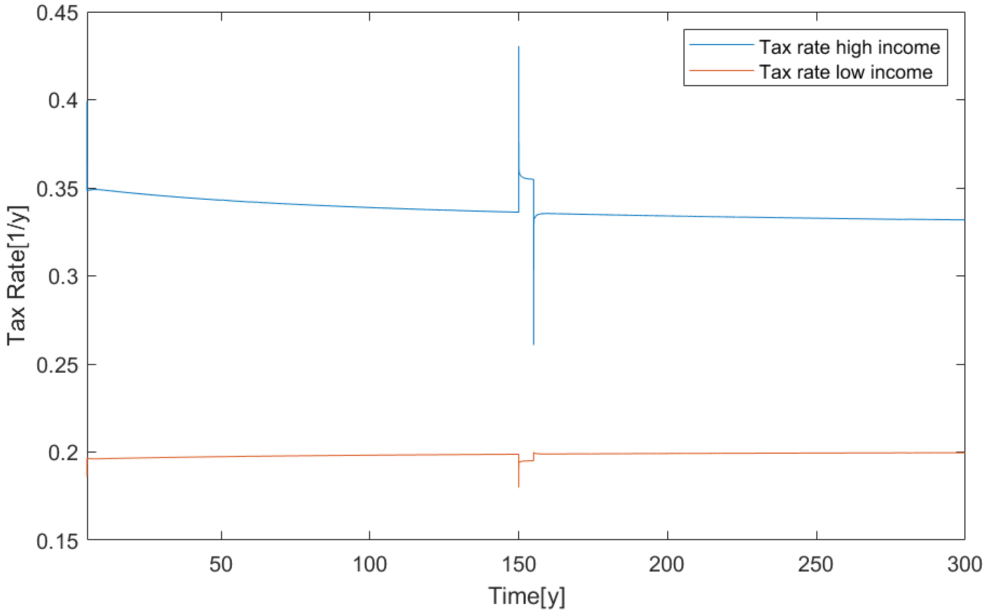


(a) Inflation rate from year 1 to year 300

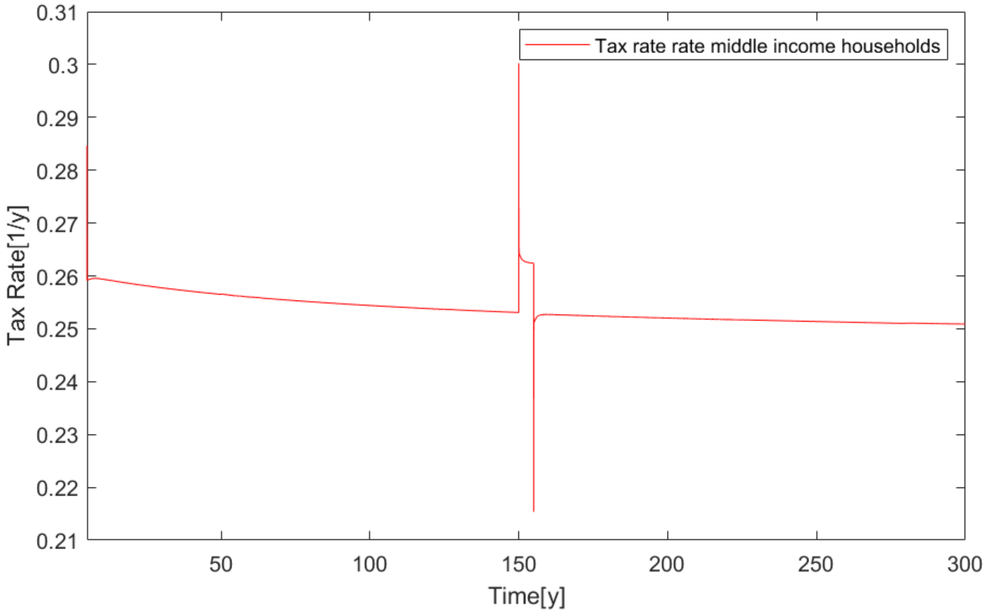


(b) Inflation rate from year 145 to year 160

Figure 4.12: SS3D:Inflation rate with 5 year demand shock after 150 years



(a) Tax rates for households low and high income



(b) Tax rates for households middle income

Figure 4.13: SS3B:Tax rates for households with 5 year demand shock after 150 years

5 Discussion

In this chapter the results from all the different simulation scenarios will be compared and discussed along with the validity of the developed model.

5.1 SS1 and SS2

> *“ The overall objective of monetary policy is to maintain a stable monetary value through low and stable inflation”*
>
> \- Norges-Bank

Any controlling measures used on the economy to curb inflation should have the goal of keeping the inflation both low and stable. The success of the different alternatives will therefore be measured on how successfully this has been achieved.

The results of SS1 shows that using the inflation rate as controlling input has the power to dampen an overheated economy to a precise target level given enough time. The policy rate reduces the maximum deviation, compared to no control, from +3% to +2% when a supply shock is inputted the system. The average inflation is significantly lowered in the shock period but this also seems to cause instabilities and lead to a small recession when normal conditions return. This small recession is realistic when looking at the research on economic history, as previously discussed in Section 2.3.3, and adds to the validity of the model. The rate of change seen in policy rate in the SS2 case is considerably lower than those seen in western countries after the coronavirus pandemic and leading up to subprime mortgage crisis of 2008[Trading-Economics, 2023]. This suggests that the control could have been more aggressive, but this might also lead to larger instabilities.

In the demand shock case the amplitude is almost unaffected but the average deviation is greatly reduced, suggesting interest rates effectively dampen the inflationary effects of long term surges in demand. Also here the rapidly changing policy rate causes small oscillations in the economy.

To further develop the model, making it more realistic, the dynamics of interest rate and how the effects of changes in interest differ between households and firms should be added. The model could also be expanded in some way to show the unwanted effects on unemployment and how this again affects the inflation rate. This would also bring a social aspect into the model where the goal is not necessarily just inflation control but also prosperity in society. The model developed in this thesis is made for long term analysis, but adjusting the model to more easily show the short term effects could be beneficial and necessary if this type of model is to be used by the entities governing monetary policies.

5.2 SS3

By looking at Figure 4.8 it is clear to see that dynamically increasing tax rates when inflation is rising has a dampening effect and also reduces the maximum deviation from the target inflation. In this model the time constants of households are much lower than those of the government and firms. This enables the controlling action to have this dampening effect by quickly reacting to increases in inflation with a time delay of about a month.

In the classical government type modelled here the government spends what it collects through taxes and therefore an increase in taxes leading to increasing income for government also leads to increased spending. This side effect can be seen in Figure 4.8 and Figure 4.9 where in the supply shortage case when things return to normal conditions the inflation rate drops slower than it did in the case with no controlling actions. This is because the increased taxes has created a temporary increase in government spending. This is also visible in the demand case where the inflation rises during the whole period as government spending steadily increases and money is let back out into the economy.

When operating an MMT type government this side effect goes away, as seen in Figure 4.11 and Figure 4.12. Here, the extra money collected through tax increases can be thought of as destroyed, or put into an account that the government doesn't need to spend from, e.g. "The Norwegian Government Pension Fund Global" in Norway. This both helps stabilize the inflation and lower the peak inflation rates.

The government spending dynamics used in this model is a strong simplification. "Destroying" the extra money collected through increased taxes should be entirely possible as it does not alter the planned budget. Increasing or decreasing the government budget is not an easy task, as much of the expenses are based on long term trends, e.g. the wages of government employees or pensions are not easily reduced. The government might put off investments in infrastructure, but this might also lead to lower productivity down the line and just delay the problem. Reducing spending and increasing taxes might also cause political problems for the governing party if the benefits are not great enough or not communicated to the people effectively.

When talking about inflation in a not self sustained country there is no escaping the imported inflation, and the exclusion of a foreign sector in this model is a knock on the credibility of the results. This exclusion also prevents the model from showing how the interest rate rides two horses, controlling both currency value and inflation. In order to make a truer model it should include some form of foreign sector and currency dynamics as a part of the system or as a disturbance.

From the results it is unclear how the interest rates and inflation affect the distribution of wealth in society. If the goal is to control the economy to insure the highest level of prosperity for all, this should be implemented in the model and studied further.

6 Conclusion

This thesis has analyzed how the economy reacts to inflation control. Both through the current situation with monetary control enacted by the central banks and through an alternative approach using fiscal policy. New digital technology to implement dynamic tax rates and transaction fees has also been simulated. These scenarios have been simulated using a developed dynamic model of price formation and a stock-flow model consisting of a central bank, commercial banks and the real economy. In all simulated scenarios the model of price formation seems to give realistic results. When using policy rate as sole control input, the economy settles at the desired growth rate given enough time. The policy rate is an effective control input in the case of demand-shock to the economy, but shows some tendencies to create oscillations and overshoot or undershoot in situations where rapid changes in actuation is necessary. With alternative methods using dynamic tax rates and transaction fees, the results are similar to those using policy rate, but exhibit less oscillation and faster response times, effectively lowering the peak inflation rates. The fiscal policies tested in this thesis were designed to incorporate wealth distribution and welfare along with affecting the aggregate demand. The results from the analysis of current control and simulations suggest that the current control system could benefit from incorporating more control inputs to enable more precise control of the states in the macroeconomy, e.g. the currency value and the inflation rate. A greater cooperation between monetary and fiscal policy measures also increases the effectiveness of both while reducing the side effects. Incorporating more inputs and greater cooperation should give the possibility of effective control that has a less damaging effect on social equality and welfare in society than controlling solely using policy rate, but further research is needed on the subject.

Further work

Suggested further work includes further developing the dynamic model of the economy incorporating the dynamics of currency value and its effect on imported inflation, developing a more detailed model of society to better the insight into the effects on wealth distribution and welfare. The new concepts for control of currency value here only discussed verbally could also be modelled and simulated. The perhaps most interesting possible future work would be working towards actual implementation of the concepts in the real world through pilot projects, local projects and finally country-wide implementation. This would also enable tuning of the model and parameters to be more realistic when given real world feedback.

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Appendix

A

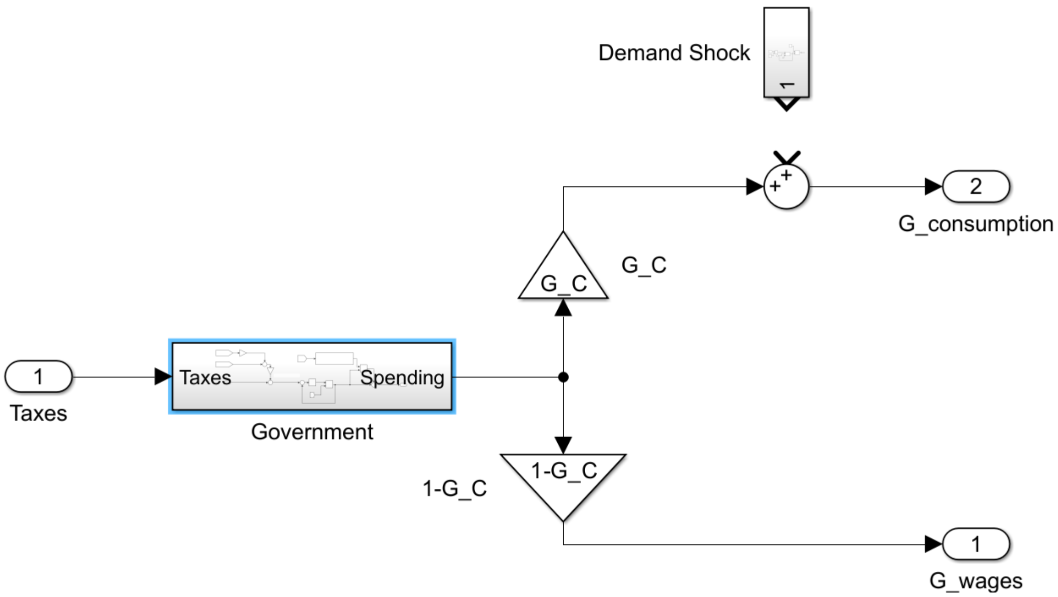

Figure A.1: Government implementation Simulink

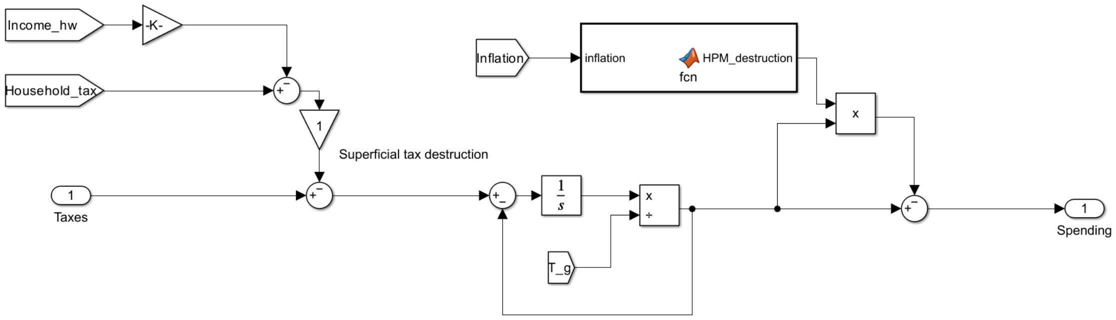

Figure A.2: Government implementation inside "Government" block Simulink

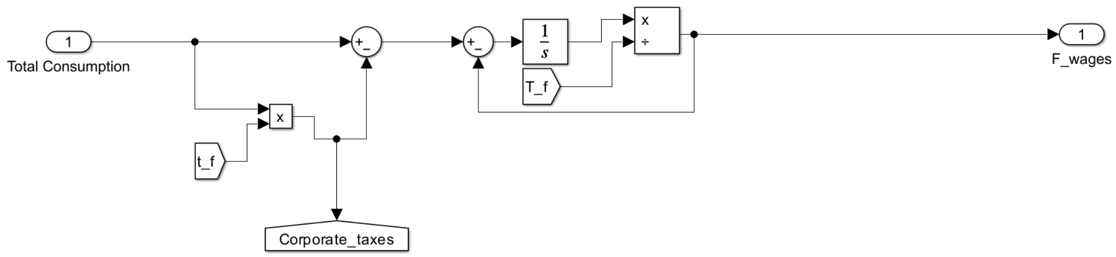

Figure A.3: Firms implementation

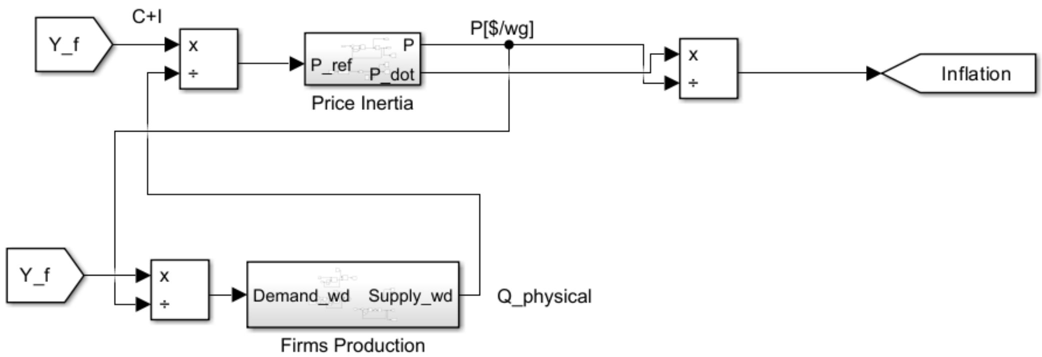

Figure A.4: Price Dynamics Simulink implementation

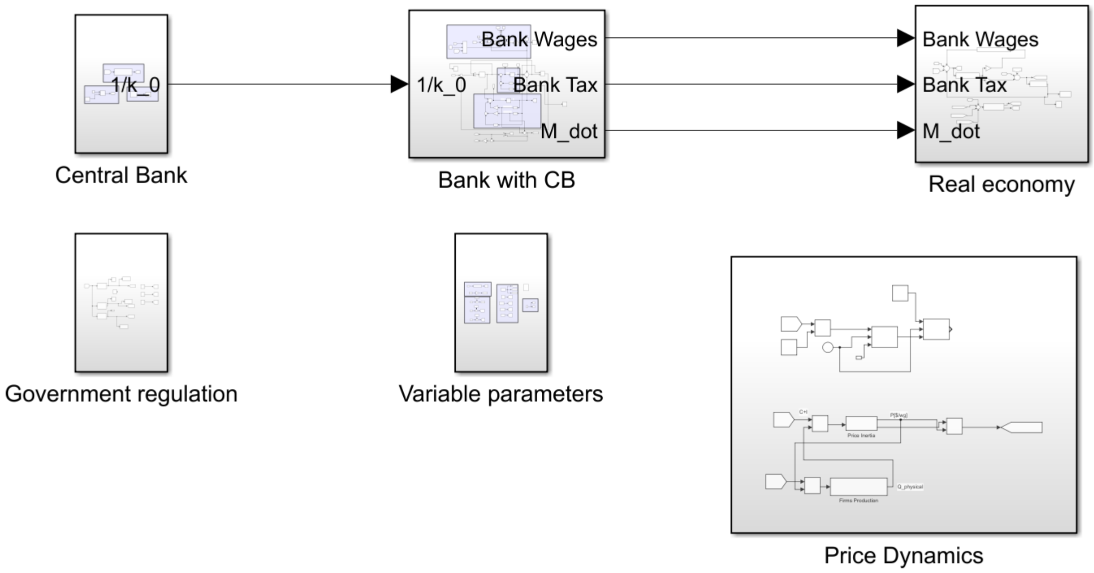

Figure A.5: Total Simulink system overview

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