# Impacts of a New Harmonised Regulatory Index on a Small Open – Economy DSGE Model of UK Regulation


Jonathan Lloyd


**A Thesis Submitted in Fulfilment of the Requirements of the Degree of Doctor of Philosophy**


Economics Section

Cardiff Business School

Cardiff University


Thesis Supervisors:

Professor Patrick Minford (Primary)

Dr David Meenagh (Secondary)

Dr Vo Phuong Mai Le (Secondary)

Dr Zheyi Zhu (Secondary)

March 2021

# Abstract

This thesis attempts to assess the implications of prudential regulation on economic stability and welfare. In this pursuit, I implement regulation directly into a Small Open - Economy Dynamic Stochastic General Equilibrium (DSGE) model that entails Zero Lower Bound (ZLB) properties and a banking sector that lends to credit constrained entrepreneurs. Here, regulation appears both in the consumption Euler equation through the mortgage lending channel and in the external credit premium equation through the bank lending channel. The regulatory variables utilised in this thesis are modelled on actual quantities obtained from a Regulation Intensity Index (RII) within the HarMap database, created for the purpose of this analysis. The model is initially evaluated based on calibrated parameters before testing and re-estimating the model by the Indirect Inference Wald Test, a simulation-based algorithm that formally selects the optimal parameter values. Here, the model employs un-filtered non-stationary data for the period 1995Q1 to 2016Q4. The results of the welfare analysis reveal that regulation can stabilise the economy and increase welfare when regulation is allowed to respond to the output gap. However, regulation is destabilising when uncoordinated with monetary policy.

# Acknowledgements

This Ph.D. was funded by the Economic and Social Research Council’s 2+2 scholarship award.

I would like to give thanks to my supervisors, Professor Patrick Minford, Dr David Meenagh, Dr Vo Phuong Mai Le and Dr Zheyi Zhu for their invaluable advice, support and time.

Thanks also to all the lecturers and staff at Cardiff Business School, including Gareth Rees, Lydia Taylor and Sol Alim in aiding my navigation through the academic waters.

A special thanks to my colleagues: Dr Robert Forster, Dr Luís Pinheiro de Matos, Dr Timothy Jackson, Dr Edward Gould, Dr Chaowei Wang, Sarah Oufan, Gabriel Wong and Emmanuel Azom, my experience at Cardiff University would not have been the same without them.

A very special thanks to my friends, family and my girlfriend for their enduring support, often in my absence.

I dedicate this thesis to my parents who made the sacrifices necessary for me to be able to attain an education to the highest degree.

# Contents

# List of Figures

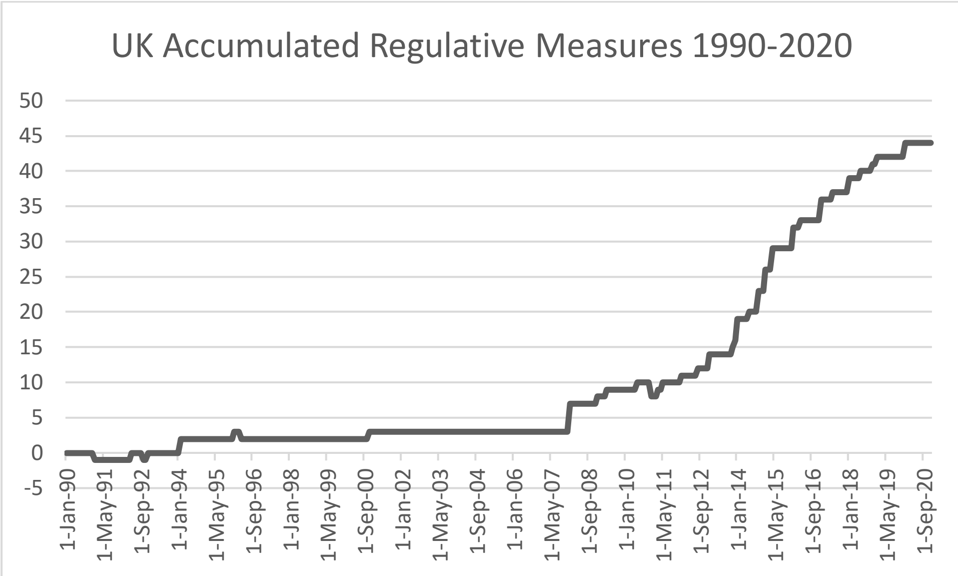
# List of Tables

# 1 Introduction

The financial crisis that began in 2007 has highlighted the importance of the financial sector and its potential role in amplifying shocks to the wider economy. The financial consequences of the economic crisis resulted in knock on effects that rippled through the credit channel, constraining bank dependent borrowers and squeezing the profits of lenders which worked to exacerbate the effects on the wider economy and ultimately lead to a long and protracted recovery.

While the amplifying effects of shocks directly affecting financial agents have only recently been introduced to the literature, the importance of the banks' balance sheet condition in transmitting shocks has long been recognised in the empirical literature. For example, it has been documented that more liquid and capitalised bank balance sheets are better positioned to withstand shocks to the financial sector. As a result, the financial crisis has reinforced such ideas and brought with it the introduction of a wide array of regulatory practises such as the liquidity ratios and risk-sensitive capital requirements as stipulated by the Basel accords. Figure 1.1 below depicts the change in regulative measures throughout the past two decades and is recorded for the purposes of this thesis. Here, each tightening policy action is recorded as a one-point increase whilst each loosening measure is recorded as a one-point decline. The net of all policy actions from within the UK is then graphed. As can be seen, there has been a marked increase in accumulated regulation since 2007, this has in turn raised new concerns that financial regulation may itself have substantial feedback effects on the real economy.

Figure 1.1: Total UK Accumulated Regulative Measures




Hence, this study looks to investigate the potential effects of regulation on economic stability and welfare. In order to achieve this, I implement a Dynamic Stochastic Generical Equilibrium (DSGE) model as they are particularly useful in analysing monetary policy decisions and can be adapted to evaluate regulatory decisions in a similar manner.

I begin this thesis by providing an in-depth overview into the regulatory framework within the UK with the aim of detailing the relationships between the multiple governing bodies and institutions that shape financial activity. I then give examples of the attempts to record the actions of the prudential authorities through the means of large-scale databases. This literature can generally be split into two categories; those papers that aim to track regulatory developments and those that attempt to evaluate the measures taken by the prudential authorities. In this regard, I discover justification to develop a harmonised database that includes data points from the multiple databases and datasets on prudential action within the UK. I find that there is a lack of data points within each individual dataset or database from which to base an analysis of UK regulation independently. As a result, I create the HarMap database that draws information from multiple databases and datasets, surveys, policy statements and up to date information from the relevant prudential authorities. In the pursuit of analysing the effects of prudential regulation, I utilise the data within this database combined with econometric techniques to develop a Regulation Intensity Index (RII) as a measure of regulative intensity, to which I can then implement within a DSGE model of UK regulation. This thesis explores a gap in the small branch of literature on DSGE models that attempt to model regulation. Recent papers that fall into this category include the works of Rubio and Yao (2020), and Le et al. (2018) who feature a model that includes regulation, however only appearing through the error terms on bank behaviour. Against this background, I detail a descriptive model of the regulatory measures taken within the UK and extend the model to include welfare implications. In this pursuit, I implement regulation directly into a Small Open – Economy DSGE model with Zero Lower Bound (ZLB) properties and a banking sector that lends to credit constrained entrepreneurs. Here, regulation appears both in the consumption Euler equation through the mortgage lending channel and in the external credit premium through the bank lending channel, thus affecting both corporate and general finance. The regulatory variables utilised in this thesis are therefore modelled on actual quantities obtained from the HarMap database. Given the contemporary nature of macroprudential policy, I note that the parameters of regulation are somewhat controversial, so that it is important to use an unbiased estimator allied to a powerful test. As a result, this thesis employs the Indirect Inference methodology to both test and discover the optimal set of parameter values that match observed UK economy data. I then evaluate the dynamics of the model and regulatory variables by analysing the impulse response functions and the variance decomposition. As a final step in answering the research question, I evaluate the variances of both inflation and output in order to discern the welfare implications of regulatory policies as compared to monetary policy alone.

The rest of the thesis is organised into the following parts. Section 1.1 provides the current layout of the UK regulatory framework. In section 2 I review the literature surrounding prudential regulation. In section 3 I describe the process of recording and creating two aggregate indices of regulation, one on banking and the other on consumer borrowing. In section 4 I detail the model I have employed following closely that developed in Le et al. (2011, 2016, 2021), here I explain how I augment the framework to include the regulative indices to which I have created. In section 5 I describe the estimated model with regulation; I review the estimates and the model properties. In section 6 I utilise the model features to evaluate the welfare effects of different policy regimes. In section 7 I conclude my research.[1]

## 1.1 The UK Regulatory Framework

### 1.1.1 Organisational Structure of the BoE

Monetary stability is characterised by stable prices and confidence in the currency, stable prices are maintained by seeking to ensure that the increase in the price level is in-line with the Government's inflation target as set out through the Monetary Policy Committee (MPC). Financial stability involves protecting against threats to the whole financial system and providing crucial services to households and businesses in good times and bad. Explicitly, the Bank of England (BoE) has the financial stability objective to protect and enhance the stability of the financial system of the United Kingdom as authorised through The Bank of England Act (1998). The bank aims to achieve this via the financial stability strategy set out by the Financial Policy Committee (FPC). Following the financial crisis of 2008, responsibility over the regulation and supervision of the banking and insurance industries was transferred from the Financial Services Authority (FSA) back to the BoE, with the FPC becoming the designated

[1] The FORTRAN code implemented in chapter 5 is based on the code created by my supervisor Dr Zheyi Zhu.

body. Modelled on the well-established Monetary Policy Committee (MPC) the FPC held its first interim meeting in 2011 with formal powers granted in the next year.

### 1.1.2 Bank of England

The Bank's duties rest in protecting and enhancing the stability of the financial system of the United Kingdom, aiming to work with the other relevant bodies including the Treasury, the Prudential Regulation Authority (PRA) and the FCA. The Bank's Special Resolution Unit is responsible for resolving failing banks using the special resolution regime. In line with the (BoE's) objectives to improve the stability of markets and the wider financial system - the bank works with the Financial Conduct Authority (FCA) and overseas regulators to supervise financial market infrastructures (FMIs). There is a memorandum of understanding between the BoE and the FCA whilst the BoE follows the international Committee on Payment and Settlement (CPSS) and International Organisation of Securities Commissions (IOSCO) principles for financial market infrastructures. The BoE supervises three main types of FMI; Recognised Payment Systems, Central Securities Depositories and Central Counterparties (CCPs).

### 1.1.3 Monetary Policy Committee

The Bank of England's Monetary Policy Committee is responsible for making decisions about the Bank Rate. It is also responsible for making decisions on quantitative easing, forward guidance and other aspects of the government's monetary policy framework. Its secondary aim is to support growth and employment as effective on March 2013.

### 1.1.4 Financial Policy Committee

The aims of the FPC are to contribute to the Bank's Objectives to protect and enhance financial stability, through identifying and taking action to remove or reduce systemic risks, with a view to protecting and enhancing the resilience of the UK financial system. The FPC also has a secondary objective to support the economic policy of the Government. This is achieved by two sets of powers - powers of direction and power of recommendation. The FPC has the power to direct the FCA, PRA and other regulators to take action on a number of specific policy tools that will be apparent within the HarMap dataset included in this thesis. The tools include; the Counter Cyclical Capital Buffer (CCyB) rate, sectoral capital requirements for the UK, leverage ratio requirements, loan to value (LTV) and debt to income (DTI) limits for mortgages on owner-occupied properties, and LTV and interest cover ratio limits for UK mortgages on buy-to-let properties. The (BoE) publishes 'The Financial Stability Report' and a record of their meetings twice a year.

### 1.1.5 Prudential Regulation Authority

The Prudential Regulation Authority (PRA) is a subsidiary of the BoE with aims to contribute to the Bank's objectives to protect and enhance financial stability by promoting the safety and soundness of PRA authorised persons, including minimising the impact of their failure. This is achieved by detailing rules and regulations to prudentially significant firms including deposit takers, insurers and some investment firms. These firms are otherwise known as dually-regulated firms as their conduct is regulated by the FCA. The PRA uses two key tools to advance their objectives - regulation and supervision. The PRA and FCA operate through a system of cooperation and coordination with the PRA holding the right to veto certain FCA regulatory actions. Often the PRA and FCA will regulate certain aspects of a firm's activity in order to achieve the same outcome despite having differing reasons in which to do so.

### 1.1.6 Prudential Regulation Committee

Within the Prudential Regulation Authority sits the Prudential Regulation Committee (PRC). The PRC has responsibility for exercising the Bank's functions as the Prudential Regulation Authority, as set out in the Bank of England Act (1998) and the Financial Services and Markets Act (2000). Principally, the Prudential Regulation Committee makes the Prudential Regulation Authority's most important decisions.

### 1.1.7 Financial Conduct Authority

As a wholly separate entity to the BoE, the FCA is accountable directly to HM Treasury and Parliament. The duties of the FCA are to enhance confidence in the UK financial system by facilitating efficiency and choice in services, securing an appropriate degree of consumer protection and protecting and enhancing the integrity of the UK financial system. It aims to achieve its duties through; conduct regulation to prudentially significant dually regulated firms, prudential and conduct regulation to investment firms and exchanges, other financial services providers – including IFA's, investment exchanges, insurance brokers and fund managers. The FCA works closely with the Financial Ombudsman Service (FOS) and the Financial Services Compensation Scheme (FSCS) to control complaints, disputes and resolution.

### 1.1.8 The Payment Systems Regulator

The Payment Systems Regulator (PSR) is a separate body created by the FCA with the role of promoting competition and innovation in payments systems to ensure they work in the interests of the organisations and people that use them.

### 1.1.9 Financial Reporting Council

The Financial Reporting Council (FRC) is an independent regulator responsible for regulating auditors, accountants and actuaries and setting the UK's Corporate Governance and Stewardship Codes. The FRC alludes to FCA objectives by seeking to promote transparency and integrity in business.

### 1.1.10 The Pensions Regulator

The Pensions Regulator (TPR) is a public body which holds the position of the regulator of workplace pension schemes in the UK. TPR is tasked with ensuring that employers, trustees, pension specialists and business advisers can fulfil their duties to scheme members. Specifically, TPR make sure that pension schemes are run properly and that employers put their staff into a pension scheme.

### 1.1.11 The Office of the Regulator of Community Interest Companies

The Office of the Regulator of Community Interest Companies is tasked by the government to decide whether an organisation is eligible to become, or continue to be, a community interest company (CIC). CIC duties entail investigating complaints and taking action if necessary whilst it also provides guidance and assistance to help people set up CICs.

### 1.1.12 The Office for Professional Body Anti-Money Laundering Supervision

The Office for Professional Body Anti-Money Laundering Supervision (OPBAS) is a regulator set up by the government to strengthen the UK's anti-money laundering (AML) supervisory regime and ensure professional body (AML) supervisors provide consistently high standards with regards to (AML) supervision.

## 1.2 The EU Regulatory Framework

The United Kingdom left the European Union on the 31st of January 2020. Under the withdrawal agreement reached between the EU and the UK, EU legislation continued to be applied in within UK boundaries during the transition period, until the 31st of December 2020. After the end of the transition period EU law ceased to apply within the UK from the 1st of January 2021 and accordingly, provision of financial services from UK authorised institutions to EU customers on a cross-border basis was no longer be possible. Here I include the details of the EU framework in order to describe the various bodies that the UK was subject to throughout the period of the analysis, 1995Q1 to 2016Q4.

### 1.2.1 The European System of Financial Supervision

Prior to BREXIT the UK was also subject to the European System of Financial Supervision (ESFS), the most intricate and encompassing framework for financial supervision in the European Union (EU), made of the national supervisory authorities of EU member states, the European Supervisory Authorities (ESAs); one for the securities sector – the European Securities and Markets Authorities (ESMA), one for the banking sector - the European Banking Authority (EBA) and one for insurance and occupational pensions - the European Insurance and Occupational Pensions Authority (EIOPA), and the Joint Committee (JC) of the ESAs. The system also encompasses the European Systemic Risk Board (ESRB) as well as the national supervisory authorities, such as the BoE in the UK.

Whilst the national supervisory authorities remain in charge of supervising individual financial institutions, the objective of the ESAs are to improve the functioning of the internal market by ensuring appropriate, efficient and harmonised European regulation and supervision, improving coordination between national supervisory authorities in the EU. They have significant powers to propose draft rules and to take decisions binding on national supervisors, and to a lesser extent, firms.

### 1.2.2 The European Banking Authority

The European Banking Authority (EBA) is an independent EU Authority which works to ensure effective and consistent prudential regulation and supervision across the European banking sector. The overall duties of the EBA are to maintain financial stability in the EU and to safeguard the integrity, efficiency and orderly functioning of the banking sector. The EBA is specifically tasked with contributing to the creation of the European Single Rulebook (ESR) in banking, with the objective to provide a single set of harmonised prudential rules for financial institutions throughout the EU. The Authority also plays an important role in promoting convergence of supervisory practices and is mandated to assess risks and vulnerabilities across the EU banking sector.

### 1.2.3 The European Securities and Markets Authority

As part of the ESFS, the European Securities and Markets Authority (ESMA) is an independent EU Authority that aids in maintaining the stability of the European Union's financial system by improving the protection of investors and promoting stable and orderly financial markets.

It achieves this by; assessing risks to investors, markets and financial stability, compiling a single rulebook for EU financial markets, promoting supervisory convergence and directly supervising credit rating agencies and trade repositories.

As well as promoting supervisory convergence amongst securities regulators, it aims to do so across financial sectors by working closely with the other European Supervisory Authorities proficient in the field of banking (EBA), and insurance and occupational pensions (EIOPA).

Whilst ESMA is independent, there is full accountability towards the European Parliament where it appears before the Economic and Monetary Affairs Committee (ECON), at their request for formal hearings. Full accountability towards the Council of the European Union and European Commission also exists. The Authority will therefore report on its activities regularly at meetings but also through an Annual Report.

### 1.2.4 The European Insurance and Occupational Pensions Authority

The European Insurance and Occupational Pensions Authority (EIOPA) is an independent advisory body to the European Commission, the European Parliament and the Council of the European Union. It is one of the EU Agencies carrying out specific legal, technical or scientific tasks and giving evidence-based advice to help shape informed policies and laws at the EU and national level. The EIOPA's core responsibilities are to support the stability of the financial system, transparency of markets and financial products as well as the protection of policyholders, pension scheme members and beneficiaries. The EIOPA is commissioned to monitor and identify trends, potential risks, and vulnerabilities stemming from the micro-prudential level, across borders and across sectors.

### 1.2.5 The European Systemic Risk Board

Tasked by the European Commission, the European Systemic Risk Board (ESRB) is responsible for the macroprudential oversight of the EU financial system and the prevention and mitigation of systemic risk. In order to adhere to its macroprudential mandate, the ESRB monitors and evaluates systemic risk and where appropriate, issues warnings and recommendations. The ESRB has a broad responsibility, covering a wide spectrum of financial institutions such as banks, insurers, asset managers, shadow banks, and financial market infrastructures.

### 1.2.6 The Joint Committee of European Supervisory Authorities

The Joint Committee (JC) is a forum created with the task of reinforcing cooperation between the three ESAs and ensuring clarity and consistency in their practices. Specifically, the three ESAs cooperate in the areas of supervision of financial conglomerates, accounting and auditing, micro-prudential analysis of cross-sectoral developments, risks and vulnerabilities for financial stability, retail investment products and measures combating money laundering.

In addition to being a forum for cooperation, the Joint Committee also plays a key role in information exchange with the ESRB, and in developing the relationship between the ESRB and the ESAs.

### 1.2.7 The National Supervisory Authorities of EU Member States

The National Supervisory Authorities (NSAs) of EU Member States are the collective national banking, insurance and security supervisors of EU member states. Within the UK this includes the BoE.

## 1.3 International Financial Regulation and Supervision

There are associations of financial regulatory authorities at the international level. These are the international banking, insurance and security regulators together with the international forums, boards, committees and banks that are responsible for coordination, harmonisation and standardisation on a global spectrum.

### 1.3.1 International Organisation of Securities Commissions

The International Organisation of Securities Commissions (IOSCO) develops, implements and promotes adherence to a broad set of internationally recognised standards for securities regulation. It is the standard-setting body on the international spectrum, responsible for developing and assisting in the implementation of principles, standards and other supporting material for the supervision of the international securities sector. Working closely with the G20 and the FSB on the global regulatory reform agenda, The IOSCO seeks to build sound global capital markets and a strong international regulatory framework. The three categories of IOSCO members are; ordinary, associate and affiliate. The ordinary members are the national securities commissions with significant authority over securities or derivatives markets in their respective jurisdictions. Generally, associate members are supranational governmental regulators, subnational governmental regulators, intergovernmental international organisations and other international standard-setting bodies. The Affiliate members are generally; self-regulatory organisations, securities exchanges, financial market infrastructures, international bodies other than governmental organisations with an appropriate interest in securities regulation, and investor protection funds and compensation funds.

### 1.3.2 International Association of Insurance Supervisors

The International Association of Insurance Supervisors (IAIS) is a voluntary membership organisation of insurance supervisors and regulators from over 200 jurisdictions and constitutes 97% of global insurance premiums. It is the global standard-setting body responsible for developing and aiding in the implementation of principles, standards and other supporting material for the supervision of the insurance sector.

### 1.3.3 Basel Committee on Banking Supervision

The Basel Committee on Banking Supervision (BCBS) is the primary global standard-setting body responsible for the prudential regulation of banks and assists in the implementation of principles, standards and other supporting material for the supervision of the banking sector. Its mandate is to strengthen the regulation, supervision and practices of banks worldwide with the purpose of enhancing financial stability. BCBS members include organisations with direct banking supervisory authority and central banks.

### 1.3.4 The Joint Forum

The Joint Forum (JF) is an international group bringing together financial regulatory representatives from banking, insurance and securities. It works under the aegis of the BCBS, the IOSCO and the IAIS. The group develops guidance, principles and identifies best practices that are of common interest to all three sectors. Initially set up in response to an increasing number of large financial organisations providing services in all three sectors across multiple countries, the (JF) now deals with issues that are common to all three sectors, including the financial regulation of conglomerates.

### 1.3.5 The Bank for International Settlements

The Bank for International Settlements (BIS) has the primary objective of serving central banks in their pursuit of monetary and financial stability, whilst fostering international cooperation in those areas. The BIS is owned by 60 central banks representing countries from around the world that together account for 95% of global GDP. The BIS pursues its mission by fostering discussion, supporting dialogue, carrying out research and acting as a prime counterparty for central banks in their financial transactions.

### 1.3.6 The Financial Stability Board

The Financial Stability Board (FSB) is the successor to the Financial Stability Forum (FSF) and was established after the G20 London summit in April 2009. The FSB is an international body that monitors and makes recommendations about the global financial system. The Board includes all G20 major economies, FSF members, and the European Commission. The FSB is hosted and funded by the BIS.

# 2 Literature Review

## 2.1 Introduction

In the aftermath of the financial crisis that began in 2007 there has generally been a growing belief in the literature that in order to more accurately encapsulate the dynamic behaviour of the economy, financial regulation needs to expand beyond a strictly micro-based approach. As a result, we have witnessed a marked increase in the amount of research that takes on a macroeconomic perspective to financial regulation. Within this area of research, the policy debate focuses on analysing the implementation, effectiveness and use of macroprudential tools whilst research also looks to evaluate the impact on macroeconomic outcomes and their relationship with monetary policy, as is the case in this thesis. Research in this field of economics appears to be limited, in part due to the infancy of macroprudential regulation. This thesis looks to add to the growing literature on regulation in a wider sense, taking into consideration the rules and regulatory measures that also affect the corporate and mortgage sectors. Henceforth, this section will give an overview of the preceding literature.

As mentioned previously, the policy debate on macroprudential effectiveness and its interaction with monetary policy is fairly new. Researchers still lack a complete understanding and set of established models to investigate the relationship between regulation and the financial system. However, there have been a few studies that aim to achieve this. They can generally be divided into three categories based on their design and method of evaluation. The first type of research in this field aims at analysing systemic risk and how it may evolve, whilst offering practical solutions for limiting its growth. Specifically, research in this field attempts at calculating the systemic risk emanating from individual institutions and sectors. In a similar manner, the second group of research aims at investigating the size of financial institutions and how they are connected in a network analysis setting. The third type of literature entails research that investigates the relationship between the macroeconomy by embedding financial factors into macroeconomic models. The thesis and DSGE model implemented here fall under this class. In addition to this, we can define a further category that relates to those pieces of literature that create or utilise a dataset in order to form their analysis, as is also the case in this thesis, the two concepts are unified here.

The outline of this chapter is described as follows. Section 2.2 discusses the existing datasets on macroprudential policy and their uses. Section 2.3 investigates regulation within a DSGE setting. Section 2.4 describes estimated macroeconomic models of regulation. Section 2.5 describes the motivation for the thesis and its way forward in a conclusion.

## 2.2 Existing Datasets on Macroprudential Policy Measures

As mentioned previously, the literature on macroprudential policy is relatively new. Nevertheless, it appears to be a rapidly growing subject area with a small but notable number of attempts to capture and evaluate regulatory policy measures. Each attempt differs slightly in its methodology, however broadly speaking they share similar data structures - gathered from historic publications and announcements of central banks and regulatory bodies. These attempts can generally be classified into those which aim to track regulatory developments and those that aim to evaluate their effects.

### 2.2.1 Tracking Regulation

Some prudential developments have been recorded via the use of questionnaires and surveys, The International Monetary Fund compose a macroprudential policy survey with the specific task of reporting prudential measures that aim to contain systemic risk and the institutional arrangements supporting macroprudential policy in 141 of the IMF member countries. World Bank also produce a survey titled ‘The Bank Regulation and Supervision Survey’ by Anginer et al. (2019). Here data on 15 different categories of macroprudential and supervisory measures are recorded. The aim is to provide a comparable source of economy level data on how banks are supervised and regulated around the world. Currently the database covers 180 different countries. Cerutti et al. (2015) make use of the Global Macroprudential Policy Instruments survey (GMPI) developed by the IMF and expand on previous studies to document the use of macroprudential policies for 119 countries over the period 2000-2013. The paper focuses on 12 specific instruments, classifying them into borrower and lender-based policies whilst distinguishing between the effects on different segments of credit markets such as household versus corporate credit.

There have also been several attempts to detail the policy actions taken within the EU. One of the more comprehensive recordings compiled by Budnik and Kleibl (2018) is The Macroprudential Policies Evaluation Database (MaPPED), which has been developed using a carefully designed questionnaire – completed in cooperation with over 90 experts and supervisory authorities from EU national central banks that form part of the Financial Stability Committee (FSC). MaPPED attempts to detail the life cycle of prudential policy instruments and actions taken in the European Union since 1995 and includes both macro and microprudential measures that are likely to have a significant impact on the whole banking system. The analysis I implement in this thesis utilises some of the data points for the UK which are provided in the MaPPED database together with other publications and databases as described in table 3.1. Kochanska (2017) compiles the Macroprudential Measures Database (MPMDB) that includes both EU and EEA countries, the dataset covers the time period from 2002 and is continuously updated, it details the various macroprudential measures undertaken in each individual country along with the reciprocating measures in each state.

Shim et al. (2013) take an approach that specifically focuses on regulation targeted towards the housing sector and develop a database for policy actions on housing markets, the database covers 60 economies worldwide form January 1990 to June 2012. The different policy actions are summarised by type, region, timing and direction.

### 2.2.2 Evaluating Regulation

Recently, Boissay et al. (2019) have developed an interactive online repository of studies on the effects of financial regulation with the aim to track the most recent findings in the literature, the paper evaluates the impact of numerous studies and estimates from 15 countries and groups. The repository is updated annually and has data from 1991. Work by Houston et al. (2012) studies whether cross-country differences in regulations have affected international bank flows. To do this they compose 'A new Database of Financial Reforms'. The database lists indices of financial liberation along several economic dimensions, including: credit controls and reserve requirements, interest rate controls, entry barriers, state ownership, policies on securities markets, banking regulations and restrictions on the financial account. Each dimension is given a grade so that an overall score of financial liberalisation is calculated. The database includes annual information on 91 countries over the period 1973-2005. An attempt to record data on widely used prudential instruments for 64 different countries has been made by Cerutti et al. (2017), here the authors look at changes in the intensity of macro and microprudential tools together. These prudential instruments: capital buffers, interbank exposure limits, concentration limits, loan to value ratio limits and reserve requirements, are recorded on a quarterly basis for the time period 2000-2014. Alam et al. (2019) construct the integrated Macroprudential Policy (iMaPP) Database which tracks instruments across 134 different countries from 1990-2016 by combining information from existing databases, surveys, documents and official announcements. Additionally, the iMaPP database provides the current average Loan-To-Value ratio (LTV) in a particular country at any given point in time.

## 2.3 DSGE Models of Regulation

DSGE modelling is particularly advantageous for policy analysis. This is because these models entail general equilibrium properties that evolve around a time dimension, they are also naturally suited to run simulations which altogether makes them attractive for policy analysis. The seminal work of Clerc et al. (2015) is one such paper that utilises a DSGE model to analyse the effects of capital regulation. The model described in Clerc et al. (2015) has an emphasis on financial intermediation which sets it apart from the typical business cycle model. Uniquely, the construction of the model is also far away from the classical framework of microprudential supervision which therefore allows for an analysis that is unconstrained in evaluating the impact of macroprudential performance on financial intermediation. In Clerc et al. (2015), the authors introduce multiple financial frictions into a model with households, entrepreneurs, and banks to analyse the macroeconomic consequences of default which has three layers, based on the three agents in the model. The main results of this paper point that there is an optimal level of capital regulation that allows a compromise between the risk of bank failure and constraining the credit supply, at a capital ratio of around 10.5%. In terms of the dynamics of the model, the paper finds that shock propagation and amplification are large when idiosyncratic bank risk is high and capital requirements are low. The third conclusion of the paper shows that when countercyclical capital requirements are introduced, it is moderately stabilising when the steady-state level of these requirements are sufficiently high whilst moderately destabilising when the steady-state capital requirements are low. Beau et al. (2012) another such paper that employs the use of a DSGE model to understand the relationship between monetary and macroprudential policies within the euro area. To achieve this, the authors utilise a model that implements financial frictions into a heterogenous-agent based model with housing. With the two regimes employed they analyse the effects on price stability and find efficient policy outcomes can be achieved provided that the central bank knows the reaction function of the macroprudential authority. Therefore, in order to attain an efficient outcome, the central bank must factor into its own decision making the macroeconomic effects emanating from macroprudential regulation. Another method used in the design and analysis of macroprudential regulation involves the use of the LTV ratio as a proxy for regulatory rules. Two papers that follow this approach implement the Iacoviello (2005) style design to a model with collateral constrains. The first is the paper presented by Brzoza-Brzezina et al. (2015) who investigate whether macroprudential policy can provide macroeconomic stability and increase welfare. The key result of the paper is that this type of regulation is effective however should be implemented in a decentralised manner. The second paper that takes this approach to design is that of Rubio and Carrasco-Gallego (2014). Here, the authors attempt to analyse the effects of macroprudential policy on welfare and both macroeconomic and financial stability. Whilst the paper discovers that greater stability can be attained, it also notes that there is a trade-off between the welfare of borrowers and savers in the model.

A more recent study that utilises calibrated values to evaluate optimal macroprudential policy is that of Gertler et al. (2020). In this paper, the authors develop a quantitative model of credit booms and busts to test optimal macroprudential policy in the face of balancing the benefits of preventing an economic crisis against abating a boom. The model consists of both households and bankers in a bank panic setting. The authors conclude that a series of negative fundamental shocks can raise bank leverage ratios which could make the banking system vulnerable to runs, which in turn has further effects on the real economy. With regards to macroprudential policy, the authors consider the effects of a countercyclical capital buffer and find that regulatory policy improves welfare, mainly by reducing the frequency of costly financial panics. The authors also find that not relaxing capital requirements in a crisis works to lower welfare by amplifying the downturn.

## 2.4 Empirically Estimated DSGE Models of Regulation

With regards to DSGE models of regulation, there are a limited number of studies that estimate their model parameters. The majority of these papers implement Bayesian methods and the use of priors in order to select the set of parameters used in their analysis. A more recent paper published by Pariès et al. (2011) estimates a closed economy DSGE model for the euro area. Their model entails financially constrained households and firms who face an oligopolistic banking sector with capital constraints - which is the proxy for macroprudential policy. The authors proceed to investigate the monetary policy implications of increasing capital requirements and introducing risk-sensitive capital requirements. The main conclusion of the paper supports the imposition of new regulatory requirements though points that the implementation schedule of such regulation should be carried out in a protracted manner. In a US economy setting, Gelain and Ilbas (2017) estimate the Smets and Wouters (2007) model. In order to evaluate how monetary policy and macroprudential policy should interact with each other to achieve the collective goal of safeguarding financial stability, the authors implement the Gertler and Karadi (2011) banking sector directly into this model. Here, monetary policy takes its usual form as an interest rate setting rule whilst macroprudential policy is described as a tax or subsidy on bank capital. The effects of both measures and their interaction are evaluated by considering their impact on the output gap or credit growth. The paper makes the conclusion that there can be gains to output stabilisation when there is coordination between the two regimes with a higher weighting on output stabilisation for the macroprudential regulator. Another paper that aims to discover the optimal mix of monetary policy and macroprudential regulation is that of Quint and Rabanal (2014). Here, the authors estimate a two-country model of the euro area that includes real, nominal and financial frictions, thus providing a potential role for both macroprudential and monetary policy. The study suggests that macroprudential regulation has the ability to reduce macroeconomic volatility and improve the welfare of savers, however when the economy is faced with a technology shock, borrowers are worse off when compared to the baseline case, a result due to the regulatory effects on lending spreads. More recent efforts to empirically estimate a DSGE model on prudential regulation can be found in the works of  Rubio and Yao (2020). In a similar environment to that of this thesis, the authors implement financial frictions into a model characterised by low interest rates and a monetary policy rule constrained by an occasionally binding ZLB. Here, prudential regulation takes the form of an LTV rule. The main conclusions of this paper highlight a loss in the power of monetary policy in achieving its goal of financial stabilisation whilst also having the potential to be a source of instability. Based on numerical simulation results, the authors point to the potential benefits of alternative policies in the form of prudential regulation.

Aside from the more popular Bayesian approach to estimation, there is a substantially smaller set of research that undertakes an Indirect Inference approach in order to discover the optimal set of parameters estimated around a structural model. Due to the ambiguity relating to the priors used in Bayesian estimation and the potential misspecification issues that may arise, this thesis adopts the Indirect Inference approach to estimation which will be discussed in more detail throughout section 5. Within the subcategory of empirically estimated DSGE models of macroprudential policy, the work developed by Le et al. (2016) is amongst the earliest. Here, the authors augment the Smets and Wouters (2007) model structure to permit a degree of both price and wage stickiness via a New Keynesian - New Classical synthesis and implement the concept of the financial accelerator mechanism as set out in Bernanke et al. (1999). In this paper, M0 has both a role in setting the short-term interest rates on government bonds and as a means of cheap collateral against bank lending, thus allowing for monetary policy to be effective even at the ZLB. A key feature in this model relates to financially constrained entrepreneurs who in addition to their own net worth rely on loans from financial intermediaries. Hence the equation that links these two agents is the external credit premium, which in turn is affected by the macroprudential rule and the money supply amongst other features. Within this setting, the authors use the error terms to pick up the effects of regulation. Hence, though the model is estimated they do not identify the direct effects of macroprudential measures, this provides an avenue for the research posited in this thesis. The main conclusion of the paper points out that when M0 is allowed to respond to credit conditions this leads to increases in economic stability, and when paired with price level targeting it removes the need for regulation. Further developments that arise from this research can be seen in the work of Le et al. (2018) who investigate the effects of regulation in light of regular monetary policy. The paper implements a similar design to modelling regulation within the external credit premium and does not estimate macroprudential parameters empirically. Results from this paper show that whilst regulation has the ability to improve stability it has a greater potential to destabilise the economy. Notable work that stems from this line of research and attempts to include regulation within the external premium equation is the work by Zhu (2017) and Wang (2020). Here, the authors develop and empirically estimate a successful model of the UK. Specifically, the paper by Zhu (2017) adapts a small open economy model by allowing the Armington (1969) substitution elasticity between domestic and foreign goods, whilst Wang (2020) implements Quantitative Easing (QE) into a model with the possibility of hitting the ZLB. Both papers characterise the external credit premium in a similar manner however neither study empirically estimates regulatory variables, only picking up their effects through the error terms within the premium equation. A more recent paper that leads on from this line of research and closely follows that of Le et al. (2018) is a study by Lyu et al. (2021) where the authors investigate the corporation between governments and a central bank. Regulation also appears in this model however only as an error term affecting the premium.

## 2.5 Conclusion

This section has reviewed the literature surrounding the field of macroprudential policy and regulation. In undertaking this analysis, it details the prior research that has been carried out to investigate the impacts of regulation and the optimal strategy of implementation in the presence of both conventional and unconventional monetary policy.

This thesis splits the research into two groups, the first group categorises those datasets that attempt at recording and evaluating the developments of regulation. Here, the literature reveals some interesting caveats on the existing datasets. First, though there are a few datasets that attempt to map regulation across the global spectrum and within the EU, the number of datasets that specifically study the UK are limited if at all present. This result appears to manifest itself in a limited amount of datapoints for the UK which makes it difficult to study regulation affecting the country in isolation. This study attempts at addressing this issue by amalgamating and harmonising available datasets and publications, carefully crosschecking for double entries and mismatched dates in each of the datasets used. A similar point relates to the different types of regulation recorded. For example, regulation relating to housing and mortgages are often separated from databases that contain regulatory policies targeted towards the corporate sector. This study attempts to address these issues by generating a dataset that contains a large amount of data points of regulatory measures in a wider sense, including regulatory measures that affect both corporate and household finance. Additionally, this thesis notes the binary methodology of recording regulation as presented in iMaPP (2019) and leverages on this format - as will be explained in the next section.

The second group underpins the research that has been carried out to decipher the effectiveness of regulation, including strategies on how to implement it in the most effective manner. Specifically, this thesis focuses on DSGE models as they are particularly advantageous in analysing monetary policy decisions and can be adapted to evaluate macroprudential decisions in a similar manner. Here, this thesis also points to the narrow sect of DSGE models that utilise empirically estimated parameters instead of calibration based on previous literature or assumptions and theories about the macroeconomy. As macroprudential policy is a relatively new field of study and theoretical analysis is underdeveloped, it seems rational to estimate the respective parameters of regulation and utilise observed data. The optimal method of how to achieve this is of particular debate. Within the even narrower class of DSGE models that utilise empirically estimated model parameters, the vast majority achieve this through Bayesian estimation methods. This thesis highlights the ambiguity of the priors used in Bayesian estimation and the potential misspecification issues that may arise - amongst other concerns.[2] As a result, the literature review then points to the potential benefits of utilising the Indirect Inference method of estimation, to which it appears there is a lack of work that empirically estimates macroprudential regulation. This in part forms the motivation for this study.

[2] Section 5 further details the choice of estimation methods.

# 3 Regulation Intensity Methodology

## 3.1 Introduction

The decade since the onset of the global financial crisis has brought about significant structural changes in the banking sector. Regulators have responded to the crisis by reforming the global prudential framework and enhancing supervision. The key goals of these reforms have been to increase bank resilience through stronger capital and liquidity buffers whilst reducing implicit public subsidies and the impact of bank failures on the economy through enhanced recovery and resolution regimes. At the same time, the dynamic adaptation of the system and the emergence of new risks warrant ongoing attention. In adapting to their new operating landscape, banks have been re-assessing and adjusting their business strategies and models, including their balance sheet structure, scope of activities and geographic presence. Some changes have been substantial and are ongoing, while a number of advanced economy banking systems are also confronted with low profitability and legacy problems.

## 3.2 RII Methodology

In order to gauge the level of regulation in the UK, I begin creating a Regulation Intensity Index (RII), I begin scanning the literature to discover what the relevant prudential authorities in the UK are doing to achieve their collective goal of financial stability. I begin to scan the literature on financial stability with the aim of evaluating the extent to which the regulators are intervening in bank activity through the regulatory effect on bank balance sheets and in household finance through the regulatory effect on mortgages. From this I can then map the change in regulations aimed at banks and the change in regulations aimed at households. To achieve this, I combine information from multiple datasets, questionnaires, surveys and reports together with up-to-date information from the relevant prudential authorities to construct a new harmonised dataset of prudential action taken from within the UK. This new dataset, produced for the purposes of this thesis in Lloyd (2021) takes the name 'HarMap'. The list of sources utilised in its construction are listed in table 3.1 below.[3] By systematically filtering through the existing databases and publications, I harmonise each prudential action undertaken from within the UK during the period 1990Q1-2020Q4 and implement the dummy-style indicator approach to recording actions taken by the prudential authorities. Specifically, it takes values of -1 for loosening measures, 1 for tightening measures and 0 for those measures that are ambiguous. For example, tightening actions such as an increase in a loan to value ratio requirement, debt to income ratio, or counter-cyclical capital buffer are recorded as a +1 in the harmonised dataset. In a similar manner, loosening measures such as a reduction in the aforementioned regulations are recorded as a -1. Any measure that cannot be accurately decerned as either a tightening or loosening of a regulatory policy measure are recorded but not assigned a +1 or a -1, these regulations are counted as ambiguous and are assigned a 0 in the harmonised dataset.[4] For the purposes of future analysis, each type of prudential instrument is also simultaneously categorised into one of the 20 different class types that define its nature. For example, each instrument is classified as to whether it is a capital buffer, liquidity based, or a tax measure to name a few. Within each of these 20 different categories the measures are further specified by distinguishing whether each individual prudential action is targeted towards households, the corporate sector, or both simultaneously. Here, the 'corporate sector' largely translates to the banking sector and closely related non-banking financial activities such as lending activity from other non-bank financial institutions, this definition will be carried forward throughout this thesis. The RII then cumulatively aggregates those measures that are aimed at households, separately it aggregates those measures that are aimed at the corporate sector and finally it combines measures that are aimed at households and measures that affect the corporate sector

[3] Please see appendix 9.1 for a list of resources.

[4] Specific examples of each recorded action and the separate class can be found within the Lloyd (2021) HarMap dataset at https://sites.google.com/site/jonathanlloydeconomics/home

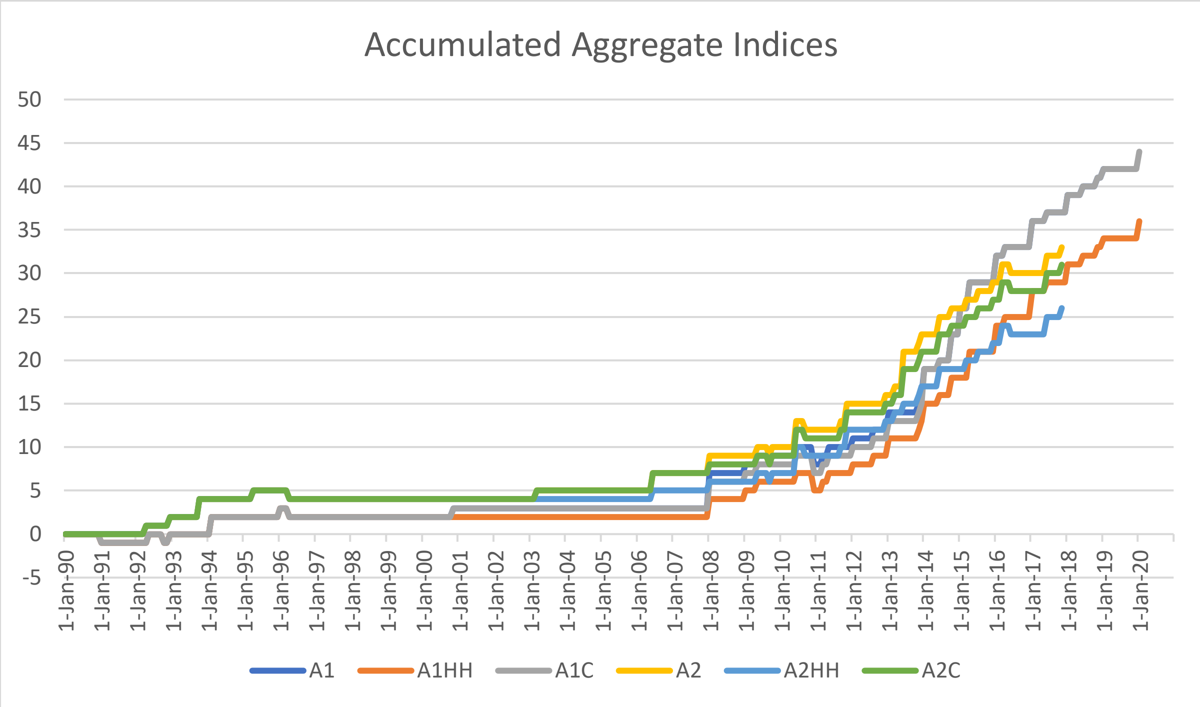
- resulting in three aggregate indices: A1HH, A1C and A1 respectively. This first dataset (Dataset 1) is recorded using the date in which the measures became effective and will help to create a clearer picture of regulation. I also create a dataset using the same methodology (Dataset 2), recorded using the date in which the measures were announced - resulting in three more aggregate indices: A2HH, A2C and A2. Dataset 2 will also be useful in providing a detailed description of regulation and in addition, this particular thesis will utilise Dataset 2 in the DSGE model described in the next chapter. This is based on the assumption that the respective representative agents will incorporate financial information into both their expectations and behaviour from the point that the announcements have been made, hence before they become effective. The six accumulatively aggregated indices are represented in figure 3.1 below. Here, each tightening prudential action is represented by a one-point increase whilst each loosening prudential measure is represented by a one-point decrease, ambiguous measures are recorded as neither an increase or decrease and are reserved for future analysis. The net of regulative policy decisions separated by dataset (Dataset 1: A1, A1HH, A1C, Dataset 2: A2, A2HH, A2C) and category (targeted towards households: A1HH, A2HH, targeted towards the corporate sector: A1C, A2C) is represented in figure 3.1.

Table 3.1: RII Sources

| Non-Database Sources | |
|---|---|
| Allen Overy | |
| Norton Rose Fulbright | |
| The Bank of England (BoE) | |
| The Bank of International Settlements (BIS) | |
| The European Banking Authority (EBA) | |
| The European Securities and Markets Authority (ESMA) | |
| The Financial Conduct Authority (FCA) | |
| The Financial Reporting Council (FRC) | |
| The Financial Services Authority (FSA) | |
| The Prudential Regulation Authority (PRA) | |
| The UK Government | |
| UK Legislation (UKL) | |
| Databases and Datasets | |
| A new Database of Financial Reforms | Houston et al. (2012) |
| Database for Policy Actions on Housing Markets | Shim et al. (2013) |
| Changes in Prudential Policy Instruments - A New Cross-Country Database | Cerutti et al. (2017) |
| The Use and Effectiveness of Macroprudential Policies: New Evidence | |
| The ESRB Macroprudential Measures Database | Kochanska (2017) |
| MaPPed | Budnik and Kleibl (2018) |
| The IMF's Annual Macroprudential Policy Survey | International Monetary Fund (2018) |
| iMaPP | Alam et al. (2019) |
| FRAME | Boissay et al. (2019) |
| The Bank Regulation and Supervision Survey | Anginer et al. (2019) |

[i] Non database sources refer to articles, publications, announcements, letters and surveys alike, that are not derived from databases or datasets. All data points derived from the databases and individual articles utilised to form the RII and HarMap dataset are harmonised by the discretion of the author of this thesis.

Figure 3.1: Accumulated Aggregate Indices




Additionally, in this thesis we are particularly interested in the isolated effects of regulation targeted towards the corporate sector on bank equity and regulation targeted towards the mortgage sector on the mortgage rate, the variables A1C and A1H respectively. These two variables will be utilised to create implied regulative effects in the following sections.

## 3.3 Series Methodology

Changes in regulation may act as a wedge in the balance sheets of banks, pushing up the rate charged on banking activities or reducing the expected return received for such services. More explicitly, it may potentially lower equity as a proportion of the total bank balance sheet. For households, these changes may either increase the mortgage rate or the required deposit amount for a given house price. Alternatively, obligating prospective home owners to find cheaper homes *ceteris paribus*.

I then look to see if there is evidence of this hypothesis in the data. To achieve this I construct two series, one on bank equity as a proportion of assets and the other on mortgage value as a proportion of total house value, Series 1 and Series 2 respectively.

To construct the series on bank equity, I obtain data on UK bank balance sheets from the Bank of England (BoE). Specifically, I obtain data on assets and subtract liabilities to derive equity. The equity is then divided by assets to give Series 1. Data on assets is obtained as the monthly amounts outstanding of UK resident banks' (excl. Central Bank) sterling assets in total, in sterling millions and is not seasonally adjusted. Liabilities are obtained as the monthly amounts outstanding of UK resident banks' (excl. Central Bank) sterling liabilities in total, in sterling millions and is also not seasonally adjusted. Series 1 is displayed in figure 3.2 below.

To construct the series on mortgages I obtain gross price-paid data for the UK from Land Registry (LR) together with data on gross mortgage lending from the BoE. The series is then derived by dividing gross lending by gross house value to give Series 2. The price-paid data is the sum of all individual house price purchases in England and Wales between 1995 and 2018 which is available from LR. The gross secured lending to individuals shows the monthly amount of total sterling secured lending to individuals, which is not seasonally adjusted and includes all loans secured on residential properties. Series 2 is represented in figure 3.3 below.

Figure 3.2: Series 1

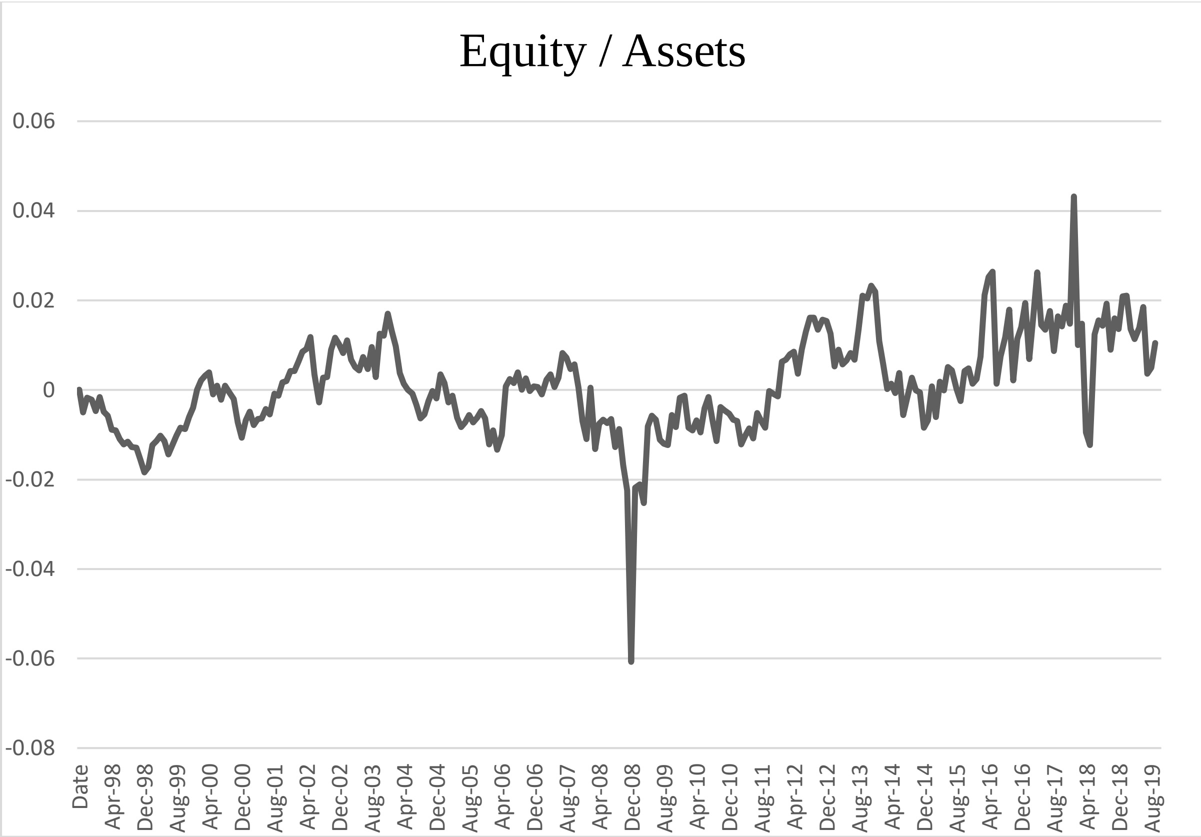
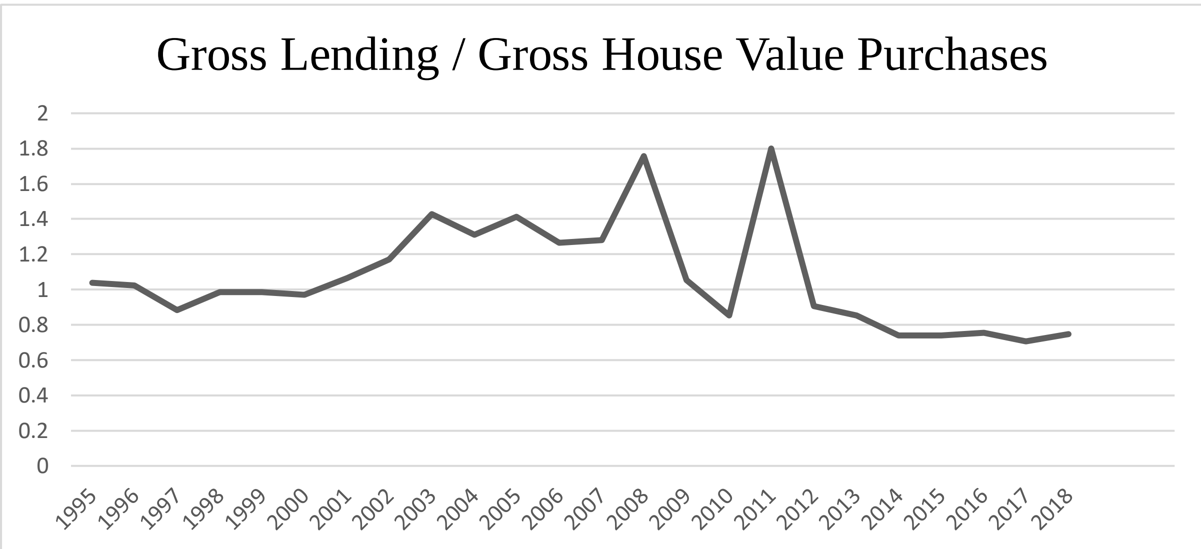



Figure 3.3: Series 2



## 3.4 Regulatory Effect

To derive an implied regulative effect, Series 1 and Series 2 are regressed via OLS on the appropriate aggregate indices together with their one period lags and one period leads, the resulting coefficients are then multiplied by their respective dummy series and finally the product of these results is summed to obtain the implied regulative effect. Specifically, using Dataset 2 the first regression regresses the lag of Series 1 on $A2C$, $A2C_{+1}$ and $A2C_{-1}$, the aggregate index of regulation targeted towards the corporate sector, its lead and lag respectively. Therefore, this regression estimates the total effect of regulatory measures targeted towards the corporate sector regressed on bank equity. As a result, we then obtain the individual OLS coefficients derived from this regression as displayed in table 3.2. In the next step I obtain the aggregate index $A2C$ and multiply this column of data by the coefficient for $A2C$ in table 3.2. Similarly, I select the aggregate index $A2C_{+1}$ and multiply this series by the coefficient for $A2C_{+1}$. The same procedure is applied again, here I multiply the series $A2C_{-1}$ by its respective coefficient in the table. In the same manner I multiply the lag of Series 1 by its respective coefficient. As a result, I obtain 4 new columns based on each series and index multiplied by their respective regression coefficients. The 4 new columns are summed together to obtain the implied regulative effect of corporate regulation on bank equity, which I will enter into the DSGE model as $\tau_t$ in section 4. The result is graphed in figure 3.4 below.

The next regression relates to the effect of regulation targeted towards the mortgage sector on Series 2. Therefore, utilising Dataset 2 this regression regresses the lag of Series 2 on $A2HH$, $A2HH_{+1}$ and $A2HH_{-1}$, the aggregate index of regulation affecting the mortgage sector, its lead and lag respectively. Therefore, this regression estimates the independent effect of regulatory measures affecting households on the mortgage series. The results of the individual OLS coefficients are obtained and shown in table 3.2. In a similar manner to the process described above, I multiply each series by its respective coefficient and sum the results to obtain an implied regulative effect of regulation targeted towards the mortgage sector, the resulting series will be utilised in our DSGE model. This series is displayed in figure 3.5 below and will be represented by the variable $\Xi_{2_t}$ in section 4.

Table 3.2: Regulative Regression Coefficients

| Variable | Coefficient | Variable | Coefficient |
|---|---|---|---|
| S1(-1) | 0.728295 | S2(-1) | 0.965296 |
| A2C | 0.000892 | A2HH | 0.005901 |
| A2C_PLUS | 0.000841 | A2HH_PLUS | -0.002899 |
| A2C_MINUS | -0.001514 | A2HH_MINUS | -0.004644 |

The above data in table 3.2 is derived from regressions carried out within the HarMap Dataset. Where S1(-1) is the lag of the equity series ‘Series 1’, A2C is the index of regulatory measures targeted towards the corporate sector recorded on announced date, A2C PLUS is the lead of this variable and A2C MINUS is the lag. Similarly, S2(-1) is the lag of the mortgage series ‘Series 2’, A2HH is the index of regulatory measures targeted towards the corporate sector recorded on announced date, A2HH PLUS is the lead of this variable and A2HH MINUS is the lag. Together, this table displays the results of the OLS regressions described in section 3.4 above.

Figure 3.4: Implied Corporate Regulative Effect

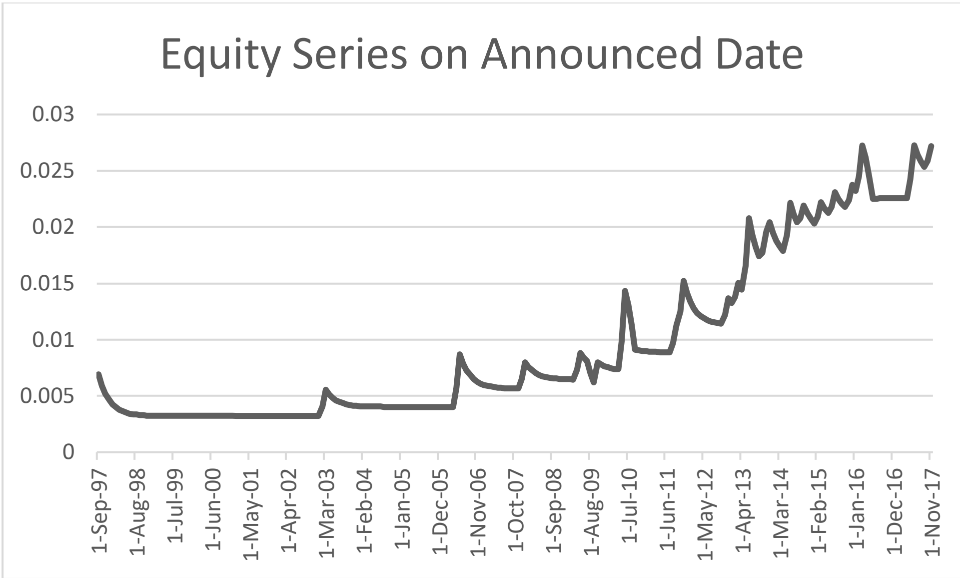
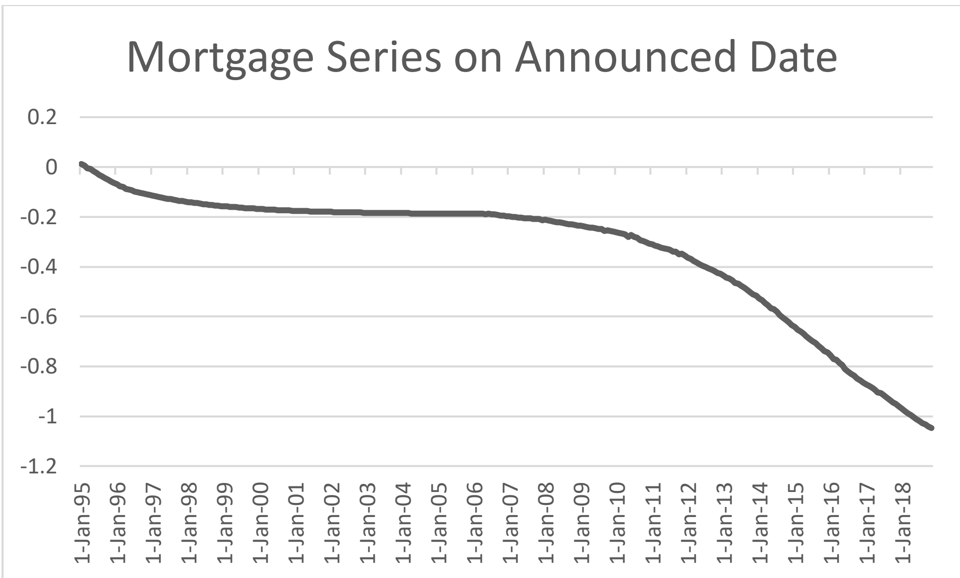



Figure 3.5: Implied Mortgage Regulative Effect



## 3.5 Conclusion

Though the dataset used for this analysis has taken extensive measures to ensure robustness, such as cross checking each individual entry derived by both announced date and effective date, I note some potential areas for improvement in future research. The first point refers to the binary nature of the regulative index created for the purpose of this analysis. While the binary dummy style indicator methodology to record the prudential actions offers a clear and distinguishable representation of the aims of the prudential authorities, the trade-off in not using an alternative measure in which each individual prudential action is scored above a |+1| is one in which the strength of each individual action is not comparable to another. Though the end result of this analysis attempts to develop an overall measure of the intensity of regulation, intensity before implementation into the DSGE model is based on the frequency of prudential actions, it would in principle be useful to have a measure of the intensity of each individual prudential action. The second point refers to a lack of data availability in the development of Series 2, as information for home purchases derived from LR is only largely available for England and Wales, assertions and conclusions about regulations that are targeted towards the UK will not be as accurate if aggregate house price paid data was also available for Scotland and Northern Ireland without the need for data manipulation. Alternative methods of extrapolating the price paid data to include Scotland and Northern Ireland could be administered. However, this comes with its own accuracy trade-offs. In addition to this, I expect the inaccuracy the analysis based on this discrepancy not to be significant as the combined populations of Scotland and Northern Ireland are relatively small in comparison to that of the joint populations of England and Wales[5].

[5] The combined populations of Northern Ireland and Scotland constitute 12.6% of the joint populations of England and Wales. This is based on the 2011 census which recorded the population of England as 53.0 million, Scotland as 5.3 million, Wales as 3.1 million, and Northern Ireland as 1.8 million.

In summary, this section details the process and methodology implemented in creating an index of regulation for the UK. In order to achieve this, I harmonise a wide set of regulatory databases to create a comprehensive set of data points for regulation within the UK. I then implement a dummy style indicator approach to recording regulatory changes and create a measure of regulatory intensity. As a final step, I utilise data obtained from the BoE and LR together with the RII for both the mortgage and corporate sectors in order to create 2 new regulatory series - $\Xi_2$ and $\tau$ – respectively, the mortgage and corporate regulatory variables. These 2 new series can then be implemented into a DSGE model for policy analysis. The next chapter details the model design to which these two regulatory series shall be implemented.

# 4 An Open Economy DSGE model with Regulation

## 4.1 Introduction

Since the onset of the financial crisis that began in 2007, there has been two distinct trends within the economic domain. The first has been the prominent use of macroprudential regulation within the financial sector as a means to smooth economic fluctuations, whilst the second relates to the underlying assumptions of standard macroeconomic models that have been in use. It has become evident that in order to understand the true dynamics of the economy, the financial sector should be assigned a more prominent role in analysis. Contrary to popular belief, the addition of financial market frictions is not new to the academic literature, early contributions to this field include the work by Bernanke et al. (1999), Carlstrom and Fuerst (1997) and Kiyotaki and Moore (1997) amongst others. These papers have largely formed the basis of work in this field and those in the preceding 35 years to date. However, in-spite of their influence within the academic arena, this specific area of macroeconomic research has generally been neglected as part of informed policy. Instead, policy has evolved around the New Keynesian (NK) theory and structure. Though these models often encompass elements of frictions such as sticky wages and prices, the majority of NK models were formulated on the assumption of complete markets without financial market frictions. It was only after the great recession and its effects were experienced that policy makers began to point to frictions of the financial nature as key to understanding the macroeconomy. As a result, this has led to a renewed interest in macroeconomic models that facilitate the analysis of the interactions between financial frictions and macroeconomic fluctuations. There is now a growing literature in this field of macroeconomics. Namely, Christensen and Dib (2008) and more recently Le et al. (2016). These studies generally exhibit mechanisms in-which endogenous developments in credit markets work to amplify and propagate shocks to the macroeconomy, regarding financial frictions as a potential cause of innovations to the wider economy.

First, to capture the dynamics of the financial frictions previously discussed, the work set out in this thesis follows Le et al. (2016) who leverage on the framework developed in Smets and Wouters (2007) by augmenting the model structure to permit a degree of both price and wage stickiness via a New Keynesian - New Classical synthesis. The authors were also able to implement the concept of the financial accelerator mechanism as set out in Bernanke et al. (1999). This thesis therefore deviates from the Iacoviello (2005) model setup that is common in the literature regarding macroprudential policy. Instead, in this thesis I adopt an elementarily lucid framework that embodies an economy in which some households set up banking firms who lend to other households that utilise these funds for both general consumption and mortgages backed by their income. Whilst these households place deposits at the banks, they borrow due to frictions, in order to finance durable goods and housing.

Similarly, these banks lend to financially constrained entrepreneurs against their net worth following Bernanke et al. (1999). It is through these two avenues that the indices of regulation targeted towards the corporate sector, and regulation targeted towards households and mortgages can affect the cost of credit. In this paper M0 has both a role in setting the short-term interest rates on government bonds and as a means of cheap collateral against bank lending, thus allowing for monetary policy to be effective even at the ZLB. This thesis adapts the feature set by Zhu (2017) in adjusting to a small open economy model by allowing the Armington (1969) substitution elasticity between domestic and foreign goods. It also implements the two state dynamics, above and at the ZLB as stipulated in Wang (2020).

The second addition of this thesis is to analyse the second trend that developed in the aftermath of the financial crisis. Namely, the effect of macroprudential regulation in the economy. To achieve this, I directly incorporate the two regulative effect series described in chapter 3 into the model. I achieve this by implementing the corporate series into the model through the bank lending channel and the credit premium. On the other hand, I implement the mortgage series through the household channel via the mortgage rate. I will then apply this model to unfiltered non-stationary UK data. I then simulate and estimate the model by the Indirect Inference method.

The rest of the chapter is then organised in the following manner: 4.2 Introduces the model without Quantitative Easing (QE) and the ZLB crisis. 4.3 Details monetary policy in the absence of a ZLB crisis. 4.4 Expresses the market clearing condition. 4.5 Displays monetary policy with QE and the ZLB crisis. 4.6 Introduces the log linearised model list and shock series. 4.7 Provides the calibration details 4.6 Closes the chapter with a conclusion.

## 4.2 The Model Economy Without ZLB Crisis

Within a small open-economy setting the model features seven distinct agents: Households, who consume a bundle of both home and imported goods with a preference towards domestically produced goods, supply part of their labour to differentiated sticky wage labour unions and the other part supplied in a competitive market without labour unions. Meanwhile there is a continuum of risk-neutral entrepreneurs (intermediate goods producers) who purchase capital from capital producers using loans from financial intermediaries backed by their own net worth as part of a debt contract. Entrepreneurs hire labour from labour unions and couple this with the capital purchased from capital producers to produce intermediate goods. Here, the Smets and Wouters (2007) framework is augmented and modified by implementing the financial accelerator following the specifications in Bernanke et al. (1999). Specifically, entrepreneurs are now subject to idiosyncratic shocks which cause a wedge between the rate paid by entrepreneurs and the risk-free rate required by house-holds to hold their cash deposits with financial intermediaries.

Capital producers operate in a perfectly competitive sector, each period they utilise installed capital and investment to produce new capital stock which is then rented to entrepreneurs period by period. Retailers (final goods producers) operating within a perfectly competitive market, aggregate intermediary goods as retail goods to sell to households. Wage and price-setting follows the NK-NC synthesis proposed in Le et al. (2016) which results in composite entrepreneurial goods that are the product of entrepreneurial production sold in an imperfectly competitive market with sticky prices and entrepreneurial production sold partly in a competitive world with flexible prices, the price of these intermediary products is a weighted average of the prices received in both types of market structure. Aggregate output is then transformed into consumption, investment, capitalised goods and net-exports. Government revenue is financed by taxation and monetary policy is guided by a Taylor Rule. Appendix 9.3 provides reference to the interactions of agents and the flow of resources throughout the model economy through the use of a descriptive flow diagram.

### 4.2.1 Households

Households have the option of choosing the levels of: consumption, labour supply hours and savings to maximise their non-separable utility function. The expected utility of the representative household is outlined as following:

$$U = maxE_0\left\{\sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma_c}(C_t - hC_{t-1})^{1-\sigma_c}\right] \exp\left(\frac{\sigma_c - 1}{1+\sigma_l} L_t^{1+\sigma_l}\right)\right\} \tag{4.1}$$

Where $\beta$ is the discount factor, $E_t$ is the rational expectations operator, $C_t$ is consumption, $h \in (0,1)$ denotes the intensity of habit formation which introduces the non-separability of preferences over time, $L_t$ represents labour hours, $\sigma_l$ and $\sigma_c$ are respectively the Frisch elasticity of labour supply and the intertemporal elasticity of substitution in consumption. The budget constraint of each household can be represented as:

$$P_t C_t + B_t + D_t + S_t B_t^f \leq R_{t-1} B_{t-1} + R_{t-1}^f S_t B_{t-1}^f + R_{t-1} D_{t-1} + W_t L_t \tag{4.2}$$

In this model, we acknowledge that a proportion of households will utilise their mortgage as a form of collateral to fund spending. It is through this mechanism that regulation can stabilise general consumption, by loosening regulation when credit is expensive and vice versa. This form of regulation can be seen to manifest in $R_t$, an identity equal to $1 + r_t{}'$ where $r_t{}' = r_t + \Xi_{2_t}\kappa$ denotes the regulatory premium above the nominal interest rate, caused by regulation affecting the mortgage sector as stipulated by $\Xi_{2_t}$ and κ – respectively, the variable that denotes our implied mortgage regulative effect and the coefficient on this variable. Similarly, the foreign gross interest rate is $R_t^f$. Households total expenditure $Y_t$ consists of consumption, investment in both domestic and foreign bonds, $B_t$ and $B_t^f$ respectively, and the option to deposit their disposable income in the bank in the form of a deposit $D_t$. $S_t$ is the nominal exchange rate which stipulates the amount of foreign currency that can be exchanged for a unit of domestic currency, whereas $Q_t$ is the real exchange rate defined as $Q_t = \frac{P_t^f}{P_t} S_t$, it indicates how much domestic goods can be exchanged for goods in the foreign country. $P_t$ is the general price level of the domestic country and $P_t^*$ is the foreign country general price level which can be read in terms of the domestic currency as $P_t^* S_t$. $P_t^f$ is the foreign consumption price from the perspective of a domestic agent. Effectively we take $P_t^* \approx P_t^f$ as the model represents a small open economy that bears little impact on the wedge between the foreign country general price level and the foreign consumption price, *videlicet* $S_t$ is effectively equal to unity in this model. Here, foreign risk-free bonds issued in the foreign market are taken to be equivalent to the price of a foreign basket of goods, hence equivalent to the foreign CPI. Formally, the optimisation problem of a representative household can be expressed as following:

$$L_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma_c}(C_t - hC_{t-1})^{1-\sigma_c}\right] \exp\left(\frac{\sigma_c - 1}{1+\sigma_l} L_t^{1+\sigma_l}\right) - \lambda_t \left[C_t + \frac{B_t}{P_t} + \frac{S_t B_t^f}{P_t} + \frac{D_t}{P_t} - \frac{R_{t-1}B_{t-1}}{P_t} - \frac{R_{t-1}^f S_t B_{t-1}^f}{P_t} - \frac{R_{t-1}D_{t-1}}{P_t} - \frac{W_t L_t}{P_t}\right] \tag{4.3}$$

The first-order conditions (FOCs) of the above optimisation problem are detailed below:

$$\partial C_t : [C_t - hC_{t-1}]^{-\sigma_c}\left(\frac{\sigma_l - 1}{1+\sigma_l} L_t^{1+\sigma_l}\right) = \lambda_t \tag{4.4}$$

$$\partial L_t : \left[\frac{1}{1-\sigma_c}(C_{t+s} - hC_{t+s-1})^{1-\sigma_c}\right] \exp\left(\frac{\sigma_c - 1}{1+\sigma_l} L_{t+s}^{1+\sigma_l}\right) L_t^{\sigma_l} = -\lambda_t w_t \tag{4.5}$$

$$\partial B_t : \frac{\lambda_t}{P_t} = E_t\left(\beta R_t \frac{\lambda_{t+1}}{P_{t+1}}\right) \tag{4.6}$$

$$\partial B_t^f : \frac{\lambda_t}{P_t} S_t = E_t\left(\beta R_t^f \frac{\lambda_{t+1}}{P_{t+1}} S_{t+1}\right) \tag{4.7}$$

The optimal choice of consumption (4.4) and domestic bonds (4.6) result in the consumption Euler equation:

$$\frac{[C_t - hC_{t-1}]^{-\sigma_c}\left(\frac{\sigma_l - 1}{1+\sigma_l} L_t^{1+\sigma_l}\right)}{P_t} = E_t\left(\beta R_t \frac{[C_{t+1} - hc_t]^{-\sigma_c}\left(\frac{\sigma_l - 1}{1+\sigma_l} L_{t+1}^{1+\sigma_l}\right)}{P_{t+1}}\right)$$

Re-arranging the above equation:

$$\frac{[C_t - hC_{t-1}]^{-\sigma_c}\left(\frac{\sigma_l - 1}{1+\sigma_l}L_t^{1+\sigma_l}\right)}{[C_{t+1} - hC_t]^{-\sigma_c}\left(\frac{\sigma_l - 1}{1+\sigma_l}L_{t+1}^{1+\sigma_l}\right)} = E_t\left(\frac{P_t}{P_{t+1}}\beta R_t\right) \tag{4.8}$$

Using real terms to measure the domestic and foreign bonds, the budget constraint can also be represented as:

$$C_t + b_t + d_t + S_t\frac{P_t^f}{P_t}b_t^f \leq R_{t-1}b_{t-1} + R_{t-1}^f S_t\frac{P_t^f}{P_t}b_{t-1}^f + R_{t-1}d_{t-1} + W_t l_t$$

Substituting for the real exchange rate, the equation can then be written as:

$$C_t + b_t + d_t + Q_t b_t^f \leq R_{t-1}b_{t-1} + R_{t-1}^f Q_t b_{t-1}^f + R_{t-1}d_{t-1} + W_t l_t$$

Where $b_t$, and $b_t^f$ are respectively the real domestic and foreign bond prices. The optimal conditions for domestic and foreign bonds are derived as:

$$\partial b_t: \lambda_t = E_t(\beta R_t \lambda_{t+1}) \tag{4.9}$$

$$\partial b_t^f: \lambda_t Q_t = E_t\left(\beta R_t^f \lambda_{t+1} Q_{t+1}\right) \tag{4.10}$$

Together, the optimal choice of domestic and foreign bonds (4.9) and (4.10) generates the uncovered real interest parity condition (UIP) which here expresses the difference between the expected domestic gross interest rate and the foreign gross interest rate as equal to the relative change in the real exchange rate $\frac{Q_{t+1}}{Q_t}$:

$$E_t(\beta R_t \lambda_{t+1}) = E_t\left(\beta R_t^f \lambda_{t+1}\frac{Q_{t+1}}{Q_t}\right) \tag{4.11}$$

Since we have that $R_t$ equals to $1 + r_t'$, the corresponding foreign gross interest rate is set as $R_t^f = 1 + r_t^{f\prime}$. Then, the UIP condition expressed in terms of the domestic gross interest is shown below:

$$(1 + r'_t) = E_t \frac{Q_{t+1}}{Q_t} \left(1 + r_t^{f\prime}\right) \tag{4.12}$$

Which here expresses the difference between the domestic and foreign gross interest rates as equal to the expected relative change in the exchange rate.

### 4.2.2 Foreign sector

The models' open economy setting is exemplified by the households' option of consuming both foreign and domestic goods and services, typically the difference between such consumption sets $C_t$ is distinguishable by both the innate characteristics of the goods and services that make up each set, and by the location in which the product is produced. These characteristics are identifiable to each consumer and may manifest as a preference for native produce over foreign goods and services, or *vice versa*. In the model, we signify a bias towards domestic produce by $\omega$ where $0 < \omega < 1$. Domestic goods and services are denoted as $C_t^d$ and foreign produce is labelled as $C_t^f$.[6] The aggregated consumption set is then a product of domestic and imported goods and takes the familiar form of a constant elasticity of substitution (CES) structure:

$$C_t = \left[\omega\left(C_t^d\right)^{-\rho} + (1 - \omega)\zeta_t\left(C_t^f\right)^{-\rho}\right]^{-\frac{1}{\rho}} \tag{4.12}$$

[6] Both $C_t^d$ and $C_t^f$ are final production goods and their specific construction is not characterised by a particular production process. This follows Armington's (1969) theory of demand for products distinguished by place.

Where $\rho = \frac{\sigma - 1}{\sigma}$ is the substitution parameter,[7] denoted as $\sigma = \frac{1}{1-\rho}$ it represents the elasticity of substitution between domestic and foreign products.[8] $\zeta_t$ is an error of preference in the demand for imported goods. Total expenditure on consumption can be expressed as:

$$P_t C_t = P_t^d C_t^d + P_t^f C_t^f \tag{4.13}$$

Where $P_t^d$ is the price of goods produced domestically, $P_t^f$ is the price of imported goods represented in the domestic currency and $P_t$ is the domestic consumer price index (CPI). The above equation can be expressed as:

$$C_t = p_t^d C_t^d + Q_t C_t^f \tag{4.14}$$

Where $p_t^d = \frac{P_t^d}{P_t}$ and $p_t^f = \frac{P_t^f}{P_t}$ are the domestic and foreign price level relative to CPI. As discussed previously, $Q_t = \frac{P_t^f}{P_t} S_t$ is the real exchange rate. The Lagrangian for the optimisation problem can then be defined as:

$$L = \left[\omega\left(C_t^d\right)^{-\rho} + (1-\omega)\zeta_t\left(C_t^f\right)^{-\rho}\right]^{-\frac{1}{\rho}} + \lambda\left(C_t - P_t^d C_t^d - Q_t C_t^f\right) \tag{4.15}$$

By first utilising the first-order conditions with respect to $C_t^d$ and $C_t^f$ we have:

$$C_t^d = (\omega)^{\sigma}\left(P_t^d\right)^{-\sigma} C_t \tag{4.16}$$

$$C_t^f = ((1-\omega)\zeta_t)^{\sigma}(Q_t)^{-\sigma} C_t \tag{4.17}$$

[7] Where $\rho = 1$ denotes linear substitution between domestic and foreign goods, $\rho = -1$ denotes perfect complements.

[8] In this model, the elasticity of substitution is fixed at $\sigma = \frac{1}{1+\rho} > 0$, $\sigma^f = \frac{1}{1+\rho^*} > 0$.

As $S_t$ is equal to unity we can symmetrically show that the foreign demand for both domestic $\left(C_t^d\right)^*$ and foreign goods $\left(C_t^f\right)^*$ is determined according to:

$$\left(C_t^d\right)^* = (\omega^f)^{\sigma^f}(P_t^*)^{-\sigma^f}C_t^* \tag{4.18}$$

$$\left(C_t^f\right)^* = \left((1-\omega^f)\zeta_t^*\right)^{\sigma^f}(Q_t^*)^{-\sigma^f}C_t^* \tag{4.19}$$

Where $\left(C_t^d\right)^*$ and $\left(C_t^f\right)^*$ are from the foreign country perspective. Similarly, $\omega^f$ represents foreign consumers' bias towards domestically produced goods, where $0 < \omega^f < 1$. $C_t^*$ represents total consumption whilst $\sigma^f$ represents the substitution elasticity of goods from a foreign viewpoint. $\zeta_t^*$ is a foreign error of preference to the demand for imports. Linearisation of equation (4.17) via a first-order Taylor series expansion around $pd = \sigma = \zeta = 1$ gives:

$$\ln C_t^f = \ln C_t - c\ln Q_t + \widehat{\text{Constant}} + \varepsilon_{im,t} \tag{4.20}$$

Where $\varepsilon_{im,t} = \sigma\ln\zeta_t$ is a shock to import demand. Similarly, log-linearisation of the export function reads:

$$\ln\left(C_t^f\right)^* = \ln C_t^* + \sigma^f\ln(1-\omega^f) + \sigma^f\ln\zeta_t^* - \sigma^f\ln Q_t^* \text{ (4.21)} \tag{4.21}$$

Symmetrically, $Q_t^* = \frac{p_t^d}{p_t^*}$, and $P_t^*$ is the foreign price level or foreign CPI and since $Q_t^* = \frac{p_t^{f^*}}{p_t^*} = \frac{p_t^d}{p_t^*}$, then $\ln Q_t^* = \ln P_t^d - \ln Q_t$. Equation (4.21) can be expressed as:

$$\ln\left(C_t^f\right)^* = \ln C_t^* + \sigma^f\ln(1-\omega^f) + \sigma^f\ln\zeta_t^* - \sigma^f\ln P_t^d + \sigma^f\ln Q_t \tag{4.22}$$

Replacing $C_t^d$ and $C_t^f$ with expressions of equations (4.16) and (4.17) in equation (4.14):

$$\left[\omega\left((\omega)^{\sigma}\left(P_t^d\right)^{-\sigma}C_t\right)^{-\rho}\right) + (1-\omega)\varsigma_t(((1-\omega)\varsigma_t)^{\sigma}(Q_t)^{\sigma}C_t)^{-\rho}\right]^{-\frac{1}{\rho}} = C_t$$

Which leads to:

$$1 = \omega^{\sigma}\left(P_t^d\right)^{\rho\sigma} + [(1-\omega)\zeta_t]^{\sigma}Q_t^{\rho\sigma}$$

Through the above equation, via loglinear approximation with a first-order Taylor expansion around the point $Pd \simeq Q \simeq \zeta = 1$:

$$\ln P_t^d = \widehat{\text{Constant}} - \frac{1-\omega}{\omega}\frac{1}{\rho}\ln\zeta_t - \frac{1-\omega}{\omega}\ln Q_t \tag{4.23}$$

Substituting $\ln P_t^d$ in equation (4.22) with the expression in (4.23):

$$\ln\left(C_t^f\right)^* = \ln C_t^* + \sigma^f\ln(1-\omega^f) + \sigma^f\ln\zeta_t^* - \sigma^f\left(\widehat{\text{Constant}} - \frac{1-\omega}{\omega}\frac{1}{\rho}\ln\zeta_t\right) + \frac{1}{\omega}\sigma^f\ln Q_t$$

The export demand function becomes:

$$\ln\left(C_t^f\right)^* = \ln C_t^* + \frac{1}{\omega}\sigma^f\ln Q_t + \widehat{\text{Constant}} + \varepsilon_{ex,t} \tag{4.24}$$

where $\varepsilon_{ex,t} = \sigma^f\ln\zeta_t^* + \sigma^f\frac{1-\omega}{\omega}\frac{1}{\rho}\ln\zeta_t$ is the export demand shock, and $\widetilde{\text{Constant}}$ is used to collect the constant term.

With regards to the foreign bond market, the evolution of net foreign bonds follows the principle that the capital account and the current account balance. The current account surplus constitutes real net exports plus the revenue from foreign bond investments, explicitly $(EX_t - Q_t IM_t) + r_t^f b_t^f Q_t$. The capital account deficit can be shown as the decrease in net foreign assets per period as measured as $\left(b_{t+1}^f - b_t^f\right)Q_t$. Then, for the balance of payments to be in equilibrium we have that:

$$(EX_t - Q_t IM_t) + r_t^f b_t^f Q_t + \left(b_{t+1}^f - b_t^f\right)Q_t = 0$$

By re-arranging we can express the above equation as the evolution in net foreign bond positions:

$$\Delta b_{t+1}^f = \left(\frac{EX_t}{Q_t} - IM_t\right) + r_t^f b_t^f \tag{4.25}$$

### 4.2.3 Final Goods Producer

Unlike intermediate goods producers, in this model the final goods producers are indirectly affected by regulation through the price paid for aggregated intermediate goods. The final goods producer purchases these intermediate goods $Y(i)_t$ from intermediate goods producers and compiles them into a composite product through the Dixit-Stiglitz aggregator:

$$Y_t = \left(\int_0^t Y_t(i)^{\frac{1}{1+\lambda_{p,t}}} di\right)^{1+\lambda_{p,t}} \tag{4.26}$$

Consumers then purchase $Y_t$ in a perfectly competitive market. $\lambda_{p,t}$ is an exogenous shock process that acts as a mark-up of prices above marginal cost and follows the AR(1) process: $\ln\left(\lambda_{p,t}\right) = \rho_p \ln\left(\lambda_{p,t-1}\right) + \eta_t^p$.

Final goods producers maximise the profit function:

$$\text{Max } Y_t P_t - \int_0^1 Y(i)_t P(i)_t di$$

Subject to (4.26). The resulting intermediate goods demand function takes the form:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} Y_t \tag{4.27}$$

Taking the integral of the above demand function and imposing the zero-profit condition on the production function of the intermediate goods producer $P_t Y_t = \int_0^1 P_t(i) Y(i)_t di$, we then see that the price of the final consumption good $P_t$ will be a CES aggregate of the prices of intermediate goods $P_t(i)$:

$$P_t = \left(\int_0^t P_t(i)^{\frac{1}{\lambda_{p,t}}} di\right)^{\lambda_{p,t}} \tag{4.28}$$

In this model regulation has the ability to influence (4.28) indirectly, through entrepreneurial balance sheet changes stemming from deviations in the cost of credit, a factor augmented by the prudential rule.

### 4.2.4 Intermediate goods producers

In this model, entrepreneurs are intermediate goods producers, the nature of which differs to that detailed in the Smets and Wouters (2007) model, following Le et al. (2016) the model utilises the Bernanke et al. (1999) framework by directly implementing financial frictions into the model via the financial accelerator mechanism and the credit channel. Explicitly, in this model entrepreneurial net worth does not accumulate to a level in which it can be used to finance the purchase of new capital from the capital producers.[9] Entrepreneurs are therefore reliant on financial intermediaries to make up the difference for capital acquisition. It is through this pathway that macroprudential measures have the potential to smooth volatility by stabilising the credit premium. Specifically, regulation that is aimed at controlling the corporate sector, modelled in this thesis with $\tau$, can be seen as aimed at regulating the risky rate on bank credit and thereby investment. Therefore, to stabilise investment regulators tighten rules when credit is cheap and loosen policy when credit is expensive. As in Smets and Wouters (2007), entrepreneurs produce intermediate goods by hiring labour, they receive this indirectly from labour packers who in-turn obtain the resource from labour unions and ultimately households. In this model however, entrepreneurs no longer rent capital from households – instead they purchase this new installed capital from capital producers using loans financed through their own net worth - extended via the credit channel. After this capital is utilised in the production of intermediate goods, this old capital is then sold back to capital producers. An entrepreneur ($i$) produces intermediate goods through the production function:

$$Y_t(i) = K_i'(i)^a[\gamma^t L_t(i)]^{1-a}\varepsilon_t^\alpha - \gamma^t\Phi \tag{4.29}$$

Where $K_t^s(i)$ and $L_t(i)$ enter the production function as capital services and aggregate labour input. $\Phi$ represents the fixed costs of production whilst $\gamma^t$ denotes the labour augmenting deterministic growth rate. The parameter $\alpha$ measures the share of capital utilised in production whilst $\varepsilon_t^\alpha$ is a productivity shock which follows an ARIMA(1,1,0) process as :

$$\ln\varepsilon_t^\alpha = \ln\varepsilon_{t-1}^\alpha + \rho_a(\ln\varepsilon_{t-1}^\alpha - \ln\varepsilon_{t-2}^\alpha) + \eta_t^\alpha \tag{4.30}$$

[9] Intermediate goods producers are risk-neutral and face a constant probability $\theta$ of surviving to the next period, this ensures that their total net worth will not exceed the total value of new capital purchases.

In order to solve for the following entrepreneurial maximisation equation:

$$max R_t^{rental} Z_t(i) K_{t-1}(i) - a(Z_t(i)) K_{t-1}(i) \tag{4.31}$$

each individual entrepreneur selects the optimal capital utilisation rate $Z_t(i)$. The income of renting capital services is $R_t^{\mathrm{rental}} Z_t(i) K_{t-1}(i)$. And the cost of changing capital utilisation is $a(Z_t(i))K_{t-1}(i)$, where at the steady state $a(1) = 0$ and $z = 1$. The optimisation problem can be expressed by the following equilibrium condition:

$$\partial z_t \colon R_t^{rental} = a'(z_t) \tag{4.32}$$

To derive the optimal level of capital and labour services, we maximise the entrepreneurial firm $(i)$'$s$ profit function:

$$P_t(i) Y_t(i) - W_t L_t(i) - R_{\mathrm{f}}^{rental} K_i^s(i) \tag{4.33}$$

Subject to (4.29), which yields the first-order conditions:

$$\partial L_t(i) \colon MC_t \gamma^{(1-\alpha)t} (1-\alpha) \varepsilon_t^{\alpha} \left( \frac{K_t^s(i)}{L_t(i)} \right)^{\alpha} = W_t \tag{4.34}$$

$$\partial K_t^s(i) \colon MC_t \gamma^{(1-\alpha)t} \alpha \varepsilon_t^{\alpha} \left( \frac{K_t^s(i)}{L_t(i)} \right)^{\alpha-1} = R_t^{rental} \tag{4.35}$$

Where $MC_t$ is the marginal cost in producing an additional intermediate product. Combining equations (4.34) and (4.35) determines a capital to labour relationship across producers as:

$$K_t^s = \frac{\alpha}{1-\alpha}\frac{W_t}{R_t^{\text{rental}}}L_t \tag{4.36}$$

Whilst the marginal cost is expressed as:

$$MC_t = \frac{\left(R_t^{\text{rental}}\right)^{\alpha}(W_t)^{1-\alpha}}{\varepsilon_t^{\alpha}\alpha^{\alpha}(1-\alpha)^{1-\alpha}} \tag{4.37}$$

According to Calvo (1983), there will be a fraction of entrepreneurs $1-\xi_p^s$ who are capable of re-optimising prices each period. The remaining share of entrepreneurs can only change prices following an adjustment process with partial indexation. Prices that do not become re-optimised are partially indexed to lagged inflation, as exemplified by the backward-looking inflation term in the following indexation rule:

$$P_t(i) = \left(\frac{\pi_{t-1}}{\pi}\right)^{l_p} P_{t-1}(i) \tag{4.38}$$

Where $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate and $\pi$ is the value of steady state inflation[10]. The profit maximisation problem for the entrepreneur is set out as:

$$\text{MaxE}_t \sum_{s=0}^{\infty} \beta^s \xi_p^s \frac{\Xi_{t+s}P_t}{\Xi_t P_{t+s}} Y_{t+s}(i)\left[\widetilde{P_t(i)}\left(\Pi_{t,t+s}\right) - MC_{t+s}\right] \tag{4.39}$$

[10] $l_p = 1$ results in perfect indexation whilst $l_p = 0$ means no indexation.

Subject to the intermediate goods demand function:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} Y_t \tag{4.27}$$

Where $\beta^s \frac{\Xi_{t+s}P_t}{\Xi_t P_{t+s}}$ is the nominal discount factor, $\Pi_{t,t+s} = \Pi_{k=1}^{s}\left(\frac{\pi_{t+k-1}}{\pi^*}\right)^{l_p}$ and $P_t(i)$ is the chosen optimal price level. $MC_t$ is the marginal cost as derived in equation (4.37). Substituting out $Y_{t+s}(i)$ in equation (4.39) with (4.27) gives:

$$\text{MaxE}_t \sum_{s=0}^{\infty} \beta^s \xi_p^s \frac{\Xi_{t+s}P_t}{\Xi_t P_{t+s}} \left(\frac{P_t(i)}{P_t}\right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} Y_t\left[\widetilde{P_t(i)}\left(\Pi_{t,t+s}\right) - MC_{t+s}\right] \tag{4.40}$$

Then, the first-order condition with respect to $P_t(i)$ is given by:

$$\sum_{s=0}^{\infty} \beta^s \xi_p^s \frac{\Xi_{t+s}P_t}{\Xi_t P_{t+s}} [(1-\omega)Y_{t+s}P_t(i)^{-\omega}P_t^{\omega} + \omega Y_{t+s}MC_{t+s}P_t(i)^{-\omega-1}P_t^{\omega}] = 0$$

For convenience we set $\omega = -\frac{1+\lambda_{p,t}}{\lambda_{p,t}}$ then simplify the above equation as:

$$\sum_{s=0}^{\infty} \beta^s \xi_p^s \frac{\Xi_{t+s}P_t}{\Xi_t P_{t+s}} (\omega-1)Y_{t+s}P_t(i)^{-\omega}P_t^{\omega}$$
$$= \sum_{s=0}^{\infty} \beta^s \xi_p^s \frac{\Xi_{t+s}P_t}{\Xi_t P_{t+s}} \omega Y_{t+s}MC_{t+s}P_t(i)^{-\omega-1}P_t^{\omega}$$

Then the optimal price level chosen by the intermediate goods producer is:

$$\widetilde{P_t(i)} = \frac{\sum_{s=0}^{\infty} \beta^s \xi_p^s \frac{\Xi_{t+s} P_t}{\Xi_t P_{t+s}} Y_{t+s} MC_{t+s} P_t(i)^{-\omega-1} P_t^{\omega}}{\sum_{s=0}^{\infty} \beta^s \xi_p^s \frac{\Xi_{t+s} P_t}{\Xi_t P_{t+s}} Y_{t+s} P_t(i)^{-\omega} P_t^{\omega}} \frac{\omega}{(\omega-1)}$$

For those intermediate goods that are sold in an imperfectly competitive market, the aggregate price index is formulated as:

$$P_t = \left[ \xi_p \left( P(i)_{t-1} \left( \frac{\pi_{t-1}}{\pi_t} \right)^{l_p} \right)^{\frac{1}{\lambda_{p,t}}} + \left(1-\xi_p\right) \left(\widetilde{P_t(i)}\right)^{\frac{1}{\lambda_{p,t}}} \right]^{\lambda_{p,t}} \tag{4.41}$$

Following Le et al. (2016) we take the notion that final output is comprised of a fixed proportion $\nu$ of intermediate goods derived from the competitive market and $(1-\nu)$ derived from the imperfectly competitive market. In the competitive market there is no price mark-up hence:

$$P(i)_t^{NC} = MC \tag{4.42}$$

Therefore, in the NC-NK synthesised model we have that the aggregated price equation is a weighted average of both the NC and the NK equations:

$$P_t^{Hybrid} = \nu_p P_t + \left(1-\nu_p\right) P_t^{NC} \tag{4.43}$$

### 4.2.5 Labour Unions and Labour Packers

Following the Smets and Wouters (2003, 2007) framework, labour markets are made up of labour unions and labour packers. The labour unions differentiate and allocate homogenous labour which is supplied by households, whilst the labour packers purchase labour from the unions and aggregate it via the Kimball (1995) composite aggregator, the composite labour is then sold to entrepreneurs:

$$L_t = \left( \int_0^t L_t(i)^{\frac{1}{1+\lambda_{w,t}}} di \right)^{1+\lambda_{w,t}} \tag{4.44}$$

Where $L_t$ is composite labour and $L_t(i)$ is differentiated labour services. $\lambda_{w,t}$ measures shocks to the aggregator and follows an AR(1) process as $\ln\left(\lambda_{w,t}\right) = \rho_w \ln\left(\lambda_{w,t-1}\right) + \eta_t^w$. The profit function of the labour packer can be defined as:

$$L_t W_t - \int_0^1 L(i)_t W(i)_t di \tag{4.45}$$

Where $Wt$ is the price of composite labour and $W_t(i)$ represents the price of intermediate labour. The labour packer chooses the optimal amount of labour services to minimise costs as can be seen by the following cost minimisation problem:

$$\underset{L_t L(i)}{Min} \int_0^1 L(i)_t W(i)_t di$$

Subject to equation (4.44), the resulting FOC leads to the following labour demand equation:

$$L_t(i) = \left(\frac{W_t(i)}{W_t}\right)^{-\frac{1+\lambda_{u,t}}{\lambda_{w,t}}} L_t \tag{4.46}$$

Labour unions act as intermediaries between households and labour packers, setting wages that follow Calvo pricing contracts. Specifically, each period there is a fraction $1-\xi_w$ of labour unions that can optimally re-set wages whilst for the other unions this remains fixed. The fraction $\xi w$ of labour unions who cannot re-set will have current wages altered by Calvo pricing and partial indexation. The optimal wage set by unions who are able to re-optimise their wage results from the following optimisation problem:

$$\mathrm{MaxE}_t \sum_{s=0}^{\infty} \beta^s \xi_w^s \frac{\Xi_{t+s} P_t}{\Xi_t P_{t+s}} L_{t+s}(i) \left[\widehat{W_t(\iota)} \left(\Pi_{t,t+s}^w\right) - W_t^h\right] \tag{4.47}$$

Where $\widetilde{W}_t(i)$ is the newly set wage, $\Pi_{t,t+s}^w = \Pi_{k=1}^s \left(\frac{\pi_{t+k-1}}{\pi^*}\right)^{l_w}$. Subject to the labour demand equation (4.46), the optimal wage rate will satisfy the following condition:

$$\sum_{s=0}^{\infty} \beta^s \xi_p^s \frac{\Xi_{t+s} P_t}{\Xi_t P_{t+s}} \left[(1-\omega^w) L_{t+s} W_t(i)^{-\omega^w} W_t^{\omega^w} \right.$$
$$\left. +\omega^w L_{t+s} W_{t\,t+s}^h W_t(i)^{-\omega^w - 1} W_t^{\omega^w}\right] = 0$$

Where $\omega^w = -\frac{1+\lambda_{p,t}^w}{\lambda_{p,t}^w}$. Then the aggregate wage index is given by:

$$W_t = \left[\xi_w \left(W(i)_{t-1} \left(\frac{\pi_{t-1}}{\pi_t}\right)^{l_w}\right)^{\frac{1}{\lambda_{w,t}}} + (1-\xi_w)\left(\widehat{W_t(\iota)}\right)^{\frac{1}{\lambda_{w,t}}}\right]^{\lambda_{w,t}} \tag{4.48}$$

As in Le et al. (2016) the NC-NK synthesis is then a fixed fraction $\nu^w$ of labour derived from an imperfectly competitive market whilst the remaining $1-\nu^w$ is obtained from the competitive market. If wages are perfectly flexible and the mark-up is zero, then the real wage would be equal to the marginal rate of substitution between consumption and leisure, equations (4.4) and (4.5) respectively. The resulting synthesised wage equation can then be defined as:

$$W_t^{Hy\text{brid}} = \nu^w W_t + (1-\nu^w) W_t^{NC} \tag{4.49}$$

### 4.2.6 Capital Producers

As with final goods producers, capital producers are indirectly affected by regulation in this model through their relationship with entrepreneurs and the price paid $P_t^k$ for purchasing old depreciated capital $K_{t-1}$, of which the former may fluctuate in response to changes in the credit premium. Within this framework, capital producers can be perceived as agents who recycle capital in the economy, they function in a competitive market and therefore take prices as given. Each period, they purchase existing capital $K_{t-1}$ from entrepreneurs and combine it with investment $I_t$ to create new capital $K_t$ which is then sold back to entrepreneurs. With every unit of investment, capital producers create $\left[1-S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t$ worth of capital, which together with the depreciated capital stock purchased from entrepreneurs gives the evolution of capital equation:

$$K_t = (1-\delta)K_{t-1} + \varepsilon_t^i \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \tag{4.50}$$

Where $It$ is investment, $K_t$ is capital holdings, $\delta$ is the depreciation rate of capital and $\varepsilon_t^i$ denotes a random investment shock that follows an AR(1) process as: $ln\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i, \eta_t^i \sim N(0, \sigma_i)$. Following the framework in CEE (2005), capital goods producers face quadratic investment adjustment costs of the form $S\left(\frac{I_t}{I_{t-1}}\right)$, with steady state $S = S' = 0$ and $S''(.) > 0$. The optimality condition of the capital producer takes the form:

$$\text{Max}E_t\left[\sum_{t=0}^{\infty} \beta^t \lambda_t M_t\right] \tag{4.51}$$

$$M_t = P_{t+1}^k\left[(1-\delta)K_{t-1} + \varepsilon_t^i I_t\left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right)\right] - P_t^k(1-\delta)K_{t-1} - I_t$$

Subject to equation (4.50)

Where $M_t$ represents the profits of the capital producers, defined as the revenue generated from selling capital $K_t$ at the real price of capital next period $P_{t+1}^k$ minus the cost of depreciated capital purchased from intermediate goods producers $P_t^k$ and investment $I_t$. The marginal rate of transformation between purchased depreciated capital stock and newly created capital is unity, therefore the real price of new capital and used capital are equal. By the first-order conditions related to the optimisation problem we derive the following investment demand function:

$$1 = \varepsilon_t^i P_t^k\left(1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right) - \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t} P_{t+1}^k \varepsilon_{t+1}^i S'\left(\frac{I_t}{I_{t-1}}\right)\left(\frac{I_t}{I_{t-1}}\right)^2\right] \tag{4.52}$$

Equation (4.52) is the investment Euler equation that underpins the relationship between the price of new and purchased capital to both investment and marginal adjustment costs. The presence of which - dissipates the reaction of investment to various shocks and in turn affects the price of capital.

### 4.2.7 The Credit Premium

Both regulation and the external credit premium play key roles in this model, they relate the balance sheets of financial intermediaries to credit constrained entrepreneurs who intermediate new capital, labour and loans to produce intermediate products. Specifically, entrepreneurs purchase new capital stock $k_t$ each period at price $P_t^k$ by utilising their own net worth together with externally financed loans from the bank. It is through this avenue that entrepreneurs are subject to regulation and idiosyncratic shocks that manifest within the credit premium. The role for regulation can be seen as an attempt to stabilise the credit premium and therefore investment, including fluctuations that may be amplified to the wider economy. The regulators have the ability to increase the RII when credit is cheap and the credit premium is low (in an upturn) and lower the RII when credit is expensive and the premium is high (in a downturn). At the end of period $t$, entrepreneurs purchase new end-of-period capital stock $K_{t+1}$ at price $P_t^k$ to utilise in period $t$+1. Then, in period $t$+1 entrepreneurs will receive revenue from the marginal production of intermediate capital goods $P(i)_{t+1}\frac{aY_{i+1}}{K_{1+1}}$ combined with investment and gain proceeds from selling $(1-\delta)K_{t+1}$ worth of capital to capital producers for price $P_{t+1}^k$. At the end of period $t$, entrepreneurs collectively combine their own net worth $N_{t+1}$ with a debt contract to borrow $B_t$ in order to finance the purchase of newly installed capital $K_{t+1}$. This is derived from the capital producers at a price of $P_t^k$ which is determined by Tobin's q. The level of debt is calculated as $(Q_t K_{t+1} - N_t)$. The entrepreneurs return should be no less than the opportunity cost $R_t B_t$. The expected rate of return on capital for the intermediate goods producer is given by the equation:

$$E_t[R_{t+1}^k] = E_t\left[\frac{P(i)_{t+1}\frac{aY_{i+1}}{K_{1+1}} + P_{t+1}^k(1-\delta)}{P_t^k}\right] \tag{4.53}$$

Where $E_t[R_{t+1}^k]$, the expected rate of return on capital (the average marginal external financing cost) is equal to the value of the marginal product of capital (the rental rate of capital) $P(i)_{t+1}\frac{\alpha Y_{t+1}}{K_{t+1}}$ plus $P_{t+1}^k(1-\delta)$ the returns from re-selling the undepreciated capital stock back to the capital producers, all per cost of acquiring the stock of capital $P_t^k$ at $t-1$. Equation (4.53) describes the linkage between the financial position of the entrepreneurs and the cost of external finance, which will be more expensive than internal funds, due to the presence of default risk caused by the asymmetric information problem between entrepreneurs and the financial intermediary. As outlined in Le et al. (2016), in the case of default the financial intermediary must post an auditing cost to recover a fraction of the collateral that entrepreneurs have put up in order to obtain finance, whereas in the case of no default the financial intermediary obtains the agreed return plus the original loan. This monitoring process is costly and therefore drives a premium between the cost incurred by entrepreneurs in obtaining finance in the market via the lending rate, and the opportunity cost of an entrepreneur's use of internal finance. With the above state-contingent constraints imposed from the financial intermediary, the entrepreneur maximises profit by choosing the optimal amount of capital. Here, the optimal capital purchases are proportional to net worth and determined by the expected discounted rate of return on capital $s_t = E\left\{\frac{R_{t+1}^k}{R_{t+1}}\right\}$.

$$P_t^K K_{t+1} = \psi(s_t)N_{t+1}, \psi(\cdot) > 0, \psi(1) = 1 \qquad (4.54)$$

Equivalently, we can re-write the above equation as:

$$E[R_{t+1}^k] = \varepsilon_t^{epr} s\left(\frac{N_{t+1}}{P_t^k K_{t+1}}\right)R_{t+1}, s'(\cdot) < 0 \qquad (4.55)$$

$s'(\cdot)$ is a representation of the cost of external finance, $e^{pr_t}$ is the finance premium shock which could be described as a shock to the supply of credit and follows an AR(1) process as $ln\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i, \eta_t^i \sim N(0, \sigma_i)$. In equilibrium, equation (4.55) shows that for the externally financed entrepreneur, the discounted rate of return to capital will be equal to the external finance premium, whilst for the partly self-financed entrepreneur, the return to capital should be equal to the marginal cost of external finance. After log-linearisation the external finance premium equation takes the following form:

$$E_t r_{t+1}^k - (r_t - E_t \pi_{t+1}) = \chi(qq_t + k_t - n_t) + \xi_t + epr_t$$

The most important role for banks in this model is to provide credit backed by collateral to entrepreneurs following the Bernanke et al. (1999) mechanism utilised in Le et al. (2016). In order to provide this credit, the banks require collateral in the form of net worth, the evolution of which is expressed as:

$$N_{t+1} = \varepsilon_t^{nw} \theta V_t \tag{4.56}$$

Here $V_t$ and $\theta$ represent respectively, the value of entrepreneurial equity and the fixed survival rate of firms. The net worth of entrepreneurs is bounded by the fixed death rate of firms $(1 - \theta)$, which ensures net worth is kept below the demand for capital. The total stock of firms is kept constant by an equal birth rate of new firms. This ensures that entrepreneurial net worth does not accumulate to a level in which they can use internal funds to finance the purchase of new capital, entrepreneurs are therefore reliant on the financial intermediary for capital acquisition.

The entrepreneurs expected lifetime is $\frac{1}{1-\theta}$, the entrepreneur who dies will exit the market and consume their entire net worth measured by $(1-\theta)Vt$. $\varepsilon_t^{nw}$is a shock to equity and follows the auto-regressive process:

$$\ln\varepsilon_t^{nw} = \rho_{nw}\ln\varepsilon_{t-1}^{nw} + \eta_t^{nw} \tag{4.57}$$

The net worth of the surviving entrepreneurs is equal to the ex-post gross return on capital investment $R_t^k P_{t-1}^k K_t$ minus the cost of borrowing externally $E_{t-1}\left[R_t^k\left(P_{t-1}^k K_t - NW_{t-1}\right)\right]$. Aggregate entrepreneurial net worth evolves according to the following law of motion:

$$W_{t+1} = \varepsilon_t^{nw}\theta V_t = \varepsilon_t^{nw}\theta\left[R_t^k P_{t-1}^k K_t - E_{t-1}\left[R_t^k\left(P_{t-1}^k K_t - NW_{t-1}\right)\right]\right] \tag{4.58}$$

Entrepreneurs who exit the market in period $t$ consume their remaining net worth so that entrepreneurial consumption fluctuates in proportion to the aggregate net worth of exiting entrepreneurs.

$$C_t^e = (1-\theta)V_t \tag{4.59}$$

## 4.3 Monetary Policy without ZLB Crisis

This section details the role of monetary policy under the state in which QE and the ZLB crisis are not present. In such a state of the world the central bank follows a traditional monetary policy rule that details how interest rates will react to deviations of inflation and output from their steady state values.

$$\frac{R_t}{R^*} = \varepsilon_t^r\left(\frac{R_{t-1}}{R^*}\right)^{\rho}\left[\left(\frac{\pi_t}{\pi^*}\right)^{r_p}\left(\frac{Y_t}{Y_t^*}\right)^{r_y}\right]^{1-\rho}\left(\frac{\frac{Y_t}{Y_{t-1}}}{\frac{Y_{t^*}^*}{Y_{t-1}^*}}\right)^{r_{\delta y}} \tag{4.60}$$

Where $R^*$, $Y_t^*$ and $\pi_t^*$ denote the steady state values of the nominal interest rate, output and inflation respectively. $\rho$ represents the degree of interest rate smoothing whilst $r_p$, $r_y$, and $r_{\delta y}$ measure the responses to inflation, output and the change in output respectively. The monetary shock $\varepsilon_t^r$ follows an AR(1) process ln $\varepsilon_t^r = \rho_r \text{ln } \varepsilon_{t-1}^r + \eta_t^r$. In a state of the world where there is no zero lower bound crisis, we assume that M0 is determined by the total supply of money $Mt$ via the discount window.

$$m_t = \psi_0 + \psi_1 M_t + \varepsilon_t^{m2} \tag{4.61}$$

Where $\psi_1 \in (0,1)$, $\varepsilon_t^{m2}$ is a shock to the money supply which follows an AR(1) process as $\text{ln}\varepsilon_t^{m2} = \rho_{m2}\text{ln}\varepsilon_{t-1}^{m2} + \eta_t^{m2}$. Following Le et al. (2016), we detail an equation for the supply of money which we define as equal to deposits $(= credit) + M0$. Here we use the firms' balance sheet[11]:

$$(M = CR + M0 = K + COLL + M0) \tag{4.62}$$

Where COLL denotes collateral, the above equation can be written in log-linearised form as:

$$M_t = (1 + v - c - \mu)K_t + \mu m_t - v n_t$$

Where $M_t$, $K_t$, $m_t$ and $n_t$ are respectively the logs of Money, capital, M0 and net worth. The constant includes collateral and has been omitted. $\mu$, $v$ and $c$ are respectively the ratios of net worth, M0 and collateral to money.

[11] The balance sheet of the firm will be presented in the following section along with the balance sheets of other sectors.

## 4.4 Market Clearing Condition

The zero-profit condition of the final goods producers and employment agencies is combined with both the household and government budget constraints and the evolution of net foreign assets to derive the aggregate resource constraint:

$$Y_t = C_t + I_t + a(Z_t)K_{t-1} + C_t^e + EX_t - IM_t + \varepsilon_t^g \tag{4.63}$$

Where $\varepsilon_t^g$ is a government spending shock that follows an AR(1) process as: $\ln\varepsilon_t^g = \rho_g \ln\varepsilon_{t-1}^g + \eta_t^g$.

## 4.5 Monetary Policy with QE & ZLB Crisis

We implement the possibility of hitting the ZLB on the bank rate by switching to a version of the model that characterises the state in which the ZLB crisis is present, this is achieved by augmenting the Taylor Rule when the bank rate solves for this level or below and replacing it with this exogenous lower bound. In such a state of the world, unconventional monetary policy including QE will be deployed. Following Le et al. (2016) we assume that to avoid bankruptcy banks request an amount of collateral from the firms to which they lend. In addition to this, we assume that banks and firms have an interest in firms holding as much cash as can be acquired for collateral. This leads from Le et al. (2016) who show that firms expected returns are increased whilst the cost of bankruptcy recovery is reduced, as when cash is held it can be recovered without loss of value. The elimination of this cost can be seen to lower the credit premium for a given set of leverage. M0 is regarded as the cheapest type of collateral and we can therefore measure the impact of QE through the credit premium. These balance sheet changes - represented by a + and a - can be explained in table 4.1 through the medium of an open market operation in which the central bank issues M0 to households in exchange for the government bonds they own. In such a case, households deposit extra cash with the financial intermediaries who then lend these funds to firms. The firms then utilise the loanable funds as collateral in future lending deals with banks, so that a larger part of collateral is held as M0. With the increased collateral held in the form of money, this will lead to a reduction in the credit premium as previously discussed. The reduction in the credit premium induces a future rise in investment and leverage whilst the other collateral is converted into capital stock[12]. To add these features into the model we set $\xi$, $\tau$ and $\Gamma$ as macro-prudential rules that regulate bank behaviour. Here, $\tau$ is modelled on actual quantities as stipulated in section 3, it is the variable that denotes our RII of regulative policy actions for the corporate and banking sector whilst $\Gamma$ is the coefficient on this variable. $\tau$ enters as an instrument that directly affects the credit premium. $\xi$ alternatively, can be thought of as a macroprudential shock that is not exclusive to regulations specific to the banking or corporate sector but that feeds into the credit premium. $\xi$ evolves as an exogenous I(1) time-series process which acts as an exogenous shock rather than modelled with quantities. This now gives the monetary and regulatory authorities four instruments: $\xi_t$, $\Xi_{2_t}$, $\tau_t$, $m_{\mathrm{t}}$ and $r_t$. Then, in a state of the world in which there is a ZLB crisis, the equation for the credit premium is presented as:

$$E_t cy_{t+1} - (r_t - E_t \pi_{t+1}) = s_t = \chi(qq_t + k_t - n_t) - \psi_3 m_t + \xi_t + \tau_t \Gamma + epr_t$$

Where $E_t cy_{t+1}$ is the expected return on capital, $s_t$ is the credit premium and $\psi_3$ measures the elasticity of the premium to M0. When the ZLB is bounded, we allow M0 to target the equilibrium value of the credit premium. As the credit premium tends to be correlated inversely with the broad money supply, when the credit premium is above the steady state the money supply will adjust higher to bring M0 down. Strictly speaking, when the policy rate is above

[12] Following Le et al. (2016) we have described the balance sheets as if firms hold M0 directly; in practice firms do so in the form of a marked deposit with the bank, as seizable collateral in the event of bankruptcy. This is seen in the above balance sheets as $\mathrm{Coll}_M DEP(M0)$, an asset of firms reflecting their M0 deposit; on the bank side it is recorded as a liability, as banks hold the corresponding M0 as an asset.

the ZLB, the short-term interest rate is set by following a Taylor Rule. When the rate is at or below the ZLB, the model automatically suspends the interest rate rule and sets the short-term rate at an exogenous value[13]. We can therefore express the equations for M0 in two parts:

$$m_t = m_{t-1} + \psi_2(s_t - s^*) + \varepsilon_{t,zlb}^{m2}, r_t \leq 0.0625 \quad (4.64)$$

$$m_t = \psi_0 + \psi_1 M_t + \varepsilon_t^{m2}, r_t > 0.0625 \quad (4.65)$$

Equation (4.64) represents M0 at or below the ZLB whilst equation (4.65) represents M0 above the ZLB. Here $\psi_1$ and $\psi_2$ are both positive coefficients that measure respectively, the money response to credit growth and the money response to the premium. $s^*$ is the steady state level of the credit premium and $\varepsilon_{t,zlb}^{m2}$ is the quantitative easing shock that follows an AR(1) process.

Table 4.1: Sectoral Balance Sheets

| Firm | | Bank | | Household | | Central bank | |
|---|---|---|---|---|---|---|---|
| Asset | Liability | Asset | Liability | Asset | Liability | Asset | Liability |
| $\text{Coll}_{\text{NonM}}$ $(-)$<br>$\text{Coll}_M DEP(M0)(+)$<br>K(+) | Net worth<br>Credit (+) | Credit(+)<br>M0(+) | Deposit (+)<br>$\text{Coll}_M DEP(MO)(+)$ | Deposit (+)<br>GB(−) | CONS | Borrowing | GB(−)<br>M0(+) |

[ii] Where $\text{Coll}_{\text{NonM}}$ = collateral held as non-monetary; $\text{Coll}_{\text{M}}$ = collateral held as money; $\text{Coll}_M DEP(M0)$ = marked money collateral; K = capital investment; GB = government bonds; CONS = stock of private savings; Borrowing = accumulated government borrowing; M0 = monetary base.

[13] We follow Le et al. (2016) and take the interest rate to be 0.25% p.a.

## 4.6 Log-Linearised Model List & Stochastic Processes

This section details all the model equations in log-linearised form. Each equation is normalised with one endogenous variable. All variables are in natural logarithm form, apart from those variables that are already in the form of percentages and ratios.

**Consumption Euler equation with mortgage regulation**

$$C_t = C_1 C_{t-1} + C_2 E_t C_{t+1} + C_3 (L_t - E_t L_{t+1}) - C_4 \left(r_t + \Xi_{2_t}\kappa - E_t \pi_{t+1}\right) + eb_t$$

$$C_1 = \frac{\frac{\lambda}{\gamma}}{1+\frac{\lambda}{\gamma}} C_{t-1} C_2 = \frac{1}{1+\frac{\lambda}{\gamma}} C_3 = \frac{(\sigma_c - 1)\frac{w_*^h L_*}{C_*}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c} C_4 = \frac{1-\frac{\lambda}{\gamma}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}$$

**Real Unconverted Interest Rate Parity**

$$q_t = E_t q_t + r_t^f - r_t$$

**Labour Demand Equation**

$$l_t = -w_t + \left(1 + \frac{1-\psi}{\psi}\right) rk_t + k_{t-1}$$

**External Finance Premium Equation with corporate regulation and without QE**

$$E_t cy_{t+1} - (r_t - E_t \pi_{t+1}) = \chi(qq_t + k_t - n_t) + \xi_t + \tau_t \Gamma + epr_t$$

**External Finance Premium Equation with corporate regulation and with QE**

$$E_t cy_{t+1} - (r_t - E_t \pi_{t+1}) = \chi(qq_t + k_t - n_t) - \psi m_t + \xi_t + \tau_t \Gamma + epr_t$$

**Net Worth Evolution Equation**

$$n_t = \frac{N}{k}(cy_t - E_{t-1} cy_t) + E_{t-1} cy_t + \theta n_{t-1} + enw_t$$

**Capital Services Equation**

$$k_t^s = k_{t-1} + z_t$$

**Capital Utilisation Equation**

$$z_t = \frac{1-\psi}{\psi} rk_t$$

**Hybrid Wage Equation**

$$w_t^{NK} = \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{(1-\sigma_c)}lp}E_t w_{t+1} + \frac{1}{1+\beta\gamma^{(1-\sigma_c)}l_p}w_{t-1} + \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}}E_t\pi_{t+1} - \frac{1+\beta\gamma^{1-\sigma_c}l_w}{1+\beta\gamma^{1-\sigma_c}}\pi_t$$
$$-\frac{l_w}{1+\beta\gamma^{1-\sigma_c}}\pi_{t-1} - \frac{1}{1+\beta\gamma^{1-\sigma_c}}\left(\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_w\right)(1-\xi_w)}{\xi_w\left(1+\left(\phi_p-1\right)\epsilon_w\right.}\right)\left(w_t - \sigma_l l_t - \left(\frac{1}{1-\frac{h}{\gamma}}\right)\left(c_t - \frac{h}{\gamma}c_{t-1}\right)\right) +$$
$$ew_t$$

$$w_t^{NC} = \sigma_l l_t - \left(\frac{1}{1-\frac{h}{\gamma}}\right)\left(c_t - \frac{h}{\gamma}c_{t-1}\right) - (\pi_t - E_{t-1}\pi_t) + ew_t^s$$
$$w_t^{hybrid} = w^w w_t^{NK} + (1-w^w)w_t^N C$$

**Hybrid Keynesian Phillips Curve**

$$\pi_t^{NK} = \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}lp}E_t\pi_{t+1} + \frac{l_p}{1+\beta\gamma^{(1-\sigma_c)}lp}\pi_{t-1}$$
$$-\frac{1}{1+\beta\gamma^{1-\sigma_c}l_p}\left(\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_p\right)\left(1-\xi_p\right)}{\xi_p\left(1+\left(\phi_p-1\right)\epsilon_p\right.}\right)\left(ar_t^k + (1-\alpha)w_t\right)\Bigg) - ep_t$$
$$\pi_t^{NC} = (1-\alpha)w_t + \alpha r_t^k$$
$$\pi_t^{hybrid} = w^w \pi_t^{NK} + (1-w^w)\pi_t^{NC}$$

**Tobin Q Equation**

$$qq_t = \frac{1-\sigma}{1-\sigma+R_*^k}E_t qq_{t-1} + \frac{R_t^k}{1-\sigma+R_*^k}E_t rk_{t+1} - E_t cy_{t+1}$$

**Investment Euler Equation**

$$I_t = \frac{1}{1+\beta\gamma^{(1-\sigma_c)}}I_{t-1} + \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}}E_t I_{t+1} + \frac{1}{(1+\beta\gamma^{(1-\sigma_c)})\gamma^2\varphi}qq_t + ei_t$$

**Production Function**

$$y_t = \phi[\alpha k_t^s + (1-\alpha)l_t + ea_t]$$

**Taylor Rule Equation**

$$r_t = \rho r_{t-1} + (1-\rho)\left(r_p\pi_t + r_y y_t\right) + r_{\delta y}(y_t - y_{t-1}) + er_t$$

**Prudential Rule**

$$r_t' = r_t + {\Xi_2}_t \kappa$$

**Quantitative Easing with ZLB crisis**

$$m_t = m_{t-1} + \psi_2(cy_t - cy *) + \varepsilon_{tzlb}^{m2}, r_t \leq 0.0625$$

**Money supply equation without QE**

$$m_t = \psi_0 + \psi_1 M_t + \varepsilon_t^{m2}, r_t > 0.0625$$

**M2 Equation**

$$M_t = (1 + \nu - \mu)k_t + \mu m_t - \nu n_t$$

**Foreign Bond Evolution Equation**

$$b_t^f = \left(1 + r_t^f\right) d_{t-1}^f + \frac{EX}{Y}\frac{P_*^d}{Q_*} ex_t + \frac{EX}{Y}\frac{P_*^d}{Q_*} q_t - \frac{IM}{Y} m_t$$

**Export Equation**

$$x_t = c_t^f + \frac{1}{\omega}\sigma^f q_t + eex_t$$

**Import Equation**

$$m_t = c_t - \sigma q_t + eim_t$$

**Resource Constraint**

$$y_t = \frac{c}{y}c_t + \frac{i}{y}i_t + \frac{k}{y}R^k z_t + \frac{c^e}{y}c_t^e + \frac{x}{y}x_t - \frac{m}{y}m_t + eg_t$$

**Gross Interest Rate**

$$R_t = \left(1 + r_t + \Xi_{2_t}\kappa\right)$$

**Stochastic Shock Processes**

The dynamics of the model follows 15 shock processes with two exogenous variables; foreign consumption $C_t^f$ and the foreign rate of interest $r_t^f$.The shock processes are listed below:

**Government spending shock (market clearing equation)**

$$eg_t = \rho_1 eg_{t-1} + \rho_2 \eta_t^3 + \eta_t^1$$

**Preference shock (consumption Euler equation)**

$$eb_t = \rho_2 eb_{t-1} + \eta_t^2$$

**Productivity shock (production function)**

$$(ea_t - ea_{t-1}) = \rho_3 (ea_{t-1} - ea_{t-2}) + \eta_t^3$$

**Investment shock (Investment Euler equation)**

$$ei_t = \rho_4 ei_{t-1} + \eta_t^4$$

**Monetary policy shock (Taylor Rule equation)**

$$er_t = \rho_5 er_{t-1} \eta_t^5$$

**Price mark-up shock (Hybrid inflation rate equation)**

$$ep_t = \rho_6 ep_{t-1} + \eta_t^6$$

**Wage mark-up shock (Hybrid wage equation)**

$$ew_t = \rho_7 ew_{t-1} + \eta_t^7$$

**External finance premium shock (External finance premium equation)**

$$epr_t = \rho_9 epr_{t-1} + \eta_t^9$$

**Net worth shock (Net Worth equation)**

$$enw_t = \rho_{10} enw_{t-1} + \eta_t^{10}$$

**Money supply shock (M0 equation with crisis)**

$$\varepsilon_{t,zlb}^{m2} = \rho_{11} errm_{t-1} + \eta_t^{11}$$

**Money supply shock (M0 equation without crisis)**

$$\varepsilon_t^{m2} = \rho_{12} errm_{t-1} + \eta_t^{12}$$

**Export demand shock (Export demand equation)**

$$eex_t = \rho_{13} eex_{t-1} + \eta_t^{13}$$

**Import demand shock (Import demand equation)**

$$eim_t = \rho_{14} eim_{t-1} + \eta_t^{14}$$

**Exogenous foreign consumption process**

$$c_t^f = \rho_{15} c_{t-1}^f + \eta_t^{15}$$

**Exogenous foreign interest rate process**

$$r_t^f = \rho_{16} r_{t-1}^f + \eta_t^{16}$$

## 4.7 Calibration

In this section we calibrate the model described in the previous section by applying quarterly UK data over the period 1995Q1 to 2016Q4. The model contains 78 observations in total, with all time-series data in per capita levels, except for those variables already in percentages or ratios. Data sources for calibration include amongst others: The Bank of England (BOE), and, the Office for National Statistics (ONS), Federal Reserve Economic Data (FRED), Data Stream and an extensive list of regulatory bodies. Section 8.2 contains information on all the data sources used.

Before assessing the log-linearised version of the model, I obtain structure parameters based on values derived from the literature together with actual data. The parameters in calibration can be separated into two categories, the first group determines the dynamics of the model and leverages on the consensus in the literature. Such values include the monetary policy rate and parameters relating to price and wage stickiness. I then utilise estimated data values derived for the UK and euro area using models of a similar structure. The second category of parameters determine the steady-state of the model, for example the capital-output ratio and the investment-output ratio are obtained directly from observable data. In chapter 5, I then take these unconditional structural parameters in order to re-valuate and re-estimate them via Indirect Inference, whereby we utilise the VAR properties of the auxiliary model against simulations of our proposed model.

Given a steady state annualised real interest rate of $\bar{R} = 1.01,$ we calculate a discount factor of $\beta = \frac{1}{\bar{R}} = 0.99$. The quarterly capital depreciation rate $\delta$ follows the consensus in the literature and is equal to 0.05, which leads to an annual depreciation rate of 20%. The share of capital assigned to production is set at the level of 0.3. $\phi$ corresponds to the share of fixed costs which are not utilised in production and equates to 0.5. The degree of external habit formation in consumption $h$ follows recent work in the literature and is initially calibrated to be 0.7. The intertemporal elasticity of consumption $\sigma_c = \frac{1}{0.74} = 1.39$ measures the growth rate in consumption against the real interest rate whilst the elasticity of labour supply $\sigma_l = \frac{1}{0.42} = 2.38$ measures the growth in the labour rate with respect to wage, both are derived empirically for the euro area and applied to this small open economy model. The elasticity of capital adjustment costs $\varphi$ is initially calibrated to be 5.74 whilst the elasticity of capital utilisation costs $\psi$ is equated to 0.05, which is inconsistent with Smets and Wouters (2003) and Le et al. (2012). The re-optimisation of retail price probability $\xi_p$ is set at 0.67[14] whilst the degree of inflation indexation $l_p$ follows estimation results in SW and is initially calibrated to 0.43. Similarly, the degree of wage stickiness $\xi_w$ equates to 0.7[15], whilst the level of wage indexation

[14] This implies that the average duration of retail price for a certain variety is three quarters $\left(\text{i.e.} \frac{1}{1-\xi_p} = 3\right)$.

[15] $\left(\text{i.e.} \frac{1}{1-\xi_p} = 3.33\right)$.

$l_w$ is at 0.58 in the model. According to the empirical results of Le et al. (2012), we set the proportion of sticky wages $w^w$ and the proportion of sticky prices $w^p$ at 0.1 and 0.4 respectively.

On the financing side of the model, this thesis follows Le et al. (2012) and Bernanke et al. (1999) in setting the survival rate of entrepreneurs $\theta$ to 0.99.[16] Based on the consensus in the literature for the EU and UK the elasticity of the credit premium with respect to leverage $\chi$ equates to 0.04 whilst the elasticity of the premium with respect to money $\psi_3$ is calibrated at 0.08, which implies there will be a 0.08% decrease in the credit premium for a 1% increase in the supply of money. As mentioned before, macroprudential policy is a relatively new field and the literature is narrow, as a result I initially calibrate the parameters κ and Γ as equal on the level of 0.3, I then test these parameters within the model to see if they are feasible.

With regards to the foreign sector, the values implemented follow the empirical evidence in Minford (2015) for UK based data. We set the preference bias for domestic $\omega$ and foreign goods $\omega^f$ jointly at 0.7. The elasticity of marginal substitution between the domestic and imported consumption bundles $\sigma$ is calibrated to be equal to 1 which means that for a given quantity of domestic produce, a one percent increase in the foreign to domestic price results in a one percent decrease in imported goods. The equivalent marginal substitution elasticity for the foreign country $\sigma^f$ equals to 0.7.

[16] This result means that the average entrepreneurial lifespan is approximately 6 and a quarter years: $\frac{\left(\left(\frac{1}{1-\theta}\right)\right)}{4} = 6.25$.

The calibration of the monetary parameters closely follows that of Le et al. (2016). Specifically, the response of the nominal interest rate to inflation $r_p$, output $r_y$ and the change in output $r_{\delta y}$ are set at 2.3, 0.03 and 0.2 respectively. The rate of interest rate smoothing $\rho$ equals to 0.74 in the model whilst the parameters that measure the money response to credit growth $\psi_1$ and the money response to the premium $\psi_2$ are respectively 0.05 and 0.04. This indicates that there will be a 0.04% decrease in the premium for a 1% increase in the money supply.

Aside from the macroeconomic, prudential and financial parameters, the model is also calibrated to replicate macroeconomic ratios that govern the behaviour of the real economy. Namely, the average value of quarterly steady state inflation and output growth are respectively 1.29 and 0.55 whilst the model is calibrated to attain a steady state government spending to output ratio of 0.2. Then log-linearised market clearing condition is shown to be:

$$y_t = \frac{c}{y}c_t + \frac{i}{y}i_t + \frac{k}{y}R^k z_t + \frac{c^e}{y}C_t^e + \frac{x}{y}X_t - \frac{m}{y}M_t + eg_t$$

The resulting steady state values are of the above formulation are therefore: investment-output ratio: $\frac{i}{y} = 0.18$ , capital-output ratio $\frac{k}{y} = 2.66$ , consumption-output ratio $\frac{c}{y} = 0.58$ , entrepreneurial-consumption-output ratio $\frac{c^e}{y} = 0.008$ , export-output ratio $\frac{x}{y} = 0.24$ and import-output ratio $\frac{m}{y} = 0.25$.

Table 4.2: Calibrated Coefficients

| **Description** | **Symbols** | **Calibration** |
|---|---|---|
| Households | | |
| Discount factor | $\beta$ | 0.99 |
| Elasticity of consumption | $\sigma_c$ | 1.39 |
| Elasticity of labour supply | $\sigma_l$ | 2.83 |
| External habit formation | $h$ | 0.7 |
| Degree of wage stickiness | $\xi_w$ | 0.7 |
| Degree of Wage indexation | $l_w$ | 0.58 |
| Proportion of sticky wages | $w^w$ | 0.1 |
| Preference bias in consumption | $\omega$ | 0.7 |
| Firms | | |
| Degree of price stickiness | $\xi p$ | 0.67 |
| Degree of price indexation | $lp$ | 0.43 |
| Proportion of sticky prices | $wp$ | 0.4 |
| Entrepreneur survival rate | $\theta$ | 0.99 |
| Share of capital in production function | $\theta$ | 0.3 |
| Capital depreciation rate | $\delta$ | 0.05 |
| Share of fixed costs in production function | $\phi$ | 1.50 |
| Elasticity of capital adjustment | $\phi$ | 5.74 |
| Elasticity of capital utilisation | $\psi$ | 0.05 |
| Monetary Policy | | |
| Talyor rule response to inflation | $r_p$ | 2.3 |
| Interest rate smoothing | $\rho$ | 0.74 |
| Talyor rule response to output | $r_y$ | 0.03 |
| Talyor rule response to output change | $r_{\delta y}$ | 0.2 |
| Money response to credit growth | $\psi_1$ | 0.05 |
| Money response to premium | $\psi_2$ | 0.04 |
| Financial | | |
| Elasticity of premium to leverage | $\chi$ | 0.04 |
| Elasticity of premium to money | $\psi_3$ | 0.08 |
| Regulatory | | |
| Mortgage Regulation | $\kappa$ | 0.3 |
| Corporate Regulation | $\Gamma$ | 0.3 |

Table 4.3: Steady State values in the Model

| | | |
|---|---|---|
| Consumption output ratio | $\frac{c}{y}$ | 0.58 |
| Investment output ratio | $\frac{I}{y}$ | 0.18 |
| Entrepreneurial consumption to output ratio | $\frac{ce}{y}$ | 0.008 |
| Export to output ratio | $\frac{ex}{y}$ | 0.24 |
| Import output ratio | $\frac{im}{y}$ | 0.25 |
| Capital output ratio | $\frac{k}{y}$ | 2.66 |
| Return rate of capital | $R_k^*$ | 0.04 |
| Quarterly output growth | $\bar{y}$ | 0.55 |

## 4.8 Conclusion

The aim of this study is to analyse the effectiveness of prudential regulation, specifically we want to test if the regulatory policies put forward during the period of analysis work to stabilise the economy as compared to exclusively using a monetary rule. To make the model relevant to the UK we utilise a small open economy New Keynesian DSGE model containing regulation variables both on the corporate side - nestled into the premium equation and on the house-hold side - via the Euler equation. This two-state model displays an economy characterised by unconventional monetary policy and an alternative state in which there is a regular monetary rule. We then allow the model to confront UK data over the period 1995Q1 to 2016Q4. Before continuing to the Indirect Inference test in the next chapter we calibrate the model parameters. If the calibrated model does not pass the test I then continue with the Indirect Inference estimation in the next chapter.

# 5 Evaluation and Estimation: An Indirect Inference Approach

## 5.1 Introduction

This chapter attempts to address some of the practical issues faced in the procedure of testing, estimating and evaluating a DSGE model. Here, I note some of the potential shortcomings apparent in popular methods of estimating DSGE models and offer an alternative procedure that may enhance the models' power. Generally speaking, there are two main issues that researchers are faced with when tasked with estimating and evaluating a DSGE model. The first surrounds the rise in the use of Bayesian techniques, which are often narrow and can therefore lead to the fragility of important parameter estimates across empirical studies Del Negro and Schorfheide (2008). The second, occurs as an unintended side effect of de-trending time series data before estimation. As when data is detrended the first differencing filter passes higher frequency data behaviours whilst diminishing lower frequency data. Similarly, the moving average filter passes lower frequency data and obstructs higher frequency data behaviour. The result is that the de-trended data is smoothed and does not truly reflect the dynamics of the underlying economy.

In an attempt to avoid these potential drawbacks, this thesis utilises an Indirect Inference (II) approach to evaluation and estimation by use of un-filtered non-stationary UK data for the period 1995Q1 to 2016Q4. II is an adapted simulation-based procedure for both testing and evaluating DSGE models. The method utilises the VAR coefficients of a given structural model as the auxiliary model, simulations of which are then compared to actual observed data. II estimation differs from that of II testing in that the former involves selecting parameters via an algorithm in such a way that minimises the differences between the auxiliary models' estimates and that of the actual observed data. On the other hand, II testing takes the initial parameters of the structural model as given and then proceeds to test these values.

The rest of the chapter is structured as follows: Section 2 compares the II method to other established methods of estimation. Section 3 goes on to describe how the II test procedure is performed. Section 4 draws on the advantages of using non-stationary data. Section 5 gives an analytical description of the auxiliary model. Section 6 Discusses the results of the II test. Section 7 introduces the II estimation procedures. Section 8 reports the results of the estimation. In section 9 I assess the performance of the model through the generated impulse response functions. In section 10 I analyse the variance decomposition. In section 11 the chapter concludes.

## 5.2 The choice of Indirect Inference

DSGE models were largely developed as a response to some of the disadvantages of earlier macroeconomic models. One of the shortcomings of these earlier formulations was that many of these models were not structural and so were subject to the 'Lucas Critique' (Lucas 1976). They were also criticised for incorporating "incredible" identifying restrictions (Sims 1980) and for over-fitting the data, a result of data-mining. Conversely, the technical advantages of DSGE models lay in the logical coherence of their theoretical structure and the ability to select parameter values through calibration rather than conventional econometric estimation. However, despite their theoretical advantages the strong simplifying restrictions on the structure of DSGE models resulted in a severe deterioration of fit.

One reaction that has rose in popularity is to replace calibration with Bayesian estimation, and to specify a more flexible lag structure determined more by the data. However, one restriction in Bayesian estimation is that it does not judge given models in a classical hypothesis testing sense, the method first treats all models as false and then evaluates the probability of a given model being correct - without precise criteria between right and wrong. Such misspecification in one part of the model can affect the estimation of the parameters in other sections of the model. Another issue relates to the *a priori* selection of certain parameters through calibration, Bayesian methods permit partial flexibility in the prior theory and beliefs on model parameters, therefore providing scope for the data to have an effect on the final estimations. The calibrated priors used in Bayesian estimations can be derived from related studies or from estimates of micro-data. In many cases the choice of prior is difficult to justify, often reflecting the prior of the researcher more than the likelihood function. When priors are based on related studies, this often draws on a wide variability of estimates, whilst micro-estimates suffer accuracy when aggregated. There is therefore a risk of skewing the results with the incorrect choice of prior. In fact, a recent working paper by Meenagh et al. (2021) utilised Monte Carlo experiments to test whether Bayesian estimation could create a potential estimation bias as compared with maximum likelihood or indirect estimation. Here, the authors tested a true version of a New Keynesian model with either high wage and price rigidity or flexibility. The authors treat each in turn as the true model and create Bayesian estimates of it under priors from the true model and its false alternative. The result of the analysis points that Bayesian estimation of macro models may give very misleading results by placing too much weight on prior information compared to observed data. This result occurs when we have controversial or uncertain parameter values and in such a case, imposing a Bayesian prior skews the posterior estimate towards the particular viewpoint of the author. In this thesis, the parameters of regulation are regarded as controversial, in part due to the recent adoption of macroprudential policy. As a result, the importance of utilising an unbiased estimator with a powerful test, becomes more apparent. Nonetheless, the concern remains that there would be no need to use Bayesian estimation if the model was correct, as classical estimation would yield similar parameter values, hence some researchers have opted for maximum likelihood (ML) and generalised method of moments (GMM) in order to estimate DSGE models. To identify the parameters of the DSGE models, these estimators mainly rely on the same sample as well as theoretical information on the first moments. It is then possible that the assumption of a true model may carry forward with it a misspecification problem on the DSGE model at hand, and as a result we cannot guarantee that any of the parameters of the DSGE model can be properly identified. It is also true that such classical estimation methods often utilise the Likelihood Ratio (LR) test, which often rejects DSGE models that have been calibrated to the economy.

The approach taken in this thesis follows that set by Friedman (1953) in which a models' explanatory power is based on its ability to explain the information it was designed to account for by measuring the probability that the data it aims to describe could be generated by the model. The frequency of rejection of such models appears to stem from the basis that classical econometric evaluation methods do not fully incorporate this proposition. A methodology that may evade some of the issues and resulting identification and mis-specification problems is II. The concept is an approach that has been thoroughly investigated within the classical literature and has been applied in various areas of economics, with most methods differing in the way that observed and simulated data are compared via the auxiliary model. Initially, the idea was put forward in Smith (1990) and then later extended in other works such as in Gourieroux, Monfort and Renault (1993), Smith (1993), Gallant and Tauchen (1996) and Canova (2007) to name a few. Despite this it has received substantially less attention throughout the Bayesian paradigm and has not yet been widely implemented into standard econometric software packages - the latter a result of the constraint that most modern software packages incorporate a highly adaptable computing language. Smith (1993) and Gourieroux, Monfort, and Renault (1993) noted that II yields an estimator and specification tests whose asymptotic properties are standard even though the true likelihood of the DSGE model is not known.

The fundamental process of II utilised here follows Meenagh et al. (2009) and was further developed in Le et al. (2011) by utilising Monte Carlo simulations. The authors compared the power of the II test with that derived from the likelihood and found the power of II to be much higher, especially in small samples. Meenagh et al. (2019) on the other hand show that the Likelihood Ratio test based on observed data is asymptotically equivalent to using the II Wald Test, which is based on simulated data.

The II methodology used in this thesis takes a novel approach and obtains the advantage of representing the real data of the macroeconomy in a theory free manner as an unrestricted VAR, whilst the DSGE model - which has a natural representation as a restricted VAR - serves as the auxiliary model and also has the advantage of being independent of its theoretical design. The auxiliary model then acts as the basis for evaluating the 'closeness of fit' by comparing the differences between the auxiliary model and the observed data through some metric, here the Wald Test. With regards to estimation, there is an extra step of employing an algorithm to select parameters of the auxiliary model that result in the best fit between the observed data and the auxiliary model. Details of the II test and estimation procedures will be introduced in the following sections.

## 5.3 The Indirect Inference Method

As mentioned above, in the context of DSGE testing and evaluation the basic idea underlying II is to first describe the behaviour of the data by some atheoretical time-series model such as a VAR, which is the auxiliary model. Then the parameters of the structural model are chosen so that this model, when simulated, generates estimates of the auxiliary model as close as possible to those obtained from actual data. The Wald statistic is then used as the criterion to evaluate the distance between the actual and simulated data. If the model passes the Wald test, it indicates that the behaviour of the simulated data is close to the actual data and the model is a good representation on the economy and its behaviour. If however, the model fails to pass the test then I will use II estimation to search for an optimal set of coefficients that can minimise the difference between generated data and actual data. In this case, the Simulated Annealing algorithm will be implemented to repeatedly test and subsequently discover a set of parameters that minimise the distance between the auxiliary model and the observed data. In the following sections, we will detail the steps involved in the II test and how the auxiliary model is chosen.

### 5.3.1 The Indirect Inference Test Procedure

The steps below outline the framework involved in implementing the Wald test by bootstrapping:

***Step 1:*** Calculate the shock processes of the economic model conditional on the data and parameters.
***Step 2:*** Generate the simulated data by bootstrapping the innovations.
***Step 3:*** Compute the Wald statistic.

#### *Step 1*: Calculating the shock process

The first step is to back out the structural errors from the observed data and parameters of the model. We count the amount of independent structural errors as less than or equal to the number of endogenous variables. These structural errors can therefore be calculated as the difference between the LHS value (actual data) and the RHS value. For models without expectation variables the errors are calculated by taking the RHS from the LHS. For models that exhibit expectations variables we need to estimate a VAR of all the expected variables and use this to calculate the expectations following the robust instrumental variable methods of McCallum (1976) and Wickens (1982). Specifically, the VAR process will be utilised to estimate and generate fitted values one period ahead of expectations, the residuals are then calculated by

LHS-RHS. We compute the corresponding coefficients and innovation of the shock process by OLS regression on the generated residuals series.

***Step 2*: Generate the simulated data by bootstrapping**

Once the simulated disturbances are drawn from the structural errors the simulated data is then generated by a bootstrapping procedure that involves randomly drawing from the set of i.i.d innovations with replacement and solving via a project method.[17] This random selection and replacement process preserves any simultaneity between each disturbance.[18] Once the model has been solved the process is repeated $N$ times,[19] drawing each sample independently. The specific process is detailed as follows:

***Step 2.1:*** In the first step, an initial vector of shocks is drawn and inserted into the models' 'base run', the model is then solved via the projection method with the solution becoming the lagged variable vector for the next period $t = 2$.

***Step 2.2*:** After replacement of the initial set of innovations, the second vector of shocks is then drawn and becomes the solution for the first period $t = 1$. The model is then solved for period $t = 2$ and this in turn becomes the lagged variable vector for the next period $t = 3$.

***Step 2.n*:** After replacement of the $n^{th}$ set of initial innovations, the $n^{th}$ vector of shocks is drawn and becomes the solution for the time period $t - 1$. The model is then solved for $t$ and becomes the lagged variable vector for $t + 1$.

The process is then repeated for the full sample size $N$. And the deviations between the data in the simulation and in the original data-set are estimated in order to obtain the effects of these bootstrapped innovations. In the final step the procedure involves adding back the effects of

[17] The method described here follows Minford et al. (1984, 1986) and is similar to that of Fair and Taylor (1983).
[18] This process assumes that the structural errors are generated by an autoregressive process rather than being serially independent. If the structural errors are correlated with prior values then they need to be estimated.
[19] In this model $N = 1000$

the deterministic trends on the effects of the shocks and estimating the auxiliary model on all pseudo-samples. The full sample size of simulated data and the actual data must be consistent.

***Step 3:*** **Compute the Wald Statistic**

We select the Wald statistic as our criterion for evaluating the models' performance under the null hypothesis that the true economic model is the structural model. In order to achieve this we utilise the OLS method to compute the parameter vector of the auxiliary model for both the actual and simulated data in order to obtain their distribution, from this we can then obtain the corresponding estimated coefficients $\hat{\theta}$ and $\theta_s(\beta)$. The Wald statistic is then defined as:

$$W = (\hat{\theta} - \bar{\theta}(\beta))'\Omega(\beta)^{-1}(\hat{\theta} - \bar{\theta}(\beta)) \tag{5.1}$$

Where $\Omega(\beta)$ is the variance covariance matrix of $\left(\theta_s(\beta) - \bar{\theta}(\beta)\right)$ and $\bar{\theta}(\beta)$ is the average value between the estimates coefficients $\hat{\theta}$ and $\theta_s(\beta)$ calculated as:

$$\bar{\theta}(\beta) = \frac{1}{1000}\sum_{S=1}^{1000} \theta_s(\beta) \tag{5.2}$$

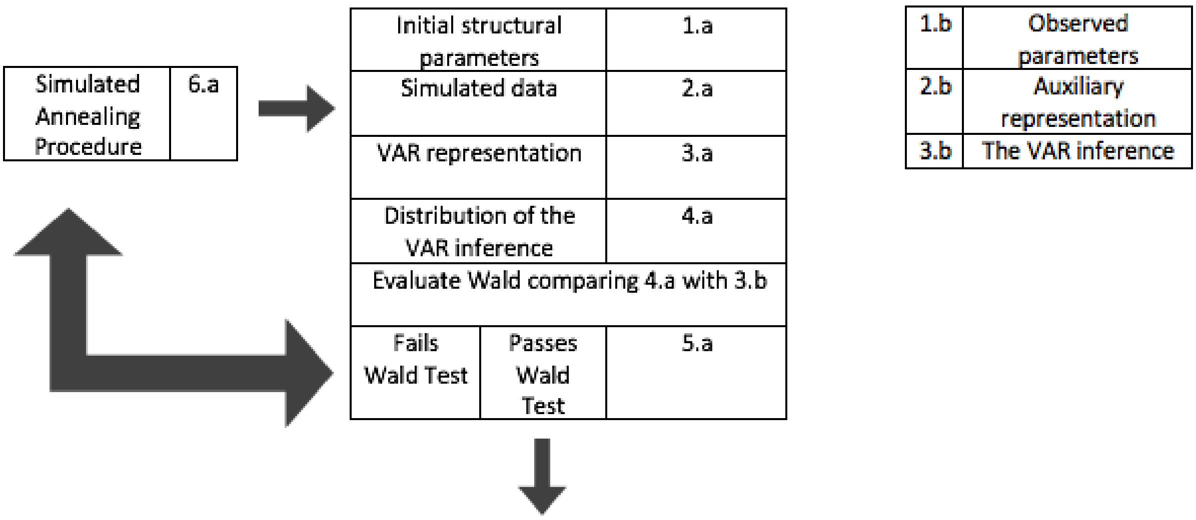
Equation (5.1) then measures the distance between the estimated parameters and the average of the simulated parameters. If the model fits the actual data at the 95% confidence level, the Wald statistic from the actual data should be within the 95th percentile of the Wald statistic from the simulated data, this can be evaluated through a regular P-value[20] or a transformed normalised t-statistic[21]. The full process of testing and estimating the structural parameters of

[20] P-value = (100 – Wald percentile)/100

[21] The transformed Mahalanobis distance can be computed as:

the DSGE model are displayed in figure 5.1, the process from 1-5 represents the testing procedure.

Figure 5.1: Estimating and Testing Structural Parameters




---

$$T = \left(\frac{\sqrt{2WS^{a}}-\sqrt{2k-1}}{\sqrt{2WS_i^{95th}}-\sqrt{2k-1}}\right)1.645$$

Where $WS^{a}$is the Wald statistic on the actual data and $WS_i^{95th}$is the Wald statistic for the 95% of the simulated data. If the transformed Mahalanobis distance is less than 1.645, the null hypothesis has not been rejected by the data.

## 5.4 Handling Non-Stationary Data

Data used and generated by DSGE models are often non-stationary with at least part of their movement each quarter being random, this is largely the cause for uncertainty surrounding forecasting and modelling the economy's long-term future. Since Whittaker (1922), methods of data filtering or data smoothing have been designed in an attempt to remove the potential effect of such measurement error and reveal the underlying trend in the data. However, it is well known that using filtered data may distort the dynamic properties of the model in undesirable ways. In fact, many statistical filters such as the popular Hodrick-Prescott Filter (HP), can be represented as a symmetric two-sided moving average of the raw data. This alters the lag dynamic structure, generating cycles where possibly none exist. As noted in Meenagh et al. (2012), this could have serious implications in the estimation process of a DSGE model, where both the expectations structure and the impulse response functions are usually matters of considerable interest. In a study by Cogly and Nason (1995), the authors show that the HP filter when applied to difference stationary series, is likely to generate a spurious cyclical structure at business cycle frequencies. Another common tool employed throughout the DSGE literature is the Band Pass filter (BP), Canova (2014) however points that such filtering mechanisms only roughly capture the power of the spectrum at certain frequencies in small samples while taking growth rates greatly amplifies the high frequency content of the data, such side effects may result in containment errors that taint final estimates. Alternatively, one could map the data to be stationary by detrending the time series data. However, this process involves the use of linear detrending or first differencing. Canova (1998) shows that transforming data in this manner prior to estimation, does not maintain the inherent fluctuations with the same periodicity. In-fact, first differencing often magnifies the high frequency noise component in data. Andrle (2008) also concluded that detrending data could not explain the movements of data, particularly when the permanent shock has a significant impact on the business cycle.

In addition to this, the data generated by DSGE models can also be non-stationary. The reasons for the presence of non-stationarity vary, this could be because the model structure causes non-stationarity, for example by making state variables functions of predetermined variables that depend on accumulated shocks or because shocks are permanent as is commonly assumed in DSGE models for productivity (real) and money supply shocks (nominal), as is the case in in this model.

Given the ambiguity of processing non-stationary data, the case for the potential preserving effects of using unfiltered non-stationary data becomes stronger. I follow the methods developed by Le et al (2011) and later extended in Meenagh et al (2012) in which we bypass the issue of non-stationarity by use of a VARX as an auxiliary model.

As mentioned earlier, the state-space representation of a log-linearised DSGE model can be represented as a (VARMA) with some restrictions (Wickens, 2014). It can then be approximated by a finite order reduced form (VAR) model. A levels VAR can be used if the shocks are stationary, but a VECM may be needed if the data generated by the model is non-stationary. For example, if productivity shocks are permanent, then the production function is not cointegrated and as a result the associated VAR representation in levels would have non-stationary disturbances. Meenagh et al (2012) show that a VECM can be used as an auxiliary model if the shocks or exogenous processes are non-stationary.

For example, if there are unobservable non-stationary variables, such as a money supply shock, then the number of cointegrating vectors will be less than the number of endogenous variables. As we have estimates of all of the coefficients of the model, we can therefore construct residuals from the data. Treating these residuals as observable variables, we would then have as many cointegrating relations as endogenous variables. This would allow us to represent the solution of the estimated model as a VECM in which the non- stationary residuals appear as observable variables, we can then use an unrestricted version of this VECM as our auxiliary model.

Following the developments of Meenagh et al. (2012) and Le et al. (2015a), I demonstrate that the chosen auxiliary model is an approximation of the reduced form of the DSGE model when under the null hypothesis of cointegration[22] and can be represented as a cointegrated VARX. After log linearisation the DSGE model can be presented in the form:

$$A(L)y_t = BE_t y_{t+1} + C(L)x_t + D(L)e_t \tag{5.3}$$

where $y_t$ is a $p \times 1$ vector of endogenous variables, $E_t y_{t+1}$ is a $r \times 1$ vector of expected future endogenous variables, $x_t$ is a $q \times 1$ vector of exogenous non-stationary variables which follow a unit root process and are assumed to be driven by:

$$\Delta x_t = a(L)\Delta x_{t-1} + d + b(L)z_{t-1} + c(L)\epsilon_t \tag{5.4}$$

Where elements of $x_t$ may have a systematic dependency on the lag of $z_t$, an exogenous stationary variable. Both $e_t$ and $\epsilon_t$ i.i.d are zero mean error vectors. All polynomials in the lag operator have roots outside the unit circle.

[22] The constraint of the null ensures that the VECM achieves cointegration under the null and the residual assumption guarantees that the DSGE model achieves cointegration.

Since $y_t$ is linearly dependent on the non-stationary vector $x_t$, then it is also non-stationary with the general solution to this system of the form:

$$y_t = G(L)y_{t-1} + H(L)x_t + f + M(L)e_t + N(L)\epsilon_t \tag{5.5}$$

Here $f$ is a vector of constants. Under the null hypothesis of the model, the equilibrium solution for the endogenous variables is the set of cointegrating relationships where $\Pi$ is $p \times p$[23]

$$y_t = [I - G(1)]^{-1}[H(1)x_t + f] = \Pi x_t + g \tag{5.6}$$

In the short run $y_t$ is also a function of deviations from this equilibrium; $y_t - [\Pi x_t + g] = \eta_t$, where $\eta_t$ is the error correction term. In the long run, the level of endogenous variables is a function of the level of unit root variables, which are in turn functions of all the past shocks. In the long run the solution to the model is:

$$\bar{y}_t = \Pi \bar{x}_t + g \tag{5.7}$$

$$\bar{x}_t = [1 - a(1)]^{-1}[dt + c(1)\xi] \tag{5.8}$$

$$\xi_t = \sum_{s=0}^{t-1} \epsilon_{t-s} \tag{5.9}$$

[23] The matrix $\Pi$ is found when we solve for the terminal conditions on the model, which constrain the expectations to be consistent with the structural model's long run equilibrium.

The long-run behaviour of $\bar{x}_t$ can be decomposed into two segments:

$$\bar{x}_t = \bar{x}_t^D \bar{x}_t^S \tag{5.10}$$

Where the deterministic trend component $\bar{x}_t^D = [1 - a(1)]^{-1} dt$ and the stochastic portion $\bar{x}_t^S = [1 - a(1)]^{-1} c(1) \xi_t$, with the long run behaviour of the endogenous variables dependent on both parts. Hence the endogenous variables consist of this trend and deviations from it, we can therefore write the solution as this trend plus a VARMA in deviations from it. An alternative formulation is as a cointegrated VECM with a mixed moving average error term as $\omega_t$.

$$\begin{aligned} \Delta y_t &= -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1} + Q(L)\Delta x_t + f + M(L)e_t + N(L)\epsilon_t \\ &= -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1} + Q(L)\Delta x_t + f + \omega_t \end{aligned} \tag{5.11}$$

$$\omega_t = M(L)e_t + N(L)\epsilon_t \tag{5.12}$$

Which can be approximated as:

$$\Delta y_t = -K(y_{t-1} - \Pi x_{t-1}) + R(L)\Delta y_{t-1} + S(L)\Delta x_t + h + \zeta_t \tag{5.13}$$

Where $\zeta_t$ is i.i.d with zero mean. Since $\bar{x}_t = \bar{x}_{t-1} + [1 - a(1)]^{-1}[d + \epsilon_t]$ and $\bar{y}_t - \Pi \bar{x}_{t-1} - g = 0$ the VECM can be written as:

$$\begin{aligned} \Delta y_t = -K[(y_{t-1} - \bar{y}_{t-1}) - \Pi(x_{t-1} - \bar{x}_{t-1})] + R(L)\Delta y_{t-1} + S(L)\Delta x_t \\ + m + \zeta_t \end{aligned} \tag{5.14}$$

According to Le et al. (2015), either (5.13) or (5.14) can be the choice of auxiliary model. Re-writing equation (5.13) as a levels VARX(1) we get:

$$y_t = [I - K]y_{t-1} + K\Pi x_{t-1} + n + \phi t + \sigma_t \tag{5.15}$$

The error $\sigma_t$ now contains the suppressed lagged difference regressors with the time trend included to pick up the deterministic trend in $\bar{x}_t$ which will affect the endogenous and exogenous variables. $x_{t-1}$ contains unit root variables which are necessary to control for the impact of past shocks on the long run path of $x$ and $y$. This VARX(1) approximation to the reduced form of the model underpins the unrestricted auxiliary model utilised throughout the II testing and evaluation in this thesis. It has the advantage that the estimation of the parameters of the VARX can be carried out by classical OLS methods. Meenagh et al. (2012) prove that this procedure is extremely accurate using Monte Carlo experiments.

## 5.5 The Choice of Auxiliary Model

The II test criterion is determined by the difference between the empirical auxiliary Wald statistic from the observed data and the simulated auxiliary Wald statistic from the simulated data as shown in equation (5.1).

Those parameters ($\theta$) of an auxiliary model may be not an accurate description of the data-generating process, but they can be estimated easily by conventional estimation methods. Therefore, there is no simple rule to identify the best auxiliary model.

A natural choice of auxiliary model is an unrestricted VAR, because a VAR is the reduced form of a DSGE model, however Minford et al. (2016) test if there are more powerful choices for the auxiliary model or 'data descriptors' and compare the power against auxiliary models derived from Impulse Response Functions and the Simulated Moments Method. Evaluating the power of these different methods in small samples using Monte Carlo simulations, they find that in a small macro model there is no difference in power, however in large complex macro models the power with Moments rises more slowly with increasing misspecification relative to the other two which remain similar.

The greater the power the less the range of uncertainty about how wrong their models could be. These findings suggest that VAR coefficients and average IRFs are more or less interchangeable for this purpose; but that Moments give less power in testing large complex macroeconomic models.

When VAR coefficients are used as the data descriptors, the estimated parameters are used to describe the dynamic property of the data whilst the variance of the errors are used to capture data volatility. With IRFs served as the data descriptions, the IRF can be transferred as a nonlinear combination of VAR coefficients and the error covariance matrix[24]

Le et al (2016) also show that the DSGE models we are examining may be over-identified, therefore the addition of more VAR coefficients by raising the order of the VAR can increase the power of the test. Analogously, adding more elements to the IRF descriptors or to the moment descriptors should do the same. However, Le et al (2016) also points that increasing the power in this way also reduced the probability of finding a tractable model that would pass the test, an inherent trade-off between power and tractability.

Additionally, empirical results in Le et al. (2011, 2015, 2016) show that when including a broader set of endogenous variables in the auxiliary model, it usually results in a strong rejection. Le et al. (2015) points out that the power of the full Wald test increases as more

[24] Minford et al. (2016) show that the error from a VAR model can be specified as a: $e_{\mathrm{t}} = Bv_t$, where $v_t$ are the structural innovations and $B$ denotes the error covariance matrix.

endogenous variables are added. This is also true when the lag order is raised, and can lead to uniform rejections. Meenagh et al (2012) also argues that such attempts usually lead to rejection when the model in question appears to share with too many elaborate structures.[25] Based on the above information, I employ a VARX(1) as the auxiliary model for model simulation and estimation and choose output, inflation and the interest rate as the key macroeconomic variables from which to base the Wald test.[26] Since these three variables can represent a general inner relationship of the model as well as describe the economy in full. A VARX(1) with three endogenous variables is described as:

$$\begin{pmatrix} y_t \\ \pi_t \\ r_t \end{pmatrix} = \mathrm{B}\begin{pmatrix} y_{t-1} \\ \pi_{t-1} \\ r_{t-1} \end{pmatrix} + C\begin{pmatrix} T \\ e^{YT} \\ b_{t-1}^{f} \end{pmatrix} + \begin{pmatrix} e_{yt} \\ e_{rt} \\ e_{\pi_t} \end{pmatrix} \tag{5.16}$$

Where $B = \begin{pmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{22} & \beta_{33} \end{pmatrix}$

Where $e^{YT}$ is the lagged productivity trend as measured by the Solow residual, $b_{t-1}^{f}$ is the lagged level of net foreign assets, $C$ captures the effect of exogenous variables that are considered as the driving factors of non-stationarity. $T$ denotes the time trend. The parameter vector $\theta$ used for calculating the Wald statistics would contain the OLS estimates in the matrix $B$ and the variance of three fitted errors as:

$$\theta = [\beta_{11}\beta_{12}\beta_{13}\beta_{21}\beta_{22}\beta_{23}\beta_{31}\beta_{32}\beta_{33}, \mathrm{var}\,(e_{yt}), \mathrm{var}\,(e_{rt}), \mathrm{var}\,(e_{qt})]' \tag{5.17}$$

---

[25] They point to models such as SW and CEE which have many nominal rigidities in goods and labour markets and real rigidities such as habit formation in consumption, investment adjustment costs, and variable capital utilisation.

[26] The target of the test is to evaluate whether the simulated data of the structural model can mimic key data from the UK economy, we include the policy rate though the policy rate has been close to the ZLB bound since 2009.

We then analyse whether the model can replicate the joint behaviour of the three chosen endogenous variables. If the model can match the joint distribution of at least twelve parameters[27] the model passes the test. Note, if we were to choose four key variables instead, then we would have to match at least twenty parameters in $\theta$. Therefore, the addition of one extra variable would dramatically increase the testing power, in such cases the model is usually rejected.

## 5.6 Indirect Inference Test Results

Before we conduct the indirect inference estimation, we perform the indirect inference test with a set of calibrated parameters, we then begin the testing process discussed above under the hypothesis that the calibrated model replicates the actual data. Table 5.1 reports the Wald statistic and normalised Transformed Mahalanobis Distance (TMD) of the II test results. In this test we utilise an empirical estimate of the asymptotic distribution of the Wald statistic which has been obtained by the bootstrap method explained previously. It signifies that the estimated Wald statistic does not follow a Chi-squared distribution, therefore a reported Wald statistic of less than 90 does not necessarily mean that the model has passed the test, we simply use the TMD t-statistic as a reference for our assessments.

Table 5.1 shows the TMD value for the auxiliary model based on calibrated parameters to be 2.49, which is higher than the critical value of 1.65. This indicates that the model cannot explain the data behaviour with the initial calibrated parameters. Since we cannot be certain if the problem is from the model or the calibrated parameters, we proceed to search for the optimal set of parameters that can minimise the Wald statistic through II estimation. It should be noted that the discount factor $\beta$, the depreciation rate $\delta$, the preference bias in domestic and foreign

[27] Here the vector $\theta$ does not include the parameter matrix C. It turns out to be 21 parameters if C included.

consumption $\omega = \omega^f$ and the entrepreneurs' survival rate $\theta$ will remain as fixed parameters of the model throughout testing and estimation.

Table 5.1: Wald Test Results Based on Calibration

| Variable included | Trans Value | Wald Value |
|---|---|---|
| r, inflation,y | 2.49 | 56.29 |

## 5.7 Indirect Inference Estimation Procedure

Our results from the Wald test indicate that our calibrated model does not match the actual data dynamics of the real economy. At this point we cannot decipher if this is a result of the chosen calibrated parameters or the structure of the model. In this section, we use the II estimation method to discover the set of parameters that will minimise the distance between the simulated data and observed data. To begin with, we assume that the model structure is accurate and proceed to test by use of the Wald statistic, repeating this process with different sets of parameters until we discover the set that will minimise the distance between our auxiliary model and simulated data. Here we utilise the Simulated Annealing method (SA) in order to search for the optimal parameters.

Based on the objective of minimising the energy output involved in heating a material and lowering the temperature to decrease defects, the SA method is a metaheuristic procedure that approximates the global maximum or minimum within a large search space and is appropriate in optimisation problems in which an approximate maximum or minimum is sufficient.[28] When the SA algorithm is employed, an initial set of parameter vector is selected and the Wald at that point is assessed.

[28] The estimation is mainly based on Matlab code file: 'run_wald'. This file can be provided upon request.

In this thesis the SA algorithm works by randomly generating a new set of parameter values at each iteration and evaluating the Wald statistic by processing steps 1-3 of section 5.2.1. The possible range of values that this new set of parameters can take are based on a probability distribution, and as in this thesis - they are bounded to be within 30% of the initial calibrated parameters. Before moving to a new set of parameter values, the algorithm analyses all neighbouring states for parameter values that lower the distance between the simulated data and the auxiliary model, and importantly - with a certain probability - values that raise the distance. The reason for this is so that the algorithm avoids being trapped in a local minimum and is able to explore globally, for more possible solutions. Then an *annealing schedule* is selected to systematically decrease the acceptable Wald threshold as the algorithm proceeds. As the Wald statistic decreases, the algorithm reduces the extent of its search to converge to a minimum or to the extent that a set computational budget has been achieved, here 1000 iterations.

The objective of carrying out II evaluation and estimation here has been to test the model unconditionally against the data and to find a certain set of structural parameters that ensure the model is a close fit. As discussed in Le et al (2012), Bayesian ML and other conventional interval estimations are comparatively consistent and asymptotically normal in estimation - however, with II the testing power is much stronger in small samples as shown through Monte Carlo experiments. Therefore, II has the comparative benefit of yielding reliable results in small samples, if we use the II to estimate the model and to test its specification. The full process of testing and estimating the structural parameters of the DSGE model are displayed in figure 5.1, the cycle through from points 1-6 represents the full estimation procedure.

## 5.8 Indirect Inference Estimation Results

Applying the Indirect Inference method of estimation for the chosen parameters in the model, the best fitting coefficients were selected according to the SA algorithm. Table 5.2 summarises the results, column 3 provides the initial calibrated parameters whilst column 4 reports the set of parameters derived through the II estimation procedure. As mentioned before, the discount factor $\beta$, the depreciation rate $\delta$, the preference bias in domestic and foreign consumption $\omega = \omega^f$ and the entrepreneurs' survival rate $\theta$ are fixed parameters and do not change after to estimation.

Within the household sector, we can see that the intertemporal elasticity of consumption $\sigma_c$ has marginally decreased by 2.87%, this indicates that consumption is relatively insensitive to changes in the real interest rate when compared to the initial calibrated parameter value. On the other hand, the elasticity of labour supply $\sigma_l$ has significantly increased by 28%, this signifies that the supply of labour in the UK is significantly more elastic, implying that workers are more willing to supply labour for a given wage rate increase. The external habit formation $h$ has increased by 10%, this shows that increases in current consumption have a relatively larger effect on lowering the marginal utility of present consumption whilst increasing the marginal utility of next period consumption. With regards to the nominal rigidities of wage, the proportion of sticky wages $w^w$ has reduced to 0.33 while the parameter that denotes the degree of wage stickiness $\xi_w$ and wage indexation $l_w$ are estimated to be 0.91 and 0.74 respectively, a roughly 30% increase for both parameters from their calibrated values. This indicates that wages adjust to inflation at a more responsive rate whilst wages tend to be less responsive to changes in labour market conditions.

On the firm side, the proportion of sticky prices $w^p$ has increased to 0.24. The degree of price stickiness $\xi_p$ has increased by 20.8% whilst the degree of price indexation $l_p$ has reduced by

32%, this indicates that firm prices adjust more responsively over time whilst prices adjust slower in response to inflation when both are compared to their initial calibrated values. Both the elasticities of capital adjustment $\varphi$ and capital utilisation $\psi$ have increased to 6.45 and 0.18 respectively. The share of capital in production $a$ has however - decreased by 43%, signifying that capital accounts for less in the production of total output. The share of fixed costs in production $\phi$ has had a smaller increase of 14%.

With regards to monetary policy, the Taylor Rules' response to inflation $r_p$, output $r_y$ and change in output $r_{\delta y}$ have all increased, indicating that interest rates are estimated to be more responsive to deviations in these macroeconomic variables. On the other hand, the level of interest rate smoothing has decreased in value to 0.66, a 10.8% change from its initial level. In terms of unconventional monetary policy, both the money response to credit growth $\psi_1$ and the money response to the premium $\psi_2$ have become less sensitive, 0.01 and 0.03 respectively. This indicates that the response of money is less sensitive to the credit premium and the level of credit growth in the estimated model.

With regards to the credit premium, the estimation results show that the elasticity of the premium with respect to leverage $\chi$ should be 33% more responsive, whilst the elasticity of the premium with respect to money $\psi_3$ should be 50% less sensitive, this signifies that the premium should be more responsive to the amount of borrowing that entrepreneurs undertake and half as responsive to the money supply in the estimated model.

The regulation variables can be interpreted as changes in the respective regulative indices, whilst the estimated coefficients of regulation can be interpreted as representing the magnitude of the impacts of regulation on this model. So that if these regulative coefficients are estimated to be higher, this would mean that when regulation is increased within our indices - as was the case following the financial crisis of 2008, then the magnitude of the impacts of these regulatory increases on our model will be larger than if the coefficients were estimated relatively lower - and vice versa. Within the model, this would manifest itself by increasing the credit premium, pushing up the rate charged on loans from the bank or lowering the expected return. Similarly, households will require larger deposits or face higher mortgage rates, through the effect on the Euler equation. Table 5.2 shows that the regulative coefficients for corporate regulation $\kappa$ and mortgage regulation $\Gamma$ both take lower estimated coefficients, a 21% and 47% reduction in comparison to their initial values. This indicates that in our estimated model, regulation appearing in the premium equation will be less impactful in altering the credit premium, whilst mortgage regulation will have less of an effect in influencing consumer behaviour through the consumption Euler equation of the estimated model.

Table 5.2: Calibrated and Estimated Coefficients

| **Description** | **Symbols** | **Calibration/Previous** | **Current Estimation** |
|---|---|---|---|
| Households | | | |
| Discount factor | $\beta$ | 0.99 | 0.99 |
| Elasticity of consumption | $\sigma_c$ | 1.39 | 1.43 |
| Elasticity of labour supply | $\sigma_l$ | 2.83 | 3.65 |
| External habit formation | $h$ | 0.7 | 0.77 |
| Degree of wage stickiness | $\xi_w$ | 0.7 | 0.91 |
| Degree of Wage indexation | $l_w$ | 0.58 | 0.74 |
| Proportion of sticky wages | $w^w$ | 0.4 | 0.33 |
| Preference bias in consumption | $\omega$ | 0.7 | 0.7 |
| Firms | | | |
| Degree of price stickiness | $\xi_p$ | 0.67 | 0.81 |
| Degree of price indexation | $l_p$ | 0.43 | 0.29 |
| Proportion of sticky prices | $w^p$ | 0.1 | 0.24 |
| Entrepreneur survival rate | $\theta$ | 0.99 | 0.99 |
| Share of capital in production function | $a$ | 0.3 | 0.17 |
| Capital depreciation rate | $\delta$ | 0.05 | 0.05 |
| Share of fixed costs in production function | $\phi$ | 1.50 | 1.71 |
| Elasticity of capital adjustment | $\varphi$ | 5.74 | 6.45 |
| Elasticity of capital utilisation | $\psi$ | 0.05 | 0.18 |
| Monetary Policy | | | |
| Taylor Rule response to inflation | $r_p$ | 2.3 | 2.72 |
| Interest rate smoothing | $\rho$ | 0.74 | 0.66 |
| Taylor Rule response to output | $r_y$ | 0.03 | 0.09 |
| Taylor Rule response to output change | $r_{\delta y}$ | 0.2 | 0.36 |
| Money response to credit growth | $\psi_1$ | 0.05 | 0.01 |
| Money response to premium | $\psi_2$ | 0.04 | 0.03 |
| Financial | | | |
| Elasticity of premium to leverage | $\chi$ | 0.04 | 0.06 |
| Elasticity of premium to money | $\psi_3$ | 0.08 | 0.04 |
| Regulatory | | | |
| Corporate regulatory | $\kappa$ | 1.00 | 0.79 |
| Mortgage regulatory | $\Gamma$ | 1.00 | 0.53 |
| | T-stats ($y$, $\pi$, $r$) | 3.27 | 1.17 |
| | Wald percentile | 100 | 87.3 p-value: 0.127 |

The II estimation process has the aim of searching for and selecting those sets of parameters that minimise the TMD statistic. As a final step in the estimation process, the model is re-tested based on the estimated parameters as described in figure 5.1. The results of testing on the estimated parameters are printed in table 5.3. Here we can see that the TMD value for the auxiliary model is 1.17 which is lower than the critical value of 3.27. Alternatively, it can be seen that the estimated model securely passes the test with a p-value of 12.7%. Both statistics therefore confirm that the estimated parameters based on the hybrid NK-NC model with regulation can replicate the UK data.

Table 5.3: Wald Test Results Based on Estimation

| Variable included | Trans Value | Wald Value |
|---|---|---|
| r, inflation, y | 1.17 | 3.27 |

## 5.9 Empirical Analysis of Model

This section details the dynamic behaviour of the model, first I evaluate the Impulse Response Functions of key macroeconomic, financial and regulatory variables to an array of separate shocks. Then, the variance decomposition is calculated in order to decipher which variables are most important in driving fluctuations in the UK economy. To achieve this, I display the contributions of each shock to the variance of the observed macroeconomic variables for the time period 2007Q1-2016Q4, which covers the period with and without the ZLB crisis.

### 5.9.1 Impulse Response Functions

Once the model has been solved and the base run has been calculated as described by the process in section 5.2.1, we can now examine the models' dynamics following a one-off rise in a number of variables of interest. This allows us to visualise the models transition to its steady-state which may be caused by either an initial position starting outside of the economy's steady-state, a shock or a structural change which alters the model economy's original steady-state. The setup of this analysis allows us to assess the possible outcomes of changes in policy, the dynamic evolution of consumer behaviour or certain macroeconomic, financial and regulatory variables. This process is carried out by introducing a change in one or more of the variables, then the evolution of each of the other variables[29] in the economy is compared to the original base solution of the model.  Here, Impulse Response Functions (IRFs) display the deviations of a particular variable of interest from the base or steady state following a demand or supply shock. In this thesis I examine the IRFs of the model economy to the innovations of selected macroeconomic, financial, regulatory, demand and supply variables. The shocks are represented on the y-axis where a 10% rise in a variable is denoted by 0.1 and time represented in quarters is shown on the x-axis. The solid line represents the model out of crisis times whilst the dashed line represents the economy during a crisis period when QE is employed.

### 5.9.2 Mortgage Regulation Shock

Figure 5.2 plots the dynamic responses to a shock in mortgage regulation. In this model, mortgage regulation is modelled around the policies and directives that attempt to moderate the potential systemic risks that may evolve from developments within the housing sector. This is implemented by placing certain restrictions on lending and purchasing practises that alter the way in which consumers, businesses and financial intermediaries behave.

First, we analyse the dynamic evolution of the impulse response functions following an increase in the mortgage regulation shock for the no-crisis period. Here, the economy is not bounded by the ZLB. Following the mortgage regulation shock, we observe an increase in the external premium and whilst the reduction in the interest rate partially offsets the reduction in

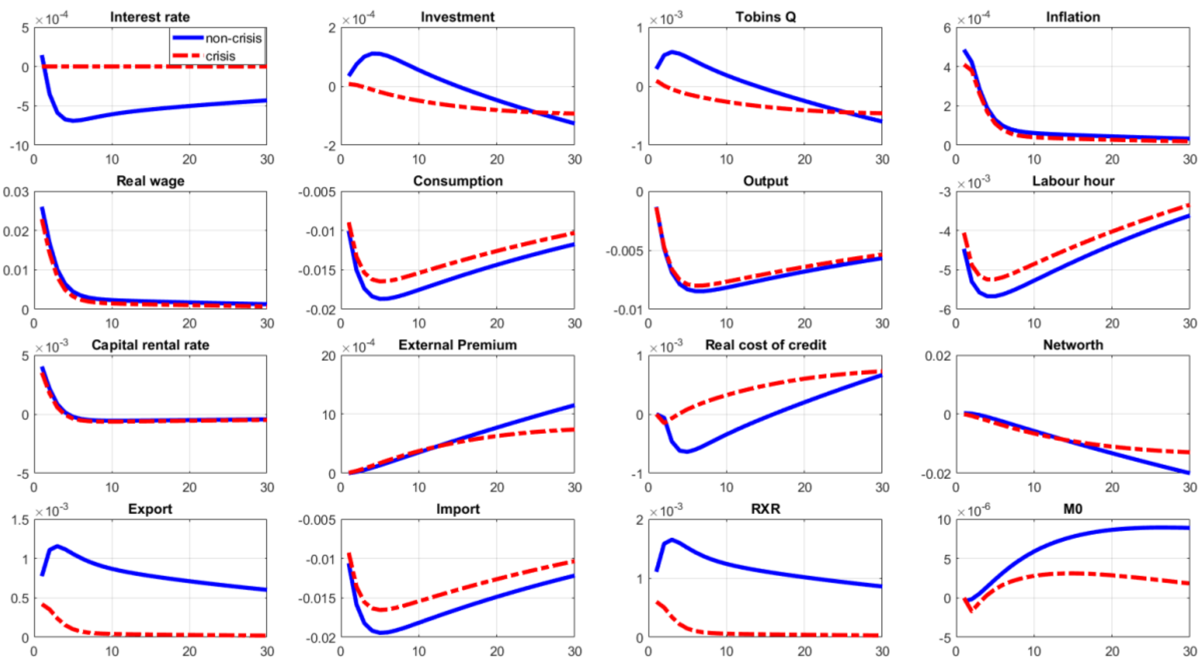
[29] This may also include initial variable changes.

investment, output remains lower. The real wage initially increases however the fall in labour hours and output result in lower consumption. Net worth is also partially offset by monetary policy.

With regards to the foreign sector, the initial increase and subsequent sharp reduction in interest rates assists a devaluation in GBP which allows domestic producers to become more competitive on the international market. This is exemplified by the increase in exports and the reduction in imports.

In the state in which there is a ZLB crisis and the Taylor Rule is suspended we witness a similar pattern for consumption, output, labour hours, the rental rate on capital, and the external premium. However, as the Taylor Rule becomes suspended the reduction in investment is not offset by interest rate. With regards to the foreign sector, net exports increase, though by substantially less than when the Taylor rule is active when comparing the two states in the long run.

Figure 5.2: Mortgage regulation shock



### 5.9.3 Corporate Regulation Shock

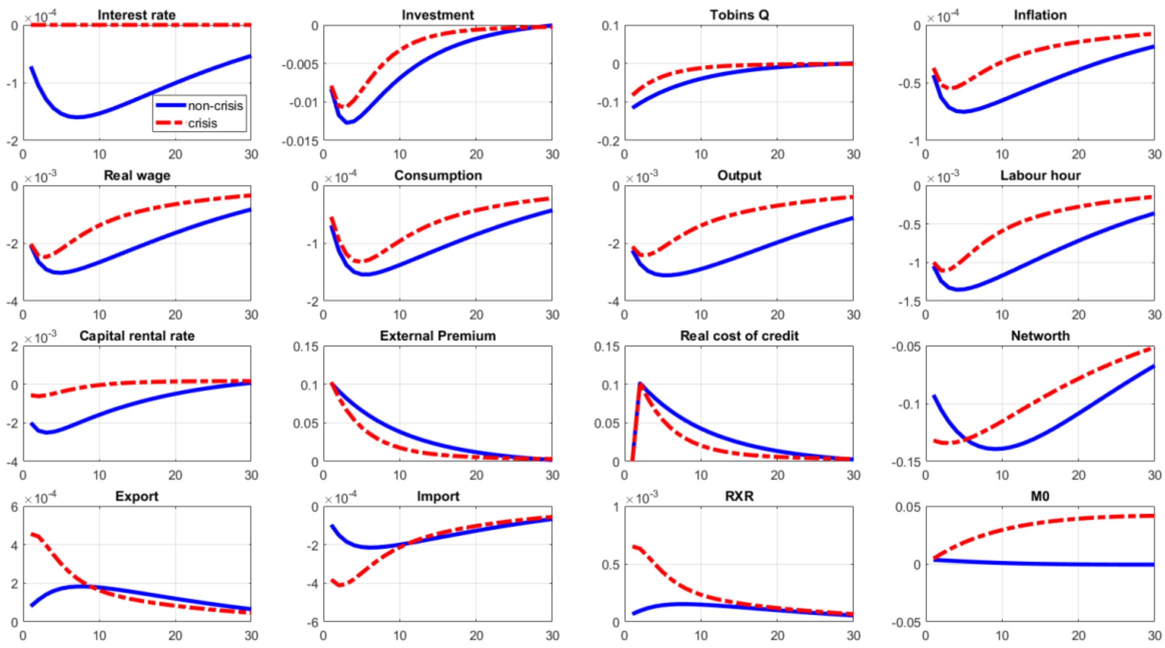
Figure 5.3 plots the dynamic responses to a shock in corporate regulation. In this thesis, corporate regulation is modelled around the rules that attempt to mitigate developments from within the wider financial sector. This is achieved by placing certain controls on corporate activity which in turn alter the way businesses and financial intermediaries operate.

Following a corporate regulation shock, we analyse the dynamic behaviour under the no-crisis state. Initially we observe a reduction in output and subsequently inflation, this puts downward pressure on the Taylor Rule's response. Simultaneously, investment and net worth are lowered as the loan conditions become more stringent and the post borrowing profit margins are reduced. As investment and output decline, so does the real wage and total labour work hours which causes a decline in consumption.

With regards to the foreign sector, the reduction in interest rates induces a devaluation of GBP, this allows the economy to become more competitive on the international stage as is observed by the increase in net exports.

When the economy is in a crisis state the Taylor Rule is suspended. From figure 5.3 we witness a similar response in comparison to the no-crisis state. Namely, there is a reduction in output, inflation, interest rates, investment, net worth, real wage, labour hours and consumption. Intuitively, M0 remains higher and the credit premium is increased. With regards to the foreign sector, we witness an even greater increase in net exports. This is is due to the absence of the Taylor Rule response hence there is less force causing an appreciation in GBP and a decrease in international competitiveness.

Figure 5.3: Corporate regulation shock

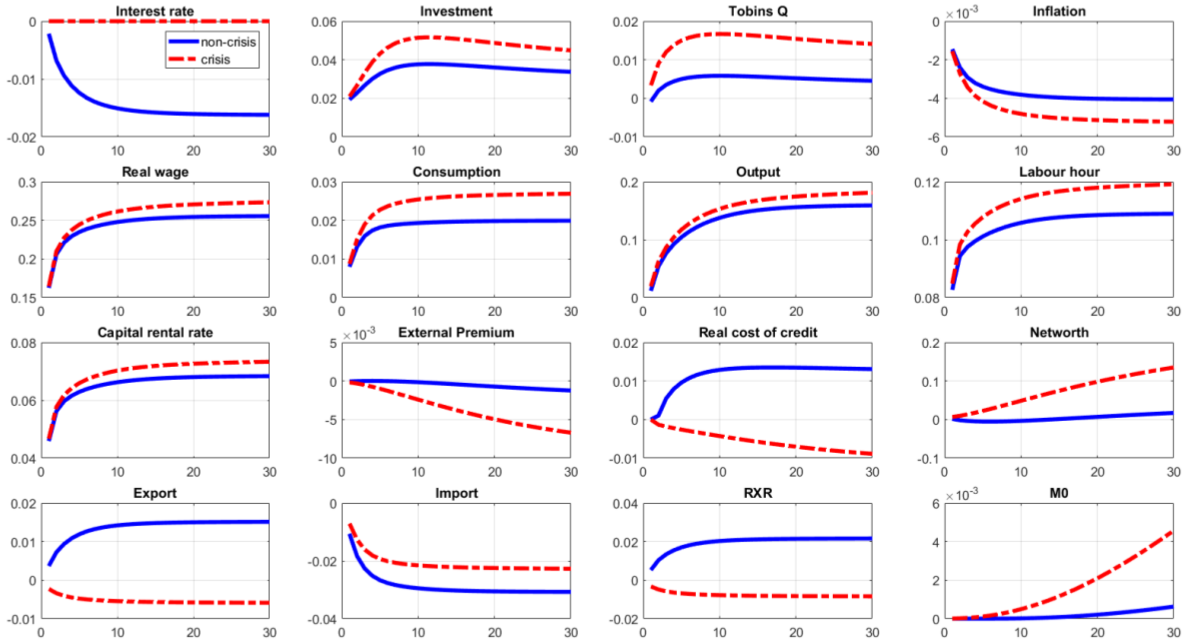



### 5.9.4 Productivity Shock

Figure 5.4 displays the impulse responses to a positive 10% non-stationary productivity shock. With increases enduring 30 quarters in both states of the world, the positive increase in productivity has permanent effects on output, investment, consumption and the real wage amongst other variables. The increases in labour hours worked drive output and the real wage rate permanently higher. In turn, the higher demand for capital increases entrepreneurial net worth whilst the supply shock reduces costs putting downward pressure on inflation and the marginal cost of production. In the crisis economy the Taylor Rule is suspended and instead M0 increases whilst in the no-crisis economy interests decline.

On the foreign market in a no-crisis environment, the increase in domestic efficiency allows the UK to become more competitive on an international setting, causing increases in exports and a reduction in imports as can also be seen through the higher exchange rate. The contrast in export dynamics between the two states of the world can be explained by the ZLB. As mentioned before, in the no-crisis setting the supply shock allows interest rates to reduce. However, during periods of crisis interest rates are bounded at zero and as a result interest rates remain relatively higher, causing a relative appreciation of the GBP.

Figure 5.4: Productivity shock



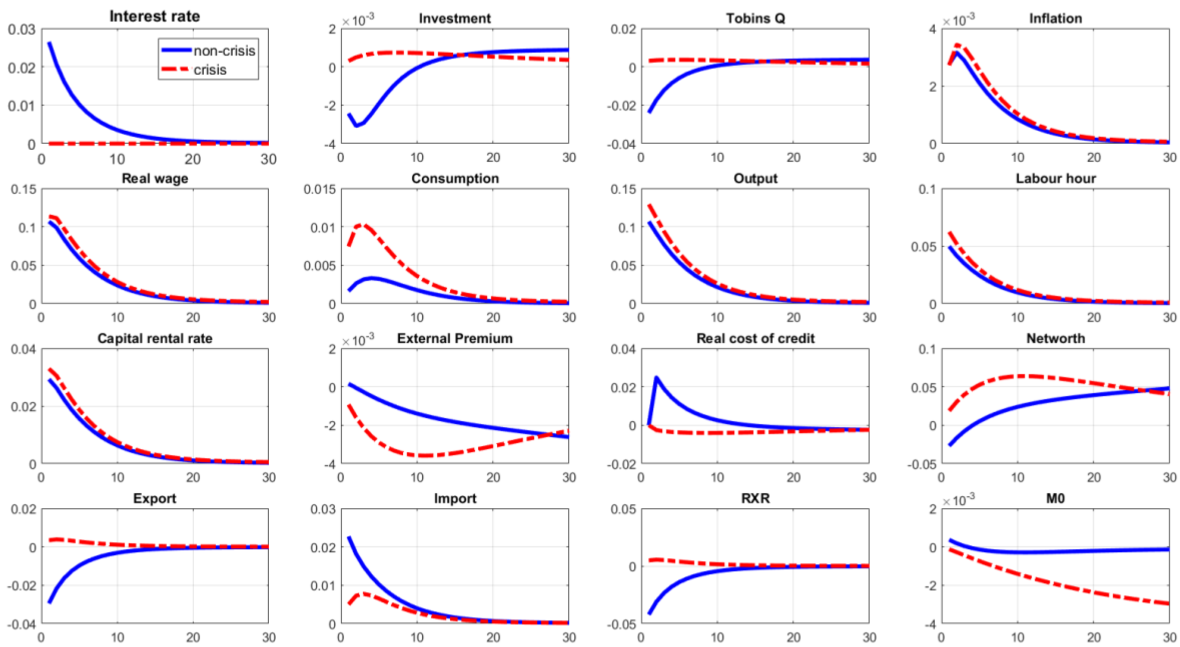

### 5.9.5 Government spending shock

Figure 5.5 shows the effects of an increase in government spending in the economy. In the no-crisis environment, there is a rise in the general price level caused largely by demand pull inflation. Subsequently, there is a Taylor Rule response and investment is ‘crowded out’. Consumption on the other hand rises as expectations of future job prospects set in. As expected, the real wage increases and labour hours follow. Rises in the net worth of entrepreneurs allow them to be less financially constrained, as result they require fewer funds from the financial intermediaries and there is therefore a reduction in the credit premium over the 30 quarters analysed.

Within the foreign sector there is a net reduction in the balance of trade, as increases in output and demand spill-over to imports whilst the Taylor Rule responds to curb inflation, it causes a relative appreciation of the currency and hence a reduction in international competitiveness and lower exports.

During the ZLB crisis the Taylor Rule becomes suspended. There is a marginally higher consumption level in comparison to the no-crisis state which is caused by the relatively lower prevailing interest rate, though the substitution effect of higher wages and labour supply is great and hence consumption increases in both states of the world. The lower interest rate translates to a relative depreciation in GBP and as a result the domestic country becomes more competitive compared to the non-crisis case, as can be seen by the reduction in imports and rise in exports. Lower interest rates allow entrepreneurs to be more profitable, their net worth increases and the external premium reduces in comparison to the no-crisis state.

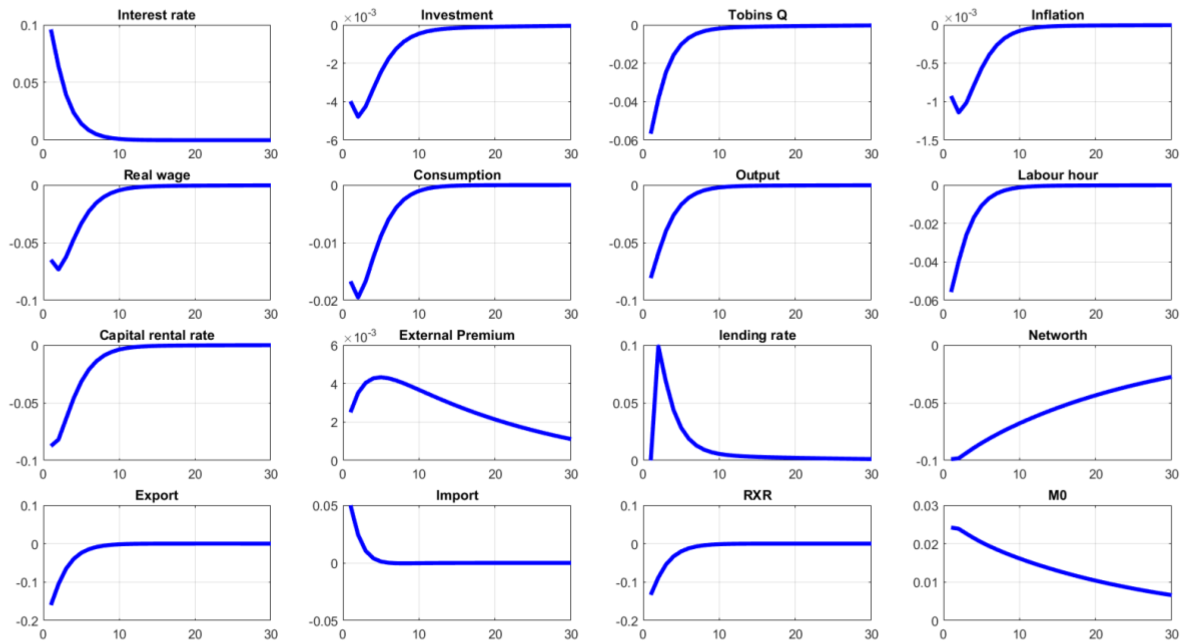
Figure 5.5: Government spending shock



### 5.9.6 Taylor Rule shock

Figure 5.6 shows the effects of a positive increase in the nominal interest rate. The figure does not display the state of the world in which there is a ZLB crisis, since we are introducing a positive monetary policy shock this is not the case by definition. As the real interest rate rises the marginal propensity to save increases as does the cost of financing business, hence this leads to a reduction in both consumption and investment. The reduction on the demand side filters into the rest of the economy, as seen by the fall in output, labour hours and real wages as is typical within New Keynesian dynamics. With an increase in the output gap inflation is lowered. Meanwhile, as entrepreneurs are credit constrained in this model, an increase in interest rates erodes potential entrepreneurial profits which as a result leads to reductions in net worth. The increase in interest rates raises the external premium which causes an added reduction in investment. From the international sector, the reduction in inflation and the increase in interest rates causes inflows of money into the country and a related appreciation in GBP, this in turn has an effect on the balance of trade. Exports become more expensive and decline whilst imports become relatively cheaper and increase.

Figure 5.6: Taylor Rule shock




### 5.9.7 Quantitative easing (M0) shock

Figure 5.7 shows the effects of a rise in the money supply (M0) and characterises unconventional monetary policy by QE. It is of course possible to have a rise in the money supply without a ZLB crisis, therefore we analyse both states of the world. During the no-crisis state, the rise in the money supply initially reduces the external premium which allows credit constrained entrepreneurs to make more profits, as the cost of undertaking business activity has reduced. Entrepreneurial net worth increases whilst the increased earning potential spurs investment and in turn output. The increases in output push for real wage rises which attract more labour. Subsequently, the combination of increases in real wage and labour hours work to stimulate consumption, though this is partially offset by the Taylor Rule response to inflation.

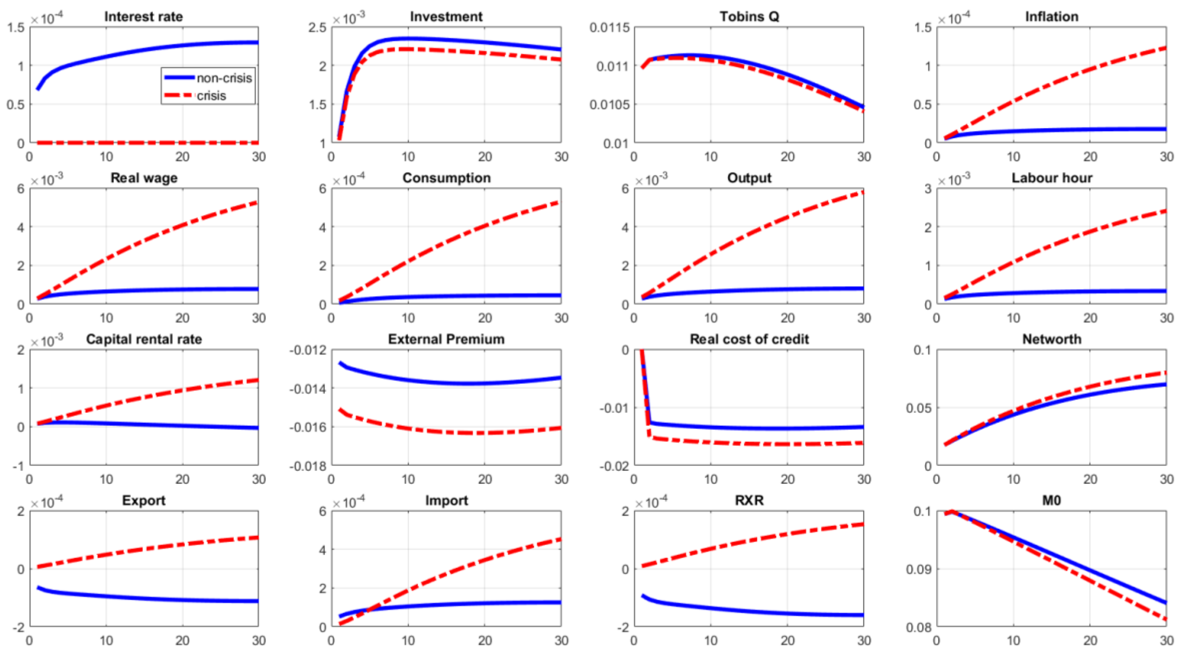
With regards to the foreign sector, the money supply tends to devalue the domestic currency and cause an increase in exports, however the effect of the increased interest rate through the

Taylor Rule response is relatively large and offsets this effect leading to a reduction in exports. Similarly, the increased interest rates and the increased money supply cause spill over on international spending.

When the economy faces the ZLB crisis, the Taylor Rule is suspended and the central bank employs unconventional monetary policy through the process of QE. Similarly, there is a fall in the external premium which stimulates investment and has demand side effects in the real economy. However, in this situation inflation is not curbed by the Taylor Rule and we see a steady rise in output consumption and inflation as compared to the no-crisis state.

With regards to the foreign sector, the increase in the money supply inclines to devalue the domestic currency. In contrast to the no-crisis state, the Taylor Rule is bounded and is not able to offset the resulting increases in exports. Imports on the other hand, also increase and offset the lower competitive state of the devalued currency as a result of the increased money supply and consumption.

Figure 5.7: M0 shock



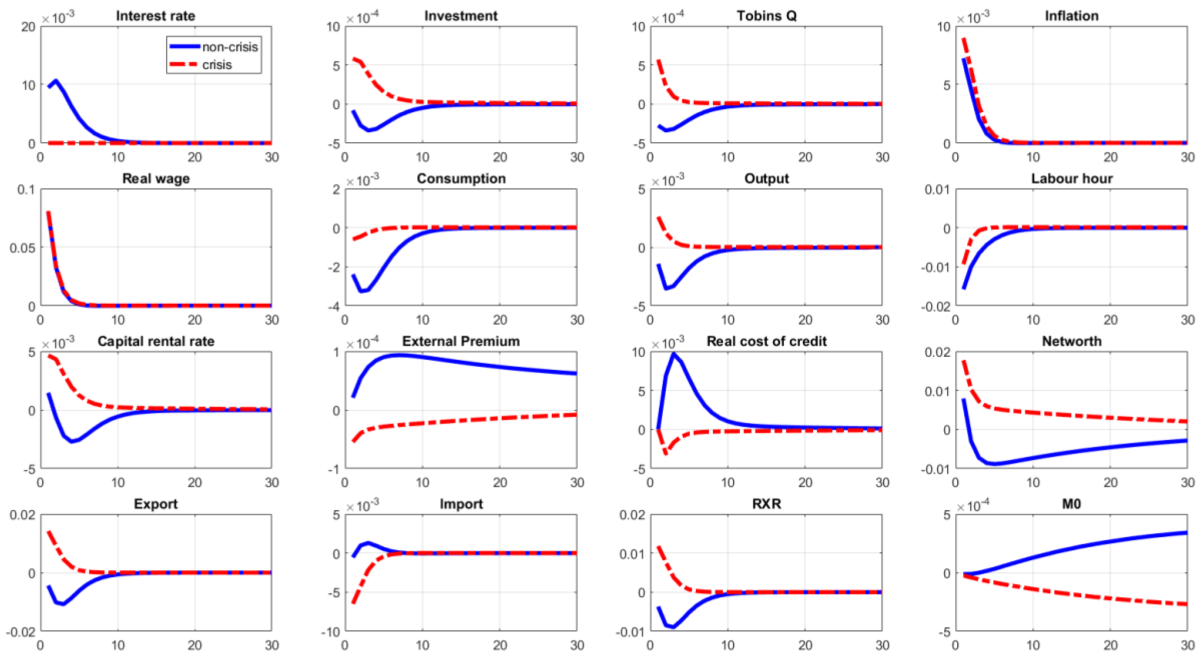
### 5.9.8 Wage mark-up shock

Figure 5.8 displays the outcomes of a one-off rise in the real wage. Observing the dynamics of the no-crisis state, we can see that through the sticky reaction of nominal wages a one-period shock in the wage equation disappears gradually over the next few quarters. As the marginal costs of firms increase so does inflation. As prices rise, output declines which mitigates the increase in marginal costs. The Taylor Rule's response to rising inflation further inhibits aggregate demand and output whilst this curbs inflation to its steady state at around 8 quarters.

For the foreign sector, the increase in real wages and marginal costs results in a decrease in competitiveness which reduces exports and increases imports, this is further exacerbated by the Taylor Rule Response to inflation which works to appreciate GBP.

In the crisis state, the rise in real wages causes a rise in the general price level. However, the Taylor Rule response is bounded and as a result output and consumption are relatively higher compared with the no-crisis state. The real cost of credit declines and as a result investment increases. As interest rates are bounded, net exports remain higher.

Figure 5.8: Wage mark-up shock



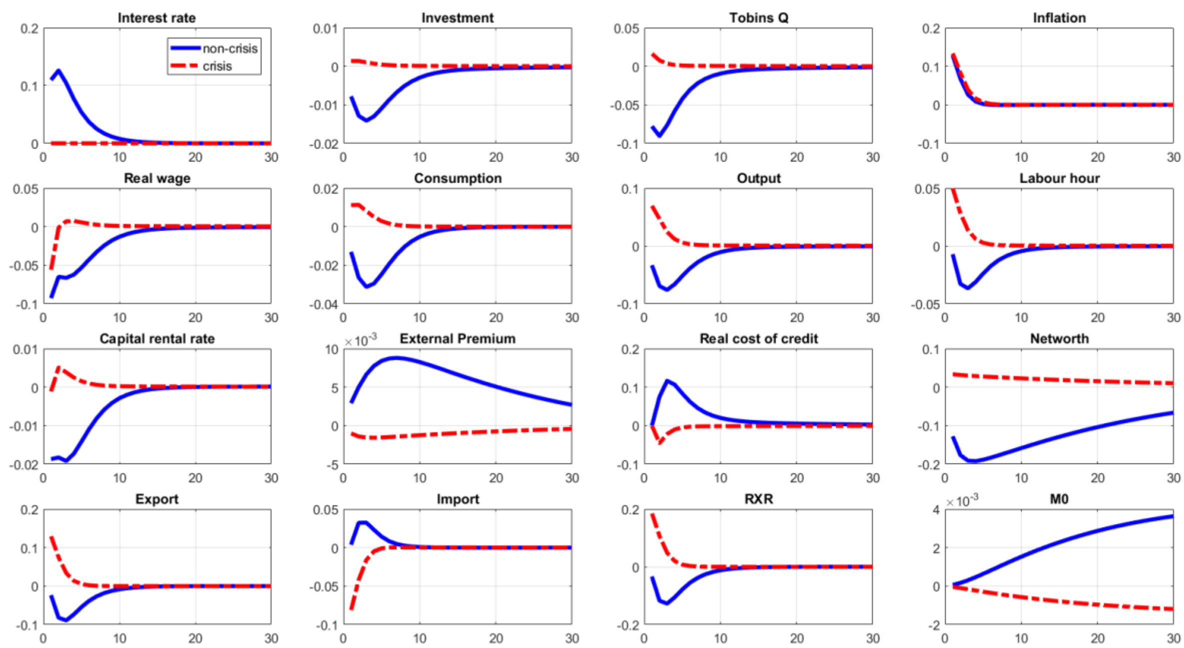
### 5.9.9 Price mark-up shock

Figure 5.9 displays the effects following a one-off rise in prices. The effects are similar to that of the wage mark-up shock. As prices increase, there is a Taylor Rule response which inhibits output growth and consumption.

In the foreign sector, the rise in prices has the effect of decreasing international competitiveness and reducing net exports. This is further aggravated by the increase in interest rates following the Taylor Rule's response to rising inflation. The effect is an upward pressure on the domestic currency and a downward pressure on net exports.

In the crisis state there is no Taylor Rule response to rising inflation, and as a result there is a rise in consumption, output, and labour hours whereas this is not the case in the no-crisis state. Similarly, the domestic currency does not appreciate as is the case in the no-crisis period, this is due to the suspension of the Taylor rule and consequently this causes net exports to rise.

Figure 5.9: Price mark-up shock



### 5.9.10 Impulse Response Summary

The impulse response functions to regulative shocks appear to display the expected effects of depressing output, and inflation. During the state of the world in which there is no-crisis, the Taylor Rule remains operative and there is a marked offset from monetary policy as is indicated though the decline in interest rates. During the period in which there is a crisis, the economy becomes bound by the ZLB. The impulse response functions highlight a strong offset on the credit premium which is originating from QE as is seen through the rise in M0. The offset appears to be much stronger for the corporate regulation shock as the corporate regulatory rules modelled in this thesis directly affect the premium, whereas the mortgage shock has less of an effect, only arising indirectly through lower net worth. The impulse response functions to the other shocks in the model behave in a familiar manner when faced with a regular Taylor Rule regime. During the crisis period and the ZLB, the Taylor Rule is suspended and there is an absence of interest rate responses to inflation, with an equivalently small QE response the output multipliers of demand shocks are fairly higher than compared to when the Taylor Rule is operative. Under the ZLB regime the economy's output response to a QE shock is greater as interest rates cannot apply downward pressure. With cost-push shocks under the ZLB regime, the cost of borrowing falls and output can be seen to rise with higher inflation. Under the Taylor Rule regime output falls in reaction to the increased wage and price mark-up changes, whilst interest rates work to further exacerbate the decline in output.

## 5.10 Variance Decomposition

The purpose of regulation targeted on corporate activity can be viewed as an attempt to prevent the systemic risk and macroeconomic costs associated with financial instability. Specifically, corporate regulation is targeted towards mitigating developments from within the wider financial sector, whilst mortgage regulation is targeted towards developments that arise within the housing sector. The variance decomposition provides insights into the main forces driving economic fluctuations. The contribution of each of the structural shocks to the variance of selected variables of interest are reported in table 5.4 for the time period 2007Q1 – 2016Q4.

The two variables that are responsible for most of the variance in the interest rate are the price mark up and monetary policy shocks, 24.48% and 22.89% respectively. The price mark-up plays a relatively larger role in this model as compared to the literature, whilst it is common that monetary policy accounts for large variation. The regulatory variables on the other hand play a minor role in determining the variation in interest rates, here 3.16% for the mortgage variable and a negligible 0.01% for the corporate variable.

With regards to the variance determinants of investment, the premium variable accounts for a significant proportion of the variability in investment at 52%, this is unsurprising as in the model the premium acts as a wedge between the profit margins in entrepreneurial balance sheets. Similarly, as profits are in-part recycled in the form of net worth, the net worth variable accounts for a significant 10.37% of the total variation in investment.

The variance decomposition for inflation reveals that the price mark-up accounts for the largest share of total variability at 47.82%, again this is unsurprising as by definition it is a cost push shock. Productivity accounts for the second largest share of inflation variability at 15.01% whilst the monetary policy variable has the third highest effect at 14.25%, which is intuitive as controlling inflation is one of the objectives of monetary policy. Both the regulatory variables account for a small percentage in the variability of inflation, a collective 3.02%.

The variable that accounts for the largest variability in wages is the labour supply at 60.94%, this is a straightforward result as the more labour is supplied the more labour must be paid. The mortgage variable here accounts for the second highest percentage in wage variability at 9.56% followed by productivity at 7.62%.

For the consumption variable, four variables appear to be of significance; productivity, labour supply, preferences and the mortgage regulation variable at 20.68%, 15.42%, 24.07% and 30.17% respectively. Leisure, consumption and labour hours worked are directly interconnected, the more one works the more disposable income they attain, whilst the impact of preference shocks on consumption follows what is found in the literature. The effect of the mortgage variable is significant, it appears that changes in consumption are impacted by mortgage regulation. As often is the case, consumers use their house as a form of collateral in order to obtain finance which they will use to engage in consumption.

The total variance of output is greatly accounted for by productivity 27.26% and labour supply 16.28% as is exemplified by the classic CES production function utilised in this model. Imports 11.88% and monetary policy 8.52% also play a significant large role in the variability of output. In this model it would appear that conventional monetary policy accounts for more variability in output in comparison to QE 0.61%.

Changes in the real exchange rate appear to be driven by monetary policy 28.24% and productivity 25.97%, and the price mark-up 15.01%. Monetary policy through the Taylor Rule causes changes in the inflows and outflows of money to the country, hence the interest rate causes the currency to appreciate or depreciate. Similarly, productivity and the price mark-up both affect inflation and subsequently the value of the domestic currency.

### 5.10.1 Variance Decomposition Summary

The variance decomposition shows that the addition of regulatory variables does have an impact on some of the variable's variances in the model. Notably, when the mortgage variable is included in the model this variable accounts for 24% of the variation of consumption 9.6% of the variance in wages and roughly 4% of the total variance of interest rates and investment. On the other hand, the inclusion of the corporate regulation variable has negligible contributions to the variables of interest. It is apparent, that the main contributions to variances here are the variables of labour supply, price mark-up and productivity whilst on the demand side the main shocks appear from trade, foreign demand and monetary policy.

Table 5.4: Variance decomposition (2007Q1 to 2016Q4)

| | Int. rate | Investment | Inflation | Wage | Consumption | Output | RXR |
|---|---|---|---|---|---|---|---|
| **Gov spend** | 0.48 | 0.96 | 0.06 | 0.30 | 0.02 | 2.02 | 0.49 |
| **Preference** | 4.49 | 1.96 | 0.34 | 6.52 | 30.17 | 2.77 | 0.68 |
| **Investment** | 0.01 | 14.89 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 |
| **Monetary Policy** | 22.89 | 0.57 | 14.25 | 1.98 | 4.23 | 8.52 | 28.24 |
| **Productivity** | 7.90 | 1.62 | 15.01 | 7.62 | 20.68 | 27.26 | 25.97 |
| **Price mark-up** | 24.48 | 0.57 | 47.82 | 2.32 | 4.71 | 6.66 | 15.01 |
| **Wage mark-up** | 0.02 | 0.95 | 0.01 | 0.12 | 0.00 | 0.06 | 0.02 |
| **Labour supply** | 15.34 | 0.86 | 6.25 | 60.94 | 15.42 | 16.28 | 1.32 |
| **Premium** | 10.61 | 52.00 | 10.07 | 0.48 | 0.05 | 3.65 | 0.51 |
| **Net worth** | 4.17 | 10.37 | 1.02 | 0.12 | 0.01 | 0.85 | 0.19 |
| **QE (M0)** | 0.11 | 5.41 | 0.01 | 0.08 | 0.01 | 0.61 | 0.09 |
| **Export** | 0.29 | 1.01 | 0.70 | 3.23 | 0.20 | 8.83 | 5.52 |
| **Import** | 0.12 | 1.02 | 0.78 | 3.68 | 0.23 | 11.88 | 6.29 |
| **F int. rate** | 0.40 | 0.95 | 0.05 | 0.28 | 0.02 | 1.92 | 10.42 |
| **F consumption** | 4.52 | 0.99 | 0.61 | 2.77 | 0.17 | 7.72 | 4.79 |
| **Corporate** | 0.01 | 1.59 | 1.00 | 0.01 | 0.00 | 0.04 | 0.01 |
| **Mortgage** | 3.16 | 4.28 | 2.02 | 9.56 | 24.07 | 0.90 | 0.44 |

## 5.11 Conclusion

This chapter has discussed and developed the ideas around the estimation and evaluation of the DSGE model presented. I have introduced the II method and why I believe it is an appropriate approach to implement in this analysis, citing the robust methodology for testing and optimally selecting those parameter values that match the data. In addition to this, we have also discussed the benefits of utilising unfiltered data in order to avoid some of the potential spurious data issues that detrending may cause. When the non-stationary calibrated data was tested via the II procedure it showed that it could not pass the Wald Test, I therefore estimated the model parameters using II and obtained parameter values that matched the data. In terms of the behaviour of the model, the impulse response functions to regulative shocks appeared to display the expected effects of depressing output, and inflation whilst there was an offset of QE on the credit premium. Whilst the variance decomposition showed that the addition of the regulative variables did have a limited effect, a tangible proportion of the variances of consumption and wages could be accounted for by the mortgage regulation variable. In order to fully grasp the effects of regulation, the next section in this thesis will take a simulation-based approach to assessing the impacts of regulation on welfare.

# 6 Can regulation improve the economy's stability?

In this chapter I investigate whether regulation does have the potential to play a useful role in stabilising the economy and the extent to which this stabilisation is provided by monetary policy alone. As discussed in Benigno et al. (2012), there are two common approaches in evaluating welfare within a DSGE context. The first includes solving the model using a second-order approximation to the structural equations for a given policy and then evaluating welfare using this solution. The second method includes characterising the optimal Ramsey policy. In this thesis, I take advantage of a powerful numerical technique that involves bootstrapping the model for all shocks impacting on it over 500 samples. From the results of these simulations, I then calculate the average variances that are derived from the different regulatory and monetary regimes employed. The aim is to evaluate the extent to which regulation works to assist monetary policy in stabilising the economy with respect to the key parameters of policy - inflation and output. Therefore, the welfare cost denoted here as $\mathrm{W_c}$ combines these two variances as a weighted average and commonly represents the average loss in utility faced by the consumer, though for simplicity of focus I do not measure this. The measures of stability utilised here give clear results as shown in table 6.1. I test the hypothesis that when faced with regulatory intervention as modelled as a random autocorrelated process, the stability achieved by monetary policy may be hindered. However, if regulation is deployed in response to the economy in a feedback manner, it can indeed aid monetary policy in achieving stability.

$$\mathrm{W_c} = \frac{1}{2}[Var(\pi_t) + \bar{\omega}Var(y_t)] \tag{6.1}$$

where $\bar{\omega} = \frac{1}{\sigma_c}$. From equation (6.1) we can see that the welfare cost is a weighted average between the variances of inflation and output, of which the latter is influenced by the elasticity of consumption. As the elasticity of consumption increases this raises the potential for welfare.

This welfare cost is calculated for different mixes of monetary and regulatory regimes and compared with the baseline welfare cost.

The baseline case in this test is a regular monetary regime that does not involve the inclusion of regulatory measures. The monetary regime in this scenario is typified by a Taylor Rule which utilises money as a backup in response to deviations in M2, whilst incorporating QE when faced with the ZLB. This baseline case is represented in column 1 of table 6.1 below.

Column 2 represents a deviation from the baseline case where in addition to the baseline regime, regulation is included through the addition of two extra regulatory shocks. As can be seen from table 6.1, this has the effect of increasing the variances of both output and inflation which causes an increase in the welfare cost of 8.84% - a result primarily based on the effect of adding further shocks of regulation onto other shocks in the economy.

In the next case represented in column 3 we add regulation however in this scenario we also allow for a contemporaneous (single unit coefficient) feedback from the output gap to corporate regulation. The results from table 6.1 show that welfare improves when compared to both the case in which there is regulation but no regulative feedback and the baseline case in which there is no regulation at all, as represented by a 27.46% and 21.05% respective decrease in welfare cost.

Similarly, in column 4 we allow for feedback from the output gap to mortgage regulation. The results are displayed in the 4th column and also indicate an improvement to welfare, of 47.03% in comparison to the baseline case and 51.34% in comparison to the regime in which there is no feedback to regulation. There is also a 32.91% decrease in the welfare cost compared to the case in which there is corporate regulation and feedback. As the change in inflation variability is relatively small, this signifies that the welfare change is mainly driven by the reduction in the variability of output and indicates that feedback to the mortgage regulatory variable is more important at stabilising output and welfare.

In the final column we include a joint feedback to both corporate and mortgage regulation and find the highest level of welfare is attained as compared to all the previous cases. In this scenario the welfare cost is reduced by 60.88% as compared to the baseline case and 64.06% when compared to the case in which there is regulation but no feedback. In all cases in which there is a reduction in welfare cost, this appears to be a result of stabilising output variance. Looking at table 6.1 we can see that the inclusion of regulation increases the variance of inflation in all scenarios and improvement in welfare comes at a cost of marginally higher inflation variability. This increase in the variability of inflation could potentially be a result of regulation diluting the inflation response in the Taylor Rule whilst somewhat strengthening the output gap response.

Based on the results presented above, this thesis confirms that regulation has the capacity to improve economic stability when calibrated to have feedback from the output gap to regulation. However, when there is no calibrated feedback the inclusion of regulation worsens stability. Therefore, the implication for policy is that macroprudential regulation should be coordinated with monetary policy to respond to the economy as this yields the highest welfare as seen in this analysis. Conversely when regulation is operated at the micro level without regard to the greater economy it causes shocks on its own regard and worsens economic stability.

Table 6.1: Welfare cost under Monetary and Regulatory Regimes

| | Existing regime +without regulatory variables | Existing regime +with regulatory shocks no feedback | Existing regime + corporate Regulatory feedback | Existing regime + mortgage Regulatory feedback | Existing regime + corporate and mortgage Regulatory feedback |
|---|---|---|---|---|---|
| **Var (output)** | 1.5836 | 1.7281 | 1.2231 | 0.7954 | 0.5667 |
| **Var (Inflation)** | 0.0584 | 0.0604 | 0.0764 | 0.0614 | 0.0599 |
| **Welfare cost*** | 0.5857 | 0.6375 | 0.4624 | 0.3102 | 0.2291 |

Table 6.1 has assumed a coordination policy through a unit feedback onto the output gap which in principle could be achieved. However, given the institutional framework of regulation within the UK, it would be a challenging coordination exercise to implement a regulatory response to contemporaneous deviations in the output gap within quarterly time domain.

### Original Taylor rule

$$r_t = \rho r_{t-1} + (1-\rho)\left(r_p \pi_t + r_y y_t\right) + r_{\delta y}(y_t - y_{t-1}) + er_t$$

### Monetary reform

$$m_t = m_{t-1} + \psi_2 (s_t - s*)$$

### Corporate regulatory

$$cor_t = 0.98 cor_{t-1} + 1 * (y_t - y*) + e_t^{cor}$$

### Mortgage regulatory

$$mor_t = 0.93 mor_{t-1} + 1 * (y_t - y*) + e_t^{mor}$$

# 7 Conclusions

The recent financial crisis and the dramatic events which brought financial markets into turmoil has resulted in a stark increase in the number of research papers and policy debates that focus on a macroeconomic perspective to financial regulation. Two trends that have emanated from this include the rise in the number of research papers that attempt to incorporate banking sectors and other financial frictions into a DSGE modelling framework. The other trend relates to the marked increase in financial regulation that is targeted towards financial activity. This thesis looks at the nexus between monetary policy and regulation. Specifically, it looks to answer if macroprudential policy can have welfare enhancing capabilities in the presence of a monetary rule.

In order to achieve this, I create an index of regulation by carefully harmonising a multitude of datasets on regulatory measures. I then combine this index with data obtained from Land Registry and the Bank of England to create variables of regulation that can be empirically tested and estimated within a DSGE model of the UK.

In section 4, I employ a small open economy DSGE model with credit constrained entrepreneurs and the possibility of hitting the zero lower bound (ZLB). I then add regulation into this two-state model by implementing the regulative index variables developed in Section 3. I end this chapter by calibrating the model parameters based on the literature.

Once the model had been calibrated, I then utilised the Indirect Inference method to test whether the model parameters could explain the data behaviour within the UK. I simulated and tested the unfiltered UK data in order to evaluate whether the calibrated model parameters can pass the Wald Test. The results showed that the model and its calibrated parameters could not match the data for the period 1995Q1-2016Q4. As a result, I employed the Indirect Inference method of estimation in order to discover the optimal set of parameters around the structural model. The Wald test based on the estimated parameters revealed that these parameter values could in fact match the simulated data for the UK over the period of analysis. In this section we also observe the dynamic behaviour of the UK economy. We analyse the results from the impulse response functions and the variance decomposition to assess how the inclusion of regulative factors affect the economy, both at times when there is no ZLB crisis and at times when unconventional monetary policy is employed. The response functions showed that for periods in which there is a crisis, there appears to be a strong offset on the credit premium originating from QE. This is especially true for corporate regulation that is modelled within the external finance premium. With regards to the variance decomposition, we can see that including regulatory variables does have an impact on some of the variances in the model. Specifically, the mortgage regulation variable accounts for 24.07% of the variation in consumption and 9.56% of the variation in wages. Besides this, the effect of regulation on variances appears to be limited.

Section 6 looks toward the welfare implications of introducing regulation by simulating multiple policy scenarios. The result of this analysis shows that regulation worsens welfare when introduced without a feedback from the output-gap to regulation. However, when regulation is calibrated to have a feedback to the output gap, welfare is enhanced. This result lends support to the idea that regulation should be co-ordinated with monetary policy to respond to the macroeconomy.

Based on this study, future research may look towards the optimal strategies for co-ordinating the feedback of macroprudential policy to output. Though it should be noted, in this thesis I have assumed a rather basic coordination policy through a unit feedback onto the output gap which could in principle be achieved, by the process of fine tuning the variables which policy responds to, their lags and the coefficients on feedback. Such a fine-tuning exercise would be informative in principle. However, based on the different institutionally separate bodies and committees through which regulation is carried out, this would be practically difficult to implement.

# 8 Bibliography

[1] Alam, Z. et al. 2019. Digging Deeper - Evidence on the Effects of Macroprudential Policies from a New Database. Available at: https://www.elibrary-areaer.imf.org/Macroprudential/Pages/iMaPPDatabase.aspx [Accessed: 10 September 2020].

[2] Anginer, D., Bertay, R., Cull, R., Demirgüç-Kunt, A. and Mare, D. 2019. Bank Regulation and Supervision Ten Years after the Global Financial Crisis. Available at: http://documents.worldbank.org/curated/en/685851571160819618/Bank-Regulation-and Supervision-Ten-Years-after-the-Global-Financial-Crisis [Accessed: 10 September 2020].

[3] Armington, P.S. 1969. A Theory of Demand for Products Distinguished by Place of Production. *IMF Staff Papers* 16(1), pp. 159–178.

[4] Beau, D., Clerc, L. and Mojon, B. 2012. *Macro-Prudential Policy and the Conduct of Monetary Policy*. Paris.

[5] Benigno, P. et al. 2012. Linear-quadratic approximation of optimal policy problems. *Journal of Economic Theory* 147(1), pp. 1–42. doi: 10.1016/j.jet.2011.10.012.

[6] Bernanke, B.S., Gertler, M and Gilchrist, S. 1999. The financial accelerator in a quantitative business cycle framework. *Handbook of Macroeconomics* 1(Part C), pp. 1341–1393.

[7] Boissay, F., Cantú, C., Classens, S. and Villegas, A. 2019. Financial Regulation Assessment: Meta Exercise. Available at: https://www.bis.org/frame/ [Accessed: 10 September 2020].

[8] Brzoza-Brzezina, M., Kolasa, M. and Makarski, K. 2015. Macroprudential policy and imbalances in the euro area. *Journal of International Money and Finance* 51, pp. 137–154. doi: 10.1016/j.jimonfin.2014.10.004.

[9] Budnik, K. and Kleibl, J. 2018. Macroprudential Regulation in the European Union in 1995-2014: Introducing a New Data Set on Policy Actions of a Macroprudential Nature. Available at: https://ideas.repec.org/p/ecb/ecbwps/20182123.html [Accessed: 30 September 2020].

[10] Calvo, G. 1983. Calvo - Staggered Prices in a Utility Maximizing Framework. *Journal of Monetary Economics* 12(1978), pp. 383–398.

[11] Canova, F. 2014. Bridging DSGE Models and the Raw Data. *Journal of Monetary Economics* 67, pp. 1–15. doi: 10.1016/j.jmoneco.2014.06.003.

[12] Carlstrom, B.C.T. and Fuerst, T.S. 1997. Agency Costs, Net Worth, and Business Fluctuations : A Computable General Equilibrium Analysis. *The American Economic Review* 87(5), pp. 893–910.

[13] Cerutti, E., Claessens, S. and Laeven, L. 2015. The Use and Effectiveness of Macroprudential Policies: New Evidence. *Journal of Financial Stability* 28, pp. 203–204.

[14] Cerutti, E., Correa, R., Fiorentino, E. and Segalla, E. 2017. Changes in Prudential Policy Instruments - A New Cross - Country Database. *International Journal of Central Banking* 13(2), pp. 477–503.

[15] Christensen, I. and Dib, A. 2008. The Financial Accelerator in an Estimated New Keynesian Model. *Review of Economic Dynamics* 11(1), pp. 155–178. doi: 10.1016/j.red.2007.04.006.

[16] Clerc, L. et al. 2015. Capital Regulation in a Macroeconomic Model With Three Layers of Default. *International Journal of Central Banking* 11(3), pp. 9–63. doi: 10.2139/ssrn.2544607.

[17] Fair, R. and Taylor, J. 2016. Solution and Maximum Likelihood Estimation of Dynamic Nonlinear Rational Expectations Models Author. *Econometrica* 51(4), pp. 1169–1185.

[18] Friedman, M. 1953. *Essays in Positive Economics*. Chicago: The University of Chicago Press.

[19] Gelain, P. and Ilbas, P. 2017. Monetary and Macroprudential Policies in an Estimated Model with Financial Intermediation. *Journal of Economic Dynamics and Control* 78, pp. 164–189. doi: 10.1016/j.jedc.2017.01.010.

[20] Gertler, M., Kiyotaki, N. and Prestipino, A. 2020. Credit Booms, Financial Crises, and Macroprudential Policy. *Review of Economic Dynamics* 37, pp. 8–33. doi: 10.1016/j.red.2020.06.004.

[21] Houston, J.F., Lin, C. and Ma, Y. 2012. Regulatory Arbitrage and International Bank Flows. *Journal of Finance* 67(5), pp. 1845–1895. doi: 10.1111/j.1540-6261.2012.01774.x.

[22] Iacoviello, M. 2005. House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle. *American Economic Review* 95(3), pp. 739–764.

International Monetary Fund. 2018. *The IMF's Annual Macroprudential Policy Survey*. doi: 10.5089/9781498308410.007.

[23] Kimball, M.S. 1995. The Quantitative Analytics of the Basic Neomonetarist Model. *Journal of Money Credit and Banking* 27(4), pp. 1241–1277.

[24] Kiyotaki, N. and Moore, J. 1997. Credit Cycles. *Journal of Political Economy* 105(2), pp. 211–48.

[25] Kochanska, U. 2017. The ESRB Macroprudential Measures Database. Available at: https://www.esrb.europa.eu/national_policy/shared/pdf/esrb_macroprudentialmeasuresdatabase_20171215_en.pdf [Accessed: 24 August 2020].

[26] Le, V.P.M., Meenagh, D. and Minford, P. 2011. How Much Nominal Rigidity Is There in the US Economy? Testing a New Keynesian DSGE Model Using Indirect Inference. *Journal of Economic Dynamics and Control* 35(12), pp. 2078–2104. doi: 10.1016/j.jedc.2011.08.009.

[27] Le, V.P.M., Meenagh, D. and Minford, P. 2012. *Testing DSGE Models by Indirect inference and Other Methods: Some Monte Carlo Experiments*. Cardiff Economics Working Papers E2012/15 Cardiff: Cardiff University.

[28] Le, V.P.M., Meenagh, D. and Minford, P. 2016. Monetarism Rides Again? US Monetary Policy in a World of Quantitative Easing. *Journal of International Financial Markets, Institutions and Money* 44(C), pp. 85–102. doi: 10.1016/j.intfin.2016.04.011.

[29] Le, V.P.M., Meenagh, D. and Minford, P. 2018. Financial Stability: To Regulate or Not? A Public Choice Inquiry. *Journal of International Financial Markets, Institutions and Money* 57, pp. 127–140. doi: 10.1016/j.intfin.2018.07.004.

[30] Lloyd, J. 2021. HarMap Harmonised Macroprudential Database. Available at: https://sites.google.com/site/jonathanlloydeconomics/home [Accessed: 23 August 2021].

[31] Lucas, R.E. 1976. Econometric Policy Evaluation: A critique. *Carnegie - Rochester Conference Series on Public Policy* 1, pp. 19–46. doi: 10.1016/S0167-2231(76)80003-6.

[32] Lyu, J., Le, V.P.M., Meenagh, D. and Minford, P. 2021. *Has the Pendulum Swung Too Far? Macroprudential Regulation in the Post-Crisis Era*. Cardiff Economics Working Papers E2021/6 Cardiff: Cardiff University.

[33] Meenagh, D., Minford, P. and Wickens, M. 2021. *Estimating Macro Models and the Potentially Misleading Nature of Bayesian Estimation*. Discussion Paper Series DP15684 London: Centre for Economic Policy Research.

[34] Minford, L. 2015. *The Macroeconomic Effects of UK Tax, Regulation and R&D Subsidies : Testing Endogenous Growth Hypotheses in an Open Economy DSGE Model*. PhD Thesis, Cardiff University.

[35] Minford, P. 1986. Rational Expectations and Monetary Policy. *Scottish Journal of Political Economy* 33(4), pp. 317–33.

[36] Del Negro, M. and Schorfheide, F. 2008. Forming Priors for DSGE Models. *Journal of Monetary Economics* 55(7), pp. 1191–1208.

[37] Pariès, M.D., Sørensen, C. and Rodriguez-Palenzuela, D. 2011. Macroeconomic Propagation Under Different Regulatory Regimes: Evidence From an Estimated DSGE Model for the Euro Area. *International Journal of Central Banking* 7(4), pp. 49–112.

[38] Quint, D. and Rabanal, P. 2014. Monetary and Macroprudential Policy in an Estimated DSGE Model of the Euro Area. *International Journal of Central Banking* 10(2), pp. 169–236.

[39] Rubio, M. and Carrasco-Gallego, J.A. 2014. Macroprudential and Monetary Policies: Implications for Financial Stability and Welfare. *Journal of Banking and Finance* 49, pp. 326–336. doi: 10.1016/j.jbankfin.2014.02.012.

[40] Rubio, M. and Yao, F. 2020. Macroprudential Policies in a Low Interest Rate Environment. *Journal of Money, Credit and Banking* 52(6), pp. 1565–1591. doi: 10.1111/jmcb.12662.

[41] Shim, I., Bogdanova, B., Shek, J. and Subelyte, A. 2013. Database for Policy Actions on Housing Markets. Available at: https://www.bis.org/publ/qtrpdf/r_qt1309i.htm [Accessed: 14 July 2020].

[42] Sims, C. 1980. Macroeconomics and Reality. *Econometrica* 48(1), pp. 1–48.

[43] Smets, F. and Wouters, R. 2003. An estimated dynamic stochastic general equilibrium model of the euro area. *Journal of the European Economic Association* 1(5), pp. 1123–1175. doi: 10.1162/154247603770383415.

[44] Smets, F. and Wouters, R. 2007. Shocks and Frictions in US Business Cycles : A Bayesian DSGE Approach. *American Economic Review* 97(3), pp. 586–606.

[45] Wang, Z. 2020. *Unconventional Policy of UK The Study Through a SOE-DSGE Model*. PhD Thesis, Cardiff University.

[46] Zhu, Z. 2017. *The External Finance Premium in the UK*. PhD Thesis, Cardiff University.

# 9 Appendix

## 9.1 Regulation Sources and Datasets

Table 3.1: RII Sources

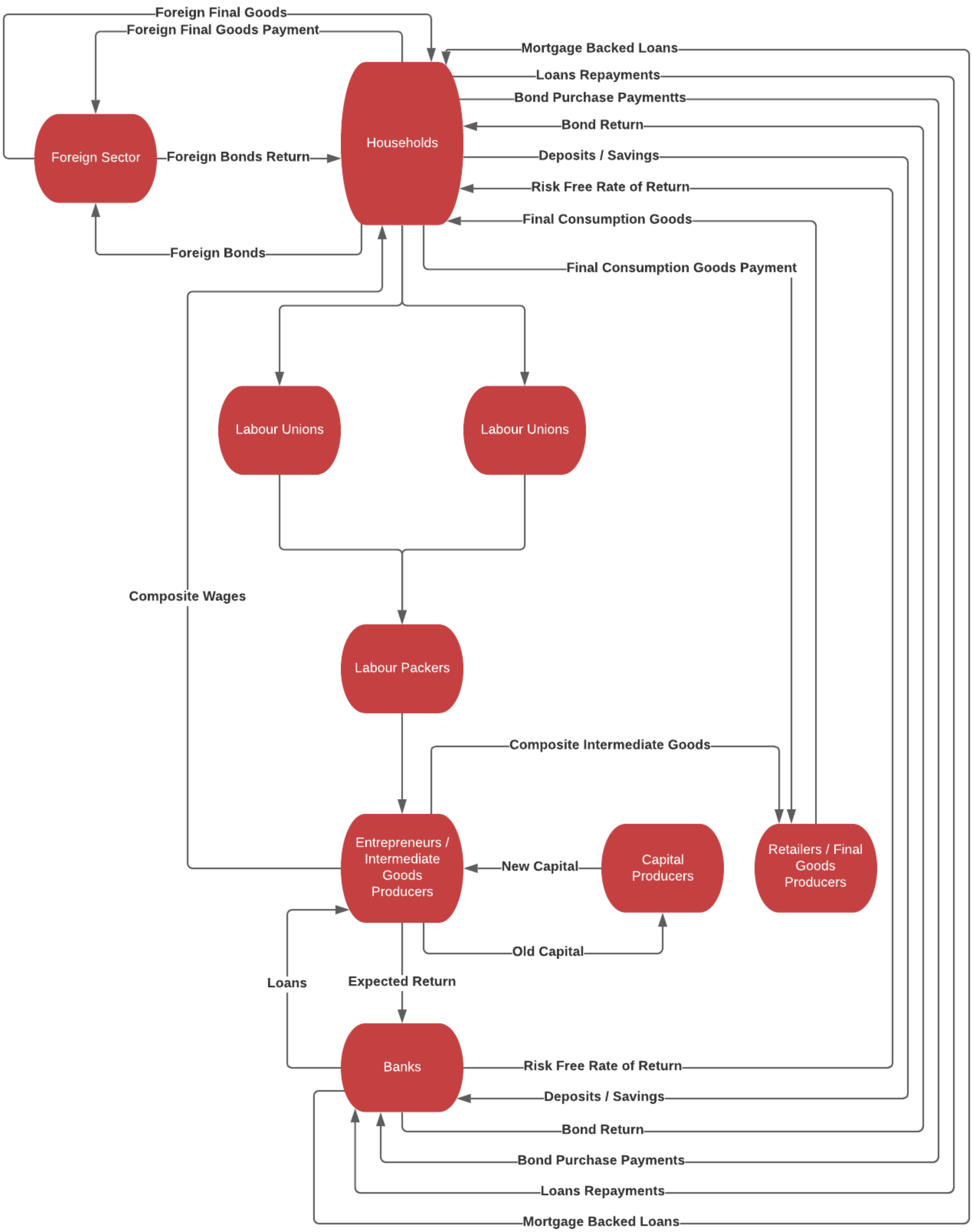
| Non-Database Sources | |
|---|---|
| Allen Overy | |
| Norton Rose Fulbright | |
| The Bank of England (BoE) | |
| The Bank of International Settlements (BIS) | |
| The European Banking Authority (EBA) | |
| The European Securities and Markets Authority (ESMA) | |
| The Financial Conduct Authority (FCA) | |
| The Financial Reporting Council (FRC) | |
| The Financial Services Authority (FSA) | |
| The Prudential Regulation Authority | |
| UK Government | |
| UK Legislation (UKL) | |
| Databases and Datasets | |
| A new Database of Financial Reforms | Houston et al. (2012) |
| Database for Policy Actions on Housing Markets | Shim et al. (2013) |
| Changes in Prudential Policy Instruments - A New Cross-Country Database | Cerutti et al. (2016) |
| The Use and Effectiveness of Macroprudential Policies: New Evidence | |
| The ESRB Macroprudential Measures Database | Kochanska (2017) |
| MaPPed | Budnik and Kleibl (2018) |
| The IMF's Annual Macroprudential Policy Survey | International Monetary Fund (2018) |
| iMaPP | Alam et al. (2019) |
| FRAME | Boissay et al. (2019) |
| The Bank Regulation and Supervision Survey | Anginer et al. (2019) |

## 9.2 Data Sources

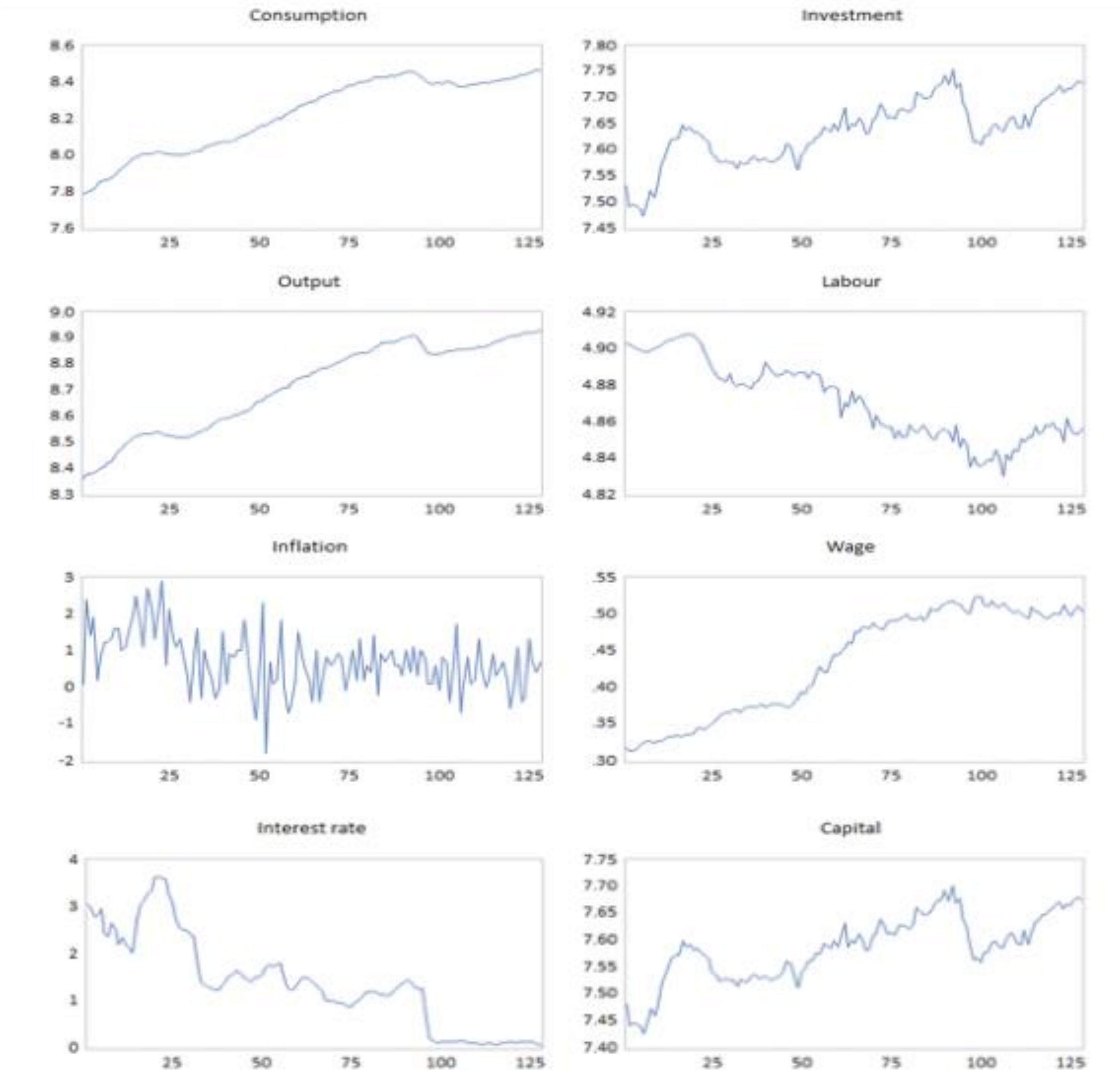
| Symbol | Variable | Definition, Description | Sources |
|---|---|---|---|
| $\Xi_2$ | Mortgage Regulation | RII as described in section 3 | Multiple Publications[30] |
| $\tau$ | Corporate Regulation | RII as described in section 3 | Multiple Publications[31] |
| $R$ | Nominal interest rate | 3-month average sterling T-bill | BoE |
| $I$ | Investment | Gross fixed capital formation + Changes in inventions | ONS |
| $P^k$ | Price of capital | Calculated from model equation | N/A |
| $K$ | Capital | Calculated from model equation | N/A |
| $\pi$ | Inflation | Quarterly percentage change in price GDP deflator | ONS |
| $W$ | Wage | Average wage and earning / Total actual working hours, divided by GDP deflator | ONS |
| $C$ | Consumption | Household final consumption expenditure | ONS |
| $Y$ | Output | Gross domestic product | ONS |
| $L$ | Labour | employment / total actual hour worked | ONS |
| $R^k$ | Rental rate of capital | Calculated from equation | N/A |
| $S$ | External finance premium | Difference of bank lending rate and risk-free rate | BoE |
| $N$ | Net worth | FTSE all share index, divided by GDP deflator | Data Stream |
| $M0$ | Quantitative easing | M0 Stock in UK | Federal Reserve Economic Data |
| $M2$ | Total money supply | M2 money stock in UK | Federal Reserve Economic Data |
| $EX$ | Export | Total UK export | ONS |
| $IM$ | Import | Total UK import | ONS |
| $Q$ | Real exchange rate | Inverse of quarterly average sterling effective exchange rate | ONS |
| $P$ | General price level | Consumer Price Index of All items in the UK | Federal Reserve Economic Data |

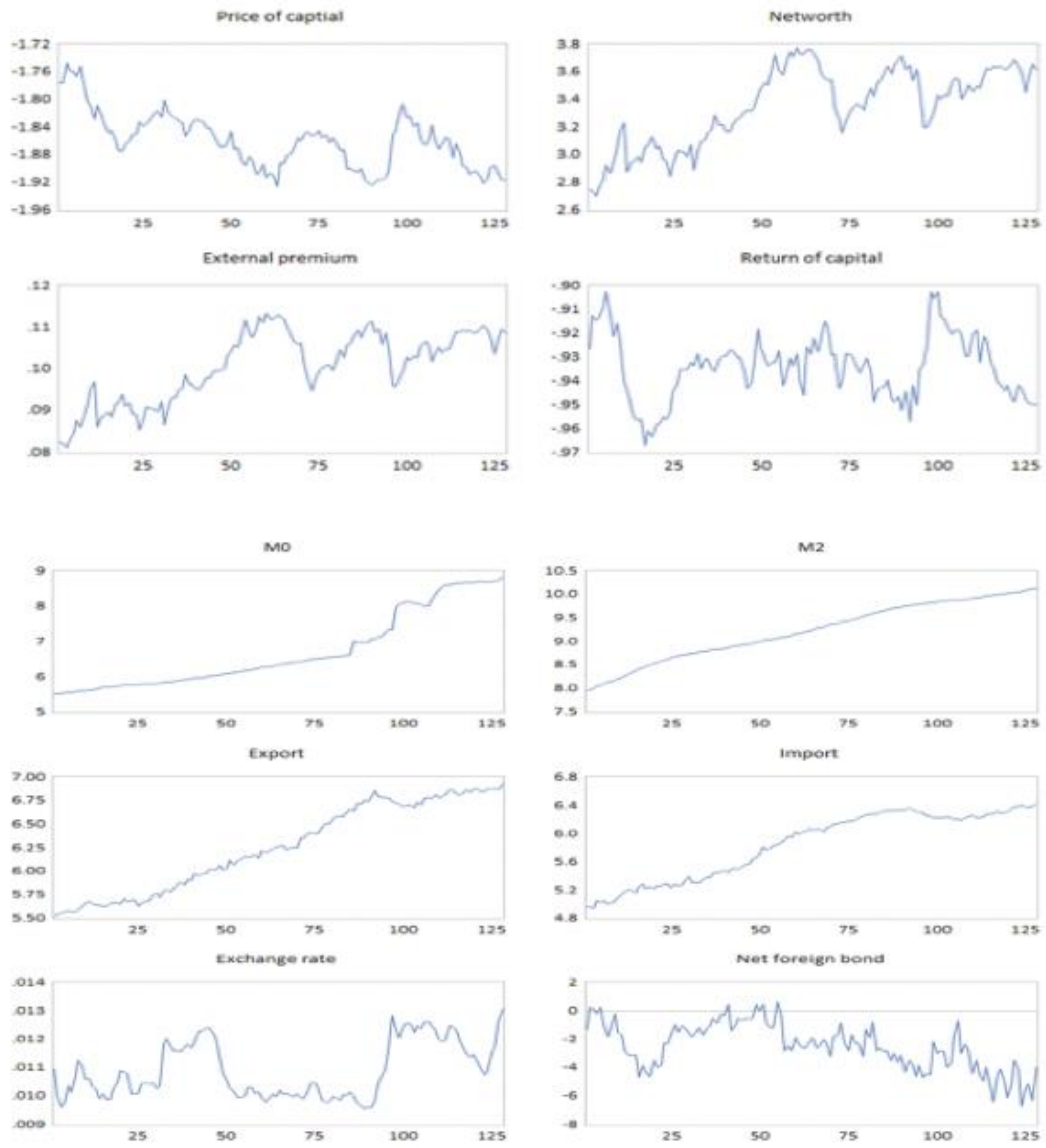
[30] Please see table 3.1 in appendix 9.1
[31] Please see table 3.1 in appendix 9.1

## 9.3 Model Diagram



## 9.4 Actual Data: 1985Q1 – 2016Q4




Price of captial
Networth
External premium
Return of capital
M0
M2
Export
Import
Exchange rate
Net foreign bond