Greening Q.E.

Evaluating effects of Green Quantitative Easing on Global Warming using a global ecological macroeconomic model

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Evaluating effects of Green Quantitative Easing on Global Warming using a global ecological macroeconomic model

Thesis submitted in fulfilment of the requirements for the degree of Master of Science in Engineering Policy Analysis

by

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Executive Summary

Key conclusions

- Evaluation in a stock-flow-fund ecological macroeconomic model shows that implementation of a globally applied policy of green Quantitative Easing by central banks can significantly contribute to a mitigation of climate change.
- A policy based on a broad interpretation of the ECB mandate leads to a mitigation of 12 % points compared to a baseline scenario. A policy based on a narrower interpretation of the ECB mandate leads to 6% points.
- Climate change undermines future financial stability, even if the central bank maintains price stability.

Quantitative Easing is a policy in which central banks purchase financial assets, financed by the creation of central bank reserves, as a tool for loosening monetary policy. Current implementation of QE contributes to global warming and counteracts a transition to a carbon-free economy.

This research first aims to analyse if the ECB's mandate allows for climate considerations in QE policy. Informed by the results of this analysis it formulates alternative policies for QE. The effects of alternative policies on climate change as well as on the stability of the macroeconomy and financial system are then analysed. The research question that it aims to answer is:

What is the effect on European carbon emissions of a policy of green Quantitative Easing by the European Central Bank that is consistent with its mandate?

Different ideas on the ECB's policy space

The legal basis for the establishment of the ECB is laid down in the different Treaties of the European Union. These mandate the ECB to pursue several objectives, the primary of which is price stability. Secondary objectives flow from its assignment to support the EU's economic policy, including those for "balanced economic growth", "full employment and social progress" and " a high level of protection and improvement of the quality of the environment."

Determination of the meaning of the hierarchy between primary and secondary objectives of central banks is subject to interpretation. We focus on two:

1. Current hegemonic consensus on the interpretation of the mandate is that the ECB must devote its undivided attention to its primary objective. This interpretation is consistent with New-Keynesian school ideas on monetary policy.
2. Following a more unorthodox interpretation, it is in the service of pursuing its primary objective that secondary objectives, like climate change considerations, should form an integral part of the ECB's monetary policy. This interpretation aligns more with Post-Keynesian ideas.

Understanding the effects of QE on the financial system and climate change

The fundamental mechanism through which asset purchases aim to influence spending and inflation is through increasing the liquidity of private sector balance sheets. This is supposed to push up asset prices and stimulates expenditure by lowering borrowing costs and increasing wealth. The central bank applies a principle of market neutrality in their corporate bond purchases. This leads to an over-representation of carbon intensive sectors in the ECB's portfolio, resulting in higher overall carbon emissions.

Alternative policies for a green(er) QE

We formulate two (sets of) policy alternatives, each consistent with one interpretation of the ECB's mandate.

1. A policy alternative that avoids major adjustments in the asset mix, currency denomination and maturity and that keeps the list of eligible assets within each asset class as broad as possible. In this scenario, central banks achieve a 50% smaller carbon footprint of their portfolios. Conventional bond holdings remain unchanged.
2. Central banks employ their ability to create reserves to purchase outstanding green corporate bonds in the market in order to finance a transition to a carbon neutral economy. At the same time excluding all conventional bonds from their portfolios. This alternative has two version. One in which central banks purchases 90% of green bonds in the market, one in which central banks purchase 75%.

Effects of green QE

Evaluation in DEFINE, a stock-flow-fund ecological macroeconomic model, shows that for the first policy alternative, the rise in atmospheric temperature is reduced by about 6% points in 2100, compared to the baseline scenario. This equals the alternative when 75% of green bonds are purchased. The mitigated temperature rise in the most far reaching policy alternative is more: 12% points lower than in the baseline scenario. The deviation in temperature rises in different scenarios becomes apparent from 2040. Through lowering financing costs, green QE policies lead to higher shares of green investment and green capital, apparent immediately after implementation. More green capital leads to higher shares of renewable energy which leads to lower levels of CO_2emissions.

Stability of the financial system is evaluated through effects on firms' default rates and on leverage ratios of banks. The model shows that global warming, through climate damages, affects macroeconomic performance and financial stability. These effects become apparent around 2050 and due to the nonlinear nature of climate damages, accelerate faster than proportionate to the actual rise of temperature. When no mitigating measures to climate change are taken, bank leverages approach critical levels to the end of the century. These threaten stability of the financial system, one of the secondary objectives of the ECB. Implementation of policy alternatives dampen this deterioration. This is caused by mitigating effects on global warming and the damaging consequences thereof.

Policy implications for the ECB

Green QE is a policy alternatives that is available and consistent with the ECB's mandate. Introduction of either of the policy alternatives is not enough to limit global warming to below 2.0°and preferably 1.5°C compared to pre-industrial levels that was agreed on in the Paris agreement. But its effects justify a consideration on whether green QE should be part of a greater package of measures.

Our results furthermore imply that the assumption that if price stability is maintained, financial stability is assured does not hold in the face of global warming. Climate change undermines financial stability in the future, even if the central bank maintains price stability. These insights justify the inclusion of climate change considerations in the ECB's (and other central banks') monetary policy strategy.

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Glossary

ABSPP	Asset-backed Securities Purchase Programme
APP	Asset Purchase Programme
BoE	Bank of England
CB	Central Bank
CBI	Central Bank Independence
CSPP	Corporate Sector Purchase Programme
CBPP3	Third Covered Bond Purchase Programme
DEFINE	Dynamic Ecosystem-FINance-Economy model
ECB	European Central Bank
ESCB	European System of Central Banks
Fed	Federal Reserve System (Central banking system USA)
GVA	Gross Value Added
NAIRU	Non-Accelerating Inflation Rate of Unemployment
NGFS	Network for Greening the Financial System
NK	New-Keynesian
PK	Post-Keynesian
PKES	Post-Keynesian Economics Society
PSPP	Public Sector Purchase Programme
QE	Quantitative Easing
TFEU	Treaty on the Functioning of the European Union
TEU	Treaty on the European Union
WMO	World Meteorological Organization

Introduction

A spectre is haunting the European Central Bank - the spectre of climate action.

In July 2021, the European Central Bank (ECB) presented an action plan to include climate change considerations in its monetary policy strategy (ECB, 2021b). The plan was preceded by statements from the president of the ECB, Christine Lagarde, who on several occasions expressed her desire to take responsibility in the fight against global warming (Khalaf & Arnold, 2020; Lagarde, 2020, 2021). As climate change impacts price stability and thus the central bank's primary objective, she reasons that climate change considerations should form an integral part of its monetary policy strategy (Chistine Lagarde, 2021).

Lagarde's ideas entail a significant departure from the current consensus on the conception of the central bank's mandate. Thence, she has stood on the receiving end of criticism from other central bankers, including Jens Weidmann, head of the Bundesbank and Janet Yellen, former president of the Federal Reserve (and present US Secretary of the Treasury) ('The Economist', 2020). They worry about mission creep at central banks and point out that climate change is a job for elected officials.

Despite the criticism, Lagarde's is not a lone voice. Almost a decade ago, the governor of the Bank of England and the UK's Chief Scientific Advisor made appeals for climate considerations in monetary policy (Clark & Giles, 2014; Harvey, 2012). In 2017, the United Nations Environmental Programme published a study on the role of central banks in enhancing green finance (UNEP, 2017). Several academics showed the detrimental effects of current monetary policies and suggest climate-friendly alternatives (Dafermos et al., 2020; Jourdan & Kalinowski, 2019; Matikainen et al., 2017). Moreover, the ECB is not the only central bank heeding to these calls. The Bank of England is also considering how it might support the transition of the UK economy to net zero emissions (Bank of England, 2021).

One of the avenues that Lagarde intends to explore is that of green quantitative easing (QE). QE is a monetary policy in which central banks purchase financial assets from the open market to increase the money supply and encourage lending and investment, thereby stimulating the economy. To avoid distortionary effects on the market, the ECB applies the principle of market neutrality. The proportion in which assets of different sectors are purchased represents the respective presence of these sectors in the eligible corporate bond market. In practice, this strategy leads to an unintended bias towards carbon-intensive sectors, thereby actively inhibiting the transition to a low-carbon economy (Dafermos et al., 2020).

Green QE is a strategy in which asset purchases are applied to benefit rather than frustrate the transition to a low-carbon economy. In theory, the effects of green QE policies can be significant. The amounts of money involved in quantitative easing are massive and have further increased now that central banks announced asset purchase programmes in response to the Covid crisis. In December 2020 the ECB decided to increase the initial Covid programme with €500 billion to a total of €1.85 trillion (ECB, 2020). This adds to the bank's regular €2.80 trillion asset purchase scheme. Also outside Europe, in the US, the Federal Reserve announced a $700 billion crisis programme (Federal Reserve Board, 2020).

This thesis assesses the effects of green QE policies on climate change as well as on the stability of the

macroeconomy and financial system. Analysed policy alternatives are aligned with interpretations of the ECB's mandate. The thesis aims to contribute to the ongoing debate on climate consideration in monetary policy. A lot of research is already being done on policies to mitigate climate change, but until recently, most research focused on fiscal policies (such as carbon taxation and public investment) and not on monetary policy.

Thesis Structure

Chapter 1 extends the problem definition and presents a research approach. In chapter 2 we explore the ECB's mandate and the different perspectives on the policy space that it allows for. In chapter 3 and chapter 4 we develop a better understanding of QE and the system in which its consequences come into effect. Chapter 5 presents the experimental set up. Chapter 6 presents the results. These lead to conclusions described in chapter 7. In chapter 8 we reflect on the conducted research.

Problem Definition and Approach

1

This thesis analyses the scope for and the effects on carbon emissions, climate stabilization and economic performance of green QE policies by central banks. In this chapter, we present a review of the relevant literature on this issue, which will help to define, discuss and contextualise the main concepts – including QE and market neutrality – as well as monetary policy instruments. Through a review of the academic and policy literature, this chapter will identify a knowledge gap and arrive at a question for research. The procedure for literature selection is explained in appendix B.

1.1 Research needed on effects of Green QE on climate change

Quantitative Easing (QE) is a monetary measure that central banks employed after the 2007 financial crisis to influence interest rates and stimulate growth. Through purchase programmes of financial assets from the open market, central banks increase the money supply and encourage lending and investment (Investopedia, 2021b). The reasoning behind QE is that the purchases raise the price of these obligations and create money in the banking system. This leads to lower interest rates and cheaper borrowing for corporations and households. Cheaper borrowing is expected to lead to increased lending for consumption and investment, higher demand and therefore higher economic growth (ECB, 2021c). QE programmes may include public sector bonds, asset-backed securities, covered bonds, corporate bonds, or equities (Matikainen et al., 2017).

The amounts of money involved in QE programmes are astronomical and have further increased now that central banks are announcing programmes in response to the Covid crisis. The ECB started its Asset Purchasing Program (APP) in 2015. It consists of a Policy Sector Purchase Program (PSPP), a Corporate Sector Purchase Program (CSPP), an Asset Backed Securities Purchasing Program (ABSPP) and a Covered Bonds Purchasing Program (CBPP3). After temporarily ending the purchases in 2019, the ECB announced that it would resume its programme in early 2020. This initial Covid programme of €1.35 trillion was later raised in December by €500 billion to a total of €1.85 trillion (ECB, 2020). This added to the bank's then regular €2.8 trillion asset portfolio. Figure 1.1 and 1.2 present these amounts graphically.

In July 2021, the ECB (2021b) presented an action plan to include climate change considerations in its monetary policy strategy. Before this plan is implemented (which is not before late 2022), the ECB does not take climate change into account in its QE programmes. The official position of the ECB is that it aims to avoid distortionary effects of its policies on the financial markets. It materialises this in its QE programmes by applying the market neutrality principle, which means that the sectoral decomposition of its purchases mirror that of the eligible corporate bond market (Dafermos et al., 2020).

The evidence is mounting that the market neutrality principle, has practical implications that are in fact not neutral at all. The ECB's interventions show an unintended structural bias towards assets (bonds) of carbon-intensive corporations, simply because these carbon-intensive firms dominate the European economy and bond markets. Not only is the ECB reinforcing the status quo by mirroring the existing market,

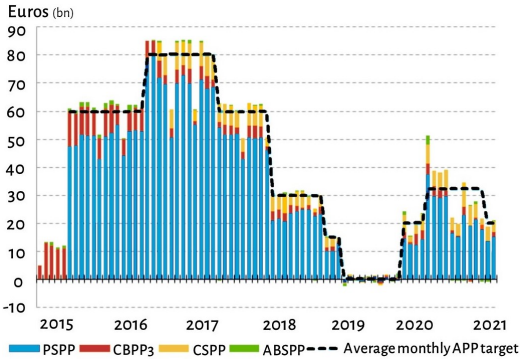

Figure 1.1: Average *monthly* APP targets by Programme (ECB, 2021a)

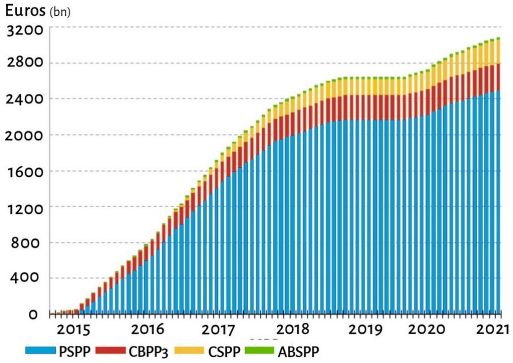

Figure 1.2: Cumulative APP Net Purchases by Programme (ECB, 2021a)

it is actively resisting a transition to a decarbonized economy (Dafermos et al., 2020; Matikainen et al., 2017; van 't Klooster & Fontan, 2019).

Research shows that the market neutrality principle leads to an overrepresentation of high-carbon sectors in the ECB purchases compared to their contribution to gross value added or employment (Dafermos et al., 2020; Jourdan & Kalinowski, 2019; Matikainen et al., 2017). Whereas 63% of assets bought through the ECB's corporate sector purchases were issued by businesses operating within the most carbon emitting sectors (like extraction and distribution of fossil energy sources, car, and equipment manufacturing), only 7% of the portfolio represents sectors and activities that are more in line with climate objectives (such as green bonds and the railway sector) (Jourdan & Kalinowski, 2019).

As the asset purchases are supposed to benefit the whole market, the idea is that this imbalance does not create unwanted advantages to specific corporations or sectors. However, evidence suggests that this assumption does not hold: corporations of purchased bonds benefit disproportionately compared to others. One of the effects of the purchases is that they create better financing conditions for these companies. Bond yields of corporations that are eligible for purchase decline by about 15 points (Abidi & Miquel-Flores, 2018). These corporations can thus borrow cheaper to obtain resources for investments and operations.

Conclusion 1 **Current, supposedly market neutral, policy inadvertently favours high-carbon sectors.**

When the information changes, some alter their conclusions. The mounting evidence against the supposedly neutral approach culminated in the aforementioned ECB announcement to include climate change considerations in its monetary policy strategy. Part of the new strategy is that the ECB will include climate change criteria in the framework that guides the allocation of corporate bond purchases (ECB, 2021b). Proposals for the new framework are expected in 2022. Alternatives are currently being researched.

For its research on a new QE framework the ECB can draw from existing literature. Many of the authors who exposed current policy as skewed towards high-carbon sectors, also proposed alternatives to the market neutrality principle (Dafermos et al., 2020; Jourdan & Kalinowski, 2019; Matikainen et al., 2017). Authors have estimated the likely consequences of these different policy alternatives for the distribution of sectors within the ECB bond purchasing portfolio. The literature on the extended effects of other purchasing strategies on factors like emissions, macroeconomic growth or stability of the financial system, however, is limited.

The effects of green QE policies would manifest themselves through the channel of green investment. To become climate-neutral by 2050, the European Commission (2019) estimates that the EU needs up to €290 billion in additional yearly investments over the coming decades. One could not be blamed for

having a hunch that the amounts involved in the ECB's monetary policy could contribute to a closing of this investment gap.

Research on the relationship between renewable investments, climate change and economic activity has been done. Eyraud, Clements, and Wane (2013) analyse the trends and determinants of renewable investments over the last 35 years. They conclude that green investment is boosted by economic growth, a sound financial system conducive to low interest rates, and high fuel prices. They also find that policy interventions have a positive and significant impact on green investment. Murovec, Erker, and Prodan (2012) support the conclusion that environmental investments in firms are amongst other factors dependent on policy measures. Romano, Scandurra, Carfora, and Fodor (2017) caution that the same policies are not appropriate to different types of countries with differentiated level of economic development. Dafermos and Nikolaidi (2021a) present a model that analyses the interactions between the ecosystem, the financial system and the macroeconomy that explicitly incorporates, amongst others, the impact of finance on economic activity, thereby distinguishing the role of central banks.

Only one of the publications that we found has explicitly assessed the impacts of greener asset purchase programmes on green investment, carbon emissions and climate change. Dafermos, Nikolaidi, and Galanis (2018) suppose that central banks start purchasing 25% of the total amount of green bonds and analyse how this affects climate change and financial stability. In their simulation, green QE leads to lower CO_2 emissions and slower global warming albeit not enough to by itself prevent a substantial rise in atmospheric temperature. Furthermore, green QE benefits financial stability. These are interesting results that call for a more extensive analysis to expand the understanding of the underlying mechanisms.

Conclusion 2 **More research is needed on the consequences of green QE policies on climate change through green investment.**

1.2 Limited policy space due to lack of consensus on position of Central Banks in light of climate change.

It is interesting to explore why, in spite of the evidence of its detrimental effects, the ECB applies the market neutrality principle. We will see that the difficulty lies not so much in developing new ideas as in escaping from old ones.

Before the very recent announcements by the ECB (2021b) and Bank of England (2021), the reactions of central banks to climate change were limited. Notwithstanding initial explorations of the topic, climate change was not taken into account in the monetary policies of Western central banks (Van Tilburg & Simić, 2021). This inaction is despite a growing acceptance of the view that central banks can no longer ignore global warming (NGFS, 2020b).

The ECB's primary responsibility is stability in prices and currency. This stability requires general economic and financial stability (Van Tilburg & Simić, 2021). The idea that climate change affects the ECB leans on two main arguments that derive from this responsibility: (1) Climate change affects the stability of the financial system. (Carney, 2015; Matikainen et al., 2017; Van Tilburg & Simić, 2021). (2) Climate change affects the ability of central banks to achieve price stability (NGFS, 2020a). Central banks themselves acknowledge the fact that climate change will increase the fragility of the financial system and create substantial climate-related risks, inter alia through house prices and mortgages (NGFS, 2020b). Because central banks have to protect the stability of the financial system, it is within their mandate to actively deal with climate change and associated risks.

The recent changes of direction by the ECB and BoE fit in an increasing consensus on the non-sustainability of central banks' abstention in climate policy. Mark Carney, former Governor of the Bank of England first discussed how the shifts in our climate bring potentially profound implications for financial stability and the economy (Carney, 2015). These remarks were followed by several other central bankers (Benoît Coeuré, 2019). In 2020 after a survey among 107 central banks, the NGFS concludes that the large majority of central bankers thinks that climate change affects monetary policy (NGFS, 2020b).

For a long time, the broad consensus on the effects of global warming to central banking did not lead to climate change considerations becoming part of monetary policy. Authors give several reasons. Carney (2015) discusses the 'tragedy of the horizon' embedded in the different time spans that characterize monetary and financial stability policies and the much longer-term perspective required to deal with climate-related risks. Dafermos (2020) states that active measures are hampered due to the fact that the consensus does not extend to *how* central banks should include climate considerations, with the key controversy revolving around the role that central banks should play. Whereas some argue that central banks should play a proactive role in the transition to a low-carbon economy and thus reducing climate-related risks, others say that its role should be limited to mitigating the exposure of the financial system (Dafermos, 2020).

Countering the calls for more climate considerations in central bank policy, stand officials who argue to limit these consideration. Though not contradicting the effects of climate change on central banking, former ECB board member Benoît Coeuré (2019) warns that the ECB cannot lead the fight against climate change. Jens Weidman, president of the Bundesbank, also rejected calls to include environmental goals in its QE programme, arguing that monetary policy that explicitly pursues environmental goals runs the risk of becoming overburdened (Piotr Skolimowski, 2019). Both want the ECB to concentrate its efforts on supporting market participants, legislators and standard-setting bodies in identifying the risks emerging from climate change and providing a clear framework to reorient financial flows and reduce such risks.

Conclusion 3 **There is consensus that climate change affects central banks, but not on how central banks should include climate change in their operations.**

The fault is not in the stars, it is in the conventional ideas on central banking. Let us explore the arguments against a more proactive role for central banks in mitigating climate change a bit further to gauge their validity. The arguments that are brought forward circle around the distinction of political, fiscal policy versus supposedly apolitical, monetary policy. In the 1970s and 1980s, a macroeconomic consensus arose that this distinction should be reflected in the policy constellation and that central banks should enjoy a large degree of independence from governments. Only through their independence are central banks best positioned to balance growth and inflation (Dall'Orto Mas, Vonessen, Fehlker, & Arnold, 2020; E. Jones & Matthijs, 2019).

The main rationale behind central bank independence is to guarantee credibility of monetary policy (Harcourt, Kriesler, & Halevi, 2018). It is argued that the credibility of monetary policy has a fundamental impact on expectations of inflation, which is a major factor in actual inflation. Governments cannot be endowed with the power to set monetary policy as they will opportunistically abuse it to game the electoral calendar. Central banks in their turn should stay away from policies that fall in the realm of politics and focus on their primary responsibility of price stability and stable currencies.

For decades, the consensus around general central bank independence was all but set in stone but has very recently started moving, set in motion by publications criticizing its underlying principles, its practical implication or both. Harcourt et al. (2018) argue that its justifications are strongly tied to the underlying neoclassical model of the economy, especially of the 'natural rate' of unemployment and the long run neutrality of money. Consequently, central bank independence is the result of political, rather than economic factors. To insulate the central bank from the government is to insulate it from accountability from the electorate, which is at odds with basic democratic principles. E. Jones and Matthijs (2019) see advantages of insulating central banks in normal times but propose that in times of crisis or unconventional measures, there should be more accountability. Even the World Bank published a critical paper in January 2021 linking central bank independence to rising inequality (Aklin, Kern, & Negre, 2021).

Balls, Howat, and Stansbury (2018) also notice that the pre-crisis academic consensus about central bank independence has broken down. They distinguish political accountability from operational independence and while they argue that a retreat on operational independence would be a mistake, they see room for more political accountability in terms of mandate-setting and appointment of officials, and oversight of wider financial stability powers. Van Tilburg and Simić (2021) draw the historic development of central

banks' mandates. They point out that central banks have often acted as financiers of crisis or emergency responses and demonstrate many historical precedents for a developmental role of central banks in helping to finance large transitions and show that they can do so without sacrificing price stability (Van Tilburg & Simić, 2021).

Conclusion 4	**The key argument against a proactive role for Central Banks in climate policy (central bank independence), is contested.**

1.3 Synthesis: Knowledge Gap and Research Question

The effects of climate change considerations in policy alternatives for QE by the ECB on climate change are not comprehensively known. Green QE has the potential to contribute significantly to the mitigation of climate change. This is halted by a lack of consensus on whether it is fitting within its role. The ECB is limited in its policy space by current interpretations of its role. Current interpretations however, lead to policy that unintentionally counteracts a transition to a carbon-free economy. The key argument behind the current interpretation of the role of monetary policy vis-à-vis fiscal policy is contested. This does not take away the fact that alternative policies can only be successful if they are substantiated by an analysis of their compatibility with the ECB's mandate.

There is currently a debate going on in academic as well as in policy circles. Academic articles on the subject are being published as recent as in this year and the ECB and BoE are currently working on new strategies. A better understanding of the consequences of different strategies for green QE will benefit the ongoing debate. We aim to make this contribution. The Research Question that we try to answer is:

Research Question	**What is the effect on European carbon emissions of a policy of green Quantitative Easing by the European Central Bank that is consistent with its mandate?**

1.4 Research Approach and Methods

This section presents the approach of the proposed research. It identifies the different phases that are to be consecutively taken to reach the research objective and answer the main research question. These phases lead to subquestions.

Research Objective	**To produce a better understanding on the consequences on carbon emissions of policy scenarios for Green Quantitative Easing by the European Central Bank that is consistent with its mandate.**

We will aim to reach the research objective by answering four consecutive subquestions. These are listed below. The next paragraphs provide a further explanation of the subquestions, how they relate to each other and describe the methods that are employed in the different research phases. Figure 1.3 represents the mutual coherence of the subquestions as wells as the research's flow through the different phases.

Subquestion 1	**How do different perspectives on its room for discretion lead to conditions for policy alternatives for green QE by the ECB?**
Subquestion 2	**How can a conceptual model describe the effects of green QE on the macroeconomy and ecosystem?**
Subquestion 3	**What are policy scenarios for green QE that are consistent with the ECB's mandate?**
Subquestion 4	**What are the effects of policy scenarios for green QE on climate change?**

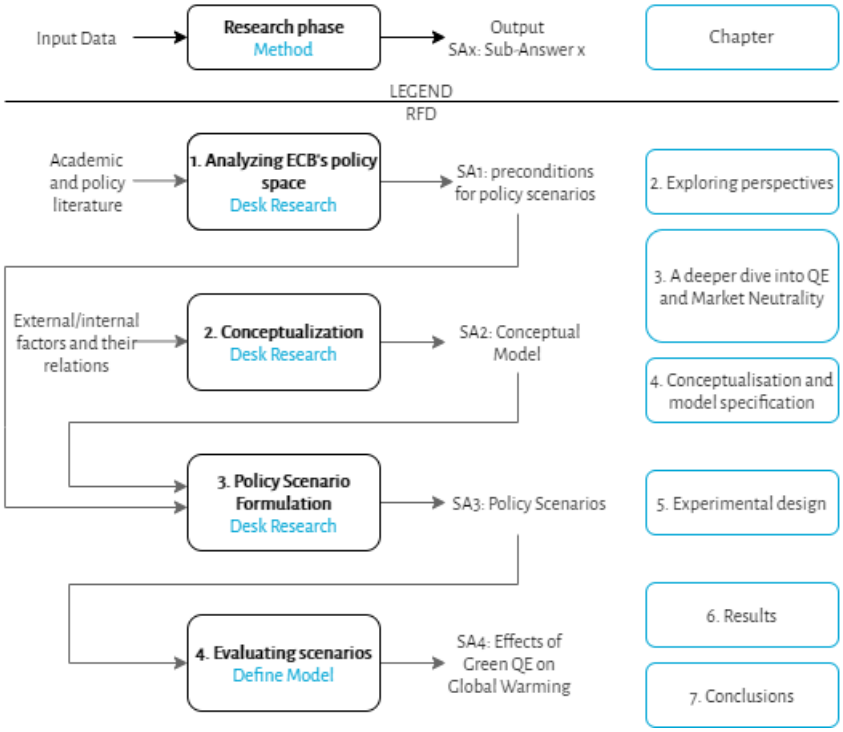

Figure 1.3: Graphical representation of Research Flow.

1.4.1 Analyzing Market Neutrality

The ECB is institutionally bound to its mandate. Its available policy space for including climate considerations is therefore limited. This phase of the research is conducted to develop a thorough understanding of interpretations of the available policy space. This knowledge is needed to understand the options that the ECB has for viable policy alternatives.

In this section we will work towards illustrations of two general visions on market neutrality and its implications for ECB policy. We will try to embed these visions in different macroeconomic schools of thought. The first one is the conventional vision in which market neutrality is defined in the standard interpretation. The argumentation stays within the new-Keynesian paradigm. In the other perspective, there is more room for a broader interpretation of the ECB's mandate. This argumentation will be consistent with more post-Keynesian ideas.

The research in this phase will be conducted through literature analysis. The input data will be academic as well as policy literature. The output consists of conditions for policy alternatives. These serve as boundaries and selection criteria in the formulation of different policies in later phases of the research. We conduct this phase of the research in chapter 2.

1.4.2 Conceptual Model

This section develops a conceptual understanding of the system in which the ECB's policies sort their effects. The effects of the ECB's policy will occur in a dynamic complex system. Understanding of this system, its important factors and their relations is required to be able formulate effective policy alternatives and assess their effects. The conceptual model will be centred around the feedback loop between the proportion of green and brown investment, global warming and the economy. High investments lead to a thriving economy. Economic activity results in carbon emissions, which result in global warming and a deterioration of the ecosystem. This in turn reduces economic output due to damages. Crop yields might fall, diseases spread and rising seas might consume coastal cities. As opposed to brown investments, green investments

are done in capital with lower or no emissions, dampening this effect. The ECB's policy alternatives affect this system by influencing the proportion of green/brown investment. With the ECB as big provider of money for green investment, costs of green compared to brown investment might decrease, leading to more green investment.

The input of this section will be the ex- and internal factors in the system and their relation. The output consists of a detailed conceptual model that provides the logic behind the formulation of potentially effective policy alternatives and the assessment of their consequences.

In this chapter we will look for an appropriate model in the existing literature to conduct our calculations with. The conceptual model will have to be compatible with the underlying logic of the model we choose. We will find that DEFINE is appropriate for our research. DEFINE is a stock-flow-fund model that was developed by Dafermos and Nikolaidi (2021a). It analyses the global interactions between the ecosystem, the financial system and the macroeconomy and incorporates explicitly, amongst other factors, the impact of carbon emissions on climate change, the endogeneity of money and the impact of finance on economic activity. Importantly, central banks are also included in the model. They determine the base interest ratio, provide liquidity to the banks and purchase government securities and corporate bonds i.e. engage in QE.

The 1.1 version of the DEFINE model incorporates factors that make it especially suited to answer the questions that we are interested in. It makes an explicit distinction between conventional investments with different degrees of carbon emissions for different sectors of the economy. It incorporates carbon taxes and green subsidies. It introduces green public investment. It incorporates loan spreads that are endogenous, which means that we can model the costs of borrowing (Dafermos & Nikolaidi, 2021a). These are all relevant factors in an analysis of the effects of different policies for green QE by central banks.

This phase of the research is done in chapter 3 where we first develop a better understanding of Quantitative Easing, its theoretical underpinnings and its practical effects. The actual conceptual model is formulated in chapter 4. Chapter 4 is also where we explain DEFINE more extensively.

1.4.3 Defining Policy Scenarios

This section builds on the previous sections to formulate policy alternatives for green QE. The policy alternatives have to correspond to the alternative interpretations of the ECB's mandate. We will therefore use the conditions that followed from different interpretations to demarcate the space wherein the policies are formulated. Also, we use the obtained understanding of the complex system in order to identify relevant factors that might affect the outcome of our policies. These might be external or internal factors. Varying the values of these factors in the experiment will allow us to improve our understanding of their importance. We come to a set of scenarios by combining policy alternatives with different values for important factors. This takes place in chapter 5.

1.4.4 Effects of Policy Scenarios

In this phase we work towards a better understanding of the effects of policy scenarios on climate change, the macroeconomy and stability of the financial system.

We are not only interested in the values of the specific indicators after simulation, but especially in the mechanisms behind them. This phase will therefore contain an analysis of the important factors with the biggest influence. We will look at how the different results come into being and at how we can characterise the different causal relations.

Our interest lies in the effects of our interventions in the bond market on climate change. Included in our results are therefore the effects on renewable energy, emissions and global atmospheric temperature. These effects come into being through our interventions' influence on bond markets, green investment and capital. We analyse these to understand the mechanisms behind their influence.

As it is conditional to the formulated alternative policies that they are consistent with the mandate and do not destabilize the macroeconomy or the financial system, we look at developments in these domains as

well. Growth rate of output and total output to analyse the former and stability of the financial system is evaluated through effects on leverage ratios of banks and firms, firms' default rates and profit.

This phase of the research is presented in chapter 6.

1.4.5 Conclusion, Reflection and Recommendations

In the last phases, we interpret our results and answers to the different subquestions to formulate a conclusion about the main research question. We indicate the policy implications for the ECB of our results.

Finally, we reflect on the conducted research by identifying and scrutinizing assumptions and limitations. Following a framework for critical reflection, we first scrutinize our own steps that we took in the course of the research. These steps include the problem description, methodology, conceptualisation, specification and model use. After the critical reflection, we evaluate the academic and societal relevance of the research. The phase finishes with recommendations for further research.

This work is done in chapter 7 and chapter 8.

Exploring perspectives on ECB's room for discretion

2

This chapter explores the outer bounds of the policy space within which the ECB can navigate. We first briefly outline the historical context of central banks role before we assess the current role of central banks. The mandate plays a central role in the policies of the central bank. It justifies its existence and stipulates the room in which the ECB policy can navigate. Opponents of climatic actions justify their stance with an appeal to the mandate (Benoît Coeuré, 2019; Piotr Skolimowski, 2019)). Even proponents of climate considerations either justify this with an appeal to the mandate or acknowledge that alternative policies have to be consistent with the mandate (Campiglio et al., 2018; Lagarde, 2021; UNEP, 2017). Before formulating alternative policies, it is therefore important to explore the outer bounds of the policy space.

Mandates are words on paper. It is subject to interpretation what these words exactly mean and what this implies for policy. The interpretations vary depending on the macroeconomic school of thought. In this chapter, we explore the different interpretations of the mandate and the different ideas that exist on policy space for monetary policy by the ECB.

2.1 Central Banks role, a brief history of monetary policy

Throughout history, monetary policy has supported governments in confronting the challenges of their times. At first primarily as banks of issue and later increasingly as guardians of stability (Van Tilburg & Simić, 2021).

The groundworks for modern banking were laid in medieval Venice and early modern Amsterdam (Bindseil, 2019). The history started in 1157 with the establishment of the Bank of Venice, the first bank in Europe that was guaranteed by its state, the Venetian republic. Four hundred and fifty years later, the next step in the development of central banks was taken with the establishment of the first bank that was able to regulate the value of the notes that it issued, the Amsterdam Exchange Bank. This allowed the bank to perform open market operations to coordinate the financial system and manage financial crises. It performed these operations in 1763 and 1773 in which it provided emergency financing to failing banks.

Historically, central banks (a neologism applied to these historical institutions) have been established to provide their government with financial means other than borrowing or taxation, which were slow or politically costly (Van Tilburg & Simić, 2021). These institutions could create money to finance spending, oftentimes wars. The act of printing money to pay for government expenses is called monetary financing. The role of central banks as financiers of wars has continued into the twentieth century.

In the course of the centuries central banks, as issuers of money, have increasingly taken on the responsibility as keepers of stability (Van Tilburg & Simić, 2021). Stability of the currency and, by extension of the financial system as a whole. This responsibility requires central banks to find a balance in the amount of money that they issue. It must keep overall money creation within limits to prevent inflation. However, to

protect the stability of the economic system, especially in times of crisis, central banks rely on creating money to support the financial system.

2.1.1 Recent Monetary policy

The ECB has the objective to maintain price stability - operationalized as an inflation rate of 2 % - and subject to that, to support the EU's economic policy, including those for growth and employment (see chapter 2). This target is symmetric. If inflation looks set to fall below target, the Bank loosens monetary policy to boost spending and inflation. Similarly, if inflation is expected to rise above 2 %, the ECB tightens monetary policy to slow spending and reduce inflation.

The conventional way for central banks to conduct monetary policy is by setting interest rates for banks, also called the '*bank rate*' or the '*policy rate*' (Benford et al., 2009). Commercial banks hold central bank money in the form of reserve balances at the central bank and receive interest on those reserves at the bank rate. Banks then face the choice of holding reserves or lending them out in the market, and so market interest rates are influenced by the level of bank rate. When the central bank sets the bank rate, this influences the price of money. This feeds through to a whole range of interest rates faced by households and companies which in turn affects their spending decisions. As a result, by changing the bank rate, the ECB can influence consumption, demand and investment, and thereby also affect the level of economic activity and real GDP.

2.2 ECB Mandate

The responsibility for monetary policy decision-making in the euro area was given to the European Central Bank on January 1st 1999. The legal basis for the single monetary policy is laid down in the Treaty of the European Union (TEU), the Treaty on the Functioning of the European Union (TFEU), and the Statute of the European System of Central Banks and of the European Central Bank (ECB, 2011). The relevant excerpts can be found in Box 1.

The ECB is established as an institution of the EU in the Treaty of the EU (EU, 2012). The Eurosystem consists of the ECB and national central banks of the Member States with the euro as currency. The European System of Central Banks consists of the ECB and the 27 national banks of all member states.

Article 127 of the TFEU states that the primary objective of the ESCB is to maintain price stability and that without prejudice to the objective of price stability, the ECSB supports the general economic policies of the EU with a view to contribute to the objectives of the EU (EU, 2012). These objectives are laid out in Article 3 of the TEU and include the sustainable development of Europe based on balanced economic growth and price stability and a high level of protection and improvement of the quality of the environment.

The independence of the ECB is established in article 130 of the TFEU. The ECB is granted full independence from political inference in the fulfilment of its mandate. The article states that neither the ECB nor national central banks, nor any member of their decision making bodies are allowed to seek or take instructions from EU institutions or bodies, from any government of a Member State or from any other body. Governments must respect the principle of central bank independence.

Article 123 of the TFEU forbids monetary financing of public deficits by the ECB or other central banks. The financing of government deficits through central banks and the offering of preferential conditions to the public sector by financial institutions is prohibited. These prohibitions aim to increase the incentives to maintain fiscal discipline as well as contribute to the credibility of the single monetary policy in the pursuit of price stability (ECB, 2011, p. 35)

The ECB interprets the treaties as establishing a hierarchy of objectives for the Eurosystem (ECB, 2011, p. 14). Not only does the TFEU refer to price stability as the ECB's primary objective, it is also an objective of the EU as a whole. The Governing Council of the ECB quantifies price stability as a "year-on-year increase in the Harmonised Index of Consumer Prices for the area of below, but close to, 2% over the medium term " (ECB, 2011, p. 64)

Box 2.2.1: Key provisions from Treaties

This box includes key provisions on monetary policy, climate change or quantitative easing from the Treaty on the European Union and the Treaty on the Functioning of the European Union (EU, 2012). **Emphases** added.

TREATY ON THE EUROPEAN UNION

Article 3	The Union shall establish an internal market. It shall work for the sustainable development of Europe based on balanced economic growth and price stability, a highly competitive social market economy, aiming at full employment and social progress, and **a high level of protection and improvement of the quality of the environment.** It shall promote scientific and technological advance.
Article 13	The Union shall have an institutional framework which shall aim to promote its values, advance its objectives, serve its interests, those of its citizens and those of the Member States, and ensure the consistency, effectiveness and continuity of its policies and actions.

TREATY ON THE FUNCTIONING OF THE EUROPEAN UNION

Article 127	The primary objective of the European System of Central Banks [...] shall be to maintain price stability. Without prejudice to the objective of price stability, the ESCB shall support the general economic policies in the Union with a view **to contributing to the achievement ofthe objectives of the Union as laid down in Article 3** of the Treaty on European Union
Article 130	When exercising the powers and carrying out the tasks and duties conferred upon them by the Treaties and the Statute of the ESCB and of the ECB, neither the European Central Bank, nor a national central bank, nor any member of their decision-making bodies shall seek or take instructions from Union institutions, bodies, offices or agencies, from any government of a Member State or from any other body. The Union institutions, bodies, offices or agencies and the governments of the Member States undertake to respect this principle and not to seek to influence the members of the decision-making bodies of the European Central Bank or of the national central banks in the performance of their tasks.
Article 123	Overdraft facilities or any other type of credit facility with the European Central Bank or with the central banks of the Member States (hereinafter referred to as 'national central banks') in favour of Union institutions, bodies, offices or agencies, central governments, regional, local or other public authorities, other bodies governed by public law, or public undertakings of Member States shall be prohibited, as shal the purchase directly from them by the European Central Bank or national central banks of debt instruments.

2.2.1 Other central banks

It is interesting to take an excursion to the mandates that other central bank pursue. Monnin and Barkawi (2015) provide an overview of mandates of the G20 economies. These differ widely in their scope and focus. The ECB is not the only central bank to have a single or prioritized focus on price stability. But several other central banks have mandates that cover two or more objectives such as financial stability, full employment

and economic development.

Debates on the central banks objectives are not exclusive to the ECB. The question whether central banks should focus solely on price stability or should pursue more objectives constitute areas for debate with other central banks as well (Monnin & Barkawi, 2015).

This thesis focuses on the ECB's role in mitigating global warming but this is not the only topic subjected to debate. Another discussion is the addition of financial stability to the mandates of central banks. Following the financial crisis, proponents of an explicit financial stability objective underline that price stability may be a necessity, but is not a sufficient condition for macroeconomic stability. They advance the idea that monetary policy can and should play a role in the prevention, management and resolution of financial crises. Critics contend that monetary is not effective in the mitigation of financial crises (Monnin & Barkawi, 2015).

2.2.2 Preliminary interpretation of mandate

The mandate of the ECB describes the pursuing of several objectives. There is the primary objective of price stability and there are secondary objectives. Through the structure of the different treaties and through connections that are made between treaties by references to each other fig. 2.1.

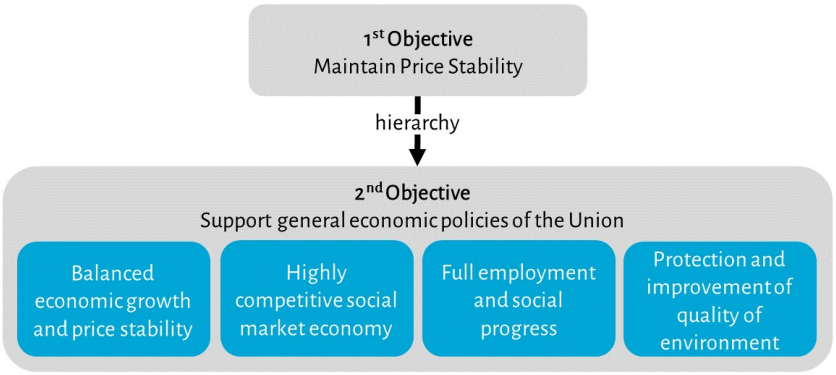

Figure 2.1: Graphical representation of ECB Mandate Structure

Monnin and Barkawi (2015) describe how different objectives can only co-exist insofar as there is no or very limited trade-off between them. Whether one advocates for expanded or narrow mandates will depend significantly on whether one sees trade-offs between the different objectives (Monnin & Barkawi, 2015, p. 165). The ECB views its primary objective of price stability as aligned with its secondary objectives. Its view is based on an economic model in which central bank credibility is at the center of inflation expectations, and an increase in these expectations raises both inflation and output variability (Monnin & Barkawi, 2015).

The ECB indeed sees the objectives as aligned but only as long as the primacy is put with the primary objective. The alignment only goes one way. Through the establishment of price stability, the ECB contributes to its secondary objectives. On the other hand, if the ECB would put too much emphasis on the secondary objectives, this impedes its ability to keep prices stable. Through mission creep (Benoît Coeuré, 2019) or through overburdening of monetary policy (Piotr Skolimowski, 2019).

Others contend that climate change affects the ECB and its ability to achieve price stability, either directly (NGFS, 2020a) or through its affection of the financial system (Lagarde, 2021; Matikainen et al., 2017; Van Tilburg & Simić, 2021). Following from this perspective, it is in the service of pursuing its primary objective that the ECB must employ measures to mitigate climate change.

We have to take a deeper dive into different views on economics to put these different views in perspective.

2.3 Macroeconomic Schools

The discipline of economics is divided into different schools of economic thought. A school is a group of economics who share a common perspective on how the economy works. They share the same presumptions and understanding of underlying mechanisms. We review two such schools. The New-Keynesian school is very influential in contemporary thinking. Post-Keynesian is more marginal in terms of influence but is gaining ground the last years.

2.3.1 General principles New-Keynesian school

New-Classical (NC) and New-Keynesian (NK) economics are the dominant schools of thought in today's macroeconomics. Apart from some disagreements, these schools are very much alike. Servaas Storm and Ro Naastepad explain the fundamentals of the New-Keynesian school. We present a boiled-down explanation below, derived from their lecture notes (Storm & Naastepad, 2020c, 2020b).

The central tenet of New-Keynesian macroeconomic models is the Phillips curve trade-off between unemployment and inflation: the idea that low unemployment leads to high inflation and vice versa. This follows from how determining factors in the economy are interrelated in a feedback loop, represented in the central circle in fig. 2.2. We use this figure to explain the central idea of NK economics.

For our explanation, we start at wages. These are determined in the bargaining process between employers and employees. The rate of labour supply/demand is a decisive factor in these negotiations. Labour supply is exogenously determined, this is the existing workforce. Labour demand is dependent on the current level of GDP. High labour demand with low supply, meaning a low rate of unemployment, enhances the bargaining power of employees, leading to higher wages. Contrarily, high unemployment weakens employees' bargaining power relative to employers', leading to lower wages.

Together with labour productivity, wages in turn affect prices. If wages grow stronger than labour productivity (the second being exogenously determined), employers pass on the higher labour costs to their products, leading to higher prices. This causes inflation.

The implication of this mechanism is that we can never have low inflation as well as low employment. Low unemployment leads to higher wages, leading to higher prices, resulting in high inflation. Policy makers are thus forced to explicitly choose between either low inflation with high unemployment, or low unemployment with high inflation. The values of which are determined by the Phillips curve. This trade-off constitutes the core of all NK macroeconomic models – and of monetary policy-making by central banks.

Inflation is inherently unstable, enter NAIRU

As is the case in our explanation above, before the 1980s the feedback loop shown in fig. 2.2 was not closed. This gave policy makers the possibility to play around with the trade-off a bit. When unemployment was desired to decline, they could temporarily live with a higher inflation and vice versa. In the 1980s the idea came about that the trade-off between unemployment and inflation did not actually exist. The Phillips curve was actually vertical.

This new conclusion followed from the insight that inflation should be considered as an inherently unstable phenomenon. Once inflation starts increasing, it will reinforce itself and quickly grow out of bounds. This is due to the idea that real inflation is tightly connected to inflation expectations. When employees expect higher inflation in the future, they will demand higher nominal wage claims to maintain purchasing power. As inflation is determined by wage cost-push, this leads to an even higher actual inflation, closing the feedback loop.

Inflation expectations thus turn into self-fulfilling prophecies. The speed of which depends on how fast employees manage to update their inflation expectations.[1] The macroeconomic system lacks self-correcting

[1] In the speed of adjustments to expectations lies a difference between the New-Keynesian and the New-Classical school.

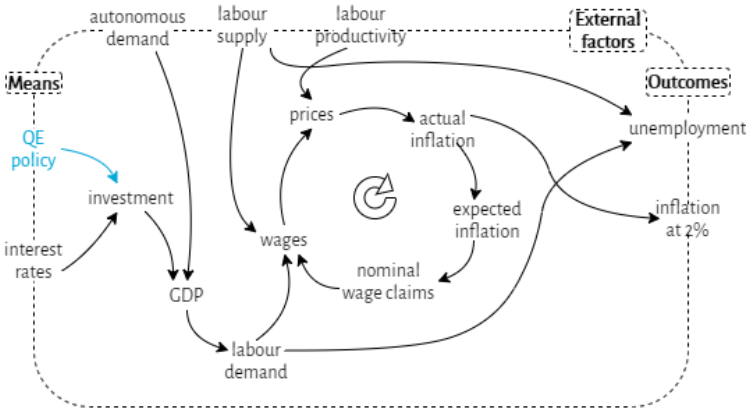

Figure 2.2: Simplified representation of most important factors in New-Keynesian macroeconomic mechanism

mechanisms. There is no inherent effect that stops the inflationary process. The only option to keep the system stable is to enforce stability upon it.

This enforcing of stability is done through the level of unemployment. Only at a specific level of unemployment can the inherently unstable system be kept at a fragile balance. Macroeconomic stability in terms of steady non-accelerating inflation is ensured only when actual unemployment is equal to the *Non-Accelerating Inflation Rate of Unemployment*, the NAIRU. New-Keynesians assume that only when actual unemployment is equal to the NAIRU, do we have nominal wage growth consistent with an inflation rate of 2%.

Implications for Monetary policy

It is central banks that have been endowed with the noble task to impose discipline and stability on the inherently unstable macroeconomic system. In order to do so, they have to keep unemployment at the NAIRU level.

The macroeconomic policy instrument at the disposal of the central bank is the nominal interest rate. The rate of interest affects private investment, and with given autonomous demand, real GDP. This in turn affect labour demand. Labour demand, together with labour supply, as we've seen above, affects wage claims and through the wage cost-push inflation process to a particular rate of inflation. Only when unemployment is kept at the NAIRU level, is inflation kept stable. Central banks raise the interest rates to reduce inflation and lower interest rates when inflation is too low.

Position of Central banks in global warming

We have seen that in the NK model, actual inflation is very much affected by expected inflation. Therefore, monetary policy is more effective if employers as well as employees believe that the central bank will manage to keep inflation at the targeted rate. The more widespread it is believed that the central bank is serious about the inflation target, the less the central bank will have to do to manage that goal. Union workers understand that it is fruitless to demand too high nominal salary raises. These will result in higher inflation, rendering the real wage increase zero. This principle is understood as central bank credibility. The implication is that the reputation of a central bank is a crucial factor. They must have the reputation that they will do whatever it takes to control inflation. To establish this, a central banks should be (1) consistent, (2) forward-looking and (3) independent. It is because of these three reasons that the central bank cannot engage in operations other than to focus on price stability. Most important thing is that the ECB hangs on its reputation as a monetary hawk.

The orthodox interpretation is that financial stability will automatically lead from price stability. But debate going on about how that holds with different reports coming out that global warming affects this.

There is debate going on, also in the ECB if this assumption will hold. It is also something that we will come bank to in our results.

Exogeneity of money and position towards QE

The aim of Quantitative Easing policies is in line with that of interest rate (highlighted in blue). QE aims to stimulate GDP in order to keep inflation stable. The idea that QE is an effective measure to stimulate GDP is consistent with the NK's approach that regards money as exogenous to the macroeconomic system. As we will see in the chapter, one of the supposed transmission channels of QE to increase money supply. Central banks purchase assets, which gives commercial banks higher reserve balances at the central bank. This supposedly gives them the opportunity to hold more loans.

It is employed when interest rate measure looses its effectivity. We extensively explain the supposed mechanisms behind this supposed result in chapter 3.

2.3.2 General principles Post-Keynesian school

Post-Keynesian (PK) economics is a school of economic thought which builds upon the ideas of mostly John Maynard Keynes. The term 'post-Keynesian' was introduced by Eichner and Kregel (1975) who highlighted the incompatibility of then orthodox economics with Keynes' ideas and proposed a return to his original insights. Today, research in the field is supported and promoted by a Post-Keynesian Economics Society (PKES). We provide a concise explanation of the most important PK tenets below. The explanation is again derived from lecture notes by Storm and Naastepad (2019, 2020a), complemented with information from the website of the PKES (PKES, 2021).

In (Post-)Keynesian economics, aggregate demand is the key driver and determinant of economic performance. The majority of this demand is exogenously determined and not by economic variables. The determining factor for investment are expectations of entrepreneurs about the future state of the economy. Investments are only somewhat sensitive to the real rate of interest. Much more important are expectations: firms will invest when they expect future demand for their products. These expectations are very much subjective. Firms will somewhat look at the real state of the economy but will also take into account what (proclaimed) experts say, other entrepreneurs' behaviour and their own sentiment. Groupthink and other social mechanisms thus play an important role. Keynes refers to this collective sentiment of business leaders as 'animal spirits'. Expectations often become self-fulling prophecies. When spirits are down, business leaders will postpone their investment, depressing aggregate demand, leading the economy to indeed go into recession. As such, economic activity cannot be reduced to the aggregate result of optimising behaviour by economic agents, but depends on expectations and sentiment.

Animal spirits are not the only example of a situation where social interactions give rise to systemic properties at the macroeconomic level. Another existing mechanism is the paradox of thrift. When many individuals simultaneously try to increase their saving, total saving at the aggregate level may not increase as aggregate demand and output will decline. The fundamental uncertainty of these and other social interactions inherent in a system of human actors require an analysis of human behaviour based on social conventions and heuristics. This is different from the New-Keynesian school that sees the system of utility maximising agents.

Another central mechanisms behind economic performance are multiplier effects. These constitute the effect that a growth in demand will lead to extra demand in the system. The production that is needed to meet growing demand itself leads to value creation. This income then generates additional effective demand which in turn leads to more production, and so on. A specific impulse in the macroeconomic system, like growing government investment, thus might lead to more added value than the amount of only that specific impulse itself.

Contrary to the NK school, in the Keynesian macromodel, there is no tendency towards full employment. Instead, Keynes argued that a market economy will tend towards an under-employment equilibrium, with unemployed people and unused production capacity. This is due to the main determinant for economic activity, investments, being mainly determined by animal spirits. There is no logical reason why the

collective decisions that follow from the unstable expectations of entrepreneurs lead to a production capacity that is consistent with a full-employment level of economic activity.

Endogenous money and implications for Monetary policy

(Post-)Keynesian theory regards money as endogenous to the system. Banks are money-creating institutions. They can create (virtual) money by issuing loans, thereby pre-financing investment. The central banks can therefore not directly control the amount of money in the economy.

The ability of the central bank to stimulate economic activity in a recession is limited. What central banks can do, is influence the money supply indirectly, for example with the interest rate. If the central bank aims to increase money supply, it lowers the interest rate. This might lead to an increase in private investment and thus GDP. More money is needed to finance investment, banks issue loans and thereby generate money.

As we have seen above, private investments are only to a limited extent determined by interest rates. Much more important are the animal spirits. What the central bank can do is lead the horse to water, but it cannot make it drink. In an economic downturn, firms may not wish to borrow if the market outlook is grim. Likewise, bank may refuse to issue loans for new risky investment but rather pile their reserves unused. Due to the multiplyer effects, fiscal policy is much more effective in influencing real GDP (and employment).

Position towards QE

Contrast to the New-Keynesian school, (post-)Keynesian macroeconomic model regards money to be endogenous to the system. As QE as a measure aims to increase money supply, it will not be effective in stimulating the economy. However, it might reach some effect through improving sentiment in the market. This will lighten up the animal spirits.

Also, as PK economists do not share the exclusionary focus on inflation with the NK school, this leaves room for its other objectives. Climate change affects central banks' ability to achieve price stability, either directly or through its affection of the financial system. This interpretation aligns more with Post-Keynesian ideas. QE as a measure can be adopted to focus on this issue.

2.4 Concluding remarks

The legal basis for the establishment of the ECB is laid down in the different Treaties of the European Union. These mandate the ECB to pursue several objectives, the primary of which is price stability. Secondary objectives flow from its assignment to support the EU's economic policy, including those for "balanced economic growth", "full employment and social progress" and " a high level of protection and improvement of the quality of the environment."

Analysis of historical and global context shows that determination of the meaning of this hierarchy between objectives of central banks is not absolute but subject to interpretation. Whether one advocates the ECB to exclusively pursue the primary objective (narrow interpretation) or also focus on secondary objectives (expanded interpretation) depends significantly on whether one sees trade-offs between the different objectives.

Current hegemonic consensus on the interpretation of the mandate is that the ECB must devote its undivided attention to its primary objective. It is through the establishment of price stability that the ECB contributes to its secondary objectives. In this explanation, the ECB cannot focus its attention on the secondary objectives, as this will impede its ability to keep prices stable, either through mission creep or through overburdening of monetary policy. This interpretation is consistent with New-Keynesian school ideas on monetary policy.

Against the conventional stands a more unorthodox interpretation. Within this interpretation, it is in the service of pursuing its primary objective that climate change considerations should form an integral part

of the ECB's monetary policy. Climate change affects central banks' ability to achieve price stability, either directly or through its affection of the financial system. This interpretation aligns more with Post-Keynesian ideas.

A deeper dive into Quantitative Easing and Market Neutrality

3

This chapter gives an extensive explanation of Quantitative Easing. We start with the formulation of a definition of QE. We concisely introduce the QE programme that the ECB employs. We take a look at what the principle of market neutrality is. We then extensively look at the (supposed) macroeconomic mechanisms that underlie QE and the transmission mechanisms through which the central banks try to exert influence on the economy with it. We finish with concerns that current practice of QE raises about effects on emissions and climate change.

3.1 Defining Quantitative Easing

The literature widely defines Quantitative Easing as a policy in which central banks concurrently purchase financial assets, financed by the creation of central bank reserves, as a tool for loosening monetary policy (Benford et al., 2009; Haldane, Roberts-Sklar, Wieladek, & Young, 2016). Central bank reserves are accounts that commercial banks hold at the central banks and use to settle inter-bank transactions with (Matikainen et al., 2017). So in other words, central banks create money for unusually large purchases of bonds (Andolfatto & Li, 2014). Typically, QE occurs in unconventional circumstances, when short-term nominal interest rates are very low, zero or even negative (Williamson, 2017). Purchases are aimed at stimulating inflation and by extension, economic growth (Matikainen et al., 2017). Assets are usually long-maturity government debt but may also be private assets, such as corporate debt or asset-backed securities (Williamson, 2017).

3.1.1 Focusing on corporate purchases

This thesis focuses on climate considerations in the QE programmes of the ECB. Campiglio et al. (2018) point out that the purchase of bonds issued by public sector entities that finance low-carbon activities is already an indirect form of green Quantitative Easing. The ECB allocates around 10% of its public sector purchase programme to bonds issued by supranational institutions, including regional and national development banks. Development banks have been at the forefront of climate mitigation financing in recent years. This means that with these bonds, the ECB might already be indirectly supporting low-carbon investments.

We are interested in the effects on emissions and climate change of the ECB's QE programme. Government securities form the majority of purchase programmes. However, for the reason explained above, carbon factors are most relevant for private securities (Schoenmaker, 2021). Therefore we will focus on the corporate segments of the purchase programmes.

3.2 QE as unconventional measure

The term Quantitative Easing was introduced to describe the programme of the bank of Japan following the 1997 Asian financial crisis. Inflation was approaching net zero. At the same time, the bank rate was already very low, approaching zero as well. There were concerns of adverse effects if the rate was further decreased. Extra stimulus could no longer be provided through a reduction of the policy rate. Instead, the central bank started to look at unconventional measures. Starting in 2001, it increased its monetary base by roughly 60 percent in an effort to raise inflation and stimulate the economy (Andolfatto & Li, 2014; Haldane et al., 2016). This program was halted in 2006.

Following the 2008 global financial crisis, a similar situation arose in the Western world. Central banks were running into the zero-bound with interest rates. At the same time there was concern that spending in the economy was too weak to meet the inflation target. The situation prompted different central banks to employ Quantitative Easing strategies. This started in 2008 with the purchase by the Fed of $600 billion of government-sponsored-enterprises' debt and mortgage backed securities. The Bank of England followed the American example in 2009.

The ECB was relatively late to the party, starting its purchase programme in 2015 (ECB, 2021a). After temporarily ending purchases in 2019, the central bank announced new programmes in response to the Covid crisis. These programmes are at present ongoing. Current holdings are approaching €3.2 trillion. We extensively introduced the amounts in chapter 1.

3.3 Market Neutrality

To determine what corporate bonds to buy, the ECB applies a principle of *market neutrality*. Corporate sector purchases are conducted "according to a benchmark that reflects proportionally the market value of eligible bonds" (ECB, 2017, p. 40). The ECB first looks at the decomposition of all eligible corporate bonds in the market in terms of country, sector, and rating group. In its purchases, it then aims to mirror the market such that the proportion of bonds in its portfolio resembles that of the eligible corporate sector bond universe.

The ECB explains and justifies this strategy with an appeal on its mandated objective to "act in accordance with the principle of an open market economy with free competition, favouring an efficient allocation of resources."(ECB, 2017, p. 40). It reasons that it is not possible to embed awareness of environmental issues or ethical and socially responsible behaviour into a large-scale asset purchase programme as to positively or negatively discriminate on the basis of environmental or social criteria would limit the effectiveness of the QE programme in its contribution to fulfilling the ECB's mandate of maintaining price stability.[1] The central bank concludes that it is up to political decision makers to agree on, define and promote appropriate policies and measures to fight other societal issues.

As several authors point out, the design of a corporate security purchase programme involves considerable political decisions, whether the ECB acknowledges so, or not (Dafermos et al., 2020; van 't Klooster & Fontan, 2019). By emphasising that its purchases are market neutral, the ECB aims to avoid making these decisions. But choosing not to include environmental or societal criteria is in itself in fact a choice, and cannot be neutral. Moreover, the pursuit of market neutrality, has its own consequences. We return to these issues after we have explained the assumed transmission mechanism of QE.

3.4 Macroeconomic mechanisms underlying QE

The aim of undertaking QE is the same as that of conventional monetary policy, to stimulate spending and thereby generated inflation, so as to meet the 2% inflation target. Benford et al. (2009) and Joyce, Tong, and Woods (2011) identify potential transmission channels though which asset purchases might affect spending and inflation. Figure 3.1 presents these channels graphically.

[1] We saw in chapter 2 that this reasoning is rooted in a New-Keynesian approach to monetary policy.

The fundamental mechanism through which asset purchases influence spending and inflation, is through increasing the liquidity of private sector balance sheets, this pushes up asset prices and stimulates expenditure by lowering borrowing costs and increasing wealth. Other stimulatory impacts may be through their broader effects on expectations and by influencing bank lending. We consider the transmission channels as described by Benford et al. (2009) and Joyce et al. (2011) in greater detail.

3.4.1 Asset prices and portfolio effects

Asset purchases by the ECB aim to increase the price of assets, not only of those directly affected but in the broader economy. Higher asset prices mean lower yields, and lower borrowing costs for firms and households, which acts to stimulate spending. Corporations can maintain output, improving the prospects for employment and consumer spending. In addition, higher asset prices stimulate spending by increasing the net wealth of asset holders.

The extended influence on the price of assets over the broader economy is exerted by (1) portfolio balance effects, (2) increased market liquidity, and (3) the bank as ready buyer.

Portfolio balance effects: When the central bank purchases assets, this increases money holdings of the sellers. They may attempt to reduce their excess money holdings and rebalance their portfolio by buying other assets. The sellers of these assets, in turn, now hold an excess money balance that they might want to lose - and so on. This process bids up asset prices and the excess balance shifts until the aggregate value of the overall asset portfolio has risen enough to bring the share of money relative to all assets to its desired level. Also, as prices rise for the assets that are purchased by the central bank, their yields fall. This pushes investors to other assets in search of a higher return, which pushes up other asset prices as well.

Market liquidity: Central bank asset purchases encourage trading. The increased liquidity of the market improves its functioning. Traders require lower premia for illiquidity of assets, the compensation that is required to encourage investment in assets that cannot be easily and efficiently converted into cash at fair market value. The decrease in these premia allows the asset prices to rise.

Bank as ready buyer By offering to be a ready buyer for commercial paper and corporate bonds, the central bank makes investors more confident that they can sell such assets if required. This lowers the yield required to compensate for perceived risk. More investors should be encouraged to participate in the market, raising demand and thus the prices of assets.

3.4.2 Money in the Economy

The next transmission channel that Benford et al. (2009) and Joyce et al. (2011) describe is that of more money in the economy. When the central bank purchases assets (either directly or indirectly via intermediate transactions), banks gain higher reserve balances at the central bank and this makes it possible for them to originate more loans and thereby increase customer deposits. This enables them to finance a higher level of liquid assets, which in turn enables them to hold a bigger stock of illiquid assets. Banks become able to hold more loans and lower the price of their loans. This might also benefit companies which do not rely on capital markets for their funding (ECB, 2017). Favourable bond market conditions might result in spill-over effects through various channels. When large companies increasingly finance themselves through bond issuances (instead of bank loans), this releases capacity in balance sheets of banks to lend to smaller companies and households. Companies and households can borrow money cheaper. they then spend the additional deposits, money is passed on to the rest of the economy.

This supposed transmission channel is only consistent with an exogenous perspective on money, as we have seen in chapter 2. Only if one regards money supply to be exogenously determined by the central banks, does this transmission channel exist. Otherwise, money is created when banks issue loans.

3.4.3 Expectations

Asset purchases could have an impact on expectations of economic agents. These include economic expectations concerning the general economy as well as expectations on future monetary policy by the

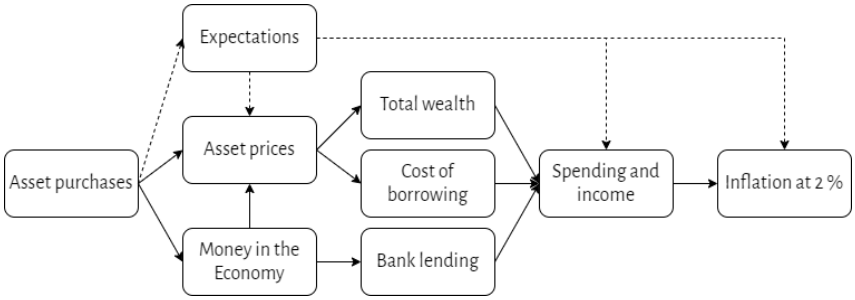

Figure 3.1: Stylized Transmission mechanism for Asset purchases (Benford et al., 2009)

central bank.

Economic outlook: Asset purchases may have broader confidence effects beyond any effects generated through the effect of higher asset prices. The ECB is an institution with high authority. Agents might base their views on the economy partly on central bank analysis. Policy announcements on asset purchases might contain 'news' about the underlying state of the economy for them. To the extent that the policy leads to an improved economic outlook, it might directly boost consumer confidence and make people more willing to spend.

Policy signalling: Also, by signalling that the ECB is committed to do whatever it takes to meet the inflation target, expectations of future inflation remains corresponding to the actual target. By helping to ensure that inflation expectations remain well anchored to the target, asset purchases could help to support spending.

3.5 Concerns to macroeconomic mechanism

Authors have attempted to assess whether the implementation of QE indeed leads to its supposed effects. Bhattarai and Neely (2016) review and critically evaluate over fifty articles with empirical studies on the effects of QE on both financial markets and the real economy. They conclude that the weight of the results favours the narrative that QE lowered yields and increased spending, inflation and aggregate output. Haldane et al. (2016) also find that central bank balance sheet expansions had a discernible and significant impact on financial markets and the economy. However, they also find that there is evidence that the effectivity of QE may vary over time, depending on the state of the economy and liquidity of the financial system. Williamson (2017) and Gros, Alcidi, and De Groen (2015) contend that the empirical evidence is open to interpretation, in part because there is only limited data to work with.

We take a closer look and try to unravel the separate elements of the consequences of QE. Quantitatively, the most direct and easily demonstrable effect of QE is on the assets being purchased.

The available evidence suggests that QE benefits the asset being purchased, and assets with a similar risk profile (Abidi & Miquel-Flores, 2016; Haldane et al., 2016). But this effect is less clear on other asset classes, in part because the impact on other assets is more difficult to separate from other influences (Joyce et al., 2011; Matikainen et al., 2017). This might have to do with a lack of substitutability between assets (Haldane et al., 2016). Investors may strongly prefer low-risk, liquid and stable investments for a long-term time horizon. The EU corporate bond market is relatively shallow and a large purchaser like the ECB can absorb quite a lot of the market. Rather than taking on more risk by buying lower-grade bonds or entering into a bidding competition with the central bank, investors might choose to look abroad to rebalance their portfolio. In that case, while asset prices in some areas increase, the pass-through to other assets, asset classes and the domestic economy would be more diffuse. (Matikainen et al., 2017).

Gros et al. (2015) assess the the impact of QE on (long-term) interest rates. They take a comparative global point of view. This gives a very different picture from the ones suggested by Bhattarai and Neely (2016), which focus on the country where QE takes place. They point out that (long-term) interest rates in the euro

area remained highly correlated with US interest rates even during QE episodes which suggests that QE might in reality have had little impact on rates.

The above articles still depart from the idea that although QE might be an unconventional measure, it still falls within bounds of what is possible in the existing macoroeconomic system. Palma (2020) takes a slightly less nuanced standpoint. In an article that at times reads like a pamphlet, Palma makes the compelling argument that QE is the last offshoot of a system that has long ago stopped growing in real terms. He makes the analysis that policymakers twisted the business cycle of upswings, followed by downswings in such a way that any panic must now immediately be followed by a new mania. The "new alchemists," which is how Palma calls the central bankers, believe that only a "perpetual mania" can deliver some semblance of growth. "So they persist in pumping in liquidity and relaxing monetary conditions, no matter how much this violates every possible principle of markets economics." (Palma, 2020)

Palma's analysis provides a critical viewpoint on the entire economic system. He lays bare the underlying mechanisms of the economic system as a whole, which, he believes, have led monetary policy into a dead-end ally. In a more recent working paper he connects this to the Ricardian tradition of understanding the economic processes as the outcome of the political articulation of conflict between rentiers, capitalists, bureaucrats and labour. History, politics and institutions matter as much (if not more) as economic fundamentals in this vision (Palma, 2021). He has to reject the premisse of current conventional, let alone unconventional monetary policy in the first place. Fascinating as his analyses are, they cannot fall inside the scope of this research. We work with the idea that QE policy is conducted. Given its existence, we want analyse if it is possible to at least design it in such a way that it is steered towards contributing to a transition to a low-carbon economy. In the next section we assess how it currently is not. We return to Gabriel Palma in the reflections in chapter 8.

Inequality effects

Before we focus on climate change, we briefly address another potential side effect of QE: rising inequality. Critics argue that policies conducted by the ECB, BoE and the Fed have increased inequality. Higher asset prices and near-zero interest rates would disproportionately benefit the wealthy (Youel, 2021). Higher asset prices increase the wealth of the holders of those assets, often already disproportionately rich.

There is significant variation in the conclusions of academic work on this effect. Researchers from the International Monetary Fund express concerns that QE and loose monetary policy have increased asset prices in the financial markets to a level that is out of step with underlying economic fundamentals (B. Jones et al., 2015). Again, this would disproportionately benefit the holders of assets, compared to the rest of the economy. Lenza and Slacalek (2018) contend that QE did not increase inequality in the euro area. On the contrary, QE would have compressed the income distribution since it caused employment that benefited households with lower incomes.

Montecino, Epstein, and Schmitt (2015) find that rising employment and mortgage refinancing had an equalizing effect, these impacts were nonetheless swamped by the large dis-equalizing effects of equity price appreciations. While they say that it is hard to isolate the effect of QE specifically from other developments, they conclude that, most likely, QE was modestly dis-equalizing. Lee (2021) finds that the QE program unambiguously benefited all households by stimulating economic activity. Its distributional effects however, were nonlinear. On the one hand, boosting profits and equity prices widened the income and consumption gap between the top 10 % and the rest of the wealth distribution. On the other hand, QE shrank inequality within the lower 90 % of the wealth distribution, primarily through stimulating employment. On net, it reduced overall wealth and income inequality (Lee, 2021).

3.6 Climate effects of QE

Several authors have studied the climate effects of the ECB's QE programmes. Table 3.1 presents an overview of their publications. The shared conclusion of these studies is that the current policies are not contributing to the transition to a low-carbon economy. This is caused by a combination of two factors: (1) an overrepresentation of bonds from high-carbon sectors in the ECB's portfolio and (2) the fact that issuers of purchased

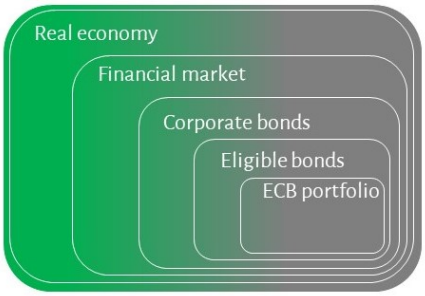

Figure 3.2: Graphical impression of ECB portfolio in real economy.

bonds benefit disproportionately compared to other companies. This section breaks these two factors down.

3.6.1 Overrepresentation of carbon-intensive sectors

Dafermos et al. (2020), Matikainen et al. (2017) and Battiston and Monasterolo (2019) demonstrate that the ECB's corporate bond purchases exhibit a pronounced bias towards carbon-intensive sectors. The skew towards these sectors is caused by the eligibility criteria used to identify corporate bonds that can be purchased by the ECB. Every step that narrows the eligible bond universe, tilts it towards high-carbon industries.

Figure 3.2 illustrates how the economy ranges on a green-grey scale. Proportions in the illustration are not to scale. The financial markets are only a portion of the real economy. Subsequently, corporate bonds are only a portion of financial markets. And so forth. The circles are not concentric and with each step in, we shift towards the greyer end of the scale. This results in an eligible bond universe that is biased towards grey sectors and ultimately, a grey ECB portfolio.

To explain how the bias towards grey sectors occurs, we start with the observation that the financial market does not reflect the real economy. A sector's contribution to employment and gross value added (GVA) might not be in proportion to its value in the financial markets. Following this observation, we establish that the corporate bond market consists of only a subset of the financial market. Equities, sovereign bonds as well as bank loans are excluded.

This subset is further narrowed by the criteria that bonds must meet in order to be eligible for purchase by the ECB. Bonds must be denominated in euros, eligible as collateral for Eurosystem credit operations, rated investment-grade by at least one credit rating agency, and have a maturity of six months to thirty years (Matikainen et al., 2017). Of the eligible bonds that remain, carbon-intensive sectors represent the largest share of the market. This carbon intensity is defined in terms of emissions per gross value added (GVA) or relative to its labour demand. Currently, the euro area bonds' market is mostly carbon-intensive (Battiston & Monasterolo, 2019).

The ECB bases its purchases on the presence of bonds in the proportion of market value of eligible bonds. Following the market neutrality principle, the presence in eligible universe reflects the presence in the ECB's portfolio (as explained in section 3.3). The ECB looks at the decomposition of all eligible corporate bonds in the market in terms of country, sector and rating group. It then aims to mirror these proportions in its portfolio.

In practice

In practice, the selection procedure indeed leads to an overrepresentation of grey sectors in the ECB bond portfolio, as is shown by different authors. Dafermos et al. (2020) identify four of the most carbon-intensive sectors: (1) fossil fuel, (2) energy-intensive, (3) non-renewable utilities, (4) carbon-intensive

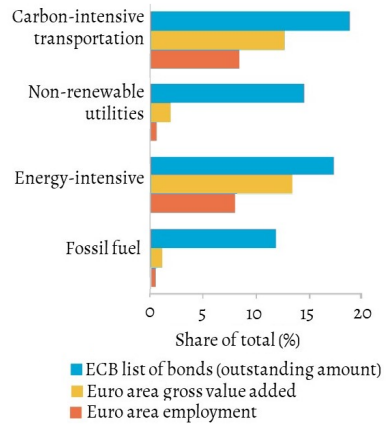

Figure 3.3: Contribution of carbon-intensive sectors to ECB bonds, compared to employment and GVA. From (Dafermos et al., 2020)

transportation. Judging from their contribution to euro area employment and GVA, these sectors are highly overrepresented in the ECB corporate bond list. Taken together these sectors comprise approximately 62.7% of the value of corporate bonds, while contributing only 29.1% and 17.8% to GVA and employment. This is shown in fig. 3.3.

Matikainen et al. (2017) also arrive at the conclusion that the sectoral distribution of purchases in the ECB's programme appears to be inconsistent with their respective contributions to gross value added. This is illustrated in fig. 3.4. All of the sectors beneath the 45 degree line – meaning more purchases than consistent with their proportional contribution to GVA – are carbon-intensive, with the exception of information and communication. The two largest sectors by purchases, manufacturing and utilities, are also the two largest in terms of contribution to emissions. Both account for a share of ECB corporate bond purchases that lies significantly above their contribution to GVA. Moreover, while contributing less than one percent to GVA, chemical and petroleum products also make up significant percentages of purchases.

On the other hand, sectors that contribute larger amounts to GVA and relatively little to emissions, like wholesale, retail trade and real estate, make up relatively small portions of purchases.

Battiston and Monasterolo (2019) analyse the relative proportion of different sectors by constructing a bond market benchmark that mimics the eligibility criteria for corporate sector bonds. They look at the exposure to economic sectors that are relevant for climate policies and for the energy transition. They notice that carbon-intensive sectors represent the largest share of this market. In particular carbon-intensive transportation, fossil-fuel, utility and energy-intensive sectors. The EU's corporate sector purchase programme closely follows the benchmark, which is mostly composed of issuances from fossil fuel and carbon-intensive companies associated to long-term maturities. In contrast, green bonds' share is still residual, despite green bonds being issued also by fossil fuel and carbon-intensive companies.

3.6.2 High proportion carbon-intensive bonds is problematic

The higher presence of high-carbon companies in the portfolio does not have to be a problem per definition. In theory, QE is meant to act as a lever operating on the economy as a whole. If the transmission mechanisms work properly, the whole economy benefits from purchases, not only the companies that issued the purchased bonds (see section 3.4). However, as we have seen in section 3.5 there is widespread doubt if QE delivers on that promise.

This results in a situation where, by favouring high-carbon corporate bonds, central banks improve the liquidity of these bonds, thereby lowering the cost of capital for high-carbon companies in comparison to low-carbon ones. This improves the competitive position of high-carbon companies, resulting in higher

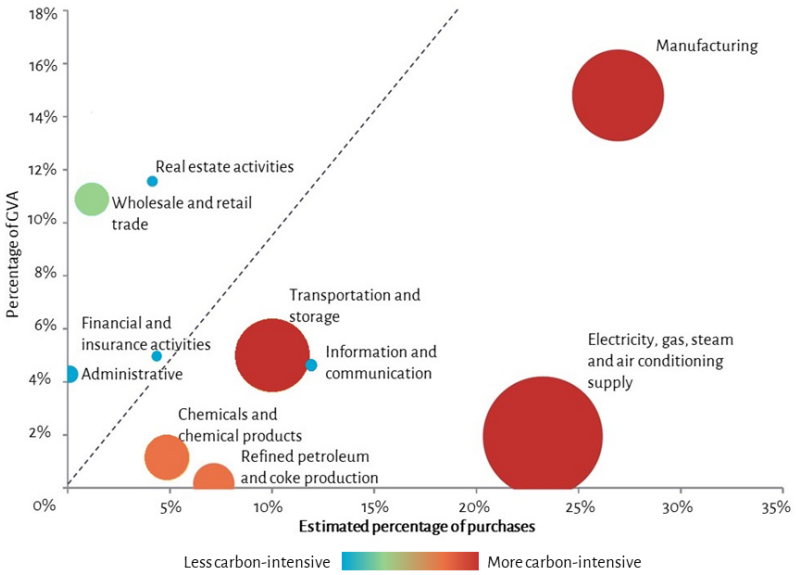

Figure 3.4: ECB CSPP, contributions to euro area GVA and to greenhouse gas emissions (Matikainen et al., 2017). Bubble size indicates relative contribution to emissions, colours indicate more (red) and less (blue) carbon-intensive sectors.

overall carbon emission (Schoenmaker, 2021).

Even though QE itself might be (intended as) a temporary policy, its effects can lead to long-term implications (Matikainen et al., 2017). In the first place from the fact that every delay in reducing carbon emissions, closes the opportunity window to keep global warming below 1,5°C. All in all, the CSPP appears to be a lost occasion to invest in sustainable capital within the eurozone countries (Jourdan & Kalinowski, 2019). But apart from that, by encouraging additional debt issuance from carbon-intensive sectors, the ECB exposes the financial system to higher transition risks in the future. Issued bonds for investment in long-dated infrastructure contributes to a carbon lock-in. This is when path dependent energy systems are constructed around fossil fuels (Unruh, 2000). The fossil fuel sector has been increasing its levels of debt even when they were on downgrade watch (Blas, 2016). This raises concerns about default risks and unsustainable levels of indebtedness in that sector (Loder, Church, & Klein, 2016).

3.7 Concluding Remarks

Quantitative Easing is a policy in which central banks concurrently purchase financial assets, financed by the creation of central bank reserves, as a tool for loosening monetary policy. The aim of undertaking QE is to stimulate spending and thereby generated inflation, so as to obtain price stability. The fundamental mechanism through which asset purchases influence spending and inflation, is through increasing the liquidity of private sector balance sheets, this pushes up asset prices and stimulates expenditure by lowering borrowing costs and increasing wealth.

Following from the interpretation that the ECB can not include climate change considerations in their monetary operations, the central bank applies market neutrality in their corporate bond purchases. However, in practice this results in a pronounced overrepresentation of carbon intensive sectors in its portfolio proportional to their contribution to employment and GVA. This improves the competitive position of high-carbon companies, resulting in higher overall carbon emissions.

Author	Year	Key Insight
Battiston and Monasterolo	2019	"The composition of the CSPP [...] is mostly populated by carbon-intensive firms."
Dafermos et al.	2020	"[...]the current corporate QE programme remains biased towards carbon-intensive sectors: these sectors are over-represented in the ECB purchases, [...]"
Jourdan and Kalinowski	2019	"Whereas EU climate policies try actively to transform the European economy to make it more sustainable, the CSPP merely reproduces the current state of the corporate bond market."
van 't Klooster and Fontan	2019	"[...] firms whose securities are purchased under the CSPP have a disproportionate carbon footprint."
Matikainen et al.	2017	"Sectoral analysis of the Quantitative Easing (QE) corporate bond purchase programmes of the European Central Bank (ECB) and the Bank of England suggests a skew towards high-carbon sectors."
Monnin	2018	"[...] current large-scale asset purchases by central banks are biased toward incumbent carbon-intensive sectors."
Schoenmaker	2021	"The ECB's asset and collateral portfolio for monetary policy operations is overweight in high carbon companies."

Table 3.1: Authors on Climate effects of current QE policy

Conceptualisation and Model Specification

4

This chapter defines the conceptual understanding of the consequences of QE. We develop an understanding of the system and relationships in which factors sort their effects. This is derived mainly from the articles by Dafermos et al on their DEFINE MODEL. These relationships are operationalized. As the model is high-level. We work our way from the top down. We start with the big picture and then quickly work our way down.

We first find a model that is appropriate for the research question that we aim to answer. This is the DEFINE model by Dafermos.

4.1 Modelling Climate change

To answer our research question, we need a model with which we can assess the effects of monetary policy on ecological as well as on macroeconomic factors. Hardt and O'Neill (2017) provide a systematic review and assessment of twenty-two ecological macroeconomic models. By lack of a mutually agreed definition of what ecological macroeconomic models entail, they identify three themes present in literature:

1. Emphasis on developing analytical methods and models that represent the dependency of the macroeconomy on the natural environment. This includes concerns on how macroeconomic processes like growth, inflation and unemployment depend on natural resources but also on how environmental damages feed back into the economy.
2. Hardt and O'Neill (2017) notice a combination of post-Keynesian and ecological economics approaches present. Authors in ecological macroeconomics reject orthodox growth models, largely because they consider underlying assumptions fundamentally flawed. This includes ideas like economic actors being rational and utility-maximising, and that this will lead to optimal equilibrium growth paths.
3. A need to manage the economy in the possible absence of growth. This can lie in a normative redefinition of the economy's purpose. However, not all the research in ecological macroeconomics is concerned with post-growth ideas.

Hardt and O'Neill (2017) classify numerical models according to two aspects, namely the economic growth theory underlying and the modeling technique that they employ.

The majority of reviewed numerical models rely on post-Keynesian ideas as underlying economic growth theory (Hardt & O'Neill, 2017). These models mostly adhere to the post-Keynesian basic framework but might include slight differences and additions. This means that the key determinant of aggregate demand is investment. Investment is considered autonomous and generally modelled as a function of capacity utilisation and the profit rate. This can be complemented by other factors.

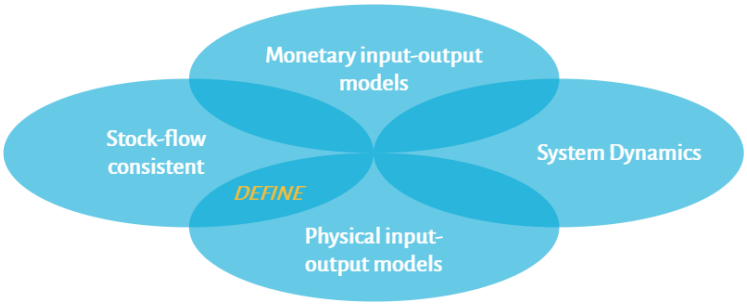

Figure 4.1: Categorisation of modelling techniques. Derived from Hardt and O'Neill (2017)

Macroeconomic ecological analysts employ four modelling techniques (Hardt & O'Neill, 2017). These four can be categorised into two opposing duos: monetary versus physical input-output analysis, and system dynamics versus stock-flow consistent modelling (see fig. 4.1). Models can be classified into one or two of these duos. In the original article, the authors also classify fifteen other models into the different quadrants of the figure. We omit these for reasons of concision.

Input-output analysis can be divided into a monetary or a physical framework. At the heart of input-output analysis lies a matrix that describes the flows between different industries. These flows can either be monetary or physical, depending on the approach taken. An assumption of the monetary approach is that physical flows of materials are proportional to monetary flows. This assumption allows for a representation of physical flows in monetary units. The physical approach does not make this assumption but directly models physical flows between industries. It is therefore potentially more comprehensive (Hardt & O'Neill, 2017).

System dynamics is a modelling approach that has been applied broadly to understand and improve the dynamic behaviour of complex systems over time (Forrester, 1994). Its basic elements are stocks, integration, flows, activity, delays and feedback. An analyst defines starting conditions after which the computer can calculate and plot all factors that are interdependent to each other over time, providing a framework of thought, that can be used to deal with complex interactions. The most well-known research that applied this approach is probably still *Limits to growth* by the Club of Rome (Meadows, Meadows, Randers, & Behrens, 1972).

Stock-flow consistent modelling is an approach that emphasises the need for consistent accounting of all monetary stocks and flows as well as financial assets and liabilities (Hardt & O'Neill, 2017). Balance sheet matrices track the balance sheets of aggregated sectors. Flows between sectors are captured by transaction flow matrices.

4.1.1 Policy themes

Hardt and O'Neill (2017) identify eight policy themes that are present in reviewed literature. We present these in table 4.1. Models can focus on several of these themes. Added in our table is a column that specifies the relevance of the given theme for our current research. The only model in the overview of Hardt and O'Neill (2017) that includes all the factors that we awarded high relevance is the DEFINE model of Dafermos et al. (2018). We asses these themes below.

Almost all models included in the review **integrate the environment** and its interactions with the economy. Hardt and O'Neill (2017) categorises these interactions into generic impacts, energy use, other resource use and waste emissions. It is important that the model that we employ to answer the research question incorporates these factors. DEFINE is one of the many models that does.

The detail with which models incorporate **economic inequality** vary. Around a third of the models cannot account for inequalities in income or wealth as they treat income as one single aggregated flow. The remaining models commonly feature a consideration of functional inequality between wage and profit

ID	Theme	Factors	Relevance
1	Integrating the environment	Generic impact, Energy use, other resource use, Waste emissions	+
2	Economic inequality	Income differences, Poverty, Distinction wages/profits	-
3	Monetary system	Banking sector, Credit constraints	+
4	Disaggregation production and consumption	Distinct characterizations of different industries	+/-
5	Work patterns	Unemployment, work patterns, wages	-
6	Business models (green investment)	Investment in green capital dependent on different parameters than normal investment	+
7	Cross-scale interactions	Single or multiple regions	+/-
8	Indicators of well-being	Health, Working time, Employment, Inequality	-

Table 4.1: Policy themes in assessed macroeconomic ecological models by Hardt and O'Neill (2017)

income. None of the models reviewed feature a description of personal income distribution using different income groups. We consider this factor not particularly relevant for our current research.

Of the models reviewed by Hardt and O'Neill (2017), all stock-flow consistent models include a representation of the **monetary system**. These models contain a banking sector that provides loans needed to finance investment. The level of detail with which this mechanism is included varies per model. In some models, banks provide all loans that are demanded, others exert some kind of credit constraint. The presence of a (detailed) monetary system is crucial for our research. DEFINE is one of the models that includes this factor.

Dissagregation of Production and Consumption is necessary to be able to represent different industrial sectors with different environmental intensities. Input-output analysis is suited to model these because it allows for the inclusion of distinct industries, the relation among these and their respective environmental impacts. Dissagragation of production and consumption is not in itself particularly crucial for the research at hand. However, it is a way to represent the disparities in environmental impact of different investment decisions. In the review of Hardt and O'Neill (2017), DEFINE does not allow for this. However, they review an older version of DEFINE. A newer version of the model (1.1) actually does include different industrial sectors.

Most of the models include **work patterns** and measures of employment. This measure is usually calculated as the number of workers that are required to produce demanded quantities. Six models also include an explicit parameters for working time. Employment levels can feed back into the economy. For example, in the determination of wages through bargaining power. While these mechanisms are relevant for the internal consistency of the model, we are not particularly interested in employment.

With **business models** Hardt and O'Neill (2017) mean whether models include a difference between green and conventional capital that business employ to finance investment. Investment in the two capital stocks depend on different parameters. For example, worsening climate change might stimulates green investment. The distinction between green and conventional capital is crucial for our research question. It is exactly the distinction that we need to be able to compare green QE policies with conventional policies. DEFINE is the only model that distinguishes between green and conventional finance.

Cross-scale interactions denote whether models include different countries and regions. The majority of models represent only a single area and so these do not include cross-border trade. Localisation of

economies is difficult to introduce in macroeconomic models due to the lack of data on international financial flows (Hardt & O'Neill, 2017). DEFINE is a global model. This does not seamlessly match with the scope of our research as we are interested in the effects of policies by the European Central Bank. DEFINE does not allow for singling out one specific central bank. However, it is still suited to model policies of central banks in general. We return to this issue in section 4.2.4.

None of the model include **well-being** as a single indicator. Some of the models (including DEFINE) can give indications on objective aspects approximating well-being. These approximations include indicators like employment, working times or health impact from pollution. We consider this factor of no particular interest for our research question.

The only model in the overview of Hardt and O'Neill (2017) that includes all the factors that we awarded high relevance is the DEFINE model. This is due to the fact that it is the only model that distinguishes between green and conventional finance. This is an important factor as it is exactly what a policy of green QE by the ECB would have consequences for. Also, the DEFINE model has been used before for a research similar to ours (Dafermos et al., 2018). We will explain this more extensively in chapter 5. In the remainder of this chapter, we further asses the appropriateness of this model for our research.

4.2 DEFINE Model

DEFINE is a global stock-flow-fund ecological macroeconomic model that enables analysts to analyse the interactions between the ecosystem, the financial system and the macroeconomy that was developed by Yannis Dafermos and Maria Nikolaidi (Dafermos & Nikolaidi, 2021a, 2021b; Dafermos et al., 2018). The model synthesises the stock-flow consistent approach of Godley and Lavoie (2007) with the flow-fund model of Georgescu-Roegen (1971). We first discuss important general principles of the model.

4.2.1 Embedded economy

DEFINE is consistent with views that portray the economy as a subsystem of the broader ecosystem. The economy is constrained by the physical limits of planet earth and the ecology. All processes in the macroeconomy occur in this context. Figure 4.2 presents a graphical representation of the embedded relationship. We see the ecosystem, or earth, the living world, that is powered by energy from the sun. Within the ecosystem is the macroeconomy. Matter and energy flow into the economic activities and out as material waste, unavailable energy and greenhouse emissions. These affect the stability of the ecosystem, feeding back into economic system. The financial system is considered to be a subsystem of the economy as a whole.

Embedding the economy in the ecosystem is consistent with ideas by Goodwin, Harris, Nelson, Roach, and Torras (2014) and Daly (1996) who include consideration of ecological, feminist, and social concerns while still using the standard microeconomic concepts and models. More recently described and popularized by Raworth (2017), she explains that this embedding is an attempt to internalize into the economic model such critical concerns as ecological sustainability, distributional equality, the quality of employment, and the adequacy of living standards. These are factors that in classic models would be explained as externalities or side-effects. She quotes John Daley, remarking that those things were formerly classified "as external costs for no better reason than because we have made no provision for them in our economic theories." But effects that were formerly treated as externalities have turned into defining social and ecological crises in the twenty-first century. Far from remaining peripheral concern outside of economic activity, addressing these effects is of critical concerns to understanding the economy. (Raworth, 2017, 143).

4.2.2 Stock-flow and flow-fund consistent

The model makes a distinction between stock-flow and flow-fund resources. Stock-flow resources are present in the ecosystem and can be mined, pumped up or materially transformed into what they produce and stockpiled for use. This harvesting can happen at any rate. Examples of stock-flow resources are minerals and fossil fuels. Flow-fund resources, on the other hand, cannot be stored for later use and can only be used at specific rates. These are resources like labour and capital.

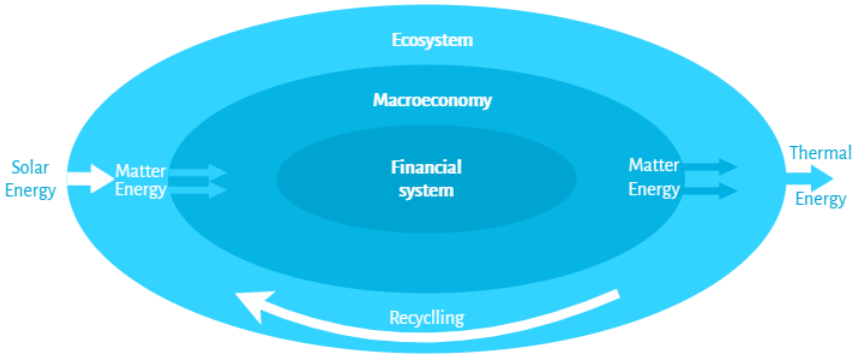

Figure 4.2: Macroeconomy as part of greater ecosystem (Dafermos et al., 2015)

There are two reasons why this distinction is significant. (1) It demonstrates that it is not possible to substitute one resource category for the other, as conventional presentation of the production function might do (Dafermos et al., 2015). (2) This approach allows for an explicit portrayal of the balance sheets and financial flows in the financial sector. This allows us to model fragility in the financial structures of firms and banks that is induced by climate change (Dafermos et al., 2018). It also allows us to model explicitly different policy alternatives for central banks.

4.2.3 Interactions real and financial sector present

Climate change is expected to disrupt the stability of the financial sector (Vermeulen et al., 2018) and affect inflation (Parker, 2018). Vice versa, financial market activity contributes, through its impact on the real economy, to climate change (De Haas & Popov, 2019). To paraphrase economist Steve Keen: Trying to analyse climate change while leaving out banks, debt, and money is thus like trying to analyse birds while ignoring that they have wings. Good luck. [1]

The financial system in DEFINE has a non-neutral impact on economic activity. Credit availability and the price of financial assets affect economic growth and employment. This feeds back into the financial sector as climate change can reduce profits, thus the dividend payments of firms and, hence, the price of financial assets. These interactions are explicitly taken into account in DEFINE (Dafermos & Nikolaidi, 2021b). Also, DEFINE uses a multiple financial asset portfolio choice framework, which allows for the analysis of the effects of different policies for green bonds.

4.2.4 Global model

DEFINE portrays the global macroeconomy. This means that it does not incorporate interactions between regions. While it allows for analysis of global central bank policy, it does not let us specify this to a European scale. A given policy might for example attract foreign investors into a region and their presence could in turn affect the market. While these interactions might be interesting, they do not constitute the primary interest of our research. We are interested in the general mechanisms behind alternative QE policies. We do not expect that regional interactions fundamentally alter these mechanisms. Our interest stems from the European discussion but after all, global warming is not a European problem. Therefore, we accept the absence of this factor in the model.

4.2.5 Allows for scenario analysis

DEFINE is programmed such that it allows for the evaluation of different scenarios. Earlier applications of the model in Dafermos et al. (2018) show that is appropriate to evaluate different QE policies. Also it is possible to enter different baseline scenarios and perform sensitivity analyses. This facilitates analyses

[1] He actually said: "Trying to analyse capitalims while leaving out banks, debt, and money is like trying to analyse birds while ignoring that they have wings. Good luck." (Steve Keen, 2014)

of the mechanisms that work behind the scenes to produce the result. This flexibility makes the model suited for answering our research question, which requires us to evaluate and understand different policy scenarios.

4.2.6 Conclusion: Appropriate

DEFINE allows for analysis of economic effects within the broader ecosystem. It includes interactions between the real and the financial sector. It allows us to model explicitly different central bank policies. We can evaluate different scenarios. As it is a global model, it does not allow us to specifically target European policies but we do not consider that a crucial absence. We conclude that DEFINE is appropriate for the research question at hand.

4.3 Model specification

This paragraph describes the basic model specification of DEFINE. There are different versions of the model. We employ version 1.1. The explanation below is derived from the manual and two articles by Dafermos and Nikolaidi (Dafermos & Nikolaidi, 2021a, 2021b; Dafermos et al., 2018). For the most comprehensive explanation of the model, see the manual.

DEFINE is built up of two main blocks, or two main feedback loops (see fig. 4.3). The first presents the interactions within the ecosystem and between the ecosystem and macroeconomy. It encapsulates the interactions between carbon and temperature, the carbon cycle and the flows and stocks of matter and energy. The second structure presents the interactions within the economy and between the real economy and the financial sector. This block encapsulates behaviour of households, firms, (central) banks and the government.

These feedback loops are represented in the model by a skeleton that consists of four matrices: the matrices belonging to the ecological block: (1) the physical flow matrix, (2) the physical stock-flow matrix, and those belonging to the macroeconomic block: (3) the transaction flow matrix and (4) the balance sheet matrix.

The economy depletes and degrades the ecosystem. The use of fossil energy for example produces a flow of carbon emissions into a stock of carbon concentration in the atmosphere. This increases the temperature, leading to global warming. Global warming then feeds back into the economy via capital destruction, reduction of work force and a fall of productivity of labour and capital. Use of non-fossil energy and higher efficiency of fossil-fuel use reduces emissions and mitigates climate change. This can be achieved through green investment. Another way to reduce emissions is through sequestration. Due to technological progress, the cost of these investments declines when their use increases.

Within the macroeconomy, there are households, firms, banks, central banks and the government. Agents take bounded rational decisions based on heuristics. Households consume depending on their income and wealth. They also make decisions on what they do with their money, whether they put it in deposits, government securities or bonds. Firms use profits, bonds or loans to finance their investment in green or conventional capital. Commercial banks provide loans and decide on interest rates. In their decision to either or not provide loans they are constraint by capital requirements and other factors. Central banks set the base interest rate. Governments collect taxes, decide about government consumption and investment, provide green subsidies and can implement bailout programmes.

4.3.1 Modelling consequences of green QE on climate change

This section provides an explanation of how the consequences of green QE policies on emissions and climate change are modelled in DEFINE. We highlight a selection of the formulas in the model to illustrate our explanation. This selection does not cover all underlying mechanisms of the model and thus does not give a comprehensive explanation of DEFINE. We cover only what is necessary to explain the relevant factors for assessing consequences of QE. All remaining formulas can be found in appendix A. A complete explanation of DEFINE is given in Dafermos and Nikolaidi (2021a).

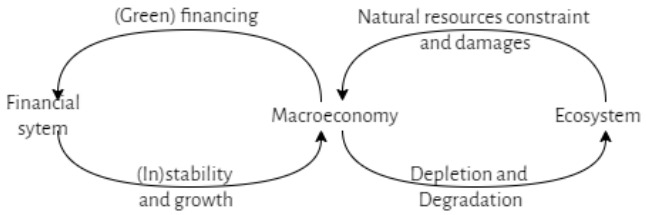

Figure 4.3: Aggregate presentation of system and feedback loops in DEFINE model. Derived from Dafermos et al. (2017)

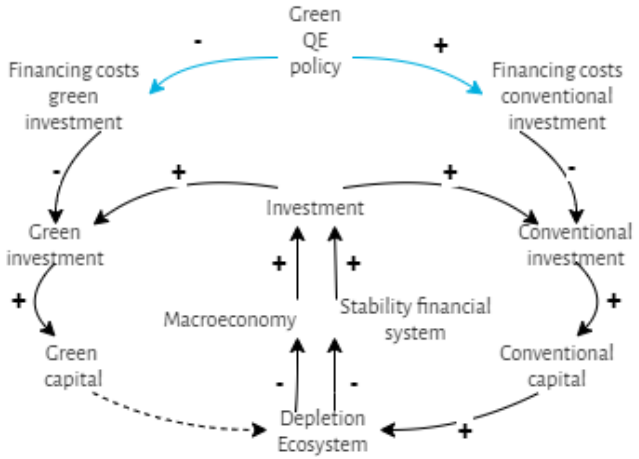

Figure 4.4: Visual presentation of conceptual model of the subsystem of (green) finance, the ecosystem and macroeconomy in DEFINE

Figure 4.4 shows a simplified graphical presentation of the subsystem in DEFINE in which the relationships between green financing costs, green investment, depletion of the ecosystem, and its consequences for macroeconomy and stability of the financial system are formalised. The explanation below follows the paths in the figure, beginning with the blue arrows. Green QE policies affects costs for green and conventional investments. These cost levels affect investment levels and in turn the amount of green and conventional capital. Use of conventional capital deteriorates the ecosystem. The quality of the ecosystem feeds back into levels of macroeconomic activity and the stability in the financial system. These in turn affect investments and thus close the feedback loop. Below, we look at these relationships in more detail.

The central bank can purchase green and conventional bonds

Firms issue bonds that the central bank can purchase. These bonds can be issued either to finance green, or conventional investments. Equation (4.1) shows that the total amount of green bonds is determined by the amount held by households plus the amount held by central banks. When the amount of green bonds held by the central bank increases, this increases the total amount of green bonds. Equation (4.2) and (4.3) define the values of green and conventional bonds held by the central banks. Both are shares of total outstanding green respectively conventional bonds in the market.

$$B_{Gt} = B_{GHt} + B_{GCBt} \tag{4.1}$$
$$B_{GCBt} = S_G B_{Gt-1} \tag{4.2}$$
$$B_{CCBt} = S_C B_{Ct-1} \tag{4.3}$$

where:

B_C	= total conventional bonds	B_{GH}	= green bonds held by households
B_{CCB}	= conventional bonds held by central banks	S_C	= share of total conventional bonds
B_G	= total green bonds	S_G	= share of total green bonds
B_{GCB}	= green bonds held by central banks	t	= time

Lower yields of green bonds lead to increased green investment and capital

Prices of bonds are determined with a market clearing mechanism. When more bonds are held, this increases demand and thus prices. Higher prices of bonds produce a decline in bond yields. This has two consequences. (1) With firms paying a lower rate on acquired capital, their profitability increases, leading to more desired investment. (2) Lower green bond yield leads to firms increasing the proportion of desired investment covered via green bonds. Firms invest in conventional and green capital by using retained profits, loans and bonds.

Green investment by firms are determined in equation (4.4). β is the share of green investment in overall desired investment. The share of green investment is determined in equation (4.5). It is affected by two factors. The first factor $(\beta_0 + \beta_1)$ is a combination of exogenous developments. These can be institutional or policy changes that promote green investment, like green subsidies or carbon taxes. The second factor reflects elements that are endogenous to the model. It includes the relative borrowing costs on investing in green versus conventional capital. Firms tend to increase green investment when the cost of borrowing for green investment decline compared to conventional. Sh_L is the share of loans in the total liabilities of firms. *int* denotes the interest rates on green and conventional loans. *Yield* denotes the yield on green and conventional bonds. Bond yields are the expected earnings an investor realizes on a bond.

$$I_G^D = \beta I^D \tag{4.4}$$

$$\beta = \beta_0 + \beta_1 - \beta 2[sh_{L-1}(int_G - int_C) + (1 - sh_{L-1})(yield_{G-1} - yield_{C-1}] \tag{4.5}$$

where:

I_G^D	= desired green investment	int_C	= interest rate on conventional loans
I^D	= desired investment	sh_L	= share of loans in the total liabilities of firms
β	= share of green investment	$yield_G$	= yield on green bonds
$\beta_0 + \beta_1$	= exogenous developments	$yield_C$	= yield on conventional bonds
int_G	= interest rate on green loans	t	= time

Green investment leads to the creation of green capital. Equation (4.6) shows that the total amount of green capital of a specific sector present in a year is determined by green capital of a year earlier plus green investment minus depreciation of old capital. The total amount of green capital is the sum of all sectors in the macroeconomy (4.7).

$$K_{G(PRI)it} = K_{G(PRI)it-1} + I_{G(PRI)it} - \delta_t K_{G(PRI)it-1} \tag{4.6}$$

$$K_{G(PRI)t} = \sum K_{G(PRI)it} \tag{4.7}$$

where:

i	= sector	δ_t	= factor for depreciation
$K_{G(PRI)it}$	= green private capital	t	= time
$I_{G(PRI)it}$	= green private investment		

Increased green capital leads to lower emissions

Industrial emissions are determined by a factor ω times the total amount of energy that is demanded. From this amount we subtract the emissions that are caught using sequestration techniques. The ω is a factor that is determined by the proportion of energy that is generated with renewable sources.

$$EMIS_{INt} = \omega_t \left(1 - seq_t\right) E_{Ft} \tag{4.8}$$

where:

$EMIS_{IN}$	= industrial emissions	E_F	= demanded energy
ω	= factor for renewable generation	t	= time
seq	= sequestration		

Climate damages affect macroeconomy

The total concentration of CO_2 in the atmosphere is formalised in equation (4.9), which shows how the cumulative CO_2 in a given year is the cumulative CO_2 in the previous year plus emissions. The atmospheric temperature is shown in equation (4.10). Atmospheric temperature rises as the cumulative carbon emissions increase. This rise is slowed down a little by a response time of the climate system to a changed level of cumulative emissions, denoted by t_1. Global warming is thus approximately proportional to cumulative carbon emissions in DEFINE.

Equation (4.11) shows the damage function, which formalises how atmospheric temperature can lead to climate damages. The proportional gross damage (D_T) lies between 0 (no damage) and 1 (complete catastrophe). The terms in this formula are selected such that $D_T = 0.5$ when the atmospheric temperature rise is 4°C. This in line with literature (references in Dafermos and Nikolaidi (2021a, p. 14)).

$$CO2_{CUMt} = CO2_{CUMt-1} + EMIS_t \tag{4.9}$$

$$T_{ATt} = T_{ATt-1} + t_1 \left(t_2 \varphi CO2_{CUMt-1} - T_{ATt-1}\right) \tag{4.10}$$

$$D_{Tt} = 1 - \frac{1}{1 + \eta_1 T_{ATt} + \eta_2 {T_{ATt}}^2 + \eta_3 {T_{ATt}}^{6.754}} \tag{4.11}$$

where:

$CO2_{CUM}$	= cumulative emissions	η	= parameters of the damage function
D_T	= proportional gross damage	T_{AT}	= atmospheric temperature
$EMIS$	= total emissions	t	= time

Output in the model is determined by aggregate demand. This is in line with post-Keynesian ideas. Climate damages affect the aggregate demand. Also, as a result of environmental problems, supply-side constraints might arise. The variable for damages (D_T) therefore enters into both in the demand side and in the determination of factors on the supply side.

On the supply side, climate damages affect the depreciation and productivity of capital and the productivity of labour. Equation (4.12) shows the formula for the determination of capital depreciation. The total depreciation in a given year is the sum of the regular depreciation and the depreciation as a result of climate change, corrected for adaptation measures.

Equation (4.13) shows the productivity of capital (v_t). Capital productivity in a given year is the capital productivity of the previous year times *(1 - damages)*, corrected for avoided damages through adaptation. Labour productivity λ is calculated following the same principle, only added is a factor for productivity growth (g_λ). It is the labour productivity of the previous year times *(1 - damages)*, corrected for adaptation. Labour productivity growth is affected by exogenous technology factors and by the growth rate of output,

consistent with the Kaldor-Verdoorn law. For the comprehensive explanation of the determination of labour growth, see Dafermos and Nikolaidi (2021a, p. 19).

$$\delta_t = \delta_0 + (1 - \delta_0)\,(1 - ad_K)\,D_{TFt-1} \tag{4.12}$$

$$v_t = v_{t-1}\,[1 - (1 - ad_P)\,D_{TPt-1}] \tag{4.13}$$

$$\lambda_t = \lambda_{t-1}\,(1 + g_{\lambda t})\,[1 - (1 - ad_P)\,D_{TPt-1}] \tag{4.14}$$

where:

ad_P	= damages to productivity avoided through adaptation	D_{TP}	= damages to productivity of resources
ad_K	= damages to capital avoided through adaptation	g_λ	= productivity growth
δ	= capital depreciation	λ	= labour productivity
δ_0	= capital depreciation without climate damages	v	= capital productivity
D_{TF}	= damages to fund-service resources	t	= time

Damages enter the demand site of the economy in the determination of investment as well as consumption.

Total desired investment is determined in equation (4.15). Factors include the rate of profit, rate of capacity utilisation and unemployment rate. However, for reasons of simplicity we summarise these here in the factor ψ. This factor is multiplied by the amount of private capital in the previous year. The result is then multiplied with a factor *(1 - damages in the previous year)*. High damages thus suppress investment. Added to investment is the depreciated capital of the previous year. The model assumes that depreciated capital is always replaced.

We determine household consumption (equation (4.16)) as a factor of income and wealth of the previous year. Income and wealth of the previous years are proxies of expected disposable income in the given year and thus something that households base their spending on. Again, we multiply this factor by *(1 - damages)* to account for deprived income or wealth as a result of climate damages. We note that this formula for consumption only holds when there are no supply side constraints on the economy. If the overall demand in the economy is higher than the supply-determined output, consumption adjusts so that overall demand in the economy is below the constraint level.

$$I^D_{(PRI)t} = (\psi * K_{(PRI)t-1}) * (1 - D_{Tt-1}) + \delta_t K_{(PRI)t-1} \tag{4.15}$$

$$C_{(PRI)Nt} = (c_1 Y_{Ht-1} + c_2 V_{HFt-1})\,(1 - D_{Tt-1}) \tag{4.16}$$

where:

$C_{(PRI)}$	= private consumption	$K_{(PRI)}$	= private capital
c	= parameters of the consumption function	t	= time
D_T	= proportional gross damage	ψ	= simplified factor
δ	= capital depreciation	V_H	= household wealth
$I^D_{(PRI)}$	= demanded investment	Y_H	= household income

Effects on the stability of the financial system

We approximate the the stability of the financial system with the bank leverage ratio. Leverage ratio measures a bank's core capital relative to its total assets and thus assesses its ability to meet its financial obligations. Bank leverage is determined in equation (4.17). It is determined as the summation of all its assets, consisting of conventional loans, green loans, government securities and high-powered money. High-powered money is the sum of commercial bank reserves and currency (notes and coins) held by the public. This is divided by their total capital.

We determine total capital in equation (4.18). It is equal to their undistributed profts (BPUt) minus the amount of defaulted loans. We assume that the governments steps in when the bank leverage ratio becomes higher than its maximum value. To avoid a financial collapse, the government bails the banks out. The amount of this bailout will be such that the leverage is brougt bank to the maximum value again. The amount for an potential bailout is added to the bank's capital. We take the maximum leverage ratio to be 0.33 (or 33%).

$$lev_{Bt} = \left(L_{Ct} + L_{Gt} + SEC_{Bt} + HPM_t\right) / CAP_t \tag{4.17}$$

$$CAP_t = CAP_{t-1} + BP_{Ut} - DL_t + BAILOUT_t \tag{4.18}$$

where:

$BAILOUT$	= bank bailout	lev_B	= bank leverage
BP_U	= undistributed bank profits	L_C	= conventional loans
CAP	= capital of banks	L_G	= green loans
DL	= defaulted loans	SEC_B	= government securities
HPM	= high-powered money	t	= time

4.4 Concluding remarks

After a search in literature, we concluded that DEFINE is an appropriate model to assess our research question with. Policy themes that are crucial to our research are all included in DEFINE. It is a global stock-flow-fund consistent model that portrays the economy as a subsystem of the broader ecosystem. Interactions between the real and the financial sector are preent and it allows for scenario analysis. We highlighted a selection of the formulas in DEFINE to explain how ECB policies lead to results.

Experimental Design

5

This chapter describes the the alternative policies for QE that we formulate to analyse in the experiment. We first define what we mean with "green." Informed by our conclusions on the ECB's policy space and mechanisms with which QE affects the economy and the climate, we formulate alternative policies for QE. As there are two interpretations of the ECB's mandate, we will arrive at two (sets of) policy alternatives, each consistent with one interpretation.

5.1 Different definitions of 'green'

Definitions of what makes a bond 'green' vary significantly. A variety of green bond certifications have emerged, which all aim at evaluating whether bonds are tied to green investment (Ehlers & Packer, 2017). Rating agencies award ESG (environmental, societal, governance) ratings but there is significant disagreement between agencies (Berg, Koelbel, & Rigobon, 2019). These disagreements entail scope, measurement and weight divergences. Li and Polychronopoulos (2020) show that disagreements affect performance of companies on these ratings. There are large differences and low correlation between scores of different agencies. Companies can be ranked quite highly by one and quite lowly by another agency. The various existing definitions might pose a challenge for the ECB in the implementation of a policy of green QE in practice. The different private sector approaches suffer from significant shortcomings that open the door to greenwashing (McDonnel et al., 2019).

To remove confusion around different ESG taxonomies, the EU Commission's Sustainable Finance initiative proposed a new, public EU taxonomy. This is a list of economic activities with performance criteria for their contribution to six environmental objectives. The public EU taxonomy entered into force in July 2020 (European Commission, 2020).

In the model this is simplified into a distinction made between green capital and conventional capital. In contrast to conventional capital, green capital produces energy using renewable sources. Consequently, it does not lead to CO_2emissions. Also, green capital produces output that is characterised by lower energy intensity, lower material intensity and higher recycling rates. We explain the mechanism in section 4.3.1.

5.1.1 Strategies for greening QE

The next step after the formalisation of the "greenness'" of bonds and capital is a rationale on how the ECB determines the proportion of green bonds in its portfolio. Amel-Zadeh and Serafeim (2017) distinguish several methods for the inclusion of environmental, societal and governance considerations in investments:

1. Exclusionary/negative screening: deliberately not investing in companies that do not meet specific ESG criteria.

2. Best in class: focuses on investing in companies that perform better on ESG issues than their peers do.
3. Portfolio tilt: uses certain investment strategies or products to change specific aggregate ESG characteristics of a fund or investment portfolio to a desired level (add weighted ESG-criteria).
4. Active ownership: exercises shareholder power to engage with companies to improve their ESG performance.
5. Thematic investing: focuses on those parts of the universe that provide solutions for certain ESG issues.
6. Impact investing: deliberately aims for both financial and societal value creation.
7. Full ESG integration: explicitly integrates environmental, societal and governance issues into the valuation and selection of securities.

5.2 Policy alternatives

The paragraphs below describe the different policy alternatives that we formulate. As DEFINE is a global model, we simulate policies for central banks in general, not specifically the ECB. The time span of the experiment is 2020-2050.

Conceptually, policy alternative 2 in the experiment is comparable to the research that was done by Dafermos et al. (2018). However, where they keep the percentage of purchased bonds at 25% of the eligible bond market, we increase this percentage to 75% and 90%. Also, we include the time span of a green QE programme as an element of uncertainty. Furthermore, we conduct our research with a newer, more extensive version of the DEFINE model (1.1).

5.2.1 Reference scenario

For the reference scenario, we use the baseline that Dafermos and Nikolaidi (2021a) describe in their manual of the model. They draw on the Shared Socioeconomic Pathways framework that has been developed in the climate research community (reference in Dafermos). They use a combination of the SSP2 and SSP3 scenarios. In both scenarios there is a transition to a low-carbon economy, but it is a slow one. Both scenarios result in a temperature rise of approximately 3.2°C by 2100.

Table 5.1 presents key factors of the reference scenario. The population growth, energy intensity and share of non-fossil fuel energy until 2050 are in line with SSP3. Global economic growth is consistent with SSP2. Growth declines over the next decades, leading to an increase in the unemployment rate. Annual investment in green energy increases gradually to around 0.97% of GDP until 2050, averaging 0.8% over the years.

In the reference scenario, we assume that central banks will maintain their conventional QE programme. This is done for reasons of comparability between a programme of conventional and of green bonds. In the reference scenario the ECB continues to apply the market neutrality principle. This means that the share of green bonds in the ECB's portfolio will remain very low. Currently this share is at 7 %. For reasons of simplicity, it is put at zero in the analysis of our reference scenario.

5.2.2 Portfolio tilt

We choose the first policy alternative such that it is consistent with current New-Keynesian interpretation of the ECB's mandate. Schoenmaker (2021) shows how the central bank can green its operations "without unduly interfering in the smooth conduct of monetary policy." He derives three conditions that an alternative strategy must adhere to in order to avoid disrupting the monetary transmission mechanisms: (1) Avoid major adjustments in the asset mix, currency denomination and maturity. Alterations will affect yields. (2) Keep the list of eligible assets within each asset class as broad as possible and not target particular assets. A broad base contributes to minimizing the impact on the functioning of markets and price formation.

Variable	2018	2050
Economic growth (%)	3.04	2.19
Unemployment rate (%)	5.40	7.01
Population (billion)	7.63	10.01
Share of non-fossil energy in total energy (%)	15.0	23.0
Carbon emissions (GtCO2/year)	42.13	51.43
Annual investment green energy (% of GDP)	0.58	0.97
Yield on conventional bonds (%)	5.00	4.91
Yield on green bonds (%)	5.00	4.82
Share of Green bonds in Portfolio (%)	*0*	*0*

Table 5.1: Factors of reference scenario

Narrowing it impairs the price stability objective and might erode support for central bank independence. (3) Implement an alternative strategy in steps, so markets get the opportunity to gradually respond and central banks can learn about the possible impact of adjusted criteria.

We consider these three criteria when deciding on one of the seven different strategies by Amel-Zadeh and Serafeim (2017). Schoenmaker (2021) judges the different methods on political acceptability, objective and expected impact, and compatibility with the central bank's mandate. He concludes that methods 4-7 are not generally applicable. They require specific choices, valuations and actions from central bank officials. Negative screening (1) is less able to achieve the desired impact because it aims only to avoid the worst performers. The best in class strategy (2) limits the universe of eligible bonds too much. The tilting approach (3) is less distorting in the monetary transmission mechanism, as no assets are excluded. It increases the share of low-carbon companies at the expense of high-carbon companies but does not exclude them. With the tilting approach the central bank can thus maintain a broad asset and collateral base in line with its monetary policy mandate (Schoenmaker, 2021).

Schoenmaker (2021) defines additional eligibility criteria. These tilt the carbon footprint of the assets held by the ECB in such a way that they become less carbon heavy. With this approach, the ECB can achieve a reduction by 55% of the carbon footprint of its portfolio. We simplify this number to 50% and codify this to fit in the model by understanding it as 50% of the central banks' portfolio consisting of green bonds. The amount of conventional bonds in the ECB's portfolio remains unchanged.

5.2.3 Green QE to finance transition

In this scenario we formulate policy alternative informed by an unorthodox interpretation of the ECB's mandate. This alternative is informed by three arguments.

Adopting measures to mitigate climate change is in line with the ECB's responsibility to achieve price stability. In chapter 2 we have seen that its mandate bestows the ECB with the primary responsibility over stability in prices and currency. This stability requires general economic and financial stability (Van Tilburg & Simić, 2021). The idea that global warming affects the ECB leans on two main arguments that derive from this responsibility. (1) Climate change affects the stability of the financial system (Carney, 2015; Matikainen et al., 2017; Van Tilburg & Simić, 2021). (2) Climate change affects the ability of central banks to achieve price stability (NGFS, 2020a).

In chapter 3 we have seen that the current, supposedly market neutral approach is in fact not neutral at all. Carbon-intensive sectors are over represented in the ECB's portfolio. This leads to an improvement of the competitive position of high-carbon companies, resulting in higher overall emissions. Concluding that distortion of the market is inescapable, we explore avenues to employ the unavoidable distortion in a way that aligns with the effort to mitigate dangerous global warming.

Whereas the two arguments above still fall within accepted frames of discourse, the third argument is more radical. Central banks are responsible for price stability. That responsibility is taken away from democratic governments and put with technocrats, with the argument that democratic governments

cannot handle the responsibility. This has been basic accepted consensus for three going on four decades. With the exact same rationale, one could argue to give the same technocrats a greater responsibility in safeguarding climate stability. Despite treaties, conventions and dozens of warnings coming from the scientific community, governments are so far hardly managing to achieve significant mitigation. Under current trends, the WMO expects a global average temperature rise of 3 to 5 °C by 2100 WMO (2018). If stability of the macroeconomy justifies a responsibility for central banks, than one cannot be blamed for exploring if the avoidance of "severe risks to health, livelihoods, food security, water supply, human security" does so too (IPCC, 2018). We will come back to the desirability of giving central bank technocrats the authority to fight global warming in chapter 8.

In this scenario, the central banks takes on the responsibility to provide the financing that is necessary for the transition to a carbon neutral economy. In this scenario, central banks employ their ability to create central bank reserves to purchase either a large majority of, or all outstanding green corporate bonds in the market. At the same time excluding all conventional bonds from their portfolios.

Alternative	Policy	Green bonds	Conventional bonds
0	Reference	0	unchanged
1	Portfolio tilt	50 % of CB's portfolio	unchanged
2A	Green QE75	75% of eligible market	0
2B	Green QE90	100% of eligible market	0

Table 5.2: Experimental design with different policy alternatives

Results

6

This chapter presents the results of the conducted experiment described in chapter 5. DEFINE was used to gain insight in the system's behaviour and analyse (sets of) effects of different formulated policies for the ECB.

We first analyse the reference scenario to develop an understanding of the underlying mechanisms of the model behaviour. To understand when climate change leads to significant damages, we look at a scenario when the climate damages channel is turned off. Following our analysis of the reference scenario, we assess the effects of the implementation of our policy alternatives in terms of ecological, and macroeconomic effects, and on stability of the financial system.

6.1 Analysis Reference scenario

In order to develop a thorough understanding of the mechanisms behind our results we first analyse behaviour of specific parameters in the reference scenario. To inspect whether parameters are affected by global warming, we compare actual model result to a situation in which we turn off the damage channel of global warming. Thereby essentially looking at what parameters *would* do if damages induced by global warming did not affect them. This effectively breaks down the feedback loop between climate change and the macroeconomy.

We've seen in section 4.3.1 that proportional gross damages formalises how global warming can lead to climate damages (equation (4.11)). The proportional gross damage (D_T) normally lies between 0 (no damage) and 1 (complete catastrophe). The model allows us to force this factor to be zero. These damages affect the depreciation of capital and thus firms' performance. The damage channel is not linearly proportional to global warming. Figure 6.1 plots the developments in temperature and gross proportional damages in the reference scenario. Indeed we see that where temperature rises more or less linearly over the modelled period, climate induced damages increase exponentially. Where the damage curve stays rather flat until 2050, it shows a sharp incline after this year. This coincides with temperature rise exceeding 1,5-2.0 °C. In the following paragraphs, we see what this means for other model variables.

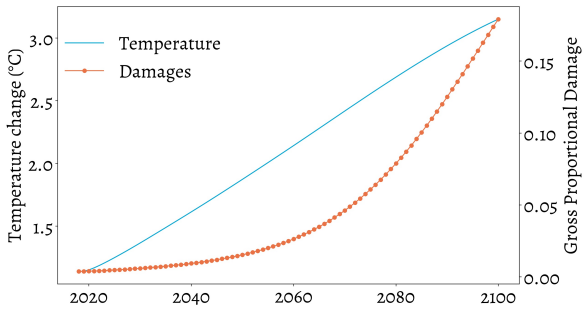

Figure 6.1: Atmospheric temperature and Gross Proportional damages in Reference scenario

We first look at firms' mean profit and default rates, shown as the black lines in fig. 6.2 and fig. 6.3. Both are indications for what we might call the the business climate. When corporations are doing well, profits will be up and default rates on loans will be down.

After a first dip in profit rates resulting from the Covid crisis, we see a steady recovery to a pre-Covid level. This growing trend continues into the decade 2030-2040. Starting halfway this decade, profit rates start to decline. This declining trend goes on until the end of the modelling period. The level for default rates, unsurprisingly, mirrors that of the profit rate. After a peak from the Covid crisis, default rates show a declining trend. After reaching its lowest level towards the end of the decade 2030-2040, they begin to increase, a trend that goes on until the end of the modelling period.

The trends in firms' profit and default rates indicate a deterioration of the business climate. We expect that this is a result of global warming. To analyse whether this is indeed the case, we turn off the damage channel. The result of these scenarios are presented as the green lines in fig. 6.2 and fig. 6.3.

For profit as well as default rates we see that rates in a scenario without damages follows that of the scenario with damages closely until around 2030. From 2030 on, the lines separate. First slowly and more or less linearly until the decade 2050-2060 after which the green lines really break loose. Where profits keep declining when damage affect performance, with the damage channel turned off, profits strongly recover towards the end of the century. The same thing happens in the default rates. Default rates in the reference scenario increase towards the end of the century with climate damages turned on. In the scenario without climate damages, the default rates stay stable towards the end of the modelling period.

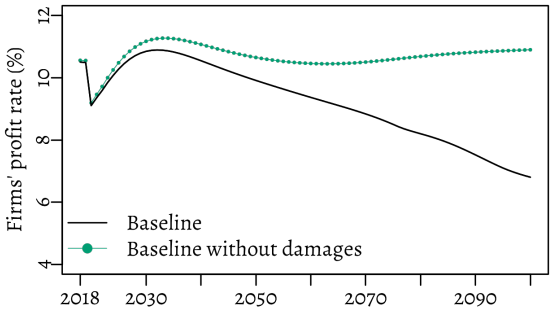

Figure 6.2: Profit rate in reference scenarios

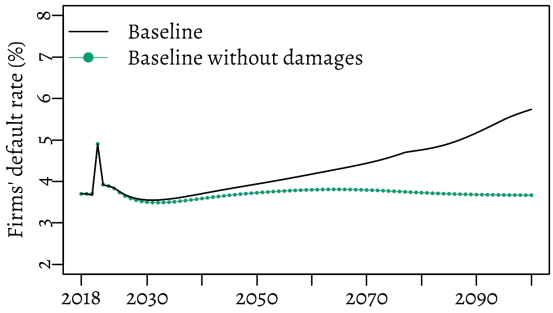

Figure 6.3: Default rate in reference scenarios

The damage to firms has serious implications for the stability of the financial system. Default rates show the rates of firms that cannot meet their liabilities. This is a risk that ultimately lies with the creditors. Defaulting firms mean that banks have to depreciate on their assets. High default rates therefore affect the solvency of banks in the financial sector. This is shown in fig. 6.4. We've seen in section 4.3.1 that DEFINE calculates bank leverage as the sum of all banks' outstanding loans, securities and deposits divided by

their total capital. It essentially indicates how much of what banks lend to others, are covered by their own assets. The lower this ratio, the better resilient is a bank to endure shocks.[1]

The model results imply that global warming warming, through climate induced damages, indeed deteriorate the stability of the financial system. In the scenario without climate damages, bank leverage ratios remain stable over the course of the modelling period. However, when climate damages are turned on, we see that bank leverage ratios remain stable until 2050-2060. After this decade, they increase exponentially until reaching a value over 20% around the decade 2070-2080. Subsequently, they keep increasing but more or less linearly. This increase stops at 33% when the maximum leverage ratio is reached and governments step in with a bailout program. Even when we take into account that the values that the model generates are indicative, we can say that bank leverage ratios towards the end of the century are extremely high at above 30%. This indicates a very fragile financial system and almost guarantees financial crises.

Total macroeconomic output is also affected by global warming (seen in fig. 6.5). From around 2060, climate induced damages start to suppress the output curve. We see that from this year on, output grows faster when climate damages do not affect the economy than when they do. Although inflation is not included in DEFINE, we might derive from its effects on GDP that global warming indirectly affects prices, at least from the New-Keynesian point of view. We have seen in chapter 2 that the NK macroeconomic school supposes that economic performance is a determinant of inflation. Climate change leading to a slumping economy thus indirectly suppresses inflation as well.

Macroeconomic performance affects emissions. Figure 6.6 shows that emissions in both scenarios keep increasing towards the middle of the century. After 2060, for a scenario with climate damages, the combination of suppressed macroeconomic performance, declining carbon intensities and increasing sequestration lead to a stabilisation and subsequent decline of emissions. When climate does not induce damage to the economy, the emissions keep increasing until the end of the modelling period.

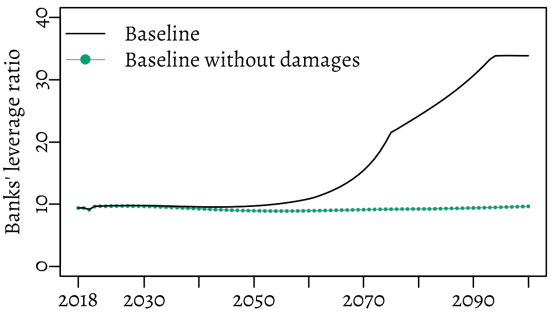

Figure 6.4: Bank leverage in reference scenarios

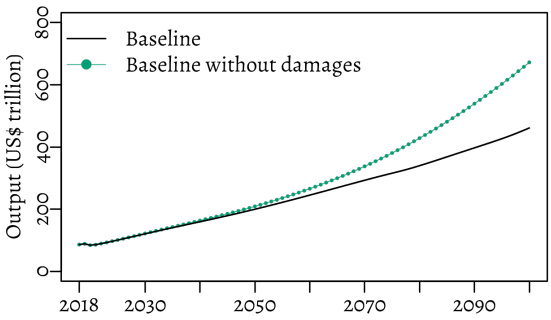

Figure 6.5: Total output in reference scenarios

[1] For more information on leverage ratios see Investopedia (2021a)

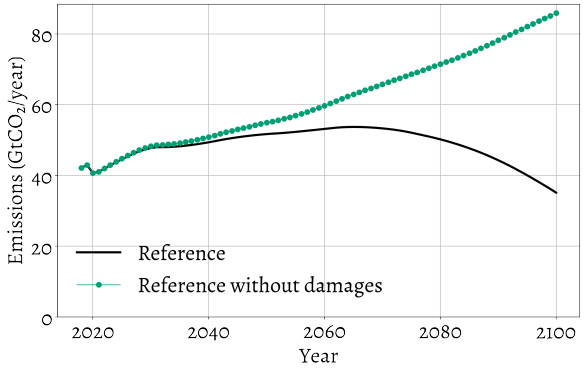

Figure 6.6: Emissions in reference scenarios

Preliminary conclusions

Global warming, through climate damages, affect the stability of the financial system and macroeconomic performance. This effect accelerates in the decade 2050-2060, when temperature rise exceeds 1,5-2.0 °C. Through suppression of firms' profit rates, climate change leads to rising firm default rates. This deteriorates the stability of the financial system as banks have to depreciate on their outstanding loans. Bank leverage ratios towards the end of the century rise to very high values at above 30%. Macroeconomic output is also affected by global warming. From around 2060, climate induced damages start to suppress the output curve. With this preliminary conclusions in mind, we can now look at how policy alternatives affect observed behaviour of parameters.

6.2 Analysis Policy Scenarios

We turn to the model results of the three policies. Values in this chapter are indicative. DEFINE is appropriate to show future developments and the direction of changes. We should not interpret results as hard predictions for future values. We are interested differences between policies and the reference scenario. Throughout the rest of the chapter, we therefore pair graphs with absolute values to graphs that present the difference in percentage points of policy alternatives to the reference scenario. The first are indicative of the direction of future developments. The latter show the difference between implementing a policy versus not implementing it and let us distinguish between the different policy alternatives. Unless otherwise stated, graphs with absolute values go left and graphs with differences go right.

In our assessment of the modelling results, we follow the causal chain of events. Our interventions first affect the bond market and through this, green investment and renewable energy. Developments in the amount of green investment and energy affect emissions. Emissions affect temperature change. As we have seen above, atmospheric temperature, through climate damages, affect macroeconomic performance and stability of the financial system.

6.2.1 Effects on bond markets, green investment and capital

The first effects of the policy alternatives are on bond yields. Figure 6.7 and fig. 6.8 show the effects on the green bond market that occur in the different policy scenarios. Figure 6.9 and fig. 6.10 show the effects on the conventional bond market.

Corporations give out bonds to finance investment.The yield on these bond denote the costs that these firms have to make in order to do investment. The word "yield" might therefore be a little bit confusing. It is called this way because that is from the perspective of the provider of the capital. It is what they yield on providing the money. Yield as such is inversely proportional to the market price of bonds. From the perspective of the corporation we establish that the lower the yield, the cheaper it can finance its

investments, the better.[2]

The yield on green bonds show an interesting development, seen in fig. 6.7. In either one of the three policy alternatives, the yield on green bonds plummet in the first years after implementation. This means that green investments can be financed at very low costs. Yields in *Green QE90* even approach zero and do not increase before the end of the experiment. Yields in *Green QE75*, *Portfolio tilt* and the reference scenario follow the same pattern. After an initial decrease, they show a slight increase towards 2070 after which they decrease again towards the end of the century. However, the initial decrease in *Green QE75*, *Portfolio tilt* is much stronger than in *Reference*. This results in yields that lie between 40% and 60% of yields in the reference scenario (fig. 6.8).

Yields on bonds are determined according to their supply/demand ratio in a market clearing mechanism. This explains observed behaviour. When the ECB buys 90% of all green bonds, this vacuums the market to such an extent that the market price is always pulled down to zero. The ECB only buying smaller proportions of the market leaves room for the regular price setting mechanism. The increasing price towards 2070 reflects the growth rate of the proportion of firms' green desired investment funded via bonds. The green bond market is expected to expand in the next years and firms are likely to use this market more in order to fund their green investment. Around 2060, when climate damages escalate, yields then start to decline again.

On the market for conventional bonds we also see an interesting development. In the scenarios when the ECB keeps its presence in the conventional bond market (*Reference* and *Portfolio tilt*), yields show an initial decline. However, around 2040 this turns into a sharp increase that shortly flattens around 2070 but then goes on until the end of the modelling period. This increase coincides with escalating climate damages, leading to increasing default rates and decreased desired investment. The increased risk on loans lead banks to increase the price of their capital. We will come back to increasing default rates in the paragraphs below.

The ECB stepping out of the market for conventional bonds in the scenarios *Green QE75* and *Green QE90* increases yields relative to the other scenarios. However, due to the sharp increase of yields in the other two scenarios, it dives under the line of those scenarios around 2050. This again implies that the increased yield on conventional bonds is a result of global warming. When policy is adopted that mitigates global warming (as we will also see below) this effect is dampened.

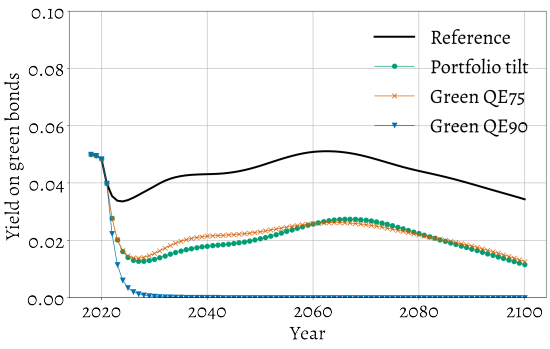

Figure 6.7: Yield on green bonds

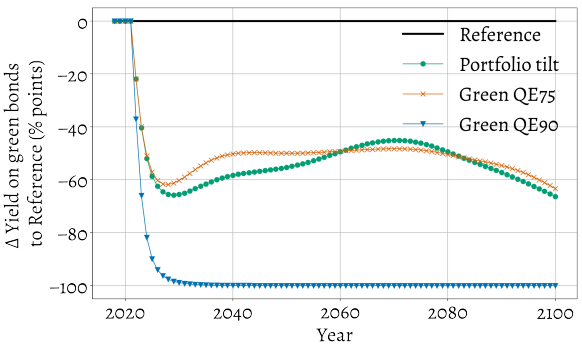

Figure 6.8: Yield on green bonds compared to reference scenario

Green investment

Figure 6.11 and fig. 6.12 show the developments in green investment. In section 4.3.1 we saw that yield on green bonds is one of the factors that influences green investment. Green investment is determined by

[2] For more information on bonds see Investopedia (2020)

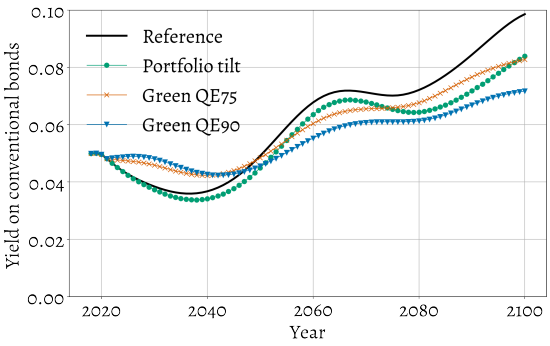

Figure 6.9: Yield on conventional bonds

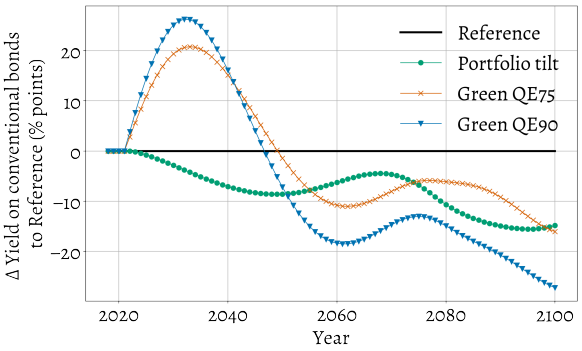

Figure 6.10: Yield on conventional bonds compared to reference scenario

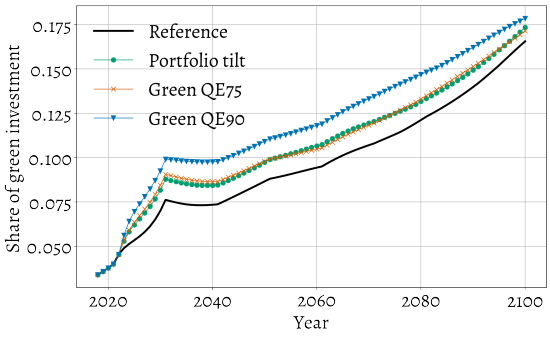

Figure 6.11: Share of actual green investment

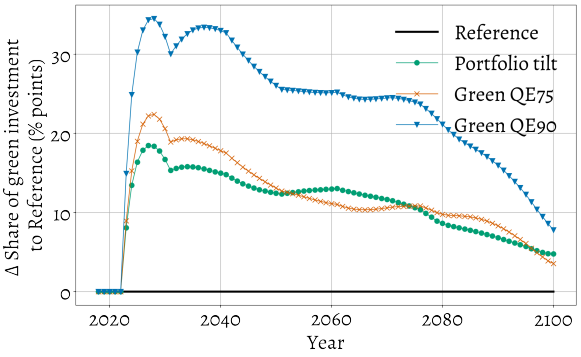

Figure 6.12: Share of green investment compared to reference scenario

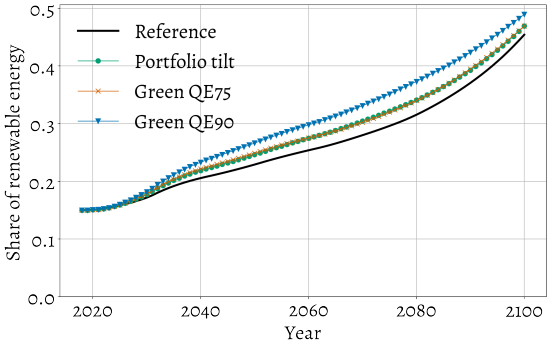

Figure 6.13: Share of renewable energy

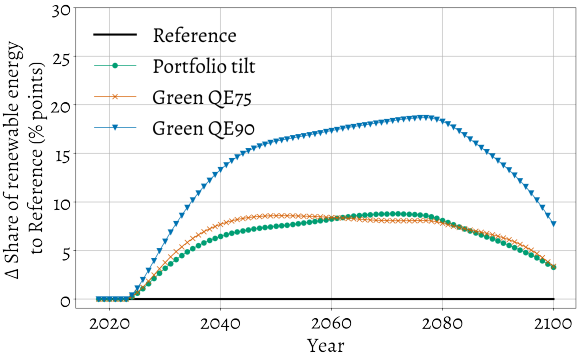

Figure 6.14: Share of renewable compared to reference scenario

three factors: (1) exogenous developments, it is assumed that it increases every year but with a declining rate, (2) the cost of green capital compared to conventional capital and, (3) the borrowing cost of investing in green capital compared to conventional capital.

We see the autonomous increase in investment reflected in the inclining graph lines. Looking at fig. 6.11 it becomes clear that the share of green investment is indeed higher in scenarios when yield on green bonds is lower. In all four scenarios, the share of green investment grows steadily over the century. However, we see that this growth is bigger when the three policy scenarios are applied. Towards the end of the century, the difference in green investment between the three scenarios and the reference scenario decreases.

Figure 6.13 and fig. 6.14 show how the share of energy that is generated from non-fossil sources is affected by implementation of different policy alternatives. All three alternatives show an increase of renewable energy share. The shape of these developments do not differ too much from each other. It is highest for the *Green QE* alternative. *Green QE75* and *Portfolio tilt* show similar values. Notably, towards the end of the century, the increase of renewable energy in the baseline scenario steepens to end relatively close to scenarios *Green QE75* and *Portfolio tilt*.

6.2.2 Ecological effects

The model generates four clearly distinguishable outputs in terms of ecological effects.

The varying shares of renewable energy use for the different alternatives result in varying CO_2 emissions, as we see in fig. 6.15 and fig. 6.16. Until 2030, emissions keep growing in all scenarios. However the growth flattens in all alternatives compared to the baseline scenario. Starting in 2030, the three policy scenarios show a decline in emissions for a number of years. The decline is steepest in *Green QE90*. *Green QE75* and *Portfolio tilt* are more gradual. Emissions in the baseline scenario show a temporary stabilisation, but no decline. After 2040, emissions show a renewed, be it modest, growth in the policy scenarios. Growth in the reference scenario is stronger. Around 2070 emissions for all scenarios start to decline again. Interestingly, this is sharpest in the *Reference*. Again, this has to do with falling economies as a result of escalating global warming.

Following the development in shares of renewable energy, we see that the CO_2 emissions in the baseline scenario catch up with those the other scenarios. This is caused by the fact that in scenarios with more global warming, damages start to depress the macroeconomy. Less economic activity leads to lower emissions.

Figure 6.17 and fig. 6.18 show the developments in atmospheric temperature. Apparent is that until around 2045, growth in atmospheric temperature is relatively similar for all scenarios. The temperature rise exceeds 1.5°C around 2035. From 2045 on, the temperature rises for our three scenarios start to flatten a little relatively to the baseline scenario. This is strongest for *Green QE90*. All scenarios break through the crucial 2.0°C in the decade around the decade 2050-2060. Relative differences between scenarios grow throughout the modelling period but stabilise towards the end. This follows from the fact that CO_2 emissions in scenarios also converge towards the end of the modelling period. Temperature change is a direct effect of emissions.

In the end of the modelling period, global warming in the *Green QE90* scenario lies at about 92% of global warming in the reference scenario. That is a difference of about 8% points. This difference is about half in the two other policy scenarios: 4% points.

The differences in global warming between the scenarios lead to different values for climate induced damages, visible in fig. 6.19 and fig. 6.20. As in the analysis of the base case, we see here that the lines in this graph are exponential, staying rather flat until 2050-2060 after which they rapidly increase. We see that differences in the damage channel between policy alternatives become apparent from 2035 and grow to considerable size towards the end of the modelling period at over 30% points.

6.2.3 Macroeconomic effects

In section 6.1 we have seen that global warming has a profound effect on macroeconomic performance. Indeed we see that the different effects on global warming of the policies, affect the economy.

Figure 6.21 and fig. 6.22 shows the paths for the growth rates of output. After the dip resulting from the global Covid pandemic, growth rates bounce back to 4% in 2022. But from then on we see a considerably

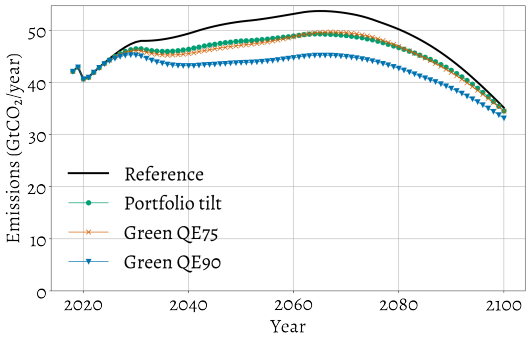

Figure 6.15: CO_2 Emissions

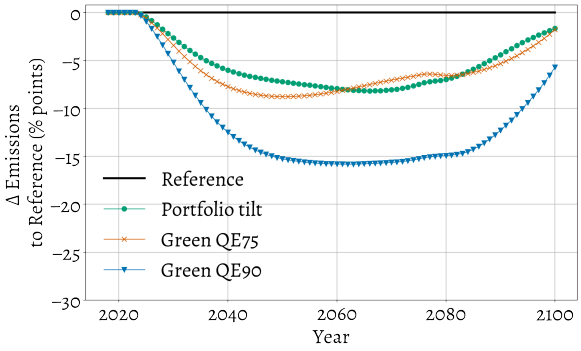

Figure 6.16: CO_2 Emissions compared to reference scenario

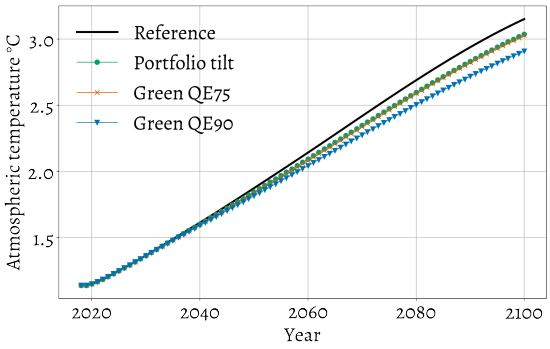

Figure 6.17: Atmospheric temperature

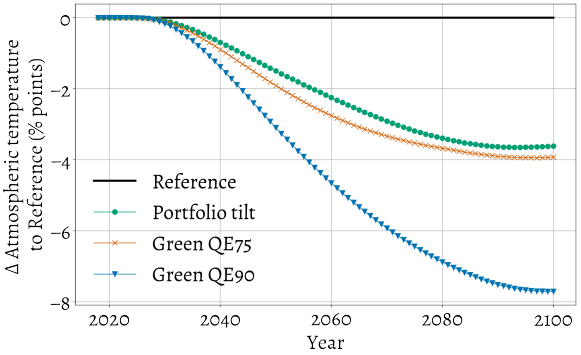

Figure 6.18: Atmospheric temperature compared to reference scenario

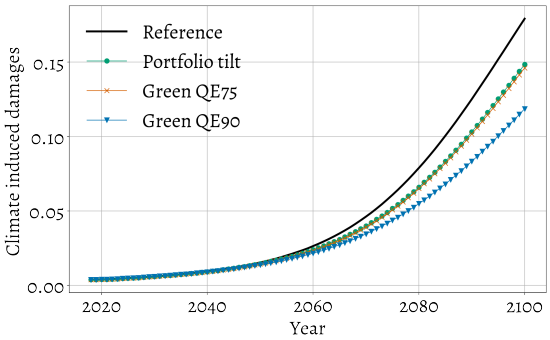

Figure 6.19: Climate change induced damages

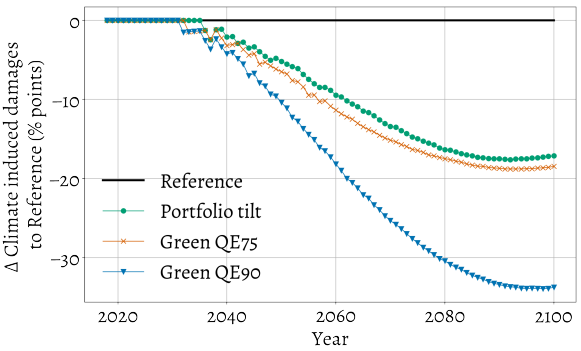

Figure 6.20: Climate induced damages compared to reference scenario

steep decline in growth rates that lasts a little over a decade. From 2035-2040 this decline continues but looses some of its steepness. Also from here on, we see that the developments in the alternatives start to differ, this is clearest in fig. 6.22. The decline in growth rates is biggest in the baseline scenario. Growth rates of our three policy alternatives also decline but slower. These differences are significant as they develop into a difference of up to 30% points. Towards the last quarter of the century, we see that the declining growth bounce on what seems a minimum. This happens first and also at the lowest rate in the reference scenario. The policy alternatives follow later and at higher rates. From the baseline it seems that

after the rate hits this minimum, it converges towards an equilibrium rate of about 1,5%. However, we cannot really determine this as it falls outside the time limit of our experiment.

Total global output is shown in fig. 6.23 and fig. 6.24. As total output is its integral, it follows the development of growth rate. Indeed we see a tiny dent in the graph as a result of the Covid pandemic. The varying growth rates for different scenarios become visible in total output around 2060. Output growth flattens in the baseline scenario compared to the three policy alternatives. Output growth remains highest in *Green QE90*. The difference in sizes of the economy towards the end of the modelling period goes to over 12,5% for the *Green QE90* compared to the baseline. Differences in the other two scenarios lie at about half: 6%.

Profit rates for firms show a similar development as macroeconomic growth. After a dip in 2020, profit rates recover to pre-crisis levels in a decreasing growth that peaks around 2030-2035. From here on, profits start to decline more or less linearly. This year coincides with the moment when climate damages start to grow. This decrease is strongest for the profit rates in the reference scenario and weakest for *Only green QE*. Rates for this scenario lie at about 9% in 2100. For *Decarbonised QE* and *Green QE* they lie a little over and under 8% respectively. Profit rates in 2100 in the reference scenario approach 6% in the baseline scenario.

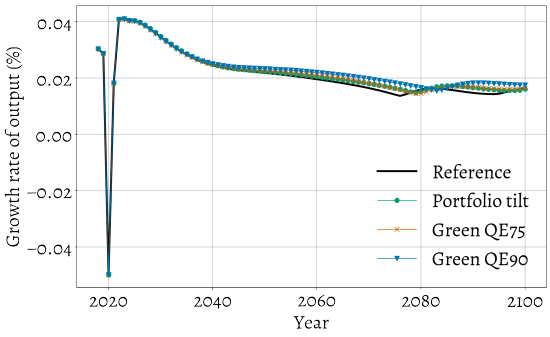

Figure 6.21: Growth rate of output

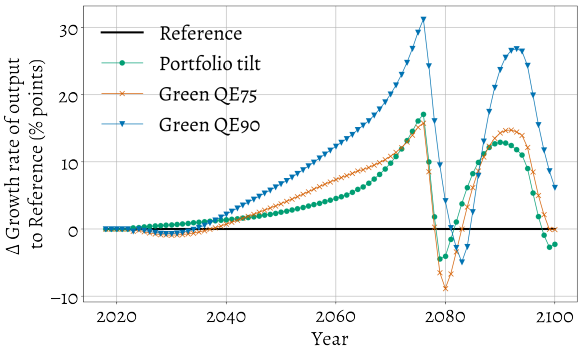

Figure 6.22: Growth rate of output compared to reference scenario

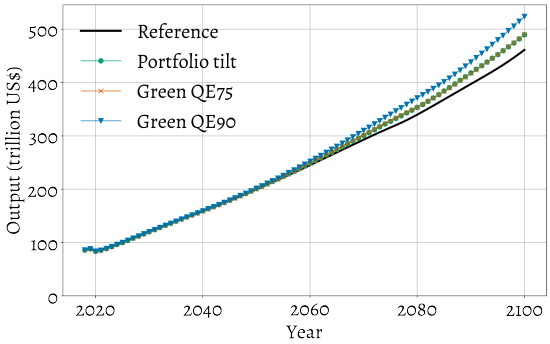

Figure 6.23: Total output

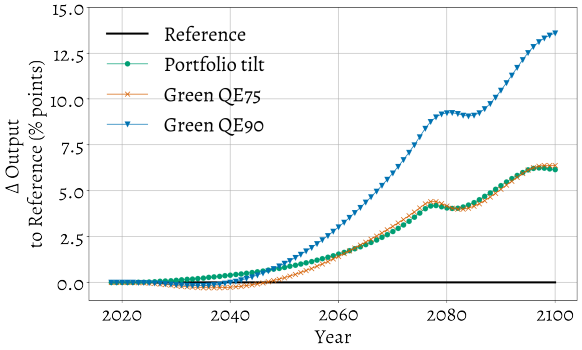

Figure 6.24: Total output compared to reference scenario

6.2.4 Effects on stability of the financial system

As in section 6.1, we represent the stability of the financial with the default rates on loans and leverage ratios of banks.

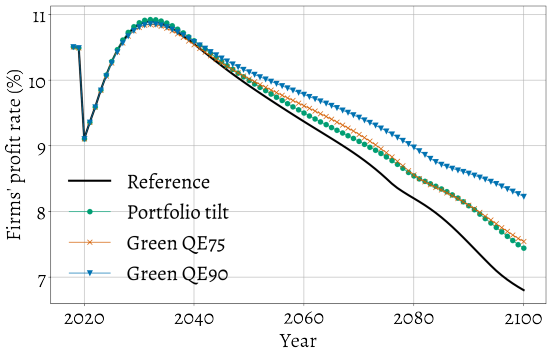

Figure 6.25: Profit rates

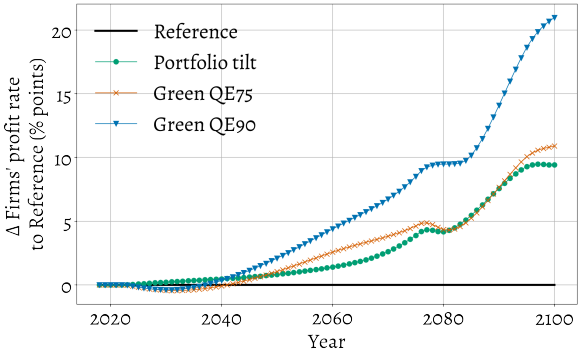

Figure 6.26: Profit rates compared to reference scenario

Firms default rates on loans are showed in fig. 6.27 and fig. 6.28. Again, these mirror the development in profit rates. Default rates show the rates of firms that cannot meet their liabilities. It is a measure of financial stability because this is a risk that ultimately lies with the creditors.

We see a spike in the default rates in 2020 as a result of the Covid pandemic and the economic crisis that results from it. Rates recover after the crisis to near pre-crisis values and keep declining until around 2030. From 2030 on, default levels for all scenarios start increasing. After 2040, this growth continues but it becomes clear that it is stronger in the base scenario compared to the three policy alternatives. Again, this coincides with the year when we start to differentiate between climate induced damage levels between the alternatives. In 2100 the differences in default rates between the policy scenarios and the baseline lie at 15% points for *Green QE90* and about half for the other two policy scenarios.

These default rates affect the stability of the financial sector. Figure 6.29 and fig. 6.30 show the bank leverage ratios in the different scenarios. We see that in the short and medium term, all four scenarios show the same development for bank leverage ratios. From 2050, we see a growing increase in the ratios for all four scenarios. We might stay that this increase is extremely steep for all scenarios though steepest in the baseline. When the ratio hits a value of over 20, its increasing growth flattens a little and continues more or less linearly. Maximum values are reached towards the end of the century and lie at 33%. At this rate, governments step in with a bailout program.

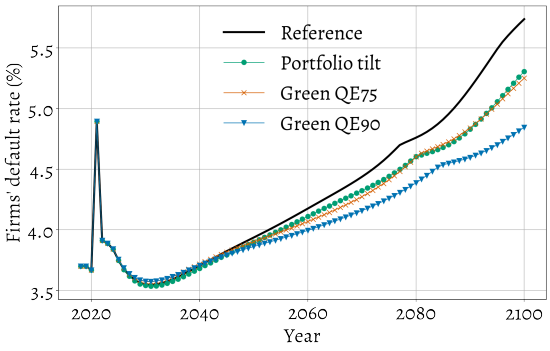

Figure 6.27: Firms' default rates

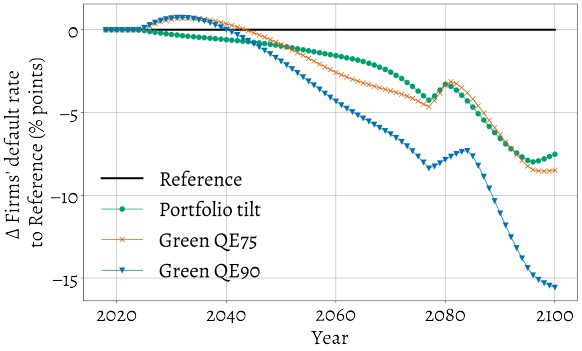

Figure 6.28: Firms' default rates

6.3 Concluding remarks

We evaluated the effects of three alternative policies for QE: *Green QE90* in which most radical changes were implemented. *Green QE75* that was based on the same argumentation as *Green QE90* but with more modest variables. *Portfolio tilt* which we consider consistent with orthodox views on central bank policies

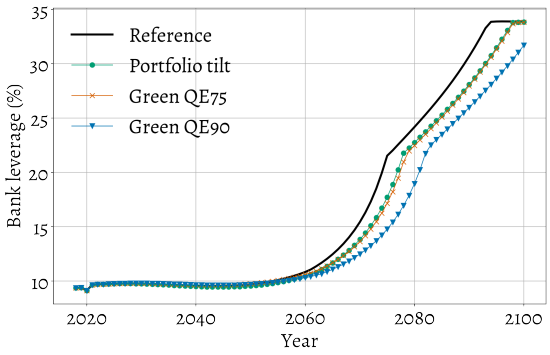

Figure 6.29: Bank leverage

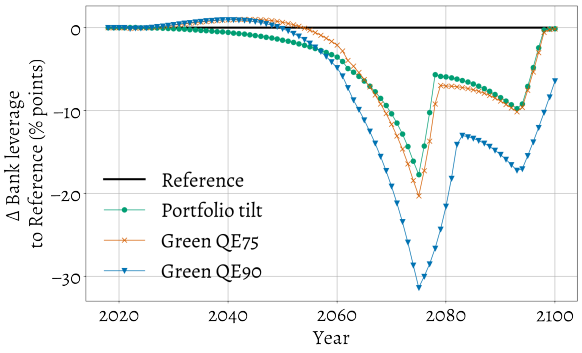

Figure 6.30: Bank leverage compared to reference scenario

was the third policy alternative. All scenarios were compared to a baseline as reference scenario. Values for the baseline scenario were taken from IPCC scenarios.

The effects of different policies were evaluated on four sets of KPIs: (1)effects on bond markets, green investment and -capital,(2) ecological effects, (3) macroeconomic effects and (4) effects on stability of the financial system.

Assessment of the reference scenario showed that global warming, through climate damages, affects macroeconomic performance and financial stability. These effects become apparent around 2050 and due to the nonlinear nature of climate damages, accelerate faster than proportionate to the actual rise of temperature. When no mitigating measures to climate change are taken, bank leverages approach critical levels to the end of the century. These threaten stability of the financial system, one of the secondary objectives of the ECB. Macroeconomic output is also suppressed by climate damages. Although inflation is not included in DEFINE, we might derive from its effects on GDP that global warming indirectly affects prices, the primary objective of the ECB, at least from the New-Keynesian point of view.

The ecological effects of the three alternatives compared to the baseline are significant and manifest themselves already in the short and medium term. Temperature change in a scenario where *Green QE90* is employed lies at 12% points lower than in the baseline scenario in 2100. The observed differences in scenarios *Green QE75* and *Portfolio tilt* are smaller but still significant. In 2100, these lie at 6% points lower than the baseline. Policy alternatives affected investment costs for green investment. These levels caused by different shares of renewable energy, leading to varying levels of emitted $CO_2$and ultimately to differences in temperature rises among scenarios.

Growth rate of output shows a decline from 2022 onward. The decline in the baseline scenario equals that of the policy scenarios in the first two decades. Starting in 2040, the decline in the policy scenarios weakens compared to that of the baseline. Mostly so for the *Only green QE*. Varying growth rates lead to differences in total output of the global economy, becoming visible from 2050-2060 on.

Stability of the financial system is evaluated through effects on leverage ratios of banks and firms, firms' default rates and profit. Until 2050, values for these factors are equal for all scenarios. After this year significant deviations between scenarios become visible. Invariably, the scenario where *Green QE90* is implemented shows the most positive development, while the values in the reference scenario deteriorates. *Green QE75* and *Portfolio tilt* score in between.

Conclusions

7

Quantitative Easing (QE) is a form of monetary policy that is conducted by the ECB. Current implementation of QE contributes to global warming and counteracts a transition to a carbon-free economy. This research first aims to analyse if the ECB's mandate allows for climate considerations in QE policy. Informed by the results of this analysis it then formulates alternative policies for QE. Subsequently, the effects of alternative policies on climate change as well as on the stability of the macroeconomy and financial system are analysed. The research question that it aims to answer is:

What is the effect on European carbon emissions of a policy of green Quantitative Easing by the European Central Bank that is consistent with its mandate?

The paragraphs below describe the steps taken to arrive at an answer to the research question. We conclude with a presentation of the policy implications for the ECB.

7.1 Perspectives on QE and the ECB's Mandate

Different ideas on the ECB's policy space

The legal basis for the establishment of the ECB is laid down in the different Treaties of the European Union. These mandate the ECB to pursue several objectives, the primary of which is price stability. Secondary objectives flow from its assignment to support the EU's economic policy, including those for "balanced economic growth", "full employment and social progress" and " a high level of protection and improvement of the quality of the environment."

Analysis of the historical and global context shows that a determination of the meaning of the hierarchy between primary and secondary objectives of central banks is not absolute but subject to interpretation. Whether one advocates the ECB to exclusively pursue the primary objective (narrow interpretation) or also focus on secondary objectives (expanded interpretation) depends significantly on whether one sees trade-offs between the different objectives.

Current hegemonic consensus on the interpretation of the mandate is that the ECB must devote its undivided attention to its primary objective. It is then through the establishment of price stability that the ECB contributes to its secondary objectives. In this explanation, the ECB cannot focus its attention on the secondary objectives, as this will impede its ability to keep prices stable, either through mission creep or through an overburdening of monetary policy. This interpretation is consistent with New-Keynesian school ideas on monetary policy.

Against the conventional stands a more unorthodox interpretation. Following this interpretation, it is in the service of pursuing its primary objective that secondary objectives, like climate change considerations, should form an integral part of the ECB's monetary policy. Climate change affects central banks' ability to achieve price stability, either directly or through its affection of the financial system. This interpretation aligns more with Post-Keynesian ideas.

Understanding the effects of QE on the financial system and climate change

Quantitative Easing is a policy in which central banks concurrently purchase financial assets, financed by the creation of central bank reserves, as a tool for loosening monetary policy. The aim of undertaking QE is to stimulate spending and thereby generated inflation, so as to obtain price stability. The fundamental mechanism through which asset purchases influence spending and inflation is through increasing the liquidity of private sector balance sheets. This is supposed to push up asset prices and stimulate expenditure by lowering borrowing costs and increasing wealth.

Following from the interpretation that the ECB cannot include climate change considerations in their monetary operations, the central bank applies a principle of market neutrality in their corporate bond purchases. However, in practice this results in a pronounced overrepresentation of carbon-intensive sectors in the ECB's portfolio proportional to these sectors' contribution to employment and GVA. This improves the competitive position of high-carbon companies, resulting in higher overall carbon emissions.

7.2 Green(er) QE significantly contribute to mitigation of climate change

Alternative policies for a green(er) QE

Informed by our conclusions on the ECB's policy space and by analysed mechanisms through which QE affects the economy and the climate, we formulate alternative policies for QE. As there are two interpretations of the ECB's mandate, we arrive at two (sets of) policy alternatives, each consistent with one interpretation.

Consistent with a conventional but broader interpretation of the ECB's room for discretion we formulate a policy alternative in which the central bank tilts its operations without interfering in the current conduct of monetary policy. This policy is designed such that it avoids major adjustments in the asset mix, currency denomination and maturity and that it keeps the list of eligible assets within each asset class as broad as possible.

Consistent with the unconventional interpretation of the ECB's room for discretion we design a policy that aims at providing the financing that is necessary for the transition to a carbon neutral economy. In this scenario, central banks employ their ability to create central bank reserves to purchase outstanding green corporate bonds in the market. At the same time excluding all conventional bonds from their portfolios.

Reference scenario

Evaluation in DEFINE, a stock-flow-fund ecological macroeconomic model, shows that global warming, through climate damages, affects macroeconomic performance and financial stability. These effects become apparent around 2050 and due to the nonlinear nature of climate damages, accelerate faster than proportionate to the actual rise of temperature. When no mitigating measures to climate change are taken, bank leverages approach critical levels to the end of the century. These threaten stability of the financial system, one of the secondary objectives of the ECB.

Effects of green QE

Evaluation of scenarios in which different policy scenarios are implemented shows that implementation of either one of the greener QE policy alternatives will lead to significant lower levels of temperature rise compared to the reference scenario, starting in the short to medium term. Through the mitigating effect on global warming and the damaging consequences thereof, implementation of green QE dampens the deterioration of macroeconomy and financial stability.

Green QE policies lead to cheaper financing for green investment. This in turn results in higher shares of green investment and green capital, apparent immediately after implementation. More green capital leads to higher shares of renewable energy which leads to lower levels of CO_2emissions.

Global warming in a scenario where the most-far reaching policy that leans on an unorthodox interpretation of the ECB's mandate is employed lies at 8 % points lower in 2100 than in the baseline scenario. Observed differences in a more modest policy alternative that is still based on the unorthodox interpretation of the mandate are smaller but still significant, 4 % points lower rise of atmospheric temperature. This equals the temperature rise when a policy is implemented that is based on a conventional interpretation of the ECB's mandate.

Growth rate of economic output shows a decline from 2022 onward, in the baseline as well as in the policy scenarios, amongst other factors caused by climate change. Starting in 2040, implementation of policy alternatives dampens this decline. Mostly so for the most unconventional policy alternative. Varying growth rates lead to differences in total output of the global economy, becoming visible from 2050-2060. Total output levels lie at about 12,5% points higher when the most far reaching alternative for green QE is implemented and at about half that level when either one of the two more modest policies are implemented.

Stability of the financial system is evaluated through effects on firms' default rates on loans and bank leverages. Until 2050, values for these factors are similar for all scenarios. After this year significant deviations between scenarios become visible. Invariably, the scenario where the most unconventional policies are implemented shows the most positive development, while the values in the reference scenario deteriorates. The policy based on a broader but conventional interpretation of the mandate scores in between. Again, this is caused by the fact that greener policy scenarios mitigate global warming, which causes the deterioration.

7.3 Policy implications for the ECB

The results of this research indicate that a globally applied policy of green QE by central banks can significantly contribute to a mitigation of temperature rise. The effect is stronger in a policy that is based on an unconventional interpretation of the ECB's mandate but a policy that is consistent with a conventional interpretation of the mandate also shows a significant effect. Introduction of either of the policy alternatives is not enough to limit global warming to below 2.0°and preferably 1.5°C compared to pre-industrial levels that 196 Parties agreed on in the Paris agreement (United Nations, 2015). But its effects justify a consideration on whether green QE should be part of a greater package of measures.

Our results furthermore imply that the assumption that if price stability is maintained, financial stability is assured does not hold in the face of global warming. According to the DEFINE model results, it is not true: climate change undermines financial stability in the future, even if the central bank maintains price stability. These insights justify the inclusion of climate change considerations in the ECB's (and other central banks') monetary policy strategy.

Green QE is a policy alternatives that is available and consistent with the ECB's mandate. Not only does it contribute to the objective of stability of the financial system in the medium to long run, without impairing on it in the short run. Implementation of green QE would signal that the ECB is serious about its responsibility in mitigating climate change. The ECB is an influential institution. Markets look at the central bank. Christine Lagarde said that she wants to explore every avenue available to combat climate change. She should seek no further.

Reflections

8

This chapter presents reflections on the conducted research. Following a framework for critical reflections by Slinger et al. (2014), we first scrutinize the steps that we took in the course of the research. After the critical reflection, we evaluate the academic and societal relevance of the research. The chapter finishes with recommendations for further research.

8.1 Critical Reflection

Reflection is a crucial phase in the research process that should be carried out to make the politics of research transparent. A researcher inescapably makes choices that shape the work. A reflective researcher does not merely report on her findings but questions and explains the choices made and thus how her finding are constructed (Mortari, 2015).

To bring structure to this reflection, we follow the characterization of the modelling cycle presented by Slinger et al. (2014), who compare the modelling cycle to an hourglass (see fig. 8.1). To their framework we add a methodology phase. In our reflection we want to elaborate on our choice for a method but as the framework is specifically constructed for modelling research, when the choice for a method has already been made, it does not include this.

Slinger et al. (2014) let a phase of convergence be followed by a phase divergence. Working towards a model, modellers make choices with which they limit their observable universe. Starting with a problem definition, they zoom in on a problem, thereby inherently loosing focus on everything that they consider beyond the scope of their research. This problem formulation fundamentally directs their research. The questions they ask determine the answer they will find. Subsequently in the phase when they construct a conceptual understanding of the system, choices are made considering simplification of reality, and again when they specify the model.

The process of divergence starts when modellers apply their model and derive meaning from it. From their model, a simplification of reality by definition, they deduce information about the real world again. Behaviour of the system in the model is extended to behaviour of the real world. In the following paragraphs we follow the hourglass model to reflect on the choices that we made in our research.

8.1.1 Problem Description

In the problem formulation we made several choices that determined later stages of the research. To explore these choices, we depart from the research question. It contains four essential elements that I highlighted below. We will look at each of these elements separately.

> What is the effect on **(1) European carbon emissions** of a policy of **(2) green Quantitative Easing** by the **(3) European Central Bank** that is **(4) consistent with its mandate**?

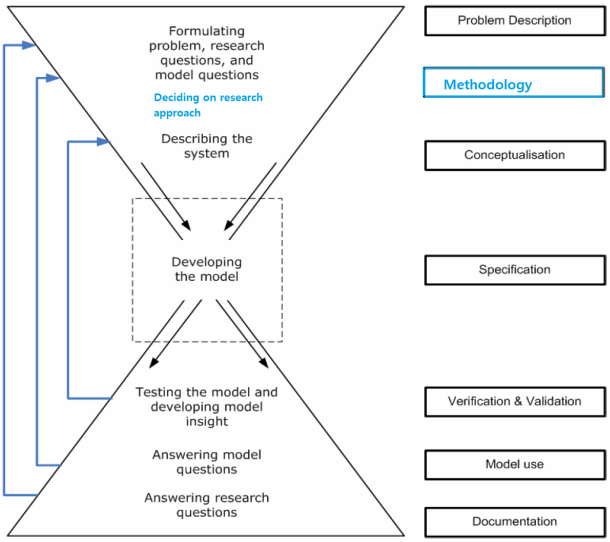

Figure 8.1: Hourglass structure of modelling cyclus, derived from Slinger et al. (2014). Addition in blue.

The research question steers us to analyse the effects on **(1) European carbon emissions** of QE and thereby away from other possible consequences. QE as a policy is designed to have an effect on the macroeconomy. Its effect on carbon emissions are a side-effect. It was a deliberate choice to focus on a secondary effect and not on its efficacy in macroeconomic terms. Also, there are other interesting side effects. We briefly touched one of those in section 3.5 when we discussed consequences for inequality. Deciding not to include these in our analysis narrowed our scope.

The existence of **(2) Quantitative Easing** as a policy was taken for granted. The continued deployment of QE is not self-evident. Not in the least because there are authors who reject QE as not effective, leading to serious side effects or both. We briefly reflected on that in section 3.5. Notwithstanding this criticism, we supposed the continued existence. Another approach could have been that we focused on other measures at the ECB's disposal, like its authority as a banking supervisor. Or we could have taken a more revolutionary approach, formulating a totally new kind of policy. Instead, we confined ourselves to QE.

By focussing on the **(3) European Central Bank** we confirmed the self-evidence of it as an institution. That will generally not be regarded as a controversial stance but it is good to be aware of it. The existence of Central Banks is not 100% undisputed. A (very) unorthodox alternative could have been to think of alternative institutional constellations. Also, asking the question is not neutral. Even though we extensively explored the validity of this presumption, asking a question about sustainability and the ECB already implies a role for the central bank. We have seen in that this is also not undisputed.

We decided to regard **(4) consistency with the mandate** as conditional for alternative policies. This had its consequences for the rest of the research. Explicitly, as it confined the universe of alternative policies to something we deemed compatible with it. This was the case specifically for the first policy alternative that we formulated, as this had to fit within current interpretations. But also for the second policy alternative, as for this one we employed a broader interpretation, but it still had to be consistent.

The mandate also worked its way through in a more implicit sense. In our results we included graphs on macroeconomic stability. This was a result of our decision to focus on the mandate as it stipulates that financial stability is a core responsibility of the ECB. Had we let the mandate out, our focus might have shifted more towards other aspects.

8.1.2 Methodology

The methodology phase is when we decided on our research approach. The combination of different elements in the research question led us to combining two different methods. We started with a qualitative analysis of the institutional context and let that follow by a quantitative part.

Literature analysis

The aim to formulate a policy that is consistent with the ECB's mandate compelled us to start with an analysis of the policy space that the mandate gives. This entailed a modest exegesis on the relevant articles in the treaties of the European Union. This was followed by a historical contextualisation of the ECB's mandate and by an assessment of different interpretations existent in the institutional context, all by means of a literature analysis.

The mandate analysis was followed by another qualitative part in which we explored QE. This was necessary because it is not an undisputed measure. It is not even agreed uopon if current application falls within the mandate, let alone if our proposed alternatives do. This part served as connection between the mandate assessment and the translation towards the model.

The interpretation of literature can by definition not be objective in the pure sense. Even if the selection process of literature had been completely unbiased, we, ecstatic as the subject might drive us, cannot step outside ourselves. Even academics are who they are. I do not regard this fact of life a limitation to this type of research but it is important to be aware of it.

Model based approach

Models are by definition simplifications of reality. A model is always a model and all are wrong but some may be useful.[1] Models are always constructed by researchers. In the process, choices are made regarding simplifications and assumptions that are necessary to capture a complex reality into the model. These choices determine the behaviour of the model and ultimately the outcome of the research. After this general reflection on model based research, we will consider the specific choices underlying our research in the paragraphs below.

8.1.3 Conceptualisation

The conceptualisation phase is characterised by the formulation of of the conceptual model to understand the important factors in the system and how they interact.

Ecological Economics

We decided to take an approach that was consistent with ecological economics. As this school of thought in economics is not mainstream, the choice for it justifies some substantiation: Ecological Economics is an emergent paradigm, but has roots both in the work of Otto Neurath, William Kapp, Karl Polanyi and Nicholas Georgescu-Roegen (references in Spash (2020)). As a school it is incompatible with mainstream economics. A ground on which this imcompatibility rests is the inclusion of implications of biophysical reality for energy and material flows. Aspects that in conventional economics would be considered as externalities. It is because of this property that ecological economics is a suited frame of understanding for the research questions that we aimed to answer. To understand the relations between a policy and climate change, it is necessary to include them both in the system.

A methodological point to be made about our approach is the following. We formulate policy alternatives substantiated by different macroeconomic schools of thought. But we compare both alternatives using a model that is based on only one of those schools. Methodological hair-splitters might argue that we are inconsistent. Different schools understand the macroeconomy in their own ways (as we have seen in chapter 2). It is a little bit of a cherry picking exercise to use elements of their perspectives but then evaluate these with a model that is based on another worldview.

[1] An expression ascribed to George Box

Conceptual model

We start with a reflection on the sequence of steps in our research. We decided in chapter 4 that we were going to work with DEFINE. After this decision was made, we were led by DEFINE and its underlying mechanisms in the formulation of the conceptual model. By consequence, what we did in these paragraphs was not so much looking at reality and trying to catch it in a comprehensible model. Our work in this chapter mainly comprised of figuring out DEFINE and explaining it to the reader. Looking back, this can be justified. DEFINE is an accepted ecological macroeconomic model and ours was not the first research that applied a non-self-made model to a question. Perhaps though, did this have implications for later phases of research. We might have better understood the results and their underlying causes and consequences, had we self gone through the process of building the model that produced them.

Then the model itself. In their own article, Dafermos et al. (2018) explain that there are various aspects of the "finance-green innovation nexus" that DEFINE does not analyse. Especially the fundamental, far-reaching changes to the economy in terms of the production systems after a transition to a green economy are very hard to represent in a model. These entail the elementary changes in the way that an eventual future economy uses energy and matter. Prediction is very difficult, especially if it's about the future.[2] DEFINE is about the very far future so the further we look ahead, the more uncertainties arise.

DEFINE does not include the concept of signalling. When the ECB stops buying bonds from corporations that do not meet it sustainability criteria, this might lead to secondary effects. The ECB is not just another neutral agent in the market. We have seen that central banks' policies have implication for the whole economy. The ECB not buying conventional bonds might have a signalling effect. Companies might fear loss of reputation if the ECB stops purchasing their bonds. To prevent this, it might stimulate them to issue green bonds and finance green investment that otherwise they would not have done. These would in turn affect emissions. We have not quantified this potential effect.

A comparable effect to that of signalling is the response of markets to the ECB pronouncing to purchase such large amounts of bonds, up to 90% of the market. If bonds can (almost) always be sold at nominal value to the ECB, they essentially become riskless. Asset holders who know this, will act accordingly. This might lead to behaviour in the market that we have not included in our model. One of the effects that this might have is that more people want to buy green bonds, and firms will benefit from this. But it might also attract speculators and bring an unhealthy dynamic in the market that works counter-productive.

We explained in section 4.2.4 that DEFINE portrays the global macroeconomy. This had two implications. (1) While it allows for analysis of global central bank policy, it does not let us specify this to a European scale. We therefore could not isolate ECB policy and strictly, could not answer the research question. (2) We could not incorporate interactions between regions. While these interactions might be interesting, they do not constitute the primary interest of our research. We are interested in the general mechanisms behind alternative QE policies. We do not expect that regional interactions fundamentally alter the these mechanisms.

8.1.4 Specification

The specification phase entails the translation of the conceptual model into the numerical model in R. DEFINE is stock-flow-fund consistent. A difference between System dynamics and SFF modelling is time dependence of feedback loops. Where SD works with continuous input variables it can include second order input variables. SFF as a discrete input method, does not provide this kind of weighting over time of these loops.

A limitation of DEFINE for the research that we conducted is that it contains no parameter for inflation. Prices are kept stable to better be able evaluate effects that lie in the far future to the nearer future. This simplification becomes a limitation for research on central bank policies. The primary objective of the ECB is to keep prices stable. DEFINE let us approximate price stability, but not directly analyse it. We

[2] An expression by Niels Bohr

permitted ourselves the freedom to derive some statement on effects on inflation from the developments in macroeconomic performance in chapter 6. However, further research could dig into this deeper.

We used a combination of scenarios formulated by the IPCC as the input for our baseline. Our results are based on a comparison of the policy alternatives to the baseline. Therefore, this was a determinative factor in our results.

8.1.5 Validation

This research contains no extensive validation or verification of the model. There are two main reasons for this: DEFINE has been applied in other academic research before (Dafermos et al., 2017, 2018). Articles on former applications of the model were accepted in respected academic journals. These researches did contain elaborate calibration, verification and validations of the model. The model has endured these tests on validity and veracity in earlier applications. This makes a new comprehensive fundamental verification and validation of the model not crucial.

Reflecting on these choices, we think that the earlier applications indeed justify that we did not perform a fundamental verification and validation on the model. However what we also did not do was a sensitivity analysis. Nor did we do extensive experimentation with the different elements of our policy alternatives or with external uncertainties that might influence result. In new iterations of this research, performing these will mean a significant contribution to the quality of it.

8.1.6 Model use

During the model use, we let the model generate the answers to our model questions. There are important remarks to be made about this part of our research.

The experiment was not comprehensive. We formulated policy alternatives that were informed by the different interpretations of the mandate. This had implications for the experimental design. The policy alternatives were combinations of different elements. On the one hand, we let central banks stop buying conventional bonds. On the other hand we let them buy green bonds. By combining these two aspects in policy alternatives, we did not analyse their separate effect. Had we isolated these factors, we could have developed a more complete understanding of how our results were generated.

In the different model scenarios, we approximated our policy alternatives but could not put them exactly into the model. For example in the alternative that was consistent with the conventional interpretation of the mandate, Schoenmaker (2021) defined that it could achieve a reduction by 55% of the carbon footprint of its portfolio. We codified this into the model by adjusting the green-conventional mix in the central banks' portfolio. This is not the same.

We took a relatively simple approach to green bonds. In our research, bonds were either green or conventional. In reality, this is more nuanced. There are many examples of investments of which the "greenness" could be subject of serious debate. We reflected on this in the first paragraphs of chapter 5. See also footnote in Dafermos et al. (2018). McDonnel et al. (2019) reflect on the significant shortcomings of different private sector approaches that open the door to greenwashing. The European Commission (2020) therefore developed a public EU taxonomy that identifies economic activities with different degrees of greenness and brownness. Further research could refine the measure for 'greenness' of bonds. For example by adopting the ECB's taxonomy and applying it on different bonds.

We isolated QE as a policy measure. We have seen that it is not enough to mitigate climate change enough to reach the goal of maximum 2°C warming. Other measures will be necessary in order to reach that. Implementation of other policy measures might lead to unsuspected interactions between measures. A fiscal stimulus to green investment could be well imagined to interfere with the working of green QE. It would be interesting to combine the different policies and see what would be their combined effect.

8.1.7 Results and conclusions

We conclude in chapter 2 that a narrow interpretation of the mandate of the ECB is consistent with New-Keynesian macroeconomics. The NK assumption is that if price stability is maintained, financial stability will follow. Our results imply that this assumption does not hold. Climate change is undermining future financial stability, even if the central bank maintains price stability. We already emphasise this in chapter 7. We return to it here because it is a fundamental finding that undermines an assumption on which many central bank policies are based, at least until very recently. In the reference scenario, when business as usual is continued, the model implies that the financial system around 2060 will be very fragile. To such a level that it is almost guaranteed that a big financial crisis will occur. For the ECB this should be alarming.

Our finding is consistent with recent papers that also conclude that global warming affects stability of the financial system, be it manageably (Allen et al., 2020; Vermeulen et al., 2018) or potentially disruptively (Bolton, Despres, Pereira da Silva, Svartzman, & Samama, 2020). It looks like the mounting evidence of the consequences of global warming to financial stability is leading (New-Keynesian) central bankers to reconsider their view. Lagarde (2021) refers to it in her speeches and the ECB (2021b) as well as the Bank of England (2021) include climate change consideration in their latest strategy reviews. We recommend more research to be done on the subject to better understand the mechanisms behind the relationship. We approximate stability of the financial system with (general) default rates and bank leverage ratios. Further research can refine these indicators and also include factors not included in DEFINE. Suggestions in Bolton et al. (2020) are for instance real estate loans turning into bad loans.

Another point of reflection is on the (non-)exceptionality of QE, and its implications for the dichotomy between fiscal and monetary policies. Where QE was originally adopted in the crisis as an exceptional measure by the ECB that wanted to do whatever it takes[3] to achieve their inflation target, the exception has - after almost a decade - become rather unexceptional. Especially now with the packages announced after the Covid crisis, QE is not likely to go away any time soon. This does not take away the fact that it was conceived as an exceptional, temporary measure. In our thesis we assume that QE will stay with us but the question is if central banks are really willing to continue for another decade (or more).

The extended duration of QE gives rise to a reflection on the position of monetary versus fiscal policy. In the EU, fiscal policy is heavily restricted by all kinds of restrictive rules. These concern rules on budget deficits but also on prevention of distortive state aid. What we see with QE is central banks stepping in to finance investment. Currently with an aim to stimulate the economy and maintain price stability, but in our policy alternatives the aim extends to stimulate (through financing) the transition to a low-carbon economy, hereby encroaching on what used to be the domain of fiscal policy.

Central banks filling in the void that governments leave is not necessarily problematic but it does constitute a shift. A shift that justifies a reflection on the legitimacy of ECB policies. It essentially leaves us at the mercy of the ECB's board room. That is a different proposition than the democratic idea underlying fiscal policies, where an electorate chooses the direction of policies. A justification for this course might be that democratic governments have so far not shown exorbitant vigor in bringing down emissions and thereby preventing global catastrophe to humankind. An enlightened ECB board room might, but might also not decide to take the course of action necessary to mitigate global warming, and we cannot hold them to account for it. Is society really willing to sacrifice our democratic principles for the prevention of the deterioration of the planet? Or must we find other ways to organise the preservation of our living environment? Let us conclude with the remark that this is a dilemma that justifies thorough consideration in further research.

8.2 Relevance and contributions

This paragraph assesses the relevance and contribution of our research. We make a distinction between academic and societal relevance. The distinction is a bit superficial. Academic output benefits society and

[3] dixit Draghi (2012)

academic culture is informed by society, especially in economics. Contributions to the societal consensus feed back into the academic realm.

8.2.1 Academic relevance

Combining Qualitative with Quantitative approach

This work comprises of two parts methodologically. First a qualitative part in which we analysed the context in which policy comes into effect. This was followed by a quantitative part in which we assessed the effects of a formulated policy. The two parts of this thesis are mutually reinforcing. The qualitative part is more than a an extended run-up to the quantitative analysis. And the quantitative part is more than a numerical illustration to the qualitative argument. Diligently contextualising the empirical work with an extensive analysis on the ECB's legal framework, and current interpretations of that framework allowed us to formulate informed policy alternatives. From here we could first construct a policy for QE that we substantiated to fall within the current interpretation of the mandate. Second, we drew alternatives that we considered not realistic in current political context. But our embedding in the mandate allowed us to identify the exact objections against such alternative policies and provide counterarguments.

In this combination lies an academic innovation. Existing research tends to focus primarily on one of two approaches. Either these are essayist analyses of central banks' role in society: to either formulate criticism or substantiate why it should not change its course. These articles mostly do not extend beyond an analysis of the consequences for the ECB's portfolio of a changed policy. Other research calculates numerically the consequences of policies but without a qualitative embedding.

Adding new applications of DEFINE to the body of academic work

This work applied the DEFINE model to assess alternative policies for the ECB. While the research does not greatly innovate the current body of academic work: we did not apply our insights to compose a new model, or even innovate the existing version of the model such that we could speak of a new version. Still the new application of DEFINE is a contribution to the academic field. We have shown that DEFINE is appropriate to assess the questions that we formulated in this research. The question that we asked were rather similar to the the questions in Dafermos et al. (2018). But we took the policies a significant step further and we, as described above, embedded the policies in their political context.

8.2.2 Societal relevance

Providing new knowledge for debate

As a policy analyst we have formulated policy alternatives that are not realistic in the current hegemonic perspective on the ECB's policy room. But the development of knowledge on effects of these policies is a contribution to the debate nevertheless. Consensus is moving into a direction where also central banks are expected to take their responsibility in the fight against global warming. Hence the statements by Christine Lagarde that were the starting point of this thesis. I am without any illusions about the influence of one master thesis, but maybe this might just be a tiny one of the straws that will eventually break the camel's back.

8.3 Recommendations for further research

With regard to further research, the following recommendations are made. These are already named in the paragraph above. Here, we put them together for overview. These are derived from our reflections and grouped per research phase:

Conceptualisation

1. Include signalling as a secondary effect.
2. Include behaviour of asset holders with ECB as ready buyer for nominal value.

3. Diversify regions so as to allow for analysis of interactions between different regions.

Specification

4. Include inflation in the model.

Model use

5. Conduct a more comprehensive experiment in order to develop a better understanding of system behaviour.
6. Introduce temporariness in policy alternatives.
7. Diversify for different shades of green.
8. Embed QE in a mix of policies to analyse combined effect.

8.3.1 Results and conclusions

9. Refine indicators for stability of the financial system
10. Research on the position of monetary vis-à-vis fiscal policies when central banks extend their policies to objectives going further than price stability.

8.4 Link to EPA program

The Engineering Policy Analysis (EPA) Master Program centers around International Grand Challenges. Typical EPA questions have a societal as well as an academic component. This thesis contained both components.

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Model equations

This appendix contains all model equations in DEFINE. An extensive explanation of all equations can be found in Dafermos and Nikolaidi (2021a).

A.1 Ecosystem

A.1.1 Matter, recycling and waste

$$MY_t = \mu(Y_t - C_{(GOV)t}) \tag{A.1}$$
$$M_t = MY_t - REC_t \tag{A.2}$$
$$REC_t = \rho_t DEM_t \tag{A.3}$$
$$DEM_t = \mu_t(\delta_t K_{t-1} + \xi DC_{t-1}) \tag{A.4}$$
$$SES_t = SES_{t-1} + MY_t - DEM_t \tag{A.5}$$
$$W_t = Mt + CEN_t + O_2 - EMIS_{INt} - \Delta SES_t \tag{A.6}$$
$$CEN_t = \frac{EMIS_{INt}}{car} \tag{A.7}$$
$$O2_t = EMIS_{INt} - CEN_t \tag{A.8}$$
$$HW_{CUMt} = HW_{CUMt-1} + hazW_t \tag{A.9}$$
$$hazratio_t = \frac{HW_{CUMt}}{POP_t} \tag{A.10}$$

$$REV_{Mt} = REV_{Mt-1} + CON_{MT} - M_t \tag{A.11}$$
$$CON_{Mt} = con_M RES_{Mt-1} \tag{A.12}$$
$$RES_{Mt} = RES_{Mt-1} - CON_{Mt} \tag{A.13}$$
$$dep_{Mt} = \frac{M_t}{REV_{Mt-1}} \tag{A.14}$$

A.1.2 Energy

$$E_t = \epsilon_t Y_t \tag{A.15}$$
$$E_{NFt} = \theta_t E_t \tag{A.16}$$
$$E_{Ft} = E_t - E_{NFt} \tag{A.17}$$
$$ED_t = E_{Ft} + E_{NFt} \tag{A.18}$$

$$REV_{Et} = REV_{Et-1} + CON_{Et} - E_{Ft} \tag{A.19}$$
$$CON_{Et} = con_E RES_{Et-1} \tag{A.20}$$
$$RES_{Et} = RES_{Et-1} - CON_{Et} \tag{A.21}$$
$$dep_{Et} = \frac{E_{Ft}}{REV_{Et-1}} \tag{A.22}$$

A.1.3 Emissions and climate change

$$EMIS_{INt} = \omega_t(1 - seq_t)E_{Ft} \tag{A.23}$$
$$g_{EMISLt} = g_{EMISLt-1}(1 - \zeta g) \tag{A.24}$$
$$EMIS_{Lt} = EMIS_{Lt-1}(1 - g_{EMISLt}) \tag{A.25}$$
$$EMIS_t = EMIS_{INt} + EMIS_{Lt} \tag{A.26}$$
$$CO2_{CUMt} = CO2_{CUMt-1} + EMIS_t \tag{A.27}$$
$$T_{ATt} = T_{ATt-1} + t_1(t_2\varphi CO2_{CUMt-1} - T_{ATt-1}) \tag{A.28}$$

$$\omega_t = \omega_{t-1}(1 + g_{\omega t}) \tag{A.29}$$
$$g_{\omega t} = g_{\omega t-1}(1 - \zeta 1) \tag{A.30}$$
$$\mu_t = \mu^{max} - \frac{\mu^{max} - \mu^{min}}{1 + \pi_1 e^{-\pi 2(K_{GNE_{t-1}}/K_{CNEt-1})}} \tag{A.31}$$
$$\rho_t = \frac{\rho^{max}}{1 + \pi_3 e^{-\pi_4(K_{GNEt-1}/K_{CNEt-1})}} \tag{A.32}$$
$$\epsilon_t = \epsilon^{max} - \frac{\epsilon^{max} - \epsilon^{min}}{1 + \pi_5 e^{-\pi_6(K_{GEt-1}/K_{CEt-1})}} \tag{A.33}$$
$$\theta_t = \frac{1}{1 + \pi_7 e^{-\pi_8(K_{GEt-1}/K_{CEt-1})}} \tag{A.34}$$
$$seq_t = \frac{1}{1 + \pi_9 e^{-\pi_{10}(K_{SEQt-1}/(K_{CE(PRI)1t-1} + K_{CE(PRI)2t-1}))}} \tag{A.35}$$

A.2 Macroeconomy and financial system

A.2.1 Output determination and climate damages

$$Y^*_{Mt} = \frac{REV_{Mt-1} + REC_t}{\mu_t} \tag{A.36}$$

$$Y^*_{Et} = \frac{REV_{Et-1}}{(1-\theta_t)\epsilon_t} \tag{A.37}$$

$$Y^*_{Kt} = \upsilon_t K_{(PRI)t} \tag{A.38}$$

$$Y^*_{Nt} = \lambda_t h L F_t \tag{A.39}$$

$$Y^*_t = min(Y^*_{Mt}, Y^*_{Et}, Y^*_{Kt}, Y^*_{Nt}) \tag{A.40}$$

$$Y_t = C_{(PRI)t} + I_{(PRI)t} + I_{(GOV)t} + C_{(GOV)t} \tag{A.41}$$

$$um_t = \frac{Y_t - C_{(GOV)t}}{Y^*_{Mt}} \tag{A.42}$$

$$ue_t = \frac{Y_t}{Y^*_{Et}} \tag{A.43}$$

$$u_t = \frac{Y_t}{Y^*_{Kt}} \tag{A.44}$$

$$re_t = \frac{Y_t}{Y^*_{Nt}} \tag{A.45}$$

$$D_{Tt} = 1 - \frac{1}{1 + \eta_1 T_{ATt} + \eta_2 T^2_{ATt} + \eta_3 T^{6.754}_{ATt}} \tag{A.46}$$

$$D_{TPt} = pD_{Tt} \tag{A.47}$$

$$D_{TFt} = 1 - \frac{1 - D_{Tt}}{1 - D_{TPt}} \tag{A.48}$$

A.2.2 Firms

$$TP_{Gt} = Y_t - \omega_t N_t - \sum int_{Cit-1} L_{Cit-1} - \sum int_{Gt-1} L_{Git-1} - \delta_t K_{(PRI)t-1} - coupon_{Ct-1} b_{Ct-1} - coupon_{Gt-1} b_{Gt-} \tag{A.49}$$

$$TP_t = TP_{Gt} - T_{Ft} - T_{Ct} + SUB_t \tag{A.50}$$

$$RP_t = s_F TP_{t-1} \tag{A.51}$$

$$DP_t = TP_t - RP_t \tag{A.52}$$

$$r_t = TP_t / K_{(PRI)t} \tag{A.53}$$

$$I^D_{(PRI)t} = \left(\frac{\alpha_{00}}{1 + e^{\left(\alpha_{01} - \alpha_1 u_{t-1} - \alpha_2 r_{t-1} + \alpha_{31} ur_{t-1}^{-\alpha_{32}} + \alpha_{41}(1-ue_{t-1})^{-\alpha_{42}} + \alpha_{51}(1-um_{t-1})^{-\alpha_{52}}\right)}} K_{(PRI)t-1} \right) (1 - D_{Tt-1}) + \delta_t K_{(I} \tag{A.54}$$

$$I^D_{(PRI)it} = sh_{(GVA)i} I^D_{(PRI)t} \tag{A.55}$$

$$I^D_{G(PRI)it} = \beta_{it} I^D_{(PRI)it} \tag{A.56}$$

$$\beta_{it} = \beta_{0it} - \beta_1 sh_{(EMIS_{IN})i} \left(tucr_{t-1} - tucn_{t-1}\right) - \beta_2 \left[sh_{Lt-1} \left(int_{Gt-1} - int_{Cit-1}\right) + (1 - sh_{Lt-1}) \left(yield_{Gt-1} - yiela\right.\right. \tag{A.57}$$

$$\beta_{0it} = \beta_{0it-1} \left(1 + g_{\beta 0t}\right) \tag{A.58}$$

$$g_{\beta 0t} = g_{\beta 0t-1} \left(1 - \zeta_2\right) \tag{A.59}$$

$$tucr_t = ucr_t \left(1 - gov_{SUBt}\right) \tag{A.60}$$

$$tucn_t = ucn_t + \tau_{Ct} \omega_t \left(1 - seq_t\right) \tag{A.61}$$

$$ucn_t = ucn_{t-1} \left(1 + g_{ucnt}\right) \tag{A.62}$$

$$g_{ucnt} = g_{ucrt-1} \left(1 - \zeta_8\right) \tag{A.63}$$

$$ucr_t = ucr_{t-1} \left(1 - g_{ucrt}\right) \frac{1 - \theta_t}{1 - \theta_{t-1}} \tag{A.64}$$

$$g_{ucrt} = g_{ucrt-1} \left(1 - \zeta_7\right) \tag{A.65}$$

$$I^D_{C(PRI)it} = I^D_{(PRI)it} - I^D_{G(PRI)it} \tag{A.66}$$

$$NL^D_{Git} = I^D_{G(PRI)it} - sh_{(GVA)i} \beta_{it} RP_t + repL_{Git-1} - \delta_t K_{G(PRI)it-1} - sh_{(GVA)i} \bar{p}_G \Delta b_{Gt} \tag{A.67}$$

$$NL^D_{Cit} = I^D_{C(PRI)it} - sh_{(GVA)i} \left(1 - \beta_{it}\right) RP_t + repL_{Cit-1} - \delta_t K_{C(PRI)it-1} - sh_{(GVA)i} \bar{p}_C \Delta b_{Ct} \tag{A.68}$$

$$I_{G(PRI)it} = sh_{(GVA)i} \beta_{it} RP_t + \Delta L_{Git} + \delta_t K_{G(PRI)it-1} + sh_{(GVA)i} \bar{p}_G \Delta b_{Gt} + def_t L_{Git-1} \tag{A.69}$$

$$I_{C(PRI)it} = sh_{(GVA)i} \left(1 - \beta_{it}\right) RP_t + \Delta L_{Cit} + \delta_t K_{C(PRI)it-1} + def_t L_{Cit-1} + sh_{(GVA)i} \bar{p}_C \Delta b_{Ct} \tag{A.70}$$

$$I_{C(PRI)S4t} = RP_t + \Delta L_{Ct} + \Delta L_{Gt} + \delta_t K_{(PRI)t-1} - I_{G(PRI)t} - I_{C(PRI)S1t} - I_{C(PRI)S2t} - I_{C(PRI)S3t} + \bar{p}_G \Delta b_{Gt} + \tag{A.71}$$

$$I_{G(PRI)t} = \sum I_{G(PRI)it} \tag{A.72}$$

$$I_{C(PRI)t} = \sum I_{C(PRI)it} \tag{A.73}$$

$$I_{(PRI)t} = I_{C(PRI)t} + I_{G(PRI)t} \tag{A.74}$$

$$\kappa_t = I_{G(PRI)t} / I_{(PRI)t} \tag{A.75}$$

$$L_t = L_{Ct} + L_{Gt} \tag{A.76}$$

$$K_{G(PRI)it} = K_{G(PRI)it-1} + I_{G(PRI)it} - \delta_t K_{G(PRI)it-1} \tag{A.77}$$

$$K_{C(PRI)it} = K_{C(PRI)it-1} + I_{C(PRI)it} - \delta_t K_{C(PRI)it-1} \tag{A.78}$$

$$K_{G(PRI)t} = \sum K_{G(PRI)it} \tag{A.79}$$

$$K_{C(PRI)t} = \sum K_{C(PRI)it} \tag{A.80}$$

$$K_{(PRI)t} = K_{C(PRI)t} + K_{G(PRI)t} \tag{A.81}$$

$$K_{GE(PRI)it} = \gamma_{Ei} K_{G(PRI)it} \tag{A.82}$$

$$K_{GNE(PRI)it} = (1 - \gamma_{Ei}) K_{G(PRI)it} \tag{A.83}$$

$$K_{CE(PRI)it} = \gamma_{Ei} K_{C(PRI)it} \tag{A.84}$$

$$K_{CNE(PRI)it} = (1 - \gamma_{Ei}) K_{C(PRI)it} \tag{A.85}$$

$$K_{SEQ(PRI)it} = \gamma_{SEQi} K_{GE(PRI)it} \tag{A.86}$$

$$K_{GEt} = \sum K_{GE(PRI)it} + \gamma_E K_{G(GOV)t} \tag{A.87}$$

$$K_{GNEt} = \sum K_{GNE(PRI)it} + (1 - \gamma_E) K_{G(GOV)t} \tag{A.88}$$

$$K_{CEt} = \sum K_{CE(PRI)it} + \gamma_E K_{C(GOV)t} \tag{A.89}$$

$$K_{CNEt} = \sum K_{CNE(PRI)it} + (1 - \gamma_E) K_{C(GOV)t} \tag{A.90}$$

$$K_{SEQt} = \sum K_{SEQ(PRI)i} \tag{A.91}$$

$$\delta_t = \delta_0 + (1 - \delta_0)(1 - ad_K) D_{TFt-1} \tag{A.92}$$

$$v_t = v_{t-1} [1 - (1 - ad_P) D_{TPt-1}] \tag{A.93}$$

$$g_{\lambda t} = \sigma_{0t} + \sigma_1 + \sigma_2 g_{Yt-1} \tag{A.94}$$

$$\sigma_{0t} = \sigma_{0t-1} (1 - \zeta_3) \tag{A.95}$$

$$\lambda_t = \lambda_{t-1} (1 + g_{\lambda t}) [1 - (1 - ad_P) D_{TPt-1}] \tag{A.96}$$

$$w_t = s_W \lambda_t h \tag{A.97}$$

$$N_t = \frac{Y_t}{h \lambda_t} \tag{A.98}$$

$$ur_t = 1 - re_t \tag{A.99}$$

$$b_{Ct} = b_{Ct-1} + \frac{x_{1t} \sum I^D_{C(PRI)it}}{\bar{p}_C} \tag{A.100}$$

$$b_{Gt} = b_{Gt-1} + \frac{x_{2t} \sum I^D_{G(PRI)it}}{\bar{p}_G} \tag{A.101}$$

$$x_{1t} = x_{10} - x_{11} yield_{Ct-1} \tag{A.102}$$

$$x_{2t} = x_{20} - x_{21} yield_{Gt-1} \tag{A.103}$$

$$x_{20t} = x_{20t-1} (1 + g_{x20t}) \tag{A.104}$$

$$g_{x20t} = g_{x20t-1} (1 - \zeta_4) \tag{A.105}$$

$$yield_{Ct} = \frac{coupon_{Ct}}{p_{Ct}} \tag{A.106}$$

$$yield_{Gt} = \frac{coupon_{Gt}}{p_{Gt}} \tag{A.107}$$

$$coupon_{Ct} = yield_{Ct-1} \bar{p}_C \tag{A.108}$$

$$coupon_{Gt} = yield_{Gt-1} \bar{p}_G \tag{A.109}$$

$$B_{Ct} = B_{CHt} + B_{CCBt} \tag{A.110}$$

$$B_{Gt} = B_{GHt} + B_{GCBt} \tag{A.111}$$

$$p_{Ct} = \frac{B_{Ct}}{b_{Ct}} \tag{A.112}$$

$$p_{Gt} = \frac{B_{Gt}}{b_{Gt}} \tag{A.113}$$

$$B_t = B_{Ct} + B_{Gt} \tag{A.114}$$

$$DL_t = def_t L_{t-1} \tag{A.115}$$

$$def_t = \frac{def^{\max}}{1 + def_0 e^{(def_1 - def_2 illiq_{t-1})}} \tag{A.116}$$

$$illiq_t = \frac{\sum (int_{Cit-1} + rep) L_{Cit-1} + \sum (int_{Gt-1} + rep) L_{Git-1} + coupon_{Ct-1} b_{Ct-1}}{Y_t + \sum (1 - CR_{Cit}) NL^D_{Cit} + \sum (1 - CR_{Gt}) NL^D_{Git} + \bar{p}_C \Delta b_{Ct} + \bar{p}_G \Delta b_{Gt}} \\ \frac{+coupon_{Gt-1} b_{Gt-1} + w_t N_t + T_{Ft} + T_{Ct} - SUB_t + \delta_t K_{(PRI)t-1}}{Y_t + \sum (1 - CR_{Cit}) NL^D_{Cit} + \sum (1 - CR_{Gt}) NL^D_{Git} + \bar{p}_C \Delta b_{Ct} + \bar{p}_G \Delta b_{Gt}} \tag{A.117}$$

$$dsr_t = \frac{\sum (int_{Cit-1} + rep) L_{Cit-1} + \sum (int_{Gt-1} + rep) L_{Git-1} + coupon_{Ct-1} b_{Ct-1} + coupon_{Gt-1} b_{Gt-1}}{TP_t + \sum int_{Cit-1} L_{Cit-1} + \sum int_{Gt-1} L_{Git-1} + coupon_{Ct-1} b_{Ct-1} + coupon_{Gt-1} b_{Gt-1}} \tag{A.118}$$

$$Y_{HGt} = w_t N_t + DP_t + BP_{Dt} + int_D D_{t-1} + int_S SEC_{Ht-1} + coupon_{Ct-1} b_{CHt-1} + coupon_{Gt-1} b_{GHt-1} \tag{A.119}$$

$$Y_{Ht} = Y_{HGt} - T_{Ht} \tag{A.120}$$

$$C_{(PRI)Nt} = (c_1 Y_{Ht-1} + c_2 V_{HFt-1}) (1 - D_{Tt-1}) \tag{A.121}$$

$$C_{(PRI)t} = C_{(PRI)Nt} \text{ if } C_{(PRI)Nt} + I_{(PRI)t} + I_{(GOV)t} + C_{(GOV)t} < Y_t^*; \text{ otherwise}$$
$$C_{(PRI)t} = pr\left(Y_t^* - I_{(GOV)t} - I_{(PRI)t} - C_{(GOV)t}\right) \tag{A.122}$$

$$V_{HFt} = V_{HFt-1} + Y_{Ht} - C_{(PRI)t} + b_{CHt-1}\Delta p_{Ct} + b_{GHt-1}\Delta p_{Gt} \tag{A.123}$$

$$\frac{SEC_{Ht}}{V_{HFt-1}} = \lambda_{10} + \lambda_{10}' D_{Tt-1} + \lambda_{11} int_S + \lambda_{12} yield_{Ct-1} + \lambda_{13} yield_{Gt-1} + \lambda_{14} int_D + \lambda_{15} \frac{Y_{Ht-1}}{V_{HFt-1}} \tag{A.124}$$

$$\frac{B_{CHt}}{V_{HFt-1}} = \lambda_{20} + \lambda_{20}' D_{Tt-1} + \lambda_{21} int_S + \lambda_{22} yield_{Ct-1} + \lambda_{23} yield_{Gt-1} + \lambda_{24} int_D + \lambda_{25} \frac{Y_{Ht-1}}{V_{HFt-1}} \tag{A.125}$$

$$\frac{B_{GHt}}{V_{HFt-1}} = \lambda_{30t} + \lambda_{30}' D_{Tt-1} + \lambda_{31} int_S + \lambda_{32} yield_{Ct-1} + \lambda_{33} yield_{Gt-1} + \lambda_{34} int_D + \lambda_{35} \frac{Y_{Ht-1}}{V_{HFt-1}} \tag{A.126}$$

$$\frac{D_t}{V_{HFt-1}} = \lambda_{40} + \lambda_{40}' D_{Tt-1} + \lambda_{41} int_S + \lambda_{42} yield_{Ct-1} + \lambda_{43} yield_{Gt-1} + \lambda_{44} int_D + \lambda_{45} \frac{Y_{Ht-1}}{V_{HFt-1}} \tag{127n}$$

$$D_t = D_{t-1} + Y_{Ht} - C_{(PRI)t} - \Delta SEC_{Ht} - \bar{p}_C \Delta b_{CHt} - \bar{p}_G \Delta b_{GHt} \tag{A.127}$$

$$\lambda_{30t} = \lambda_{30t-1}\left(1 + g_{\lambda 30t}\right) \tag{A.128}$$

$$g_{\lambda 30t} = \zeta_{10} g_{bGt-1} \tag{A.129}$$

$$b_{CHt} = \frac{B_{CHt}}{p_{Ct}} \tag{A.130}$$

$$b_{GHt} = \frac{B_{GHt}}{p_{Gt}} \tag{A.131}$$

$$DC_t = DC_{t-1} + C_{(PRI)t} - \xi DC_{t-1} \tag{A.132}$$

$$g_{POPt} = g_{POPt-1}\left(1 - \zeta_5\right) \tag{A.133}$$
$$POP_t = POP_{t-1}\left(1 + g_{POPt}\right) \tag{A.134}$$
$$LF_t = \left(lf_{1t} - lf_2 hazratio_{t-1}\right)\left(1 - \left(1 - ad_{LF}\right) D_{TFt-1}\right) POP_t \tag{A.135}$$
$$lf_{1t} = lf_{1t-1}\left(1 - \zeta_6\right) \tag{A.136}$$

$$BP_t = \sum int_{Cit-1} L_{Cit-1} + \sum int_{Gt-1} L_{Git-1} + int_S SEC_{Bt-1} - int_D D_{t-1} - int_A A_{t-1} \tag{A.137}$$

$$CAP_t = CAP_{t-1} + BP_{Ut} - DL_t + BAILOUT_t \tag{A.138}$$

$$BP_{Ut} = s_B BP_{t-1} \tag{A.139}$$

$$BP_{Dt} = BP_t - BP_{Ut} \tag{A.140}$$

$$HPM_t = h_1 D_t \tag{A.141}$$

$$SEC_{Bt} = h_2 D_t \tag{A.142}$$

$$A_t = A_{t-1} + \Delta HPM_t + \Delta L_{Gt} + \Delta L_{Ct} + \Delta SEC_{Bt} + DL_t - \Delta D_t - BP_{Ut} - BAILOUT_t \tag{A.143}$$

$$CR_t = \frac{CR^{\max}}{1 + r_0 \exp\left(r_1 - r_2 dsr_{t-1} + r_3 \left(CAR_{t-1} - CAR^{\min}\right)\right)} \tag{A.144}$$

$$CR_{Gt} = \left[1 + l_1 \left(w_{Gt-1} - w_{LTt-1}\right)\right] CR_t \tag{A.145}$$

$$CR_{Cit} = \left[1 + l_1 \left(w_{Cit-1} - w_{LTt-1}\right)\right] CR_t \tag{A.146}$$

$$CR_{CS4t} = \frac{CR_t - sh_{(NLG)t-1} CR_{Gt} - sh_{(NLC)S1t-1} CR_{CS1t} - sh_{(NLC)S2t-1} CR_{CS2t} - sh_{(NLC)S3t-1} CR_{CS3t}}{sh_{(NLC)S4t-1}} \tag{A.147}$$

$$L_{Cit} = L_{Cit-1} + \left(1 - CR_{Cit}\right) NL^D_{Cit} - repL_{Cit-1} - def_t L_{Cit-1} \tag{A.148}$$

$$L_{Git} = L_{Git-1} + \left(1 - CR_{Gt}\right) NL^D_{Git} - repL_{Git-1} - def_t L_{Git-1} \tag{A.149}$$

$$L_{Ct} = \sum L_{Cit} \tag{A.150}$$

$$L_{Gt} = \sum L_{Git} \tag{A.151}$$

$$lev_{Bt} = \left(L_{Ct} + L_{Gt} + SEC_{Bt} + HPM_t\right) / CAP_t \tag{A.152}$$

$$CAR_t = CAP_t \Big/ \left[w_{Gt} L_{Gt} + \sum w_{Cit} L_{Cit} + w_S SEC_{Bt} + w_H HPM_t\right] \tag{A.153}$$

$$w_{LTt} = sh_{(LG)t-1} w_{Gt} + \sum sh_{(LC)it-1} w_{Cit} \tag{A.154}$$

$$int_{Gt} = spr_{Gt} + int_A \tag{A.155}$$

$$int_{Cit} = spr_{Cit} + int_A \tag{A.156}$$

$$spr_t = spr_0 - spr_1 \left(CAR_{t-1} - CAR^{\min}\right) + spr_2 dsr_{t-1} \tag{A.157}$$

$$spr_{Gt} = \left[1 + spr_3 \left(w_{Gt-1} - w_{LTt-1}\right)\right] spr_t \tag{A.158}$$

$$spr_{Cit} = \left[1 + spr_3 \left(w_{Cit-1} - w_{LTt-1}\right)\right] spr_t \tag{A.159}$$

$$spr_{CS4t} = \frac{spr_t - sh_{(LG)t-1} spr_{Gt} - sh_{(LC)S1t-1} spr_{CS1t} - sh_{(LC)S2t-1} spr_{CS2t} - sh_{(LC)S3t-1} spr_{CS3t}}{sh_{(LC)S4t-1}} \tag{A.160}$$

$$GNS_t = T_t + CBP_t - C_{(GOV)t} - SUB_t - int_S SEC_{t-1} - \delta_t K_{(GOV)t-1} \tag{A.161}$$

$$SEC_t = SEC_{t-1} + I_{(GOV)t} - GNS_t - \delta_t K_{(GOV)t-1} + BAILOUT_t \tag{A.162}$$

$$I_{G(GOV)t} = gov_{IG} Y_{t-1} \tag{A.163}$$

$$I_{C(GOV)t} = gov_{IC} Y_{t-1} \tag{A.164}$$

$$I_{(GOV)t} = I_{G(GOV)t} + I_{C(GOV)t} \tag{A.165}$$

$$K_{G(GOV)t} = K_{G(GOV)t-1} + I_{G(GOV)t} - \delta_t K_{G(GOV)t-1} \tag{A.166}$$

$$K_{C(GOV)t} = K_{C(GOV)t-1} + I_{C(GOV)t} - \delta_t K_{C(GOV)t-1} \tag{A.167}$$

$$K_{(GOV)t} = K_{C(GOV)t} + K_{G(GOV)t} \tag{A.168}$$

$$K_t = K_{(PRI)t} + K_{(GOV)t} \tag{A.169}$$

$$K_{Gt} = K_{G(PRI)t} + K_{G(GOV)t} \tag{A.170}$$

$$K_{Ct} = K_{C(PRI)t} + K_{C(GOV)t} \tag{A.171}$$

$$C_{(GOV)t} = gov_C Y_{t-1} \tag{A.172}$$

$$SUB_t = T_{Ct} \tag{A.173}$$

$$gov_{SUBt} = \frac{SUB_t}{E_{NFt-1} ucr_{t-1}} \tag{A.174}$$

$$T_{Ht} = \tau_H Y_{HGt-1} \tag{A.175}$$

$$T_{Ft} = \tau_F TP_{Gt-1} \tag{A.176}$$

$$T_{Ct} = \tau_C EMIS_{INt-1} \tag{A.177}$$

$$T_t = T_{Ht} + T_{Ft} + T_{Ct} \tag{A.178}$$

A.2.3 Government sector

$$GNS_t = T_t + CBP_t - C_{(GOV)t} - SUB_t - int_S SEC_{t-1} - \delta_t K_{(GOV)t-1} \tag{A.179}$$

$$SEC_t = SEC_{t-1} + I_{(GOV)t} - GNS_t - \delta_t K_{(GOV)t-1} + BAILOUT_t \tag{A.180}$$

$$I_{G(GOV)t} = gov_{IG} Y_{t-1} \tag{A.181}$$

$$I_{C(GOV)t} = gov_{IC} Y_{t-1} \tag{A.182}$$

$$I_{(GOV)t} = I_{G(GOV)t} + I_{C(GOV)t} \tag{A.183}$$

$$K_{G(GOV)t} = K_{G(GOV)t-1} + I_{G(GOV)t} - \delta_t K_{G(GOV)t-1} \tag{A.184}$$

$$K_{C(GOV)t} = K_{C(GOV)t-1} + I_{C(GOV)t} - \delta_t K_{C(GOV)t-1} \tag{A.185}$$

$$K_{(GOV)t} = K_{C(GOV)t} + K_{G(GOV)t} \tag{A.186}$$

$$K_t = K_{(PRI)t} + K_{(GOV)t} \tag{A.187}$$

$$K_{Gt} = K_{G(PRI)t} + K_{G(GOV)t} \tag{A.188}$$

$$K_{Ct} = K_{C(PRI)t} + K_{C(GOV)t} \tag{A.189}$$

$$C_{(GOV)t} = gov_C Y_{t-1} \tag{A.190}$$

$$SUB_t = T_{Ct} \tag{A.191}$$

$$gov_{SUBt} = \frac{SUB_t}{E_{NFt-1} ucr_{t-1}} \tag{A.192}$$

$$T_{Ht} = \tau_H Y_{HGt-1} \tag{A.193}$$

$$T_{Ft} = \tau_F TP_{Gt-1} \tag{A.194}$$

$$T_{Ct} = \tau_C EMIS_{INt-1} \tag{A.195}$$

$$T_t = T_{Ht} + T_{Ft} + T_{Ct} \tag{A.196}$$

A.2.4 Central banks

$$CBP_t = coupon_{Ct-1} b_{CCBt-1} + coupon_{Gt-1} b_{GCBt-1} + int_A A_{t-1} + int_S SEC_{CBt-1} \tag{A.197}$$

$$B_{GCBt} = S_G B_{Gt-1} \tag{A.198}$$

$$B_{CCBt} = S_C B_{Ct-1} \tag{A.199}$$

$$b_{CCBt} = \frac{B_{CCBt}}{P_{Ct}} \tag{A.200}$$

$$b_{GCBt} = \frac{B_{GCBt}}{P_{Gt}} \tag{A.201}$$

$$SEC_{CBt} = SEC_t - SEC_{HT} - SEC_{Bt} \tag{A.202}$$

Literature Selection

B

The literature search focuses primarily on scientific articles. The primary database is the TU Delft library. This was sometimes expanded to include Scopus. Apart from academic databases, I searched quality media and institutions' websites to find publications from which to deduce the current state of the policy debate. Different combinations of the search terms presented in fig. B.1 were used. When articles contained references that seemed interesting I followed these leads. Also, when I considered articles particularly insight- and useful, I employed the snowball method.

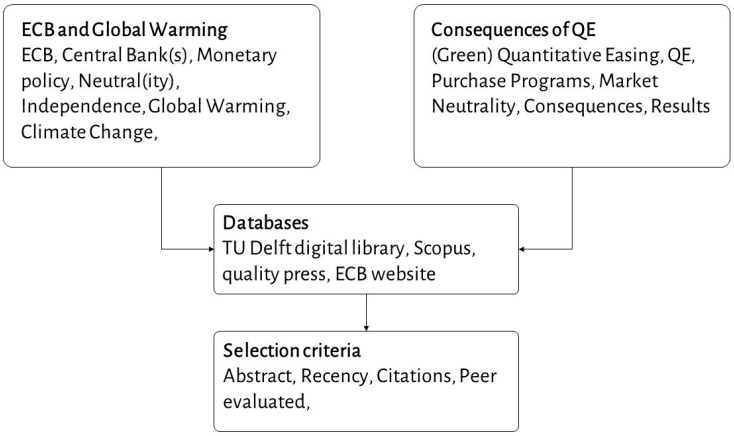

Figure B.1: Graphical representation of selection procedure literature