Cardiff University

Doctoral Thesis

FORMATION AND EFFECTS OF UK MONETARY AND MACROPRUDENTIAL POLICIES

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Overview

This thesis consists of two essays on two models: a DSGE (Dynamic stochastic general equilibrium) model and an institutional model.

Essay I (Chapters 1 to 7) builds a macro-DSGE model for the UK over 1986-2016. Chapter 1 covers the background and review the literature; Chapter 2 outlines the model setup; chapter 3 tests and estimates the model; Chapter 4 looks at model's transmission mechanism. Chapter 5 develops a narrative for the UK economy over the sample period; Chapter 6 explores model's policy implications under alternative monetary regimes; and Chapter 7 concludes.

Essay II (Chapters 8 to 12) is built upon the DSGE model set up in Essay I to investigate the behaviours of UK central bank and government. Chapter 8 provides theoretical background and motivation; Chapter 9 lays out assumptions and presents the strategic choices made by policy makers according to our model; Chapter 10 illustrates how, when combined with the macro-DSGE framework formalised in Essay I, the institutional model is able to conform qualitatively with the UK data over 1993-2016; Chapter 11 evaluates the stability under alternative monetary regimes; and Chapter 12 concludes and draws implications.

Appendices for Essay I and II are labelled with A and B respectively.

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List of Abbreviations

ADF	Augmented Dickey–Fuller	IG	Intermediate Goods
AR	Autoregressive	IRF	Impulse Response Function
ARIMA	Autoregressive Integrated Moving Average	KPSS	Kwiatkowski–Phillips–Schmidt–Shin
ARMA	Autoregressive–Moving-Average	LHS	Left-hand side
ATR1	Premium-augmented Taylor rule Regime	LIBOR	London Inter-bank Offered Rate
ATR2	Shock-augmented Taylor rule regime	LSAP	Large Scale Asset Purchase
BGG	Bernanke-Gertler-Gilchrist	LTCM	Long-Term Capital Management
BoE	Bank of England	LTV	Loan-to-value
bps	Basis points	MA	Moving Average
CCyB	Counter-cyclical Capital Buffer	MPC	Monetary Policy Committee
CMP	Conventional monetary policy	NC	New Classical
COMPASS	Central Organising Model for Projection Analysis and Scenario Simulation	NFA	Net Foreign assets
CPI	Consumer Prices Index	NK	New Keynesian
CSV	Costly State Verification	OIS	Overnight Indexed Swap
DJIA	Dow Jones Industrial Average	OMO	Open market operation
DRR	Dual Rule Regime	ONS	Office for National Statistics
DSGE model	Dynamic stochastic general equilibrium model	OPEC	Organization of the Petroleum Exporting Countries
ECB	European Central Bank	PP	Phillips–Perron
EFSF	European Financial Stability Facility	pps	Percentage points
EMS	European Monetary System	PRA	Prudential Regulatory Authority
ERM	European Exchange Rate Mechanism	QE	Quantitative Easing
ESM	European Stability Mechanism	RBC	Real Business Cycle
EU	European Union	RHS	Right-hand side
FCA	Financial Conduct Authority	RoW	Rest of the World
FDIs	Foreign Direct Investments	SMEs	Small and Medium-sized Enterprises
FG	Final Goods	SOE	Small Open Economy
FOC	First-order condition	SW	Smets-Wouters
FRED	Federal Reserve Economic Data	TFP	Total Factor Productivity
FSA	Financial Service Authority	UIRP	Uncovered Interest Rate Parity
FTSE	Financial Times Stock Exchange	UK	United Kingdom
GDP	Gross Domestic Product	UMP	Unconventional Monetary Policy
GFC	Global Finance Crisis	US	United States
G7	Group of Seven	VARMA	Vector Autoregressive Moving Average
HP filter	Hodrick-Prescott (HP) filter	VAR	Vector Autoregression
II	Indirect Inference	VECM	Vector Error Correction Model
I(1)	Integration of order one	ZLB	Zero Lower Bound

Abstract (DSGE Model)

Large bodies of macroeconomic literature have contributed to building DSGE models on the US, whereas very little has been done for the UK. We show that a standard New-Keynesian model enriched with financial friction, zero lower bound constraint, quantitative easing and foreign economy sectors can explain the UK data behaviour over 1986-2016. Through QE operations, money has been given a role in easing the credit condition via providing the cheapest collateral. Due to the non-linearity induced by regime switch, the model is estimated by a simulation-based indirect inference method. Simulations indicate that the zero lower bound constraint can bind much often than previously thought. Historical shock decomposition reveals that productivity slump is the main cause behind the sluggish recovery. Alternative monetary policy regimes are evaluated in terms of reducing welfare costs. Violation of the Tinbergen rule appears to be costly, as the dual rule regime (DRR) with an additional M0 rule that targets premium exclusively outperforms any one-instrument regimes (ATR1, ATR2) which incorporate credit condition into Taylor rules.

Chapter 1

Background and Motivation (DSGE Model)

The acute financial turmoil since 2008 has not only plunged the US into the deepest recession in decades,[1] but has spread elsewhere and developed into a full-blown credit crisis globally including the UK. Figure 1.0.1 plots the pattern of the UK per capita output (measured as total output divided by the population index) spanning three decades (1986-2016). The actual output (solid line) has remained well below the level implied by pre-crisis trend (dashed line). Just as the case with much of the western world, the UK has sustained a large and persistent output losses with GDP declining by 6.4 % during the subsequent six quarters, which constituted almost 3 years' growth. The output gap suggests the magnitude of shortfall with no evidence showing strong bouncing back following the downturns. As demonstrated by Figure 1.0.1, it was not until 2013 that the output finally got back to the size it was in 2008. However, it has never reverted to its pre-crisis trend level as indicated by the dash line.[2]

[1] The Great Financial Crisis reached its peak in the US when Lehman Brothers was forced into bankruptcy on 15 September, 2008.

[2] According to the estimates, UK per capita GDP in late 2018 is still £5900 per person lower than it could be had the crisis not struck, see https://www.ifs.org.uk/publications/13302

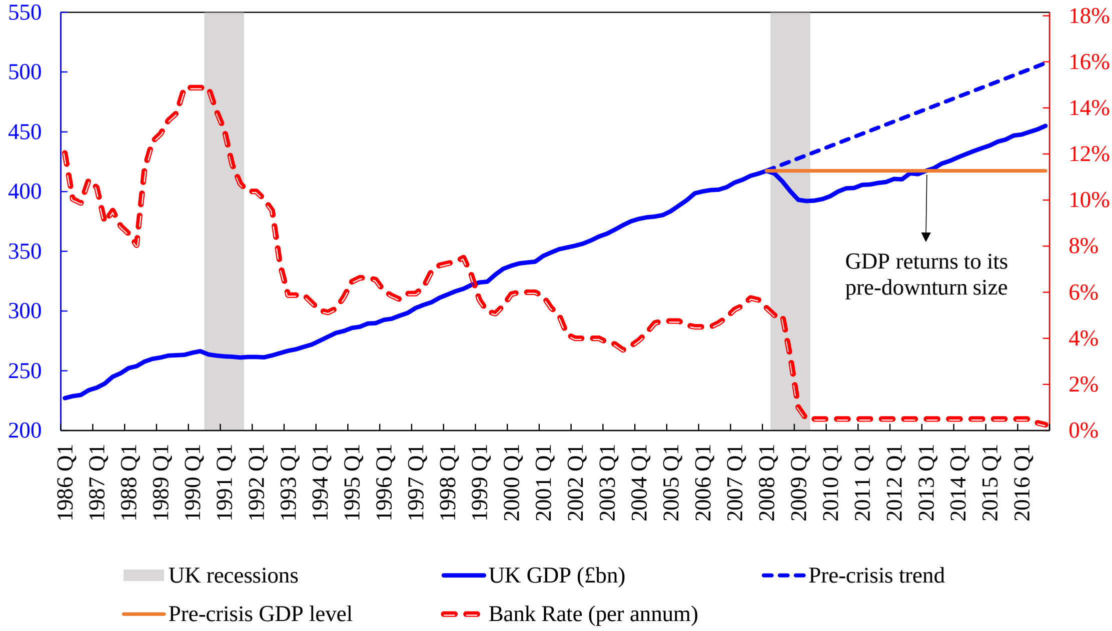


Figure 1.0.1: BoE slashed Bank Rate when the economic outlook worsened

NOTE: Data are sourced from ONS and BoE. Grey shaded bars mark UK recessions as defined in Wikipedia: "List of recessions in the United Kingdom" https://en.wikipedia.org/wiki/List_of_recessions_in_the_United_Kingdom . The UK experienced two recessions throughout our sample period: the early 1990s recession (1990Q3 - 1991Q3), and the Great Financial Crisis (2008Q2 - 2009Q2). A recession is said to be when GDP diminishes for two successive quarters.

With the calamity's roots in the banking sector, liquidity problems featuring massive widening of the credit spread have emerged in the UK interbank funding markets. For instance, the net monthly flows of business lending have almost halved from £7.4bn in 2007 to £3.9bn in 2009, pushing the cost of credit up to a median of 4 percent in the wake of credit crunches (Cowling et al., 2012). The growing concern over the world economy prospect and the near-term outlook for the UK growth pushed the monetary policy committee (MPC) to drastically cut Bank Rate to 0.5% in March 2009 and to keep it on hold for years to maintain liquidity .

Although the MPC only sets Bank Rate (or base rate), it is seen as a benchmark whose movement is likely to trigger ripple effect on other rates, and every sphere of an economy.[3] Figure 1.0.2 gives a snapshot of how other rates have been moving closely with Bank Rate (red solid line), the reason being that financial market would typically interpret any minor

[3]The official bank rate (or Bank of England base rate) is the rate at which the BoE charges commercial banks for secured overnight lending. As the single most important rate in the UK, it is decided by the MPC to meet the inflation target set by government. The Monetary Policy Committee (MPC) holds several meetings to study how the current economy fares before announcing its policy eight times a year.

changes in the Bank Rate as signals from the BoE, whose decisions to raise or lower Bank Rate hinges upon how well the economy is faring. A rise (fall) in Bank Rate is likely to cause a rise (fall) in other rates set by commercial banks, although not necessarily by the same amount. Since the onset of the Great Recession, firms have received less revenue and laid off employees. The BoE has since cut Bank Rate near zero, to boost spending and jobs with other commercial rates being dropped subsequently to be in line with Bank Rate.

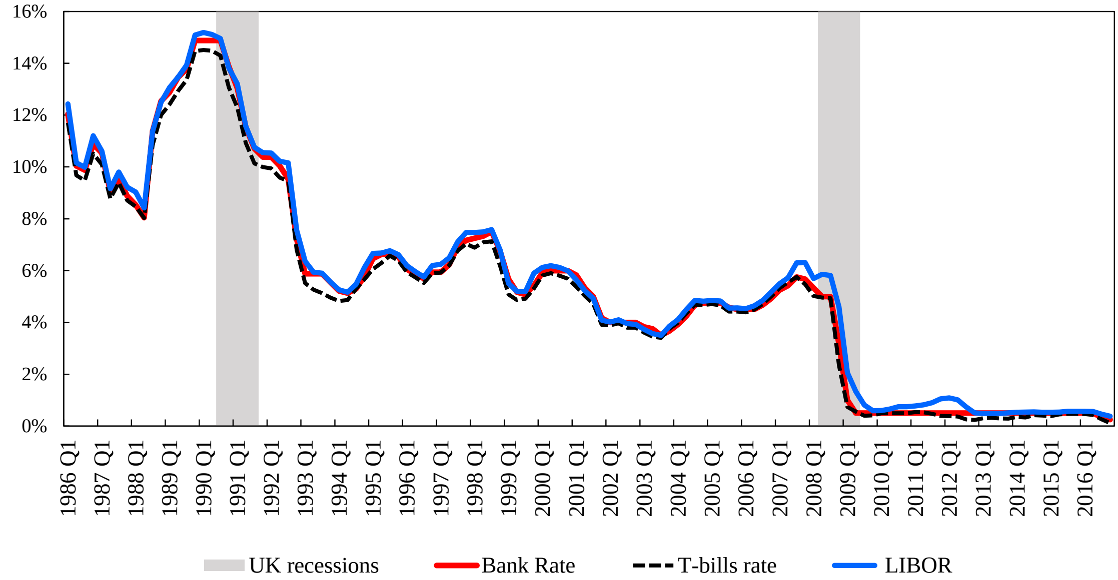


Figure 1.0.2: Ripple effect

NOTE: Data are sourced from BoE, FRED and Datastream. Data are quarterly and of the same maturity of 3 months. All the rates are expressed per annum. Our sample period ends in 2016 because the data on 3-month T-bills have been discontinued since 2017Q3.

However, the presence of Zero Lower Bound (ZLB) constraint limits the scope for further rate cuts. Against this backdrop, the BoE has announced several rounds of large scale asset purchases (LSAPs) since March 2009. The LSAPs, colloquially known as quantitative easing (QE), can be seen as a massive expansion of open market operations (OMOs) through which the BoE purchased assets (mostly are gilts) from households and private institutions and injected liquidity, in the hope of easing the credit condition. As a result, BoE's balance sheets expanded to unprecedented levels: the ratio of BoE's balance sheet to annual UK GDP went from around 6.5% on average between 1955-2007 to 22.5% in 2015 (Quint and Rabanal, 2017).

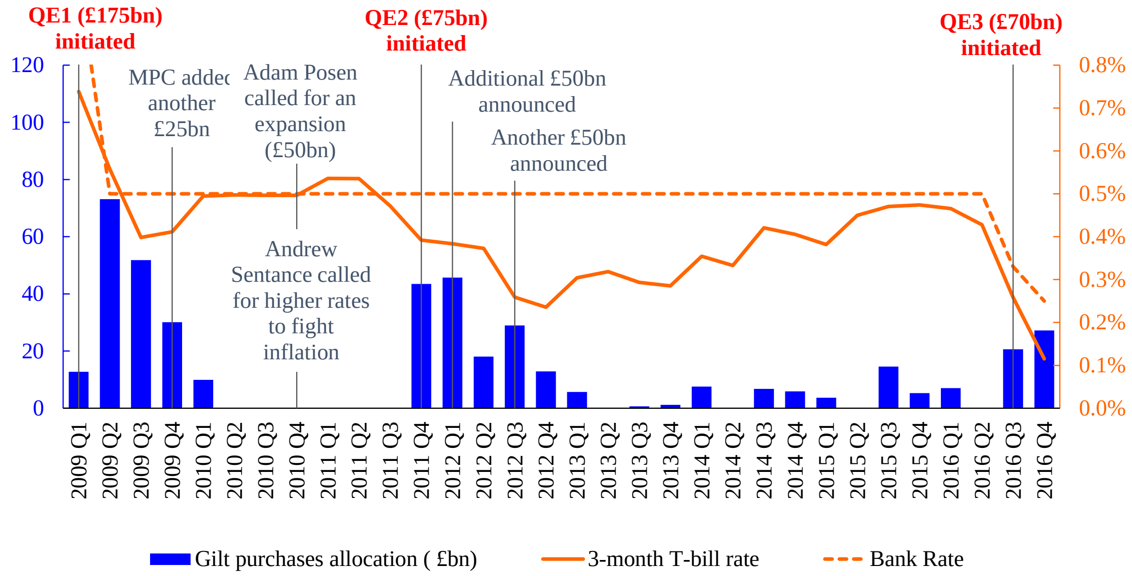


Figure 1.0.3: Gilt purchase by the BoE

NOTE: Gilt purchase data are sourced from BoE: https://www.bankofengland.co.uk/markets/quantitative-easing-and-the-asset-purchase-facility; the events marked in the figure are based on Wikipedia description about QE operations in the UK. Both Adam Posen and Andrew Sentance were then members of Monetary Policy Committee.

The BoE has deployed the Quantitative easing (QE) as an alternative to the conventional monetary policy. There are a few channels through which the QE programmes can influence the interest rates, namely policy (indirect) signal, liquidity premium and inflation premium channels.

Policy signal channel - BoE only resorts to the unconventional monetary policy when the rates are close enough to zero and cannot be dropped much further. By carrying out the QE, the indirect signal the central bank sends to the market rules out the possibility of it raising the rates in the near future, convincing the market participants that the economy is still in the phases of expansion. Upon announcements of QE by the MPC, the short-term rates are likely to remain low in the coming months.

Liquidity premium channel - A liquidity premium is the additional return required by potential investors when any given security cannot be easily sold and converted into cash for its fair market value. An asset is said to be illiquid (liquid) if its liquidity premium is high (low). During an QE operation, the cash (M0) injected to the market through gilt purchases essentially increases the amount of liquidity in the financial system. And with few bonds and more cash available in the market, there will be less difficulty in further converting bonds into cash. This results in a drop in the liquidity premium attached to the cost of borrowing.

Inflation premium channel - Although expected to reduce short and medium term rates, the QE operation in itself inevitably brings about rises in the interest rates over the long horizon by putting upward pressure on prices. Faced with the dual mandate goals of achieving both maximum sustainable growth and inflation stability, the BoE has to balance its two objectives by raising the interest rates to bring the price level under control. One year into the QE1, the MPC member Andrew Sentance called for higher rates to counter above-target inflation. Subsequently there had been gradual rise in Treasury bill rate until it levelled of in 2011 Q1.

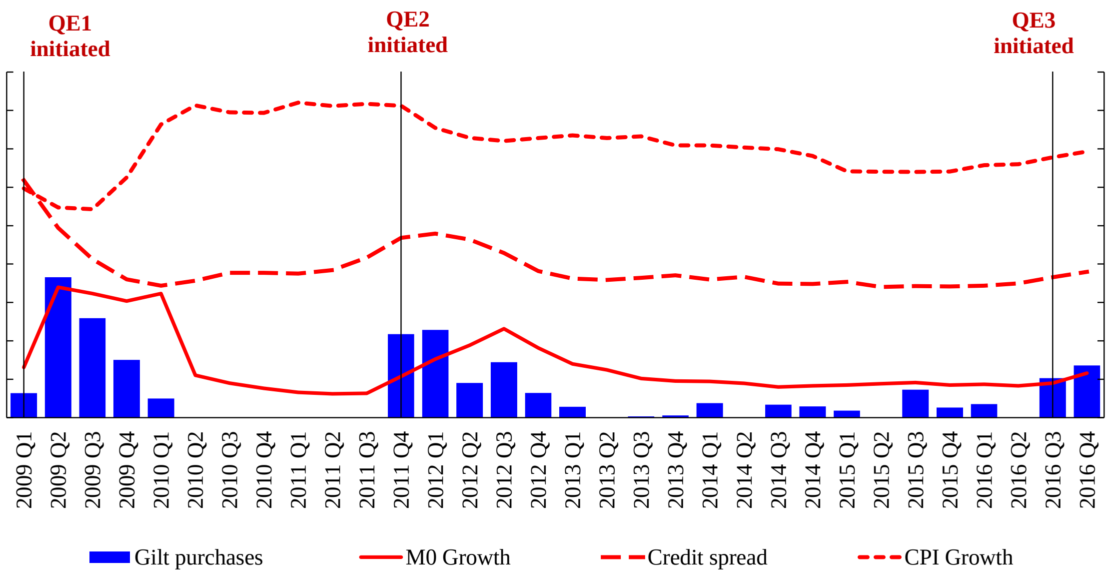


Figure 1.0.4: Qualitative impact of QE

NOTE: M0, credit spread and CPI growth have been rescaled to be laid on top of each other without overlap. For the same reason the tick labels of the axes have been removed.

Starting in 2009 Q1, the BoE has carried out large quantities of gilt purchase from non-bank financial institutions, e.g. pension funds, insurance companies and households, adding to the supply of M0 in circulation. There are immediate gains in the M0 growth following the build up of gilt purchases in each round (See Figure 1.0.4). It is supposed that the higher demand from the LSAPs would bid up bond prices, which in turn reduce the yields with fixed coupon. Moreover, the sellers of gilts are expected to re-invest their proceeds in more risky corporate bonds and equities, thereby pushing down their yields as well. The additional funds held as deposits with commercial banks, combined with reduced cost of borrowing throughout the economy, would contribute to the surge in both investment and consumption. By raising the aggregate demand and consumers' confidence, QE operations also push up the inflation. Upon liquidity injection, higher prices in the financial and housing markets create disequilibrium in the "impact phase"; and to restore balances, real output has to rise sufficiently to reach the new equilibrium in the following “adjustment phase”.

There have been growing studies that investigate the effect of QE on the UK economy. Examples include but are not limited to: Joyce et al. (2011), Breedon et al. (2012), Lyonnet and Werner (2012), Kapetanios et al. (2012), Weale and Wieladek (2016), Haldane et al. (2016) andBoneva et al. (2018). Joyce et al. (2011) provide an overview of the operation and effect of BoE’s QE1. Using a SVAR model, the authors showed the QE have raised the real UK GDP by 1.5% to 2% and increased inflation by around 0.75 to 1.5 pps, concluding that the macroeconomic effects of QE were significant. Breedon et al. (2012) employ a macro term structure model to measure the impact of QE1 in the UK on bonds and other financial assets, finding that QE1 was indeed effective in terms of reducing long-term bond yields via the portfolio-balance channel. However, the broader impact of QE on real activity (i.e. UK production, UK retail sales and the claimant count) remains controversial. Lyonnet and Werner (2012) use a general-to-specific econometric modelling methodology and find a stable relationship between the M4 lending growth and the nominal GDP growth in the UK. Kapetanios et al. (2012) quantify the effects of QE1 in the UK by focusing on the impact of lower long-term interest rates on the wider economy. Using 3 types of VAR models, the authors show that QE had a peak effect on the UK real GDP of around 1.5% and a peak effect on annual CPI inflation of around 1.25 pps. Later work by Weale and Wieladek (2016) provides evidence for the positive impacts of QE on output and inflation. Boneva et al. (2018) employ a novel approach of combining microeconometric data with macroeconomic shocks, finding that QE played a modest role in stabilizing the UK inflation expectations.

While the overall QE implementation in the UK seems successful in accelerating the growth revival, some of the analysts were somewhat skeptical about its role, especially about the second round QE initiated in 2011 Q4. Despite the BoE’s aggressive act of QE2 worth of £75 billion, there was evidence to suggest the lack of confidence among the public, probably due to the ongoing Eurozone debt crisis. The soaring credit spread (In our paper, credit spread is calculated as the difference between the 3-month LIBOR (interest rate on interbank loans) and 3-month T-bill rates (interest rates on the short-term government debts)). This spread is used as an indicator for the financial market distress as the T-bills rates are considered risk-free due to the UK government’s creditworthiness, while LIBOR are the rates that investors charge large banks and come with certain risks. During the crisis, this spread widens as large banks’ default risks rise; during the boom (stable period), the spread narrows as the default risk decreases. The loosely dashed line shows the QE2 has done little to ameliorate the problem of insufficient provision of credit. In practice, the central bank purchase bonds from households, pension funds, and hence pushes up their prices and reduces their yields. These bond seller then re-invest proceeds from selling bonds in the corporate bonds market, and this again pushes up their prices and reduces their yields. Eventually, operation of QE leads to a reduction of borrowing costs in the whole economy. During the QE2, as households lacked confidence in the economic outlook and subsequently viewed the temporary rise in asset prices as signs of bubbles (the temporary low borrowing costs and easy opportunities to leverage a financial position due to QE may lead to asset price bubbles) that would eventually burst and hence put off making investment decisions, QE2's attempt to counteract the rise in credit spread proved to be a failure. Unsure about the temporary gains in their wealth, businesses and households refrain their investment and consumption. The failure to deliver the "virtuous circle" i.e., wherein higher prices can boost confidence, spending, and profits, which in turn provides more stimulus, has made the rise in asset prices fleeting and unable to bolster GDP growth in the medium term.

In short, what is required to incorporate these new developments is a model capable of elucidating the driving forces behind the turbulence since 2008. To this end, we combine available DSGE models to create out of them a fully-fledged small open economy monetary model that can capture the UK data behaviours. Our starting point is the Smets and Wouters (2007) (hereafter, SW), which has been a well-known reference model in the New-Keynesian DSGE literature. We then introduce financial friction along the lines of (Bernanke et al., 1999) (henceforth, BGG), before applying the idea of using cash as the cheapest collateral as in Le et al. (2016a) to inject QE element. Having seen the frequent failures of New-Keynesian models in generating suitable persistence to match the data, we follow Le et al. (2011) and consider a hybrid model in which parts of the economy enjoy price and wage flexibility whereas the others do not. To accommodate the fact that trade accounts for more than 60 % of the UK GDP, we adopt the small-open-economy (SOE) framework in the style of Meenagh et al. (2010), which has proved to be a good fit to the UK.

Departing from the Modigliani and Miller (1958)'s paradigm of a frictionless credit market, numerous attempts have been made to model the credit friction as both determinate and relevant to the real economic outcome, rather than just a passive reflection of it. This is motivated partly by the fact that adverse financial disturbances have been held accountable for the severe contraction and downward shift in economic trend since the crisis (Guerron-Quintana and Jinnai, 2015). The first strand of literature, represented by Bernanke et al. (1999), assumes that financial shocks work to amplify and transmit the standard macroeconomic shocks. These modelling frameworks, most of which focus on either the US or EU, reaffirm the non-trivial role of financial friction in explaining business fluctuations (Christensen and Dib, 2008; De Graeve, 2008; Levin et al., 2004). Another strand of literature, for example, Gerali et al. (2010); Gertler and Kiyotaki (2010); Kollmann et al. (2011); Martin and Ventura (2011) take the stand that banking sectors are the sources of disruptions in themselves and attribute the crisis to the shocks originating in the banking sectors (financial shocks).

Here we introduce financial friction by including commercial banks that provide loans to intermediate goods producers (or entrepreneurs as in BGG) for their capital purchase. The loans are however, subject to "Costly State Verification (CSV)" type of contracts that require lenders to pay a monitoring cost to verify the performance of entrepreneurs (realise return of producers) in case of bankruptcy whereas the borrowers do not. As

Townsend (1979) shows, the introduction of information asymmetry allows us to motivate why the cost of external financing is higher compared to that of internal financing. The difference between the two is dubbed "external financing premium" in BGG paper, or "credit spread" in other literature. In the presence of such financial friction, the amount of credit (external financing premium) depends positively (negatively) on borrowers' net worth. This relationship arises because, borrowers with lower net worth are more likely to default. Therefore they are faced with higher commercial lending rates (charged a higher external financing premium) as a compensation for the additional risks borne by lenders. In economic downturns, decline in asset values caused by adverse macroeconomic shocks would cause a deterioration in the entrepreneurs' balance sheets and subsequently raise the cost of funds raised externally due to the "CSV" contract design. With limited access to funds, entrepreneurs face trouble growing or expanding, and are forced to cut investment, with the resulting drop in cash flows and profits further weakening their balance sheets. Simply put, there is a "vicious cycle" in operation, and the swings in entrepreneurs' net worth act to amplify the shocks to the entire economy through the "financial accelerator mechanism". [4]

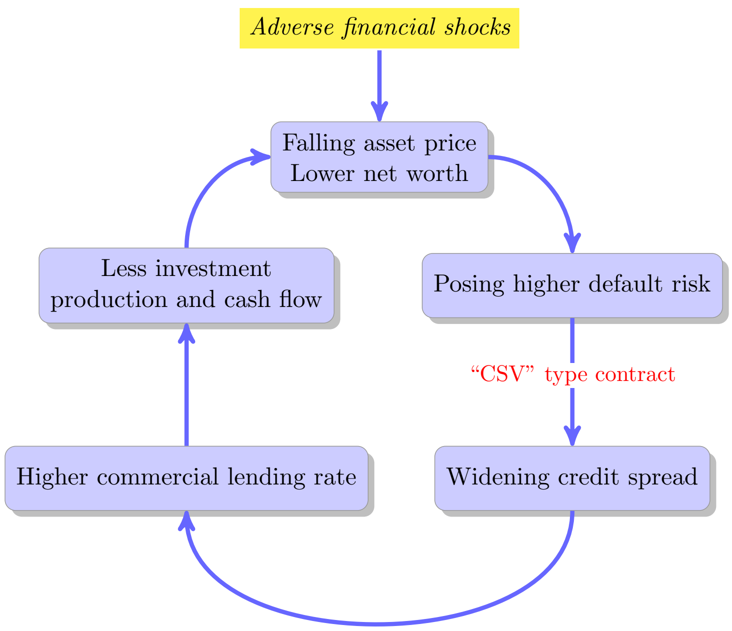


Figure 1.0.5: A vicious cycle

Recall that in the original BGG model, entrepreneurs post no collateral. We embrace the approach of Le et al. (2016a) in supplementing the BGG paper with the assumption that prior to any loan agreement, commercial banks demand some collaterals from entrepreneurs,

[4] The term "financial accelerator" has been first introduced to the macroeconomics literature in Bernanke et al. (1999), to shed light on how seemingly small shocks can eventually cause huge fluctuations in economic aggregates. Entrepreneurs' net worth in general is procyclical owing to the procyclicality nature of asset prices and profits, whereas the external financing premium tends to be countercyclical due to the "CSV" type contract design.

which are supposed to induce extra costs for their liquidation. In practice, QE operation refers to the BoE's act of increasing the money in circulation (e.g. monetary base or M0) for bond purchase from households. This explains why monetary base (M0) spiked during rounds of QE. Based on this fact, Le et al. (2016a) proposes the idea of using M0 as the cheapest collateral to associate M0 injection with the reduction of borrowing cost. The term "collateral" refers to the asset that a borrower offers to a lender as the security for a loan. That is, if the borrower defaults in his payments, the lender can seize the collateral and sells it to recoup some of all of its losses. Traditionally, most popular types of collaterals include real estate (mortgage loans), cars (car loans) and inventory. However, realization and liquidation of such collaterals can be costly. In the even that the borrower does default, it takes the lender time and effort to sell (liquidate) the collateral. Le et al. (2016a) modifies the formation of the BGG loan contract and verifies mathematically that with collateral present, the first-order derivatives of cost of debt financing or external funding cost CY, loan rate Z, and the bankruptcy threshold $\bar{\omega}$ with respect to the collateral liquidation cost (depreciation rate δ) are all positive (i.e. $\frac{dCY}{d\delta} > 0$, $\frac{d\bar{\omega}}{d\delta} > 0$ and $\frac{dZ}{d\delta} > 0$). Intuitively, the lower (higher) the depreciation rate δ, the less (more) expensive the liquidation cost of collateral, the lower (higher) the bankruptcy threshold $\bar{\omega}$ and probability of default, and the lower (higher) the cost of debt financing CY and loan rate Z. It is at this point we propose the idea of using M0 (cash) as the most liquid collateral ($\delta = 0$) to reduce CY, $\bar{\omega}$ and Z. Therefore, QE operation is modelled as the BoE's injection of M0 that will eventually be used as the cheapest collateral to reduce the cost of debt financing CY and hence credit spread $CY - R$. Cash collateral refers to cash, bank accounts, cash equivalents, or the proceeds or rents derived from other collateral held by the debtor in bankruptcy subject to creditors' liens. Examples include negotiable instruments, documents of title, securities, and deposit accounts. In the UK, the BoE defines three sets of eligible collateral: Level A collateral comprises high-quality, most liquid sovereign securities, e.g. Gilts, Sterling Treasury bills, HM Government debt denominated in US dollar, Canadian dollar and Euro, Bank of England securities, sovereign and central bank debt from Canada, France, Germany, the Netherlands and the United States. Besides, from the HMRC internal manual Corporate Finance Manual, it states in the case of stock loans, the collateral can be provided in cash.

Besides QE, there is also a role for the increasingly intrusive regulation in the wake of 2008 financial crisis. Remember that macroprudential (financial) regulation essentially operates through forcing up the cost of borrowing, to reduce the supply of credit and constrain risk-taking behaviours e.g., excessive leverage. In line with this, we model the tightening (loosening) of the macroprudential regulation via raising (lowering) the external financing premium as in Le et al. (2016a). To do so, a stochastic process has been included in the premium equation to capture its role in stabilizing financial systems. It is, however, worth noting that this two-way adjustment only works properly when the steady state regulation is pitched at a distorted level (financial premium is above its minimum), in which case the regulation could either be tightened to offset a narrowing credit spread in boom, or be loosened to counteract a widening credit spread in recession. If, on the other hand, the steady-state level is found to be the minimum, then there is only one way it can go.

For the recent decades, it is common practice for the monetary authorities to set monetary policy according to the straight-forward Taylor type interest rules. The beauty of the Taylor rule lies in its simplicity. The original Taylor rule in (Taylor, 1993) and its variations were proposed to help central banks promote the dual goal of "maximum employment (sustainable growth), and stable inflation" by making interest rate react to movements in inflation and output gap - so called "leaning against the wind" approach. Since 2008, the Taylor rule has been questioned for not being able to accommodate the movement in interest rate anymore, the reason being that the latter has been effectively bounded by zero and hence cannot be lowered any further.[5] The frequent encounters with the ZLB has since complicated the tasks of the BoE, making it difficult to achieve desirable outcomes through conventional monetary policy. Empirically, Kiley and Roberts (2017) attempt to answer the question as to how severe a problem could the ZLB pose on the monetary policy. Their simulation results based on the U.S. economy suggest that under certain economic environment, the ZLB could be binding 30% -40% of the time, a much higher proportion than previously predicted. To accommodate the structural instabilities induced by the ZLB constraint, a wealth of literature has proposed non-linear specifications of the Taylor rule, e.g. Markov-switching, smooth transitions or time-varying parameters (Kim et al., 2005; Koustas and Lamarche, 2012).

We take a different approach by proposing a model consisting of two regimes: a normal scenario, in which the interest rates solve above the ZLB and Taylor rule operates normally, and a crisis scenario, in which the interest rate is intended to fall below the threshold (according to the Taylor rule) and gets suspended at the ZLB. [6] Meanwhile, the supply of M0 is set to target external financing premium, and this feedback rule is supposed to model central bank's QE operations in times of crises (Having already established that M0 injection can eventually reduce the premium for given leverage via its role as the cheapest collateral). Once the interest rate escapes the ZLB, the model switches back to the normal regime with Taylor rule up and running; supply of M0 is set contingent on M2 and being only accommodative.

To test the model as a whole, we employ the Indirect Inference testing and estimation as opposed to the widely-used Bayesian approaches in the DSGE literature. First proposed by Le et al. (2012), indirect inference is a simulation-based methodology for evaluating the model performance. Unlike most simulation-based approaches, it chooses an auxiliary model as the window whereby to compare the actual data and the simulated data among key dimensions. The choices of the auxiliary model (key variables involved) thus determine

[5]With the ZLB constraint present, the scope for the interest rates cut is greatly limited, as households prefer holding cash on hands rather than investing in any negatively-yielding deposits.

[6] As pointed out in Le et al. (2016a), this would not undermine inflation determinacy since the crisis scenario with permanent interest rate peg would not persist forever, as effect of adverse shocks would ultimately fade away.

the aspects upon which we would like to emphasize.[7] If the model is correct, then it should yield sensible simulations not significantly different from historical data through the lens of auxiliary model. Simulated Annealing algorithm is then applied to find the optimal set of coefficients that minimise the Wald statistic. The estimation has proved to be asymptotically normal and consistent (Gourieroux et al., 1993; Gourieroux and Monfort, 1995).

[7] In practice, the auxiliary model usually takes the form of a VARMA, which can be further approximated by a VAR.

Chapter 2

Model Setup (DSGE Model)

In this chapter we discuss in brief the micro-founded DSGE model, which is built upon the well-known reference model of Smets and Wouters (2007) and Bernanke et al. (1999), with the addition of elements developed more recently - occasionally binding ZLB constraint, QE, and macroprudential regulation as in Le et al. (2016a). For this reason, we present our extended model mainly in its log-linearised form.

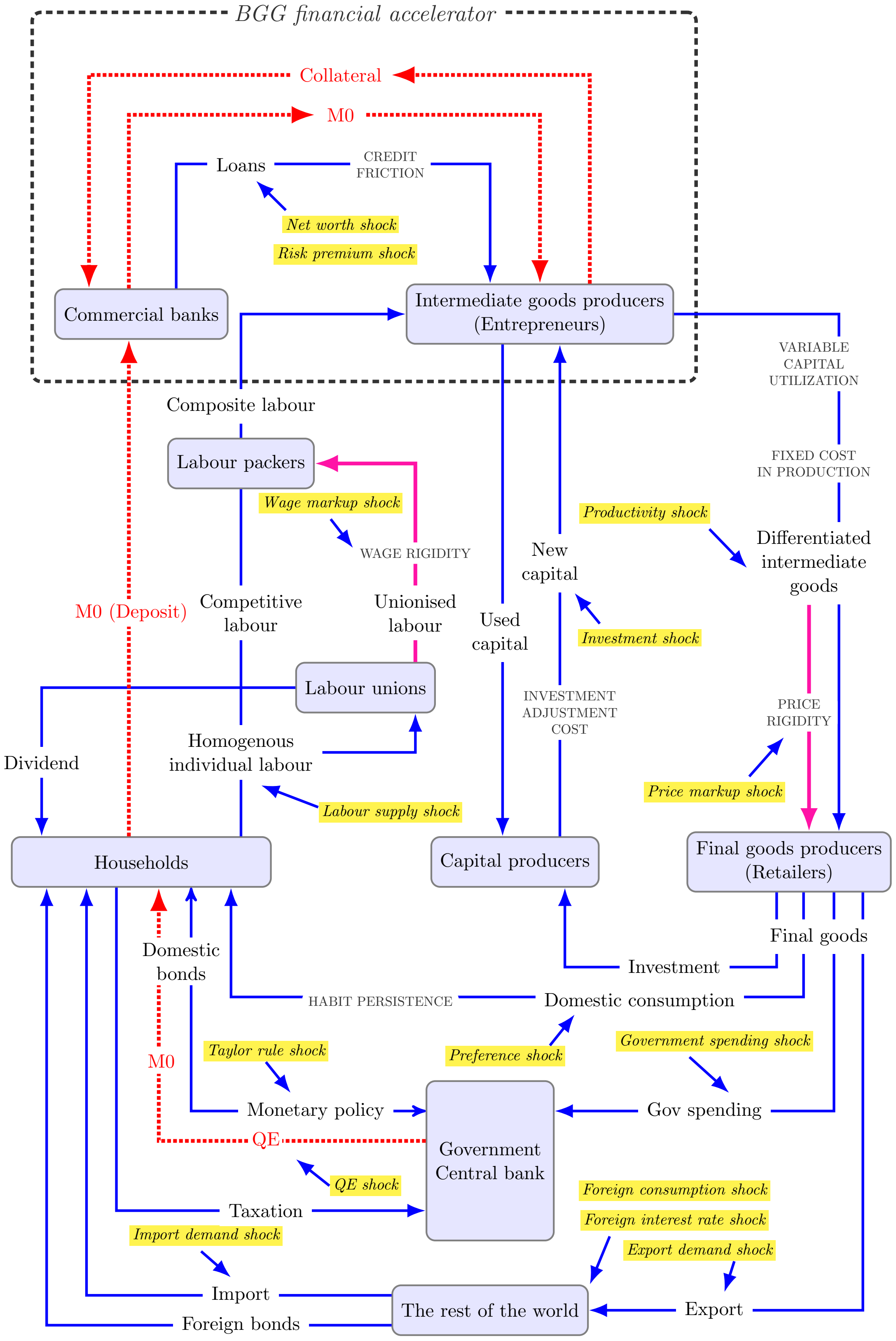


Figure 2.0.1: Sketch of the model structure

2.1 Model microfoundations

2.1.1 Households

There is a continuum of households indexed by $j \in [0,1]$, who supply labour to intermediate goods producers. Unlike in Smets and Wouters (2007), households no longer build and rent the capital, and hence their optimisation does not involve either investment I_t or capital utilisation Z_t. Within the SOE-DSGE framework, we assume that households have access to foreign bonds and imported final goods. Therefore a representative household j chooses consumption $C_t(j)$, hours worked $L_t(j)$, holdings of domestic $B_t(j)$ and foreign bonds $B_t^f(j)$ to maximize the following expected utility function:[1]

$$\max_{C_t, L_t, B_t, B_t^f} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left[\frac{1}{1-\sigma_c} (C_{t+s}(j) - \lambda C_{t+s-1}(j))^{1-\sigma_c} \right] \exp\left(\frac{\sigma_c - 1}{1+\sigma_l} L_{t+s}(j)^{1+\sigma_l} \right) \tag{2.1.1}$$

subject to the budget constraint in real terms:

$$C_t(j) + \frac{B_t(j)}{\epsilon_t^b (1+R_t) P_t} + \frac{S_t B_t^f(j)}{\epsilon_t^b (1+R_t^f) P_t} + T_t \leqslant \frac{B_{t-1}(j)}{P_t} + \frac{S_t B_{t-1}^f(j)}{P_t} + \frac{W_t^h(j) L_t(j)}{P_t} + \frac{Div_t}{P_t} \tag{2.1.2}$$

Household receives wages $W_t^h L_t$ from providing labour in the production of intermediate (whole sale) goods, dividends Div_t distributed from the labour unions, and return from past position in bonds holdings.

σ_c is the inverse of elasticity of intertemporal substitution for constant labour. When $\sigma_c > 1$, consumption C_t and hours worked L_t are complements in utility. Moreover, consumption depends positively on the current hours L_t worked and negatively on expected growth in hours worked $E_t L_{t+1}$ (see log-linearised equation (2.2.1)). This can be understood as hours worked in current period gives positive utility while expected hours worked in future periods generates disutility. As noted in Basu and Kimball (2002), one way to understand this type of utility is as follows. Since consumption and labour are complements, the increased level of consumption expenditure makes working (labour) more pleasant, and hence current labour hours brings utility in households' utility function. With the extra expenditures, things at home can be taken care of pretty well despite all of the hours spent at work; this makes households willing to continue working the same work each week even as they become richer.[2]

R_t and R_t^f are nominal riskless rate on domestic and foreign bonds, respectively. Bonds are one-period and issued at discounts from par values. Notice that B_t can be thought of as either household deposits with commercial banks or domestic government debt. In

[1] Note that with the addition of the RoW block, household's consumption C_t now is comprised of both domestic and imported goods. See Section 2.2.7 for the derivation details.

[2] Basu and Kimball (2002) assume a King-Plosser-Rebelo utility function of the form: $u(C,N) = \frac{C^{1-\gamma}}{\gamma} e^{(\gamma-1)\nu(N)}$, where $\nu(N)$ is a convex function of labour N. γ has the similar interpretation to σ_c in SW(07) and $\frac{1}{\gamma}$ is the labour-held-constant elasticity of intertemporal substitution in consumption.

equilibrium two instruments pay the same riskless return R_t and thus are perfect substitutes. During central bank's QE operations, although M0 does not pay any interests, deposit does and pays the exactly same interest (R) as the bond. Hence, our assumption that households are willing to sell bonds in exchange for $M0$ which will further be placed with commercial banks as deposits that also pay R does make sense (for details of QE operation, see Section 2.1.4.1 page 35).

P_t represents the domestic price level and S_t denotes the nominal exchange rate. Total income is used to consume final goods C_t, to pay taxation T_t and to re-invest in domestic and foreign bonds.[3] Household's habit formation is captured by the parameter λ, which provides source of real rigidity. Following De Walque et al. (2017), domestic and foreign bonds are both subject to a preference shock ϵ_t^b that represents the premium in the return to bonds. A positive preference shock increases the realised return on bonds and hence reduces the consumption. The decisions on consumption, labour supply and holdings of domestic and foreign bonds are determined by the FOCs from the maximisation of Equation (2.1.1) subject to the budget constraint Equation (2.1.2):

$$\partial C_t : \quad \exp\left[\frac{\sigma_c - 1}{1+\sigma_L} L_t^{1+\sigma_L}\right] (C_t - \lambda C_{t-1})^{-\sigma_c} = \Xi_t \tag{2.1.3}$$

$$\partial L_t : \quad \left[\frac{1}{1-\sigma_c}(C_t - \lambda C_{t-1})^{1-\sigma_c}\right] \exp\left(\frac{\sigma_c - 1}{1+\sigma_L} L_t^{1+\sigma_L}\right) (\sigma_c - 1) L_t^{\sigma_L} = -\Xi_t \frac{W_t^h}{P_t} \tag{2.1.4}$$

$$\partial B_t : \quad \frac{\Xi_t}{\epsilon_t^b (1+R_t) P_t} = \beta\, \mathbb{E}_t \left[\frac{\Xi_{t+1}}{P_{t+1}}\right] \tag{2.1.5}$$

$$\partial B_t^f : \quad \frac{\Xi_t S_t}{\epsilon_t^b (1+R_t^f) P_t} = \beta\, \mathbb{E}_t \left[\frac{\Xi_{t+1} S_{t+1}}{P_{t+1}}\right] \tag{2.1.6}$$

where Ξ_t is the Lagrange multiplier associated with the budget constraint. Households' optimal decisions on consumption and labour are standard and closely replicate the structure of SW(07). What we care about here is the determination of exchange rate. Combining Euler equations 2.1.5 with 2.1.6 yields:

$$\frac{1+R_t^f}{(1+R_t)S_t} = \frac{1}{\mathbb{E}_t\, S_{t+1}} \tag{2.1.7}$$

Note $S_t = Q_t \dfrac{P_t}{P_t^f}$, where Q_t denotes the real exchange rate, and P_t^f represents the general foreign price level. Substituting above expression for S_t into Equation (2.1.7) leads to:

$$\frac{(1+R_t^f)P_t^f}{(1+R_t)Q_t P_t} = \mathbb{E}_t \left[\frac{P_{t+1}^f}{Q_{t+1} P_{t+1}}\right] \tag{2.1.8}$$

in logs, this implies:

$$\hat{r}_t^f + \hat{p}_t^f - \hat{r}_t - \hat{q}_t - \hat{p}_t = \mathbb{E}_t\, \hat{p}_{t+1}^f - \mathbb{E}_t\, \hat{q}_{t+1} - \mathbb{E}_t\, \hat{p}_{t+1} \tag{2.1.9}$$

further rearrangement gives:

[3] T_t can be seen as subsidies if negative.

$$\mathbb{E}_t\,\hat{q}_{t+1} - \hat{q}_t = [\hat{r}_t - (\mathbb{E}_t\,\hat{p}_{t+1} - \hat{p}_t)] - [\hat{r}_t^f - (\mathbb{E}_t\,\hat{p}_{t+1}^f - \hat{p}_t^f)] \tag{2.1.10}$$

Substituting $E_t\pi_{t+1} = E_tp_{t+1} - p_t$ and $E_t\pi_{t+1}^f = E_tp_{t+1}^f - p_t^f$ into Equation (2.1.10) leads to the Real Uncovered Interest Rate Parity (UIRP) condition which pins downs the movement of real exchange rate:

$$\mathbb{E}_t\,\hat{q}_{t+1} - \hat{q}_t = (\hat{r}_t - \mathbb{E}_t\,\hat{\pi}_{t+1}) - (\hat{r}_t^f - \mathbb{E}_t\,\hat{\pi}_{t+1}^f) \tag{2.1.11}$$

The intuition behind the parity is that assuming incomplete asset markets, [4] the expected change in real exchange rate equals the real interest rate differential between the UK and the RoW. An example of this is a rise in domestic real interest rate that violates the UIRP condition must be restored by a current fall in q_t (appreciation) in anticipation of a future rise in $\mathbb{E}_t\,q_{t+1}$ (depreciation).

2.1.2 Intermediate labour union sector (hybrid wage setting)

In the SW(07) paper, households supply their homogeneous individual labour to the **labour unions** that differentiate the labour services before the latter sells them to labour packers. To match the degree of persistence observed in data, we follow Le et al. (2011) in assuming that intermediate goods producers producing intermediate (wholesale) goods have a production function that combines in a fixed proportion labour in imperfectly competitive markets (i.e., unionised labour) with labour from perfectly competitive markets. Hence, the labour supplied to the intermediate goods producers becomes:

$$L_t = L_{1t} + L_{2t} = \left[\int_0^1 (L_{1it})^{\frac{1}{1+\lambda_{w,t}}}\,di\right]^{1+\lambda_{w,t}} + \left[\int_0^1 (L_{2it})di\right] \tag{2.1.12}$$

where L_{1it} is the unionised labour, and L_{2it} is the competitive labour supplied by the ith household at time t. L_t can be thought of as representing the activities of **labour packers (labour bundlers)**. Note that $L_{1t} = \omega_{NK}^w L_t$, and $L_{2t} = (1 - \omega_{NK}^w)L_t$ where ω_{NK}^w is the share of unionised labour in the total. Hence, the aggregate wage setting is given by:

$$W_t = \omega_{NK}^w W_{1t} + (1 - \omega_{NK}^w)W_{2t} \tag{2.1.13}$$

where W_{1t} is the set according to the Calvo wage-setting equation, and W_{2t} is set equal to current expected marginal monetary disutility of work. These wages will then be passed to labour packers (bundlers) who offers above weighted wage for each unit of labour before selling aggregate labour to intermediate goods producers. Moreover, we further assume that each household's utility includes the two sorts of labour in the say way.

[4] As noted in Chari et al. (2002), imposing complete financial markets means the expected change in real exchange rate must always equal the real interest rate differentials; whereas under the assumption of incomplete financial markets, changes in real exchange rate are only expected to restore UIRP eventually, which allows random walk shocks to cause temporary violation (deviation) from the UIRP condition.

2.1.3 Final goods producers (hybrid price setting)

Final goods producers (retailers) are price takers that operate under perfect competition. They assemble intermediate (wholesale) goods purchased from intermediate goods producers. No capital or labour is required in the production of final goods.[5] As for the hybrid wage setting, we assume that final (retail) output is made up in fixed proportion of intermediate (wholesale) goods produced in an imperfectly competitive market and intermediate goods produced in perfectly competitive market. Final (retail) output hence is given by:

$$Y_t = Y_{1t} + Y_{2t} = \left[\int_0^1 (Y_{1jt})^{\frac{1}{1+\lambda_{p,t}}} dj \right]^{1+\lambda_{p,t}} + \left[\int_0^1 (Y_{2jt}) dj \right] \tag{2.1.14}$$

where the intermediate goods producers prices Y_{1t} according to the Calvo mark-up equation on marginal costs, and Y_{2t} at marginal costs. Note that $Y_{1t} = \omega^p_{NK} Y_t$, where similarly ω^p_{NK} is the share of goods sold in imperfectly competitive market. Therefore we have $Y_{2t} = (1 - \omega^p_{NK}) Y_t$. The hybrid price setting becomes:

$$P_t = \omega^p_{NK} P_{1t} + (1 - \omega^p_{NK}) P_{2t} \tag{2.1.15}$$

where P_t is the aggregate price level. The final goods producers (retailers) combine these intermediate goods before selling them as a bundle at above weighted average price.

2.1.4 Intermediate goods producers (& commercial banks)

We integrate the BGG financial accelerator mechanism into SW(07) by modifying the latter's setup and assuming that IG producers now have to take loans from commercial banks to fund their capital purchase. In line with Bernanke et al. (1999), the present model is constructed without a clearly-specified role for banks or other financial intermediaries, albeit we implicitly assume that there exist perfectly competitive commercial banks that absorb deposits from households at deposit rate (riskless) R_t and lend funds to IG producers at commercial lending rate (risky) CY_t. As in the BGG paper, it is the demand side of the credit (IG producers) that faces the financial friction.

The activities of the entrepreneurs lie at the heart of the model. They are involved in: 1) stipulation of the loan contracts to obtain funds for their capital purchase; 2) determination of the level of capital utilization; 3) production of wholesale goods. In what follows, we will briefly discuss them.

2.1.4.1 Financial friction & Unconventional monetary policy & Macroprudential policy

Risk premium Financial friction is introduced á la Bernanke et al. (1998). Unlike in the SW(07), IG producers no longer rent capital from households, instead they purchase newly-produced capital from capital producers at price PK_t in period t and uses it in

[5] This becomes less far-fetched when considering that some intermediate goods may actually be services.

production in period t+1. At t+1, IG producers receive the proceeds - the marginal product of capital RK_{t+1} from operating their capital, and the undepreciated capital $(1-\delta)$ which is then sold back to capital producers at price PK_{t+1}.

In financing their capital purchase, entrepreneurs must sign "CSV" type contract with commercial banks. Hence in equilibrium the capital arbitrage condition implies: [6]

$$\mathbb{E}_t[CY_{t+1}] = \mathbb{E}_t\left[\frac{RK_{t+1} + (1-\delta)PK_{t+1}}{PK_t}\right] \tag{2.1.16}$$

where E_tCY_{t+1} is the expected marginal rate of return on capital, which equals expected cost of external funds in equilibrium, and δ is the depreciation rate. Equation (2.1.16) states that the expected rate of return on holding a unit of capital (marginal external financing cost) from period t to t+1 consists of the marginal product of capital and the capital gain. It is nothing more than the term structure of interest rate if taken in expectations and solved forward (Gelain, 2010).

As in BGG paper, financial friction arises here due to asymmetric information between the borrower (IG producers) and lenders (commercial banks). Intermediate goods' production is subject to a idiosyncratic shock that is only known to IG producers and cannot be observed by banks. Monitoring the actual output of IG producers is costly and it only takes place in case of default.

In the face of costly monitoring, the optimal contract is the one that charges a premium over risk-free rate for taking on extra risks when lending to IG producers with higher leverage ratio (that more heavily rely on external borrowing).

Partial equilibrium contracting problem For simplicity, we drop index i. Specifically, firms chooses their capital used in the next period K_{t+1}, and the amount of borrowing $B_t = PK_tK_{t+1} - N_{t+1}$ (difference between the capital expenditure PK_tK_{t+1} and his networth N_t) prior to the realization of the idiosyncratic productivity shock ω. Therefore, the optimal contract is characterized by a gross non-default loan rate Z_t, and a threshold value of the idiosyncratic productivity shock $\bar{\omega}$.

The BGG contract consists of three parts:

1) A bankruptcy threshold at which IG firms are indifferent between default and staying in business (for convenience, we drop index i):

$$\bar{\omega}(1 + CY_{t+1})PK_tK_{t+1} = Z_{t+1}Borr_{t+1} = Z_{t+1}(PK_tK_{t+1} - N_{t+1}) \tag{2.1.17}$$

where $\bar{\omega}$ - threshold value of the idiosyncratic shock ω with $E(\omega)$=1. CY_t - required return on capital (external financing cost or risky return), PK_t - price paid per unit of capital. N_t - net worth of the entrepreneur or self-financed part of the capital purchase expenditure ($N_{t+1} = PK_tK_{t+1} - Borr_{t+1}$). According to Bernanke et al. (1999), the net worth of entrepreneurs comes from two sources: profits (including capital gains) accumulated from

[6] Note that compared to the case without financial accelerator (SW07), the steady state value of R_t^K - R_*^K changes from $\frac{1}{\beta}\gamma^{\sigma_c} - (1-\delta)$ to $\left(\frac{K}{N}\right)^{\chi}\frac{1}{\beta}\gamma^{\sigma_c} - (1-\delta)$.

previous capital investment and income from supplying labour. K_t - amount of capital purchase, Z_t - gross non-default loan rate, and $Borr_{t+1}$ - amount of borrowing. At period t, the entrepreneur buys capital K_{t+1} that will be used throughout period t+1 at the unit cost PK_t. A fraction of capital purchase is financed by their N_{t+1}, with the remainder financed by $Borr_{t+1}$ from the commercial bank. Notice that in equilibrium total loanable funds supplied to IG producers $Borr_t$ equals total household deposits with commercial banks. (2.1.17) states that conditional on a threshold value of the idiosyncratic shock $\bar{\omega}$, the gross returns firm i receives at time t+1 are equal to the loan payment.

2) On the bank's side, free entry drives profits to zero:

$$\begin{aligned}\big[1-F(\bar{\omega})\big]Z_{t+1}Borr_{t+1}+(1-\mu)\int_0^{\bar{\omega}}\omega(1+CY_{t+1})PK_tK_{t+1}dF(\omega) &= (1+R_{t+1})Borr_{t+1}\\ &= (1+R_{t+1})(PK_tK_{t+1}-N_{t+1})\end{aligned} \tag{2.1.18}$$

where $F(\omega)=Pr[\omega<x]$ is a continuous probability distribution with $F(0)=0$, so $F(\bar{\omega})$ - the probability of going bankruptcy. R_t - risk free return on capital. The LHS of Equation (2.1.18) calculates the aggregate expected payment to the bank in two scenarios. It is the sum of loan proceeds in case of no default (the first term on the LHS), and total payment received in case of default composed of residual claims, less the auditioning cost (μ). On the RHS is banks' opportunity cost of obtaining funds from households at the risk-free rate R_t.

Substituting bankruptcy threshold equation (2.1.17) into (2.1.18) can eliminate the loan rate Z_t:

$$\Big\{\big[1-F(\bar{\omega})\big]\bar{\omega}+(1-\mu)\int_0^{\bar{\omega}}\omega dF(\omega)\Big\}\Big[(1+CY_{t+1})PK_tK_{t+1}\Big]=(1+R_{t+1})(PK_tK_{t+1}-N_{t+1}) \tag{2.1.19}$$

3) Firm's maximization of its return subject to Eq (2.1.19) which combines condition 1) and 2). Firm's expected return is:

$$\int_{\bar{\omega}}^{\infty}\omega(1+CY_{t+1})PK_tK_{t+1}dF(\omega)-\big[1-F(\bar{\omega})\big]Z_{t+1}Borr_{t+1} \tag{2.1.20}$$

where the first part of (2.1.20) calculates the gross return in case of no-default ($\omega>\bar{\omega}$), and the second the part gives the total loan payments in case of non-default (with probability $\big[1-F(\bar{\omega})\big]$). When $\omega<\bar{\omega}$, firm defaults and receives nothing.

We denote by $f(\omega)$ the pdf of ω, so that $dF(\omega)=f(\omega)d\omega$. By definition $\big[1-F(\bar{\omega})\big]=\int_{\bar{\omega}}^{\infty}f(\omega)d\omega$. We define $G(\bar{\omega})=\int_0^{\bar{\omega}}\omega f(\omega)d\omega$. The expected gross share of profits going to the bank is $\Gamma(\bar{\omega})=\int_0^{\bar{\omega}}\omega f(\omega)d\omega+\bar{\omega}\int_{\bar{\omega}}^{\infty}f(\omega)d\omega$ where the first part gives the result when firm defaults, and the second part when the firm does not. Note that we define $\Gamma(\bar{\omega})=G(\bar{\omega})+\bar{\omega}\big[1-F(\omega)\big]$, so the net share of profits going to the bank (gross share of profits - monitoring cost) $=\Gamma(\bar{\omega})-\mu G(\bar{\omega})$.

Firm's maximization objective (2.1.20) becomes:

$$
\begin{aligned}
&\int_{\bar{\omega}}^{\infty} f(\omega)\omega(1+CY_{t+1})PK_tK_{t+1}d\omega - \int_{\bar{\omega}}^{\infty} f(\omega)d\omega\Big[\bar{\omega}(1+CY_{t+1})PK_tK_{t+1}\Big] \\
&= \Big[\int_{\bar{\omega}}^{\infty} f(\omega)\omega d\omega - \bar{\omega}\int_{\omega}^{\infty} f(\omega)d\omega\Big]\Big[(1+CY_{t+1})PK_tK_{t+1}\Big] \\
&= \Big[1 - \int_{0}^{\bar{\omega}} f(\omega)\omega d\omega - \bar{\omega}\int_{\omega}^{\infty} f(\omega)d\omega\Big]\Big[(1+CY_{t+1})PK_tK_{t+1}\Big] \\
&= \Big\{1 - \Big[\int_{0}^{\bar{\omega}} f(\omega)\omega d\omega + \bar{\omega}\int_{\omega}^{\infty} f(\omega)d\omega\Big]\Big\}\Big[(1+CY_{t+1})PK_tK_{t+1}\Big] \\
&= \big[1-\Gamma(\omega)\big]\Big[(1+CY_{t+1})PK_tK_{t+1})\Big]
\end{aligned}
\tag{2.1.21}
$$

where $1-\Gamma(\bar{\omega})$ is the share of profits going to the firm.

Bank's zero profit condition (2.1.19) can be rewritten as:

$$
\begin{aligned}
&\Big[\bar{\omega}\int_{\bar{\omega}}^{\infty} f(\omega)d\omega + (1-\mu)\int_{0}^{\bar{\omega}} \omega f(\omega)d\omega\Big]\Big[(1+CY_{t+1})PK_tK_{t+1}\Big] \\
&= \Big[\Gamma(\bar{\omega}) - G(\bar{\omega}) + (1-\mu)G(\bar{\omega})\Big]\Big[(1+CY_{t+1})PK_tK_{t+1}\Big] \\
&= \Big[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\Big]\Big[(1+CY_{t+1})PK_tK_{t+1}\Big] = (1+R_{t+1})(PK_tK_{t+1} - N_{t+1})
\end{aligned}
\tag{2.1.22}
$$

The optimal contracting problem with non-stochastic monitoring now can be written as firm's maximization of expected return (2.1.21) subject to bank's zero profit condition (2.1.22):

$$\underset{K,\,\bar{\omega}}{Max} = \big[1-\Gamma(\omega)\big](1+CY_{t+1})PK_tK_{t+1}$$

subject to $\big[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\big]\big[(1+CY_{t+1})PK_tK_{t+1}\big] = (1+R_{t+1})(PK_tK_{t+1} - N_{t+1})$

We define the external financing premium $PM_t = \frac{1+CY_{t+1}}{1+R_{t+1}}$, and then the leverage ratio $Lev_t = PK_tK_{t+1}/N_{t+1}$. We set up the Lagrangian and denote the multiplier by λ. The first-order conditions yield:

$$\bar{\omega} : \Gamma'(\bar{\omega}) - \lambda\big[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})\big] = 0 \tag{2.1.23}$$

$$Lev : \Big\{\big[1-\Gamma(\bar{\omega})\big] + \lambda\big[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\big]\Big\}PM_t - \lambda = 0 \tag{2.1.24}$$

$$\lambda : \big[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\big]PM_tLev_t - (Lev_t - 1) = 0 \tag{2.1.25}$$

As $\big[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})\big]$ (share of profits going to the bank) is increasing on $(0, \bar{\omega}^*)$ and decreasing on $(\bar{\omega}^*, \infty)$, the bank will never choose $\bar{\omega} > \bar{\omega}^*$ We consider $0 < \bar{\omega} < \bar{\omega}^*$ which suggests an interior solution. From (2.1.23) we can solve for λ:

$$\lambda(\bar{\omega}) = \frac{\Gamma'(\bar{\omega})}{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})} \tag{2.1.26}$$

Taking derivatives of (2.1.23) yields:

$$\lambda'(\bar{\omega}) = \frac{\mu\big[\Gamma'(\bar{\omega})G''(\bar{\omega}) - \Gamma''(\bar{\omega})G'(\bar{\omega})\big]}{\big[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})\big]^2} > 0 \quad \text{for}\, \bar{\omega} \in (0, \bar{\omega}^*) \tag{2.1.27}$$

Taking limits we obtain:

$$\lim_{\bar{\omega}\to 0} \lambda(\bar{\omega}) = 1, \qquad \lim_{\bar{\omega}\to\bar{\omega}^*} \lambda(\bar{\omega}) = +\infty \tag{2.1.28}$$

Now we define:

$$\rho(\bar{\omega}) = \frac{\lambda(\bar{\omega})}{1 - \Gamma(\bar{\omega}) + \lambda\big[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\big]} \tag{2.1.29}$$

Then from (2.1.24) we have:

$$PM_t = \frac{\lambda(\bar{\omega})}{1 - \Gamma(\bar{\omega}) + \lambda\big[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\big]} = \rho(\bar{\omega}) \tag{2.1.30}$$

where $\rho(\bar{\omega})$ calculates the wedge between the risky return on capital (loans) and risk-free return on deposit. Taking derivatives of (2.1.30) gives:

$$\rho'(\bar{\omega}) = \rho(\bar{\omega})\frac{\lambda'(\bar{\omega})}{\lambda(\bar{\omega})}\left[\frac{1 - \Gamma(\bar{\omega})}{1 - \Gamma(\bar{\omega}) + \lambda\big[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\big]}\right] > 0 \quad \text{for}\, \bar{\omega} \in (0, \bar{\omega}^*) \tag{2.1.31}$$

Taking limits yields:

$$\lim_{\bar{\omega}\to 0} \rho(\bar{\omega}) = 1, \qquad \lim_{\bar{\omega}\to\bar{\omega}^*} \rho(\bar{\omega}) = PM^* < \frac{1}{1-\mu} \tag{2.1.32}$$

Hence, for $PM_t < PM^*$, a one-on-one mapping between $\bar{\omega}$ and PM_t is guaranteed. (2.1.30) hence establishes the monotonically increasing relationship between default probability and the risk premium.

Finally, from (2.1.25) we can solve for Lev:

$$Lev_t = 1 + \frac{\lambda\big[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})\big]}{1 - \Gamma(\bar{\omega})} = \Psi(\bar{\omega}) \tag{2.1.33}$$

where we define $\Psi(\bar{\omega}) = 1 + \frac{\lambda[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]}{1-\Gamma(\bar{\omega})}$. Then, given a $\bar{\omega} \in (0, \bar{\omega}^*)$, there exists a unique Lev_t.

Computing derivations we obtain:

$$\Psi'(\bar{\omega}) = \frac{\lambda'(\bar{\omega})}{\lambda(\bar{\omega})}\big[\Psi(\bar{\omega}) - 1\big] + \frac{\Gamma'(\bar{\omega})}{1 - \Gamma(\bar{\omega})}\Psi(\bar{\omega}) > 0 \quad \text{for}\, \bar{\omega} \in (0, \bar{\omega}^*) \tag{2.1.34}$$

and taking limits:

$$\lim_{\bar{\omega}\to 0} \Psi(\bar{\omega}) = 1, \qquad \lim_{\bar{\omega}\to\bar{\omega}^*} \Psi(\bar{\omega}) = +\infty \tag{2.1.35}$$

Combining (2.1.30) that expresses PM_t as a monotonic function of $\bar{\omega}$ and (2.1.33) that expresses Lev_t as a function of $\bar{\omega}$ we obtain:

$$\frac{PK_t K_{t+1}}{N_t} = Lev_t = \nu(PM_t) = \nu\left(\frac{1+CY_{t+1}}{1+R_{t+1}}\right) \tag{2.1.36}$$

where $\nu'(PM_t) > 0$ for $PM_t \in (1, PM^*)$. Therefore, PM is an increasing function of the leverage ratio Lev_t. Log-linearising yields:

$$\mathbb{E}_t\, \hat{cy}_{t+1} - \hat{r}_t = \hat{pm}_t = \chi(\hat{pk}_t + \hat{k}_{t+1} - \hat{n}_{t+1}) + \epsilon_t^{pm} \tag{2.1.37}$$

where $\chi > 0$ is the parameter that governs the degree of financial friction. pm_t is the external financing premium given by the wedge between the cost of external cy_t and internal funds r_t. Alternative interpretations include the lending-deposit spread between commercial lending rate cy_t and deposit rate r_t,[7] or credit spread between the risky return cy_t and riskless return r_t. Equation (2.1.44) implies that the risky return (expected return on capital) cy_t is equal to the safe return (yield on bonds or deposit) r_t plus the premium to compensate for the additional risk borne by lenders. pm_t increases with the leverage ratio $\frac{PK*K}{N}$ (indicative of borrower's balance sheet position) and hence for IG producers more heavily reliant on external funds for capital acquisition, banks' willingness to borrow declines, which is reflected as a rise in the lending-deposit spread.

Introduction of QE Recall that in the original BGG model, entrepreneurs post no collateral, we follow Le, et al (2012) in supplementing the BGG model with the assumption that banks require entrepreneurs to put up a fraction c of their net worth as the collateral. The recovery of this collateral would cost a proportion δ of its original value, where δ corresponds to the depreciation rate in the SW (07) model.

The BGG contract essentially consists of three parts. We start with reviewing the original setup, before outlining the new formation due to the introduction of collateral.

1) The original bankruptcy threshold:

$$\bar{\omega}(1+CY_{t+1})\, PK_t K_{t+1} = Z_{t+1}\big(PK_t K_{t+1} - N_{t+1}\big) = Z_{t+1} Borr_{t+1} \tag{2.1.38}$$

With the introduction of collateral, at the bankruptcy threshold (2.1.38) becomes:

$$\bar{\omega}(1+CY_{t+1})\, PK_t K_{t+1} + cN_{t+1} = Z_{t+1}\big(PK_t K_{t+1} + cN_{t+1} - N_{t+1}\big) = Z_{t+1} Borr_{t+1} \tag{2.1.39}$$

where c - proportion of net worth demanded as collateral. With the collateral demanded by banks, their cost of total capital purchase becomes $PK_t K_{t+1} + cN_{t+1}$ with collateral costs included. And borrowing becomes $Borr_t = PK_t K_{t+1} + cN_{t+1} - N_{t+1}$. (2.1.39) states that conditional on the threshold value of the idiosyncratic shock $\bar{\omega}$, the gross returns firm i receives at time t+1 plus the value of collateral it gets to keep in the non-default case (LHS) are equal to the total loan payment (RHS).

As before, we define bank's leverage ratio $Lev_t = PK_t K_{t+1}/N_{t+1}$, and from Equation

[7] The term "lending-deposit spread" also appears in Quint and Rabanal (2013) which embeds BGG financial accelerator in a DSGE model for the analysis of monetary and macroprudential policies in the Euro Area.

(2.1.39) we solve for loan rate: $Z_t = \frac{(1+CY_{t+1})\,\bar{\omega}Lev_t+c}{Lev_t-1+c}$.

2) On the bank's side, free entry drives profits to zero. The original BGG setup gives:

$$\big[1-F(\bar{\omega})\big]Z_{t+1}Borr_{t+1}+(1-\mu)G(\bar{\omega})(1+CY_{t+1})PK_tK_{t+1} = (1+R_{t+1})Borr_{t+1} \quad (2.1.40)$$

where $F(\omega) = Pr[\omega < x]$ is a continuous probability distribution with $F(0) = 0$, so $F(\bar{\omega})$ - the probability of going bankruptcy. We define by $f(\omega)$ the probability density function of ω. μ - auditioning cost which is a proportion of expected return on investment. We define $G(\bar{\omega}) = \int_0^{\bar{\omega}} \omega f(\omega)d\omega$, and $\mu G(\bar{\omega}) = \mu \int_0^{\bar{\omega}} \omega f(\omega)d\omega$ gives the expected monitoring costs. δ - depreciation rate (liquidation cost), and R_t - risk free return on capital. The LHS of Equation (2.1.40) calculates the aggregate expected payment to the bank in two scenarios. On the RHS is banks' opportunity cost of obtaining funds from households at the risk-free rate R_t.

With collateral present, (2.1.40) becomes:

$$\big[1-F(\bar{\omega})\big]Z_{t+1}Borr_{t+1} + \Big[(1-\mu)G(\bar{\omega})(1+CY_{t+1})PK_tK_{t+1} + cN_{t+1}F(\bar{\omega})(1-\delta)\Big]$$
$$= (1+R_{t+1})Borr_{t+1} \quad (2.1.41)$$

where the extra term $cN_tF(\bar{\omega})(1-\delta)$ on the LHS gives the recovery of collateral net of liquidation cost in case of default. The rest of (2.1.40) is unaffected. Substituting Equation (2.1.39) into both sides of Equation (2.1.39) yields:

$$\big[1-F(\bar{\omega})\big](1+CY_{t+1})\,\bar{\omega}PK_tK_{t+1} + \Big[(1-\mu)G(\bar{\omega})(1+CY_{t+1})PK_tK_{t+1} + cN_{t+1}\big(1-\delta F(\bar{\omega})\big)\Big]$$
$$= (1+R_{t+1})(PK_tK_{t+1} - N_{t+1} + cN_{t+1}) \quad (2.1.42)$$

Again, we define $\Gamma(\bar{\omega}) = [1-F(\bar{\omega})]\bar{\omega} + G(\bar{\omega})$. Substituting this expression into (2.1.42) and dividing both sides by N_t yields:

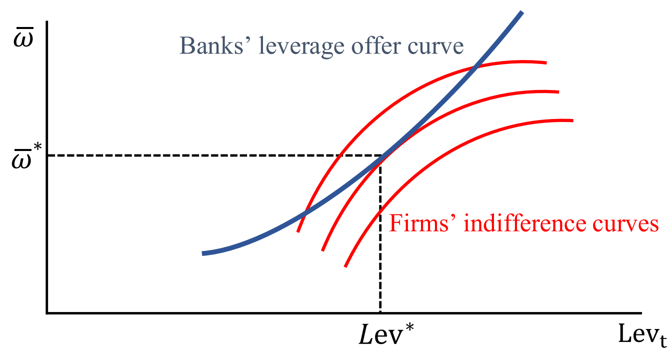
$$[\Gamma(\bar{\omega})-\mu G(\bar{\omega})](1+CY_{t+1})Lev_t = (1+R_{t+1})(Lev_t-1)+c\big[1+R_{t+1}-1+\delta F(\bar{\omega})\big] \quad (2.1.43)$$

From (2.1.57) we can solve for the leverage ratio:

$$Lev_t = \frac{1+R_{t+1}-c\big[R_{t+1}+\delta F(\bar{\omega})\big]}{1+R_{t+1}-\Psi(\bar{\omega})(1+CY_{t+1})} \quad (2.1.44)$$

where $\Theta(\bar{\omega}) = \Gamma(\bar{\omega}) - \mu G(\bar{\omega})$. (2.1.44) gives commercial banks' leverage offer curve which slopes upwards and is convex in the $[1-\Gamma(\bar{\omega})]$ space (shown in Figure 2.1.1). Note that $dLev_t/\bar{\omega} > 0$, $dLev_t/dCY_t$, and $dLev_t/d\delta < 0$.

Figure 2.1.1: The optimal contract for $(\bar{\omega}^*, L^*)$



3) Entrepreneur maximises his utility (returns), relative to his cost of funds. This defines the overall contract:

$$\int_{\bar{\omega}}^{\infty} \frac{(1 + CY_{t+1})\omega PK_t K_{t+1} + cN_{t+1} - Z_{t+1}(PK_t K_{t+1} - N_{t+1} + cN_{t+1})}{N_{t+1}(1 + R_{t+1})} dF(\omega) \quad (2.1.45)$$

Firm's returns would be 0 in case of default, so we only care about its returns when it honour its debt (the idiosyncratic shock ω is above its threshold value $\bar{\omega}$). The numerator of (2.1.45) gives the overall returns in case of non-default which equals returns from capital plus value of collateral minus debt payment. The denominator gives the total cost of funds.

Note that from the bankruptcy threshold (2.1.39) we have $Z_{t+1}\big(PK_t K_{t+1} - N_{t+1} + cN_{t+1}\big) = \bar{\omega}(1 + CY_{t+1})\, PK_t K_{t+1} + cN_{t+1}$. Substituting (2.1.39) into (2.1.45) yields:

$$\begin{aligned}
&\int_{\bar{\omega}}^{\infty} \frac{(1 + CY_{t+1})\omega PK_t K_{t+1} + cN_{t+1} - \big[\bar{\omega}(1 + CY_{t+1})\, PK_t K_{t+1} + cN_{t+1}\big]}{N_{t+1}(1 + R_{t+1})} dF(\omega) \\
&= \int_{\bar{\omega}}^{\infty} \frac{(1 + CY_{t+1})\omega PK_t K_{t+1} - \big[\bar{\omega}(1 + CY_{t+1})\, PK_t K_{t+1}\big]}{N_{t+1}(1 + R_{t+1})} dF(\omega) \\
&= \int_{\bar{\omega}}^{\infty} \frac{(1 + CY_{t+1})(\omega - \bar{\omega}) PK_t K_{t+1}}{N_{t+1}(1 + R_{t+1})} dF(\omega) \\
&= \frac{(1 + CY_{t+1})}{(1 + R_{t+1})} Lev_t \int_{\bar{\omega}}^{\infty} (\omega - \bar{\omega}) dF(\omega) \\
&= \frac{1 + CY_{t+1}}{1 + R_{t+1}} Lev_t \big[1 - \Gamma(\bar{\omega})\big] \qquad (2.1.46)
\end{aligned}$$

where $\Gamma(\bar{\omega}) = \bar{\omega}\big[1 - F(\bar{\omega})\big] + G(\bar{\omega}) = \bar{\omega} \int_{\bar{\omega}}^{\infty} f(\omega) d\omega + \int_0^{\bar{\omega}} \omega f(\omega) d\omega$. $[1 - \Gamma(\bar{\omega})]$ can be seen as the expected gross share of profits that go to the firms (borrower). It is clear that firms' returns are unaffected by the introduction of collateral as the terms cN_t got cancelled out. The indifference curves implies by this utility function are concave and plotted in $(\bar{\omega}, Lev)$ space of Figure (2.1.1). Hence, an interior solution is guaranteed.

We then compute optimum by maximizing $\frac{1+CY_{t+1}}{1+R_{t+1}} Lev_t \big[1 - \Gamma(\bar{\omega})\big]$ with respect to $(\bar{\omega}, Lev)$ subject to the leverage offer curve from the banks' leverage offer curve (2.1.44). Solving for the implicit function gives us firm' optimal choice of $\bar{\omega}$ as the solution of:

$$\Big[1 + R_{t+1} - c\big(R_{t+1} + \delta F(\bar{\omega})\big)\Big]\Big[1 + R_{t+1} - \Omega'(1 + CY_{t+1})\Big]$$
$$= \left[\frac{-c\delta F'(\bar{\omega})[1 - \Gamma(\bar{\omega})]}{\Gamma'(\bar{\omega})}\right]\Big[1 + R_{t+1} - \Theta(\bar{\omega})(1 + CY_{t+1})\Big] \tag{2.1.47}$$

where $\Omega' = \frac{\Theta'(\bar{\omega})}{\Gamma'(\bar{\omega})} + \left[1 - \frac{\Theta'(\bar{\omega})}{\Gamma'(\bar{\omega})}\right]\Theta(\bar{\omega}) \approx 1$. Besides we have the leverage offer curve which defines Lev in terms of $\bar{\omega}$. We now create two equations in this space from the firms' optimal choice and banks' leverage offer curves. We re-express firms' optimal choice (2.1.47) using banks' leverage:

$$1)\quad Lev_t\Big[1 + R_{t+1} - \Omega'(1 + CY_{t+1})\Big] = \frac{-c\delta F'(\bar{\omega})\big[1 - \Gamma(\bar{\omega})\big]}{\Gamma'(\bar{\omega})} \tag{2.1.48}$$

$$2)\quad Lev_t = \frac{1 + R_{t+1} - c\big[R_{t+1} + \delta F(\bar{\omega})\big]}{1 + R_{t+1} - \Theta(\bar{\omega})(1 + CY_{t+1})} \tag{2.1.49}$$

We now investigate the comparative static properties of changes around the equilibrium by taking the total differential of this two-equation system in $dLev$, $d\bar{\omega}$, $d\delta$ and dCY. We will evaluate the derivatives where $\delta = 0$. Note that in our model, Lev is determined by other variables while depreciation rate δ is determined by the provision of M0 as an alternative to illiquid collateral. Thus, we treat Lev and δ as exogenous to this BGG banking sector and used for solving for $\bar{\omega}$ and CY which are internal to the banking sector and unobservable in the public domain. However, from them we can solve for the observable loan rate Z from the bankruptcy threshold.

Taking the total differential for 1) yields:

$$\Big[1 + R_{t+1} - \Omega'(1 + CY_{t+1})\Big]dLev_t + Lev_t(-\Omega')dCY$$
$$= (derivative = 0)\,\bar{\omega} + \left[\frac{-cF'(\bar{\omega})[1 - \Gamma(\bar{\omega})]}{\Gamma'(\bar{\omega})}\right]d\delta \tag{2.1.50}$$

Taking the total differential for 2) yields:

$$dLev = Lev_t\left[\frac{\Theta'(\bar{\omega})(1 + CY_{t+1})}{1 + R_{t+1} - \Theta(\bar{\omega})(1 + CY_{t+1})}\right]d\bar{\omega}$$
$$+Lev_t\left[\frac{\Theta(\bar{\omega})}{1 + R_{t+1} - \Theta(\bar{\omega})(1 + CY_{t+1})}\right]dCY$$
$$+Lev_t\left[\frac{-cF(\bar{\omega})}{1 + R_{t+1} - \Theta(\bar{\omega})(1 + CY_{t+1})}\right]d\delta \tag{2.1.51}$$

Our interest lies in the effect of δ on the equilibrium values of CY, ω and Z. Notice that $\Gamma'(\bar{\omega}) = \big[1 - F(\bar{\omega})\big]$.

From (2.1.50) we have:

$$\frac{dCY}{d\delta} = \frac{cF'(\bar{\omega})\big[1 - \Gamma(\bar{\omega})\big]}{Lev_t\,\Omega'\,\Gamma'(\bar{\omega})} = \frac{cF'(\bar{\omega})\big[1 - \Gamma(\bar{\omega})\big]}{Lev_t\,\Omega'\,\big[1 - F(\bar{\omega})\big]} > 0 \tag{2.1.52}$$

From (2.1.51) we have:

$$\frac{d\bar{\omega}}{d\delta} = \frac{d\bar{\omega}}{dCY}\frac{dCY}{d\delta} + \frac{d\bar{\omega}}{d\delta} = \left[\frac{-\Theta(\bar{\omega})}{\Theta'(\bar{\omega})(1+CY_t)}\right]\left[\frac{cF'(\bar{\omega})\big[1-\Gamma(\bar{\omega})\big]}{Lev_t\,\Omega'\,\Gamma'(\bar{\omega})}\right] + \frac{cF(\bar{\omega})}{Lev_t\Theta'(\bar{\omega})(1+CY_{t+1})}$$
$$= \frac{cF(\bar{\omega})}{Lev_t\Theta'(\bar{\omega})(1+CY_{t+1})}\left[1-\frac{F'(\bar{\omega})}{F(\bar{\omega})}\frac{\Theta(\bar{\omega})\big[1-\Gamma(\bar{\omega})\big]}{\Omega'\,\Gamma'(\bar{\omega})}\right]$$
$$= \frac{cF(\bar{\omega})}{Lev_t\Theta'(\bar{\omega})(1+CY_{t+1})}\left[1-\frac{F'(\bar{\omega})}{F(\bar{\omega})}\frac{\Theta(\bar{\omega})\big[1-\Gamma(\bar{\omega})\big]}{\Omega'\,\big[1-F(\bar{\omega})\big]}\right] \tag{2.1.53}$$

The sign of $\left[1-\frac{F'(\bar{\omega})}{F(\bar{\omega})}\frac{\Theta(\bar{\omega})\big[1-\Gamma(\bar{\omega})\big]}{\Omega'\,\big[1-F(\bar{\omega})\big]}\right]$ is ambiguous and needs to be computed numerically. Consider a bankruptcy rate around 2.3% and a standard normal distribution of $ln\omega$ (with a std of 1, so that the bankruptcy threshold will be 2 stds below the mean). This implies that $\bar{\omega} = 0.135$, $F(\bar{\omega}) = 0.023$, and $\frac{F'(\bar{\omega})}{F(\omega)} = 2.3$, $\Theta(\bar{\omega}) \approx \Gamma(\bar{\omega}) = [1-F(\bar{\omega})]\bar{\omega} = 0.977 * 0.135 = 0.127$. Hence, $\left[1-\frac{F'(\bar{\omega})}{F(\bar{\omega})}\frac{\Theta(\bar{\omega})\big[1-\Gamma(\bar{\omega})\big]}{\Omega'\,\big[1-F(\bar{\omega})\big]}\right] = \left[1-2.3*\frac{0.127*(1-0.127)}{1*(1-0.023)}\right] = 0.739$ (note that $\Omega' = \frac{\Theta'(\bar{\omega})}{\Gamma'(\bar{\omega})} + \left[1-\frac{\Theta'(\bar{\omega})}{\Gamma'(\bar{\omega})}\right]\Theta(\bar{\omega}) \approx 1$) and so is positive for any values around that size of bankruptcy rate and standard deviation.

Finally, we have:

$$\frac{dZ}{d\delta} = \frac{Lev_t}{Lev_t-1+c}\left[(1+CY_{t+1})\frac{d\bar{\omega}}{d\delta} + \bar{\omega}\frac{dCY}{d\delta}\right]$$
$$= \frac{c}{Lev_t-1+c}\left[\frac{F(\bar{\omega})}{\Theta'(\bar{\omega})}\left(1-\frac{F'(\bar{\omega})}{F(\bar{\omega})}\frac{\Theta(\bar{\omega})\big[1-\Gamma(\bar{\omega})\big]}{\Omega'\big[1-F(\bar{\omega})\big]}\right) + \frac{\bar{\omega}F'(\bar{\omega})[1-\Gamma(\bar{\omega})]}{\Omega'\big[1-F(\bar{\omega})\big]}\right] > 0 \tag{2.1.54}$$

On the assumption that $\frac{d\bar{\omega}}{d\delta}$ as verified before.

So far, we have verified that:

$$\frac{dCY}{d\delta} > 0, \qquad \frac{d\bar{\omega}}{d\delta} > 0, \qquad \frac{dZ}{d\delta} > 0 \tag{2.1.55}$$

It is at this point we introduce the idea of using cash (M0) as the cheapest collateral, so as to eliminate this liquidation cost of δ. Compared with other traditional collaterals (e.g., mortgage or auto collateral), the virtue of cash collateral lies in its liquidity which means the lender could directly seize the collateral and recoup its losses in case of default without any liquidation or auditioning cost. Recall that in SW (07), money does not enter the households utility function. Once households obtain M0, they would deposit it with banks, who then lend M0 to IG firms for collateral use in the future. M0 thus finds its way into entrepreneurs' balance sheets via QE. Hence, a fall in δ due to the liquid collateral (M0) would reduce the external financing cost CY_t and also the credit spread.

We then associate the M0 collateral with central bank's QE operation: in crises the monetary authority issues M0 in exchange for the government bonds held by households, who would immediately deposit M0 with commercial banks. Entrepreneurs take interests in holding as much M0 as possible for future collateral use, as the minimum counterpart to the credit advanced. Hence the extra M0 injected by central bank via QE ends up being held as the liquid collateral pledged to the commercial banks in the future events of bankruptcy. We think of this mechanism as properly capturing how the supply of M0 spikes during QE operation.

With M0 as the cheapest collateral, the spread between risky rate and risk-free rate is reduced for given leverage ($\vartheta > 0$):

$$\mathbb{E}_t\, \hat{cy}_{t+1} - \hat{r}_t = \hat{pm}_t = \chi(\hat{pk}_t + \hat{k}_{t+1} - \hat{n}_{t+1}) - \vartheta \hat{m}_t^0 + \epsilon_t^{pm} \tag{2.1.56}$$

The use of the most liquid collateral cash injects the term M0 to the premium equation where $\vartheta > 0$, so as to capture the loosening effect of QE operations on the credit condition. As verified in Le et al. (2016a) that the liquidation cost of collateral is eliminated by M0 injections, and thus increasing the supply of M0 will be reflected as in a lower lending - deposit spread, which will in turn translate into a lower commercial lending rate.

Injection of macroprudential instrument Most prior literature resorts to balance sheet quantities stipulated by Basel rules (e.g., leverage/bank reserve/capital ratios) to capture the role of regulation. Here we embrace the approach of Le et al. (2016a) by modelling the tightening (loosening) of the regulation via raising (lowering) the regulatory term ξ_t injected to the premium equation. See also (Kannan et al., 2012; Quint and Rabanal, 2013) for similar modelling approach of macroprudential policy via the BGG financial accelerator. The macroprudential instrument τ_t in Kannan et al. (2012) and η_t in Quint and Rabanal (2013) have the same interpretation as ξ_t in our study.

The rationale for the way we model macroprudential instrument arises from the fact that financial regulation aims to force up (down) the cost of funds, so as to constrain (encourage) lending and borrowing. We assume this macroprudential instrument is deployed above and beyond current rules. In practice, tightening the macroprudential policy ($\xi_t > 0$) can be carried out via balance sheet operations like additional capital surcharges, loan-loss provisions, liquidity ratios limits, or reserve requirements. Conversely, loosening of the macroprudential policy ($\xi_t < 0$) can be associated with regulatory authority's effort to provide extra liquidity to the financial system that plays an analogous role to the QE operation.[8] It is worth emphasizing that for ξ_t to take the negative value (to reduce the spread), steady-state regulation must be pitched above the minimum, otherwise ξ_t can only be positive and acts to tighten the credit supply.

Nevertheless, due to the difficulty of measuring the macro-prudential policies for now we include ξ_t in the disturbance process referred to as "risk premium shock" in our context. For now (DSGE model), we do not differentiate the macroprudential shock ξ_t and the structural shock ϵ_t^{pm}. However, the method of disentangling them is dealt with in the

[8]According to Quint and Rabanal (2013), the macruprudential instrument can behave symmetrically, so that a loosening of the macroprudential policy ($\eta_t < 1$ in their context) can be achieved in practice through measures like the Funding for Lending Scheme launched by the BoE in 2012, or a widening of collateral standards.

institutional model. See Section 9.3, Eq (9.3.1) to Eq (9.3.5) for details of identification procedure. Equation (2.1.42) hence becomes:

$$\mathbb{E}_t \, \hat{cy}_{t+1} - \hat{r}_t = \hat{pm}_t = \chi(\hat{pk}_t + \hat{k}_{t+1} - \hat{n}_{t+1}) - \underbrace{\vartheta \hat{m}_t^0}_{\text{Effect of QE}} + \underbrace{\xi_t}_{\substack{\text{Macro}\\\text{prudential}\\\text{instrument}}} + \epsilon_t^{pm} \tag{2.1.57}$$

2.1.4.2 Level of capital utilization

After the capital purchase, entrepreneurs (IG firms) choose the optimal level of capital utilization U_t for IG goods production. The problem they solve is:

$$\max_{U_t(i)} \frac{R_t^K U_t(i) K_{t-1}(i)}{P_t} - \Upsilon(U_t(i)) K_{t-1}(i) \tag{2.1.58}$$

where $\Upsilon(U_t)$ is the adjustment cost of capital utilization that takes the form:

$$\Upsilon(U_t(i)) = R_t^K \Upsilon \Big[\exp\left(\frac{U_t(i) - 1}{\Upsilon}\right) - 1\Big] \tag{2.1.59}$$

with $\Upsilon(1) = 1$, $\Upsilon'(1) = R_t^K$, and $\dfrac{\Upsilon'(1)}{\Upsilon''(1)} = \psi$. The optimal degree of capital utilisation is determined by the following FOC:

$$\partial U_t : \qquad \frac{R_t^k}{P_t} = \Upsilon'(U_t) \tag{2.1.60}$$

2.1.4.3 Production of intermediate goods

Finally, we proceed to the production details of intermediate goods. IG firms produce differentiated goods by combining the purchased capital in operation (determined by the utilization chosen) and the hired labour via a Cobb-Douglas production function:

$$Y_t(i) = \epsilon_t^a K_t^s(i)^\alpha \left[\gamma^t L_t(i)\right]^{1-\alpha} - \gamma^t \Phi \tag{2.1.61}$$

where α - share of capital in production function, $K_t^s = K_{t-1} U_t(i)$ - effective capital used in production, Φ - fixed cost that enters as source of real rigidity, γ^t - labour augmenting deterministic growth rate, and ϵ_t^a - total factor productivity shock which is assumed to be non-stationary. IG firm's problem is to choose the quantity of production factors - effective capital in production K_t^s and labour L_t input to maximise the profits in Equation (2.1.62) subject to Equation (2.1.61):

$$\max_{L_t(i), K_t^s(i)} P_t(i) Y_t(i) - W_t L_t(i) - R_t^k K_t^s(i) \tag{2.1.62}$$

2.1.5 Capital producers

Besides intermediate (IG) and final (FG) goods producers, there also exist identical and perfectly competitive capital producers on the production side. At period t, capital producers purchase investment I_t from FG producers and undepreciated capital installed at t-1: $(1-\delta)K_{t-1}$ from IG producers to build new capital resold to IG producers at price PK_t. Capital producers also face the cost of investment adjustment as in SW(07). Capital producers' problem is to choose I_t to maximise their expected discounted profits (given by the difference between the revenue from selling newly-built capital and the cost of purchasing undepreciated capital and investment needed:

$$\max_{I_t} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \Big[PK_t\Big(K_t - (1-\delta)K_{t-1}\Big) - I_t\Big] \tag{2.1.63}$$

subject to the law of motion of capital:

$$K_t = (1-\delta)K_{t-1} + \epsilon_t^i \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \tag{2.1.64}$$

where $S(\cdot)$ - cost of adjusting investment, and ϵ_t^i -investment specific shock that affects the efficiency in transforming investment into new capital.

2.1.6 Central bank (government) and aggregations

Central bank and government conduct (conventional and unconventional) monetary, fiscal, and macroprudential policies. Macroprudential policy is covered in detail in section 2.2.4.1. In what follows we will briefly describe monetary and fiscal policies only before closing the model.

Monetary policy Monetary policy is introduced in two parts to incorporate the new developments since 2008 - a binding ZLB constraint and the conduct of unconventional monetary policy.

For the **normal regime** (for $r_t > 0.025\%$ quarterly), the BoE conducts **conventional monetary policy (CMP)** according to the Taylor rule as in SW(07). Meanwhile, the supply of M0 is set to accommodate the broad money supply M2 which is determined by bank' balance sheets quantities: [9]

$$For\ r_t > 0.025\% \begin{cases} \hat{r}_t = \rho\hat{r}_{t-1} + (1-\rho)(r_p\hat{\pi}_t + r_y\hat{y}_t) + r_{\Delta_y}(\hat{y}_t - \hat{y}_{t-1}) + \epsilon_t^r \quad (CMP) \\ \hat{m}_t^0 - \hat{m}_{t-1}^0 = \vartheta_1\,(\hat{m}_t^2 - \hat{m}_{t-1}^2) + \epsilon_t^{m0} \\ \hat{m}_t^2 = (1 - \frac{M0}{M2} + \frac{N}{M2})\,\hat{k}_t + \frac{M0}{M2}\,\hat{m}_t^0 - \frac{N}{M2}\,\hat{n}_t \end{cases} \tag{2.1.65}$$

where ρ captures the degree of interest rate smoothing; r_p, r_y and r_{Δ_y} are Taylor rule's responses to inflation, output and change in output respectively. When nominal interest rate solves above the threshold of 0.025% quarterly, monetary authorities sets CMP by gradually adjusting the nominal return on bonds and deposits in response to development

[9] We assume that Taylor rule is enforced by open market operations of some sort.

in inflation and output. ϑ_1 represents the elasticity of M0 to M2; $\frac{M0}{M2}$ and $\frac{N}{M2}$ are the steady state ratios of M0 and net worth with respect to M2, respectively.

The mechanism works as follows. The central bank set the nominal interest rate (deposit rate) R according to the unconstrained Taylor type rule that responds to developments in inflation and output. The broad money supply is determined by the firms (IG producers) balance sheet: as the broad money supply M2 = M0 (cash) + households deposits. Notice that households deposits = amount of loans made to firms entrepreneurs' borrowing = Capital expenditure - net worth. Hence, M2 = M0 + capital expenditure - net worth. The supply of M0 is set proportional to that of M2 and hence called "accommodative" which is distinct from M0's "active" role for the unconventional monetary policy in a crisis regime. The left panel simulation #18 in Figure 3.3.2 (Section 3.3.1) provides an example of this mechanism. The responses of M0 and M2 are significantly different from those under the regime switch (simulations #223, #811).

In the **crisis regime** (for $r_t \leqslant 0.025\%$ quarterly), the BoE resorts to the **unconventional monetary policy (UMP)** as the conventional rates cuts become unavailable with the nominal interest rate fixed at the ZLB. Meanwhile, M0 becomes the main tool to target the credit market, aiming to reduce premium for given leverage and boost the supply of credit as in Equation (2.1.57):

$$For\ \ r_t \leq 0.025\% \ \begin{cases} \hat{r}_t = 0.025\% \\ \\ \hat{m}^0_t - \hat{m}^0_{t-1} = \vartheta_2 \left(\hat{pm}_t - pm^*_t \right) + \epsilon^{m0}_t \quad (UMP) \end{cases} \tag{2.1.66}$$

where ϑ_2 represents the elasticity of M0 with respect to premium. Le et al. (2016a) verifies the role of M0 in bringing down the credit spread via its role in providing the cheapest collateral. Once the model enters the crisis regime as ZLB constraint binds, QE operation is triggered with the supply of M0 set contingent on credit spread. The mechanism works as follows: the wider the credit spread (the more distorted the credit market becomes), the greater the effort it requires to stabilise the premium via M0 injection (more of M0 is needed). This feedback rule allows monetary authority to alleviate the strains in the credit market before it brings credit provision back to normal.

Once interest rate solves above this threshold again, the economy switches back to the normal regime as set up in Equation system (2.1.65).

Fiscal policy Fiscal policy is assumed to take the same form as in SW(07). Government spending is determined exogenously as a time-varying fraction relative to the steady state output path:

$$\epsilon^g_t = \frac{G_t}{Y\gamma^t} \tag{2.1.67}$$

where ϵ^g_t is specified to follow to an AR(1) process that also responds to productivity process:

$$\epsilon_t^g = \rho_g \epsilon_{t-1}^g + \eta_t^g + \rho_{ga}\eta_t^a \tag{2.1.68}$$

In our setup, government only purchases home produced goods for public expenditure. Government's budget constraint is of the form:

$$P_t G_t + B_{t-1} = T_t + \frac{B_t}{R_t} \tag{2.1.69}$$

Market clearing condition With the addition of entrepreneurs' consumption and trade with the rest of the world, log-linearised economy-wide resource constraint in volume terms (real resource constraint) now becomes:

$$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{I}{Y}\hat{i}_t + \left(R_*^k k_y \frac{1-\psi}{\psi}\right)\hat{rk}_t + \frac{C^e}{Y}\hat{c}_t^e + \frac{EX}{Y}\hat{ex}_t - \frac{IM}{Y}\hat{im}_t + \epsilon_t^g \tag{2.1.70}$$

2.1.7 Rest of the world

The Smets-Wouters models (SW03, SW07) treat EU and the US as single entities isolated from the rest of the world. This simplification cannot address how the global developments have affected the object of studies. The fact that the UK economy is closely integrated with foreign countries makes it imperative to allow for the channels through which the world shocks can transmit to it.

Here we adopt a small open economy framework wherein the UK macro environment can be affected by what happens in the rest of the world, whereas any home-grown UK-specific shocks have no impact on the wider global economy.[10] The model is made up of two blocks - **the UK block** which is built upon on a fully fledged New-Keynesian model with necessary extensions to reflect the latest development in the monetary scene, and a fairly simple **world block** which contains only foreign bonds, export and import of goods and services to the UK. This simple set-up aligns with the objective to investigate to what extent the global influences have driven development in the UK output growth.

For simplicity, we assume only final goods are traded between the UK and the rest of the world (henceforth, RoW). The household consumption bundle C_t now is a composite of both domestic and imported goods that can be represented by the Armington (1969) aggregator:

$$C_t = \left[\omega (C_t^d)^{-\varrho} + (1-\omega)\varsigma_t (C_t^{im})^{-\varrho}\right]^{\frac{-1}{\varrho}} \tag{2.1.71}$$

where C_t^d and C_t^{im} are the consumption of final goods produced domestically and abroad (imported goods) respectively. Note that we start from consumption bundle C_t, and investigate how it should break down between consumption of home-produced goods C_t^d and consumption of foreign-produced goods C_t^{im}. Intuitively, home consumption of the foreign-produced goods is just another name for the import. Hence we have $C_t^{im} = IM_t$ as formalized in Eq (2.1.77). However, the equation for $C_t^{im}(IM_t)$ can only be derived after

[10] While being a typically industrialised country, the UK' share in world GDP is less than 2.5% in 2018, which seems to justify our assumption of exogeneity.

setting up the Langragian Eq (2.1.73) and solving for the first-order condition for C_t^{im} as in Eq (2.1.75). This is why import demand equation is not placed right after Eq (2.1.71) as we do not really have an equation for it at that point.

ω measures the bias towards (weight of) domestic goods in the consumption bundle, ς_t is the preference error, and $\sigma = \frac{1}{1+\varrho}$ denotes the elasticity of substitution between domestic and foreign varieties.

The domestic consumer maximises composite utility index Equation (2.1.71) subject to the expenditure constraint:

$$C_t = P_t^d C_t^d + Q_t C_t^{im} \tag{2.1.72}$$

where P_t^d is the ratio of domestic price level to the general price level. Q_t can be seen as the unit cost of foreign bond B^f, and a higher Q_t implies a real exchange rate depreciation and thus an increase in competitiveness in world market. To determine how the consumption bundle should break down between consumption of domestic and foreign varieties, household forms the Lagrangian:

$$\mathcal{L} = \left[\omega(C_t^d)^{-\varrho} + (1-\omega)\varsigma_t(C_t^{im})^{-\varrho}\right]^{\frac{-1}{\varrho}} + \Lambda\left[C_t - P_t^d C_t^d - Q_t C_t^{im}\right] \tag{2.1.73}$$

where the first-order conditions for the relative demand of C_t^d and C_t^{im} are: [11]

$$\partial C_t^d: \;\; \omega C_t^{(1+\varrho)}(C_t^d)^{-(1+\varrho)} - \Lambda P_t^d = 0 \tag{2.1.74}$$

$$\partial C_t^{im}: \;\; (C_t)^{1+\varrho}(1-\omega)\varsigma_t(C_t^{im})^{-(1+\varrho)} - \Lambda Q_t = 0 \tag{2.1.75}$$

Note that $\Lambda = 1$ when constraint binds at the maximum (i.e., the change in the utility index from a one unit rise in consumption is unity). Further simplification of Equation (2.1.75) gives:

$$C_t^{im} = C_t\left[\frac{Q_t}{(1-\omega)\varsigma_t}\right]^{-\sigma} = C_t(Q_t)^{-\sigma}[(1-\omega)\varsigma_t]^{\sigma} \tag{2.1.76}$$

Log-linearisation of Equation (2.1.76) yields the UK's demand for the imported goods from the world:

$$\hat{c}_t^{im} = \hat{im}_t = \sigma\log(1-\omega) + \hat{c}_t - \sigma\hat{q}_t + \sigma\log\varsigma_t \tag{2.1.77}$$

Likewise, the world block's demand for the imported goods from the UK yields the demand for UK export:

$$\hat{ex}_t = \sigma^F\log(1-\omega^F) + \hat{c}_t^f + \sigma^F\hat{q}_t + \sigma^F\log\varsigma_t^F \tag{2.1.78}$$

where σ^F, ω^F, ς_t^F and c_t^f (consumption in the world block)are the foreign equivalent of σ, ω, ς_t and c_t.

Exports and imports together with interest receipts/payments determine the evolution

[11] An expression for P_t^d as a function of Q_t can be derived from the maximisation of Equation (2.1.71): $1 = \omega^{\sigma}(P_t^d)^{\varrho\sigma} + \left[(1-\omega)\varsigma_t\right]^{\sigma} Q_t^{\varrho\sigma}$. The log-linear approximation with $\sigma = 1$ yields: $\hat{p}_t^d = k - \frac{1-\omega}{\omega}\frac{1}{\varrho}log\varsigma_t - \frac{1-\omega}{\omega}\hat{q}_t$, where k is a constant of integration.

of net foreign assets (nominal resource constraint):

$$\frac{Q_t B^f_{t+1}}{(1+R^f_{t+1})} = Q_t B^f_t + p^d_t EX_t - Q_t IM_t \tag{2.1.79}$$

and log-linearisation above Equation (2.1.79) yields:

$$\hat{b}^f_t = (1+\hat{r}^f_t)\,\hat{b}^f_{t-1} + \frac{EX}{Y}(\hat{ex}_{t-1} - \hat{q}_{t-1}) - \frac{IM}{Y}\hat{im}_{t-1} \tag{2.1.80}$$

where $\frac{EX}{Y}$ and $\frac{IM}{Y}$ are steady state ratios, and r^f_t is return on foreign bonds.

2.2 Model in log-linearised form

Our model has been log-linearized around the long-run trends or balanced growth path (BGP) as the model is consistent with a balanced steady state growth path driven by deterministic labour-augmenting technological progress. Equations that describe steady states as functions of model parameters are mostly carried over from SW(07). For an exhaustive derivation we refer readers to the appendices of original papers.

Consumption Euler equation:

$$\hat{c}_t = \left(\frac{\frac{\lambda}{\gamma}}{1+\frac{\lambda}{\gamma}}\right)\hat{c}_{t-1} + \left(\frac{1}{1+\frac{\lambda}{\gamma}}\right)\mathbb{E}_t\,\hat{c}_{t+1} + \left[\frac{(\sigma_c - 1)\frac{W^h_* L_*}{C*}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}\right]\left(\hat{l}_t - \mathbb{E}_t\,\hat{l}_{t+1}\right) - \left[\frac{1-\frac{\lambda}{\gamma}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}\right]\left(\hat{r}_t - \mathbb{E}_t\,\hat{\pi}_{t+1} + \epsilon^b_t\right) \tag{2.2.1}$$

where parameter λ captures the degree of external habit formation, and γ determines the steady state growth rate. σ_c and $\frac{W^h_* L_*}{C_*}$ represent the relative risk aversion (inverse of elasticity of intertemporal substitution) and steady rate ratio of labour income to consumption. r_t is the gross nominal return on government bonds or bank deposits. It states that household current consumption is a function of past and future expected consumption, expected growth in hours worked $(l_t - \mathbb{E}_t\, l_{t+1})$ and ex-ante real interest rate $(r_t - \mathbb{E}_t\,\pi_{t+1})$.

Investment Euler equation:

$$\hat{i}_t = \left(\frac{1}{1+\beta\gamma^{1-\sigma_c}}\right)\hat{i}_{t-1} + \left(\frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}}\right)\mathbb{E}_t\,\hat{i}_{t+1} + \left(\frac{1}{(1+\beta\gamma^{(1-\sigma_c)})\gamma^2\varphi}\right)\hat{pk}_t + \epsilon^i_t \tag{2.2.2}$$

where φ captures the elasticity of investment adjustment cost, and β is the discount factor held fixed throughout our study. Equation (2.2.2) states that investment is positively correlated with past and future investment and value of existing capital stock. The higher the value of φ, the less sensitive investment is to the value of capital stock.

Capital arbitrage condition:

$$\hat{pk}_t = \left(\frac{1-\delta}{1-\delta+R_*^k}\right)\mathbb{E}_t\,\hat{pk}_{t+1} + \left(\frac{R_*^k}{1-\delta+R_*^k}\right)\mathbb{E}_t\,\hat{rk}_{t+1} - \mathbb{E}_t\,\hat{cy}_{t+1} \tag{2.2.3}$$

where rk_t and R_*^k are the marginal product of capital and its steady state value; cy_t is the risky return (i.e., external financing cost or required return on capital). IG firms now have to borrow from commercial banks to finance their acquisition of capital and hence external financing cost cy_t enters the capital arbitrage equation.

Capital stock evolves according to:

$$\hat{k}_t = \left(\frac{1-\delta}{\gamma}\right)\hat{k}_{t-1} + \left(1-\frac{1-\delta}{\gamma}\right)\hat{i}_t + \left[\left(1-\frac{1-\delta}{\gamma}\right)\left(1+\beta\gamma^{(1-\sigma_c)}\right)\right]\gamma^2\varphi\,\epsilon_t^i \tag{2.2.4}$$

which states that the current capital stock is determined by its past stock, flow of new investment, and a function of relative efficiencies.

Real resource constraint is given by:

$$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{I}{Y}\hat{i}_t + \left(R_*^k k_y\frac{1-\psi}{\psi}\right)\hat{rk}_t + \frac{C^e}{Y}\hat{c}_t^e + \frac{EX}{Y}\hat{ex}_t - \frac{IM}{Y}\hat{im}_t + \epsilon_t^g \tag{2.2.5}$$

where $\frac{C}{Y}$, $\frac{I}{Y}$, $\frac{C^e}{Y}$, $\frac{EX}{Y}$, $\frac{IM}{Y}$ denote the steady state ratios of consumption, investment, entrepreneur consumption, export and import to output, respectively. Parameter ψ measures the degree of elasticity of capital utilisation cost with respect to capital inputs. Above equation states that total output is absorbed by consumption, investment, government spending, net export, and the cost associated with variable capital utilisation. Following Bernanke et al. (1999), the monitoring cost is ignored here due to its negligible impact on model's dynamics. Our extension to the SW(07) adds to the system entrepreneurs' consumption, export and import.

Output is produced using capital and labour service:

$$\hat{y}_t = \phi_p\left[\alpha\hat{k}_{t-1} + \alpha\left(\frac{1-\psi}{\psi}\right)\hat{rk}_t + (1-\alpha)\hat{l}_t + \epsilon_t^a\right] \tag{2.2.6}$$

where α is the share of capital in production, and ϕ_p equals one plus the fixed cost in production and provides source of real rigidity.

Cost minimisation yields the demand for labour:

$$\hat{l}_t = \hat{rk}_t - \hat{w}_t + \hat{k}_t \tag{2.2.7}$$

Hybrid price setting is a weighted average the corresponding NK and NC equations:

$$\hat{rk}_t = \omega_{NK}^p \left\{ \frac{\left(\frac{\iota_p}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\right)\hat{\pi}_{t-1} + \left(\frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\right)E_t\hat{\pi}_{t+1} - \hat{\pi}_t + \epsilon_t^p}{-\alpha\left(\frac{1}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\right)\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_p\right)\left(1-\xi_p\right)}{\xi_p\left((\phi_p-1)\varepsilon_p+1\right)}} + \frac{\alpha-1}{\alpha}\hat{w}_t - \frac{\epsilon_t^a}{\alpha} \right\}$$
$$+(1-\omega_{NK}^p)\left\{\frac{(\alpha-1)\hat{w}_t + \epsilon_t^a}{\alpha}\right\} \tag{2.2.8}$$

where ω_{NK}^p represents the proportion of economy dominated by sticky prices, and $(1-\omega_{NK}^p)$ denotes the rest where price flexibility prevails. For the NK part, parameters ι_p and ξ_p measure the degree of price indexation and stickiness (Calvo probability) respectively. ε_p measures the Kimball aggregator curvature in the goods market and is fixed at 10.

Following Le et al. (2011), we assume the hybrid price setting is a weighted average of the corresponding equations from both NK and NC models.

The inflation in the NK model is: $\hat{\pi}_t = \frac{\iota_p}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\hat{\pi}_{t-1} + \frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\mathbb{E}_t\,\hat{\pi}_{t+1} - \frac{1}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\frac{(1-\beta\gamma^{(1-\sigma_c)}\xi_p)(1-\xi_p)}{\xi_p\left[(\phi_p-1)\varepsilon_p+1\right]}\mu_t^p + \epsilon_t^p$, where price mark-up $\mu_t^p = mpl_t - w_t = \alpha(k_t^s - l_t) - w_t + \epsilon_t^a = \alpha(w_t - rk_t) - w_t + \epsilon_t^a = (\alpha-1)w_t - \alpha rk_t + \epsilon_t^a$ From this we can solve for rk_t, which gives the terms inside inside {} after ω_{NK}^p. To derive the NC price setting, we set price mark-up equal to zero, such that $\mu_t^p = (\alpha-1)w_t - \alpha rk_t + \epsilon_t^a = 0$. This in turn yields $rk_t = \frac{(\alpha-1)w_t+\epsilon_t^a}{\alpha}$ and gives us the term inside {} after $(1-\omega_{NK}^p)$.

Similarly, hybrid wage setting is a weighted average the corresponding NK and NC equations:

$$\hat{w}_t = \omega_{NK}^w\left\{\left(\frac{1}{1+\beta\gamma^{(1-\sigma_c)}}\right)\hat{w}_{t-1} + \left(\frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}}\right)\left(\mathbb{E}_t\,\hat{w}_{t+1} + \mathbb{E}_t\,\hat{\pi}_{t+1}\right) - \right.$$
$$\left(\frac{1+\beta\gamma^{(1-\sigma_c)}\iota_w}{1+\beta\gamma^{(1-\sigma_c)}}\right)\hat{\pi}_t + \left(\frac{\iota_w}{1+\beta\gamma^{(1-\sigma_c)}}\right)\hat{\pi}_{t-1} -$$
$$\left.\left(\frac{1}{1+\beta\gamma^{(1-\sigma_c)}}\right)\left[\frac{(1-\beta\gamma^{(1-\sigma_c)}\xi_w)(1-\xi_w)}{\xi_w\left((\phi_w-1)\varepsilon_w+1\right)}\right]\left(\hat{w}_t - \sigma_l\hat{l}_t - \frac{1}{1-\frac{\lambda}{\gamma}}\left(\hat{c}_t - \frac{\lambda}{\gamma}\hat{c}_{t-1}\right)\right) + \epsilon_t^{wnk}\right\}$$
$$+(1-\omega_{NK}^w)\left\{\sigma_l\hat{l}_t + \left(\frac{1}{1-\frac{\lambda}{\gamma}}\right)\left(\hat{c}_t - \frac{\lambda}{\gamma}\hat{c}_{t-1}\right) - (\pi_t - \mathbb{E}_{t-1}\,\pi_t) + \epsilon_t^{wnc}\right\} \tag{2.2.9}$$

where ω_{NK}^w captures the proportion of economy dominated by sticky wages, and $(1-\omega_{NK}^p)$ represents the rest that exhibits wage flexibility. Similarly, parameters ι_w and ξ_w measure the degree of wage indexation and stickiness (Calvo probability) in the NK-type sectors. ε_w measures the Kimball aggregator curvature in the labour market and is fixed at 10. Note that the NC model is flexible price/wage model with only a simple one-period information delay for labour suppliers $(\pi_t - \mathbb{E}_{t-1}\,\pi_t)$. In the NC model an inelastic labour supply leads to fluctuations in output to be dominated by supply shocks (productivity shock ϵ_t^a, and labour supply shock ϵ_t^{wnc}), whereas consumption and investment respond to output in a standard RBC manner. In the NC model, supply shocks are prime movers of all variables, while demand shocks add to the variability of nominal variables.

In the normal regime, the monetary policy is set up as follows:

$$For\ r_t > 0.025\% \quad \begin{cases} \hat{r}_t = \rho\hat{r}_{t-1} + (1-\rho)(r_p\hat{\pi}_t + r_y\hat{y}_t) + r_{\Delta_y}(\hat{y}_t - \hat{y}_{t-1}) + \epsilon_t^r \\ \hat{m}_t^0 - \hat{m}_{t-1}^0 = \vartheta_1\,(\hat{m}_t^2 - \hat{m}_{t-1}^2) + \epsilon_t^{m0} \\ \hat{m}_t^2 = (1 - \frac{M0}{M2} + \frac{N}{M2})\,\hat{k}_t + \frac{M0}{M2}\,\hat{m}_t^0 - \frac{N}{M2}\,\hat{n}_t \end{cases} \tag{2.2.10}$$

In the crisis regime, the monetary policy is set up as follows:

$$For\ r_t \leq 0.025\% \quad \begin{cases} \hat{r}_t = 0.025\% \\ \hat{m}_t^0 - \hat{m}_{t-1}^0 = \vartheta_2\,(\hat{pm}_t - pm_t^*) + \epsilon_t^{m0} \end{cases} \tag{2.2.11}$$

External financing premium is given by:

$$\hat{pm}_t = \mathbb{E}_t\,\hat{cy}_{t+1} - \hat{r}_t = \hat{pm}_t = \chi\,(\hat{pk}_t + \hat{k}_{t+1} - \hat{n}_{t+1}) - \vartheta\hat{m}_t + \xi_t + \epsilon_t^{pm} \tag{2.2.12}$$

Entrepreneurs' net worth evolves according to:

$$\hat{n}_t = \frac{K}{N}(\hat{cy}_t - \mathbb{E}_{t-1}\,\hat{cy}_t) + \mathbb{E}_{t-1}\,\hat{cy}_t + \theta\hat{n}_{t-1} + \epsilon_t^n \tag{2.2.13}$$

where θ is the survival rate held fixed at 0.97 in our study. $\frac{K}{N}$ represents the steady state ratio of capital to net worth.

Entrepreneurs' consumption equals their net worth:

$$\hat{c_t^e} = \hat{n}_t \tag{2.2.14}$$

We follow the setting of the BGG paper, where it assumes a certain survival ratio θ for the entrepreneurs. The rest that die in each period will consume all of their net worth before departing from the scene.

The demand for import is:

$$\hat{im}_t = \hat{c}_t^{im} = \sigma log(1-\omega) + \hat{c}_t - \sigma\hat{q}_t + \epsilon_t^{im} \tag{2.2.15}$$

Similarly, the demand for export is:

$$\hat{ex}_t = \sigma^F log(1-\omega^F) + \hat{c}_t^f + \sigma^F\hat{q}_t + \epsilon_t^{ex} \tag{2.2.16}$$

Movement in real exchange rate satisfies the real uncovered interest rate parity (UIRP):

$$(\hat{r}_t - \mathbb{E}_t\,\hat{\pi}_{t+1}) - (\hat{r}_t^f - \mathbb{E}_t\,\hat{\pi}_{t+1}^f) = \mathbb{E}_t\,\hat{q}_{t+1} - \hat{q}_t \tag{2.2.17}$$

Foreign bonds evolve according to:

$$\hat{b}_t^f = (1+\hat{r}_t^f)\,\hat{b}_{t-1}^f + \frac{EX}{Y}(\hat{ex}_{t-1} - \hat{q}_{t-1}) - \frac{IM}{Y}\hat{im}_{t-1} \tag{2.2.18}$$

2.3 Exogenous Processes

The DSGE model contains eleven domestic and four foreign processes. In particular, we have made a few modifications to SW(07): a non-stationary ARIMA(1,1,0) process is assumed for the TFP shock in the production function.[12] We also reduce price and mark-up shocks from ARMA(1,1) to AR(1) processes to avoid the cases where multiple non-stationary processes lead to in explosive simulation results. We inject an AR(1) process into the flexible wage setting to capture the labour supply disturbances due to changes in preference for leisure. The remaining processes are modelled as AR(1).

Specifically, let $\left[\rho_g, \rho_b, \rho_i, \rho_r, \rho_a, \rho_p, \rho_{wnk}, \rho_{wnc}, \rho_{pm}, \rho_n, \rho_{m_0}, \rho_{ex}, \rho_{im}, \rho_{r_f}, \rho_{c_f}\right]$ be auto-correlation parameters, and $\left[\eta_t^g, \eta_t^b, \eta_t^i, \eta_t^r, \eta_t^a, \eta_t^p, \eta_t^{wnk}, \eta_t^{wnc}, \eta_t^{pm}, \eta_t^n, \eta_t^{m_0}, \eta_t^{ex}, \eta_t^{im}, \eta_t^{rf}, \eta_t^{cf}\right]$ the innovations (structure shocks) of above processes which are assumed to be normally distributed with zero mean and standard deviations represented by $\left[\sigma_g, \sigma_b, \sigma_i, \sigma_r, \sigma_a, \sigma_p, \sigma_{wnk},\right.$ $\left.\sigma_{wnc}, \sigma_{pm}, \sigma_n, \sigma_{m_0}, \sigma_{ex}, \sigma_{im}, \sigma_{r_f}, \sigma_{c_f}\right]$ respectively.

Following SW(07), government spending is modelled as an AR(1) process that also responds to the productivity process:

$$\epsilon_t^g = \rho_g \epsilon_{t-1}^g + \eta_t^g + \rho_{ga}\eta_t^a, \quad \eta_t^g \sim N(0, \sigma_g^2) \quad \eta_t^a \sim N(0, \sigma_a^2) \tag{2.3.1}$$

The preference shock ϵ_t^b follows AR(1) process:

$$\epsilon_t^b = \rho_b \epsilon_{t-1}^b + \eta_t^b, \quad \eta_t^b \sim N(0, \sigma_b^2) \tag{2.3.2}$$

Investment-specific shock follows AR(1) process:

$$\epsilon_t^i = \rho_i \epsilon_{t-1}^i + \eta_t^i, \quad \eta_t^i \sim N(0, \sigma_i^2) \tag{2.3.3}$$

Monetary policy shock follows an AR(1) process:

$$\epsilon_t^r = \rho_r \epsilon_{t-1}^r + \eta_t^r, \quad \eta_t^r \sim N(0, \sigma_r^2) \tag{2.3.4}$$

The TFP shock is modelled as an ARIMA(1,1,0) process:

$$\epsilon_t^a = \epsilon_{t-1}^a + \rho_a(\epsilon_{t-1}^a - \epsilon_{t-2}^a) + \eta_t^a, \quad \eta_t^a \sim N(0, \sigma_a^2) \tag{2.3.5}$$

The price mark-up shock is reduced from ARMA(1,1) to AR(1):

$$\epsilon_t^p = \rho_p \epsilon_{t-1}^p + \eta_t^p, \quad \eta_t^p \sim N(0, \sigma_p^2) \tag{2.3.6}$$

As with the price setting, New Keynesian wage mark-up shock is reduced to an AR(1) process:

$$\epsilon_t^{wnk} = \rho_{wnk} \epsilon_{t-1}^{wnk} + \eta_t^{wnk}, \quad \eta_t^{wnk} \sim N(0, \sigma_{wnk}^2) \tag{2.3.7}$$

[12] In the SW(07) model, TFP shock is treated as AR(1). When shocks with random walks perturb the economy, the effects on some variables like consumption, investment and output would be permanent, which push the model towards freshly-set equilibria in each period. A sequence of positive (negative) non-stationary shocks would cause what looks like "euphoria or boom (disaster or crisis)"

The newly-introduced New Classical wage mark-up (labour supply) shock is modelled as AR(1):

$$\epsilon_t^{wnc} = \rho_{wnc}\epsilon_{t-1}^{wnc} + \eta_t^{wnc}, \quad \eta_t^{wnc} \sim N(0, \sigma_{wnc}^2) \tag{2.3.8}$$

Risk premium and net worth are subject to the AR(1) processes:

$$\epsilon_t^{pm} = \rho_{pm}\epsilon_{t-1}^{pm} + \eta_t^{pm}, \quad \eta_t^{pm} \sim N(0, \sigma_{pm}^2) \tag{2.3.9}$$

$$\epsilon_t^{n} = \rho_{n}\epsilon_{t-1}^{n} + \eta_t^{n}, \quad \eta_t^{n} \sim N(0, \sigma_{n}^2) \tag{2.3.10}$$

The supply of M0 follows AR(1) process:

$$\epsilon_t^{m_0} = \rho_{m_0}\epsilon_{t-1}^{m_0} + \eta_t^{m_0}, \quad \eta_t^{m_0} \sim N(0, \sigma_{m_0}^2) \tag{2.3.11}$$

The demand for export and import are both disturbed by AR(1) processes:

$$\epsilon_t^{ex} = \rho_{ex}\epsilon_{t-1}^{ex} + \eta_t^{ex}, \quad \eta_t^{ex} \sim N(0, \sigma_{ex}^2) \tag{2.3.12}$$

$$\epsilon_t^{im} = \rho_{im}\epsilon_{t-1}^{im} + \eta_t^{im}, \quad \eta_t^{im} \sim N(0, \sigma_{im}^2) \tag{2.3.13}$$

Having adopted a SOE framework, we treat foreign consumption and interest rate as exogenous processes and model both of them as AR(1):

$$r_t^{f} = \rho_{rf} r_{t-1}^{f} + \eta_t^{rf}, \quad \eta_t^{rf} \sim N(0, \sigma_{rf}^2) \tag{2.3.14}$$

$$c_t^{f} = \rho_{cf} c_{t-1}^{f} + \eta_t^{cf}, \quad \eta_t^{cf} \sim N(0, \sigma_{cf}^2) \tag{2.3.15}$$

Chapter 3

Data and Estimation (DSGE Model)

In this chapter, we begin by discussing the data construction in section 3.1. In section 3.2 we briefly review the theory of Indirect Inference testing and estimation before confronting our DSGE model with the UK data. In section 3.3 we examine the model simulated behaviours.

3.1 Macroeconomic data for the UK

We employ nineteen macroeconomic series over 1986 - 2016. SW(07)-related variables are constructed as in Harrison and Oomen (2010). Data are quarterly and unfiltered. Macroeconomics series are in general non-stationary with their random movements contributing to a large proportion of economic fluctuations. Some previous studies extract trends from the original data using data-smoothing techniques (e.g., the HP filter and band pass filter) to render them stationary. We argue that this ignores the fact that such techniques are not developed on model-related theories, instead they focus on data's statistical properties. Thus, applying techniques of this kind is likely to distort the estimates of underlying trends and bias model's fit. For example, the HP filter might incorrectly identify model's adjustment to a policy shock as a shift in underlying potential and remove it, producing spurious dynamic relations (Hamilton, 2018). On the other hand, using non-stationary data has the merit of explaining the deviations from steady time trends (as observed every now and then) with implied uncertainty. It therefore appears sensible to employ the original data to test the model in a more convincing way (Meenagh and Minford, 2012).

Figure 3.1.1 plots all series employed in our model inclusive of three foreign exogenous processes. Grey shaded bars indicate UK recessions. Data are quarterly and non-stationary. Variables are in natural logs except where already expressed in percentages.

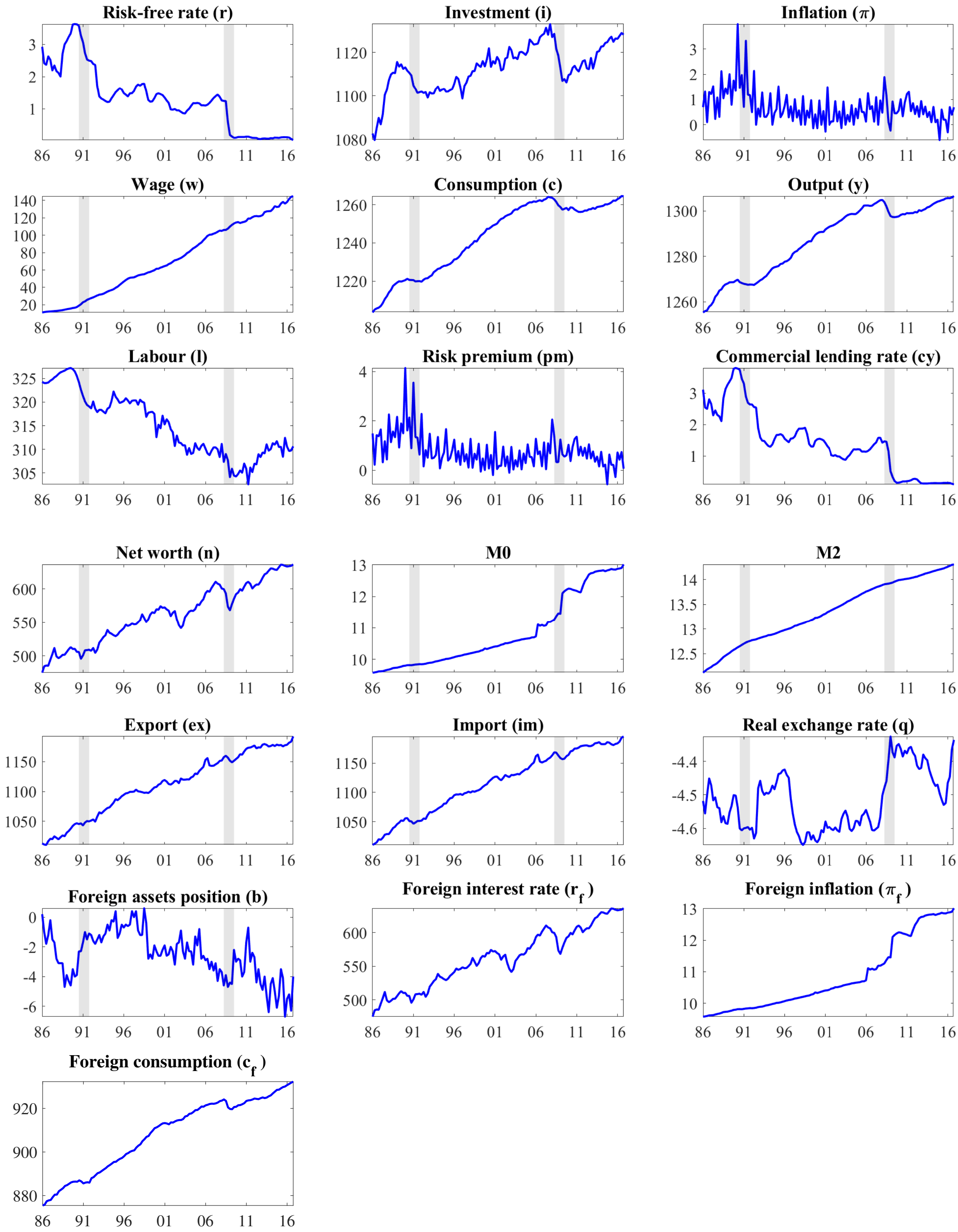


Figure 3.1.1: Data series (1986Q1 - 2016Q4)

3.2 Taking the model to the UK data

3.2.1 Model solution methods

We solve the model using a projection method proposed in Minford et al. (1984) and Minford et al. (1986), which closely resembles the method in Fair and Taylor (1980). The method was designed in a way to get around common traps like taking logs of negative numbers. In its log-linearised form, the model is solved using standard algorithms by increasing the number of passes till rational expectations converge in a reasonable number of iterations.

For equations without expectational terms, the structural errors (residuals) are directly backed out from each equation conditional on data and parameters; for equations with expectations, we employ a robust estimator which uses lagged variables as instruments in univariate time-series processes (McCallum, 1976; Wickens, 1982). It first runs an algorithm called base-run to produce values exactly the same with the input data, then it perturbs the model with shocks generated by structural errors. Shocks are bootstrapped by time vectors in order to preserve correlation between innovations.

In period 1, a vector of shocks is substituted into the baserun on top of initial lagged values. This solves the model starting from period 1 (and beyond) with its results becoming the lagged variable vector for the next period. In period 2, we draw another vector of shocks to add to its solution. The model then solves for this period and beyond, with its result in turn becoming the lagged variable vector for period 3. This process is repeated until simulation of the full sample is done. The bootstrapping is essentially the process of reordering the extracted shocks before adding the re-ordered shocks back to the model. Normally, we create 1000 bootstraps simulations which means we have created 1000 pseudo histories that could have occurred according to the model.

3.2.2 Testing and estimating the model using Indirect Inference

Due to the non-linearity induced by regime switch, we apply simulation-based Indirect inference (II) for the model evaluation and estimation. The inference is dubbed "indirect" in the sense that it is built on matching model and data through lens of auxiliary model. An auxiliary model in the form of VAR is often posited to capture the conditional mean of the data distribution, upon which we evaluate how well the model-generated pseudo history can replicate the actual data history, i.e how close the model gets to matching the data.

Process of bootstrapping: To start with, we first create a baserun which for convenience is set equal to data. Then we calculate the residuals of each equations by backing out the data and the model. The resulting structural residuals are regressed on their past values to produce the historical shocks that perturb the economy in each period. These historical shocks (innovations) are bootstrapped to preserve their correlations. By bootstrapping, we mean re-ordering shocks. More specifically, historical shocks are drawn in an overlapping manner by time vector (this explains why it is called “bootstrapping” which is a concept borrowed from statistics that refers to random sampling with replacement) and input into the model base run. Therefore, for period 1, a vector of shocks is drawn before being added into the model base-run, given its initial lagged values; so the model has been solved for period 1, which in turn becomes the lagged variable vector for period 2. In period 2, another vector of historical shocks is drawn after replacement for period 2 and added into this solution; then the model is solved for period 2 (and beyond), which in turn becomes the lagged variable for period 3. This process continues until a bootstrapped simulation is generated for the full sample. Finally we deduct the baserun from the simulated full sample to get the bootstrapped effect of the shocks. These bootstrapped (re-ordered) shock histories are then added to the Balanced Growth Path (BGP) implied by the model and the deterministic trend terms in the exogenous variables and error processes. The Balanced Growth Path (BGP) is obtained by solving for the effect of a permanent change in error(exogenous) variable at the terminal horizon T. After adding BGP to each of 1000 bootstrapped shock histories we would end up with 1000 pseudo histories that could have occurred to the economy for the full sample period.

The model parameters are split into two groups with the first either pinning down the model steady states or are simply cannot be identified from the data, and the second capturing model's dynamic properties. The first group parameters are held fixed at values based on either our data (wherever possible) or results from previous studies. Parameter values in the second group are calibrated using estimates from SW models on the US and EU, both of which share similarities with the UK. The values of parameters held fixed throughout our study are listed in Table 3.2.1:

Symbol	**Description**	**Value**
Long-run steady state ratios		
$\frac{G}{Y}$	Exogenous spending to output ratio	0.18
$\frac{C^e}{Y}$	Entrepreneurial consumption to output ratio	0.01
$\frac{EX}{Y}$	Export to output ratio	0.24
$\frac{IM}{Y}$	Import to output ratio	0.25
$\frac{K}{N}$	Capital to net worth ratio	2
$\frac{N}{M2}$	Net worth to M2 ratio	0.24
$\frac{M0}{M2}$	M0 to M2 ratio	0.07
Fixed parameters		
β	Quarterly discount factor	0.99
δ	Quarterly depreciation rate	0.025
γ	Common quarterly trend growth rate	1.004
ε_p	Kimball aggregator curvature in the goods market	10
ε_w	Kimball aggregator curvature in the labour market	10
θ	Survival rate of entrepreneurs	0.97
σ	Elasticity of substitution between home and foreign goods	1
σ^F	Foreign equivalent of σ	0.7
ω	Bias towards home goods in consumption bundle	0.7
ω^F	Foreign equivalent of ω	0.7

Table 3.2.1: Parameters and steady-state ratios held fixed throughout investigation

Steady state ratios are chosen to be consistent with the model structure and UK data. The share of capital to net worth is set to 2, indicating that external financing contributes to 50% of entrepreneurs' capital expenditure. The quarterly discount factor (β) is set at 0.99, corresponding to a steady state real interest rate of 1%; the quarterly depreciation rate is set at 0.025, implying a depreciation rate of 10% per annum. The probability of entrepreneurs surviving to the next period is set equal to 0.97, suggesting an expected lifetime of $\frac{1}{1-0.97} = 33.3$ quarters (8.3 years). The bias towards domestic goods (ω) and its foreign equivalent are calibrated at 0.7 after Meenagh et al. (2010). The elasticity of substitution between home and foreign goods σ (σ^F) is set at 1, whereas the foreign equivalent of σ (σ^F) is set at 0.7.

The evaluation criterion is based on the distance between the VAR coefficient estimates on the actual data and distribution of VAR coefficients estimates obtained from 1000 sets of simulated data. The Wald percentile is then calculated to show where in the Wald distribution from the simulations the Wald statistic for the actual data is.

$$W = (\beta^{\alpha} - \bar{\beta})' \Omega^{-1} (\beta^{\alpha} - \bar{\beta}) \tag{3.2.1}$$

where

$$\Omega = cov(\beta^{i} - \bar{\beta})$$

β^{α} - VAR parameters from the actual data; $\bar{\beta}$ - average of the 1000 sets of VAR parameters from the simulated data. As noted in Le et al. (2016b), the choices of β^{α} and $\bar{\beta}$ are not limited to VAR coefficients - data descriptors of other forms, for example impulse response functions, or particular moments which are essentially functions of the VAR coefficients are also considered to be suitable candidates. The Wald percentile shows where in the Wald simulation distribution the Wald based on the data lies. We then calculate first the Mahalanobis Distance, which is the square root of the Wald value, before further converting it into a normalised t-statistic by adjusting the mean and sample size of the chi-square distribution. If the resulting t-statistic does not exceed the threshold of 1.645, we do not reject the null that the model is correct and can generate data pattern. Broadly speaking, the smaller the t-statistic is, the better the model fits the data.

$$T = 1.645 \left(\frac{\sqrt{2W^{\alpha}} - \sqrt{2k-1}}{\sqrt{2W^{95}} - \sqrt{2k-1}} \right) \tag{3.2.2}$$

where W^{α} - Wald statistic on the actual data; W^{95} - Wald statistic for the 95th percentile of the simulated data; k - number of parameters in β. For a full explanation of the methodology, we refer readers to Le et al. (2016b).

Notice that using Indirect Inference for model testing does not necessarily require Indirect Inference estimation. If the calibrated model were able to generate the estimates of auxiliary model not far from those obtained from the actual data, then we would accept the null of true model. Nonetheless, if the model did not pass the test, we would reject the null and perform the indirect inference estimation accordingly. For parameter estimation, we first generate 1000 sets of randomized coefficients around their calibrated values within chosen bounds, then repeatedly test each set till we find the optimal one that minimizes the transformed t-statistic (< 1.645).

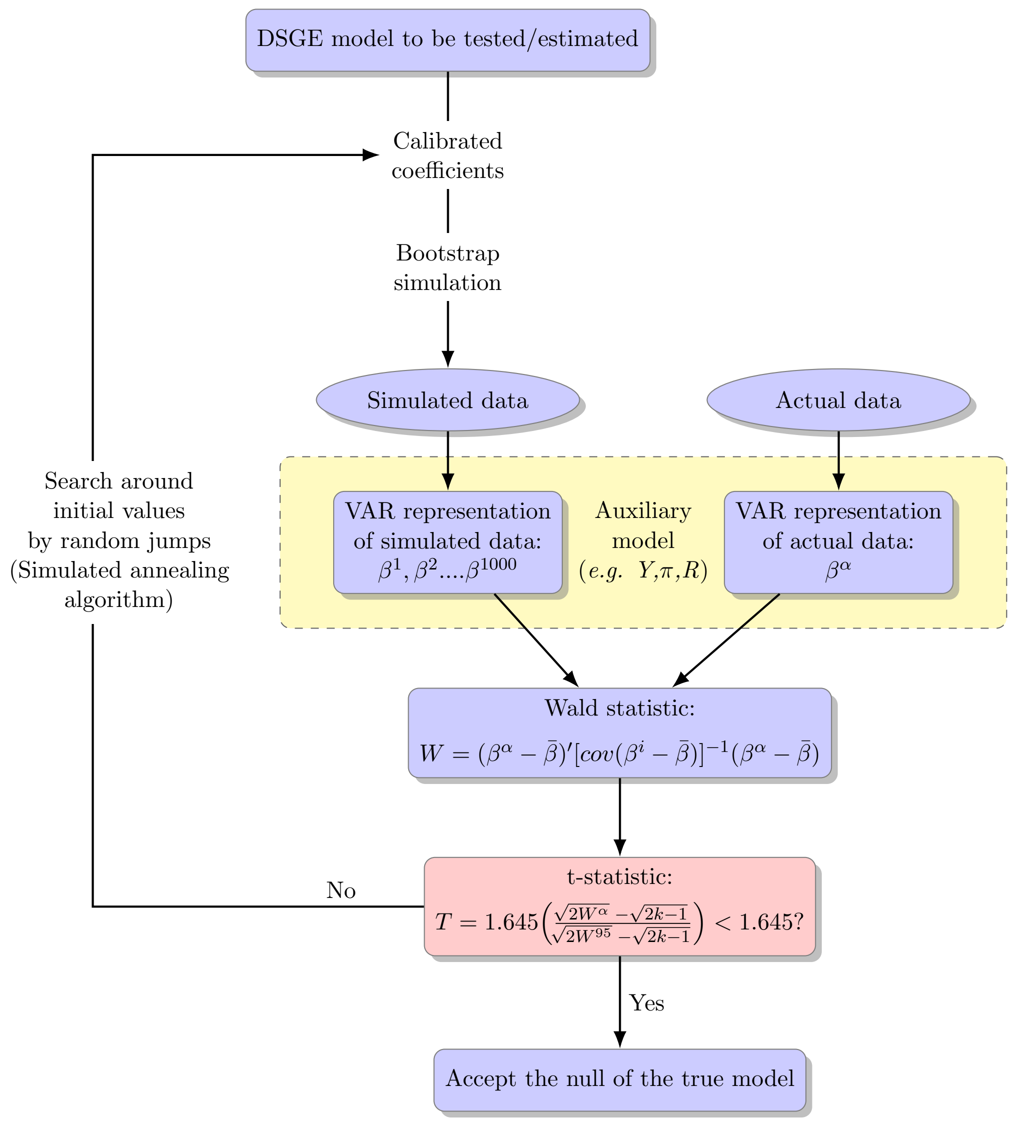


Figure 3.2.1: Process of Indirect Inference test and estimation

There are two types of Wald tests identified in Le et al. (2011): the full Wald test and direct Wald test. The former is based on the full set of variables intended to check the model's specification more broadly while the latter involves only a subset of the variables so as to focus solely on limited properties. Obviously, the power of the test gets higher as we increase the order of lags or number of variables in the auxiliary model. This, however, will put us at the risk of rejecting the model uniformly. So there is a trade-off between the power of test and tractability. Besides, the flexibility in the choice of variables to cover brings us the benefits of basing the model inference only on the essential features. In practice we usually start with a limited set of variables (Direct Wald), say output (Y), inflation (π), and interest rate (R) for the auxiliary model.

Note that if the data are non-stationary, or the model contains non-stationary shocks (e.g., technology process ϵ_t^a) or variables (e.g., foreign bonds b_t). The auxiliary model must be created in a way that it generates stationary errors. Hence we choose a VECM (Vector Error Correction Model) or a VARX (Vector autoregression with exogenous variables) instead as our auxiliary model which takes the matrix form:

$$\begin{bmatrix} y_t \\ \pi_t \\ r_t \end{bmatrix} = B \begin{bmatrix} y_{t-1} \\ \pi_{t-1} \\ r_{t-1} \end{bmatrix} + C \begin{bmatrix} T \\ \epsilon_t^a \\ b_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_t^y \\ \varepsilon_t^\pi \\ \varepsilon_t^r \end{bmatrix} \tag{3.2.3}$$

where

$$B = \begin{bmatrix} \theta_{yy} & \theta_{y\pi} & \theta_{yr} \\ \theta_{\pi y} & \theta_{\pi\pi} & \theta_{\pi r} \\ \theta_{ry} & \theta_{r\pi} & \theta_{rr} \end{bmatrix} \tag{3.2.4}$$

On the LHS is the set of endogenous variables: y_t, π_t, r_t. On the RHS, we include lagged endogenous variables in the first part, for which our interests lie in its coefficient matrix B containing 9 parameters. We incorporate in the second part of the RHS a deterministic time trend T, the non-stationary shock ϵ_t^a and the lagged non-stationary variable b_t, in order to describe the dynamics of the data.[1] The last part of RHS include the error processes of dependant variables. For the Wald calculation, we do not care about the coefficients on the exogenous variables (matrix C), only on the lagged endogenous ones (matrix B). Hence the parameter vector β consists of 9 coefficients in matrix B, plus the variances of three error processes: [2]

$$\beta = \begin{bmatrix} \theta_{yy} & \theta_{y\pi} & \theta_{yr} & \theta_{\pi y} & \theta_{\pi\pi} & \theta_{\pi r} & \theta_{ry} & \theta_{r\pi} & \theta_{rr} & var(\varepsilon_t^y) & var(\varepsilon_t^\pi) & var(\varepsilon_t^r) \end{bmatrix}' \tag{3.2.5}$$

where the first 9 parameters describe the dynamics of the data, and the last 3 capture the size of variations. The model will pass the test only if it jointly matches 12 coefficients. Now it is easy to understand if the number of endogenous variables included increases to 4, the power of the test will rise drastically as the model has to jointly match $4^2 + 4 = 20$ coefficients (all elements in a 4×4 matrix plus 4 variances for error processes). The starting calibration and estimation results for the structure parameters are presented in Table 3.2.2:

[1] Foreign bonds b_t is non-stationary because it grows with $(1 + r_t^f)$, see Equation 2.2.18.

[2] Le et al. (2012) suggest incorporating variances of the VARX residuals in vector β to measure the model's fit in capturing variation.

Symbol	**Description**	**Calibration**	**Estimation**
Taylor rule parameters			
r_p	Taylor rule response to inflation	2.3751	2.4657
ρ	Interest rate smoothing	0.7374	0.7092
r_y	Taylor rule response to output	0.0252	0.0261
r_{Δ_y}	Taylor rule response to change in output	0.0211	0.0219
Nominal friction parameters			
ξ_p	Degree of Calvo price stickiness	09728	0.9357
ξ_w	Degree of Calvo wage stickiness	0.6168	0.5933
ι_p	Degree of indexation to past inflation	0.1678	0.1614
ι_w	Degree of indexation to past wages	0.3545	0.3680
ω_{NK}^p	Proportion of sticky prices in hybrid price setting	0.0897	0.0931
ω_{NK}^w	Proportion of sticky wages in hybrid wage setting	0.4420	0.4589
Real friction parameters			
λ	Degree of external habit formation in consumption	0.7137	0.7409
φ	Elasticity of investment adjustment cost	6.8140	7.0739
ψ	Elasticity of capital utilisation cost to capital inputs	0.1044	0.1084
ϕ_p	One plus the share of fixed costs in production	1.7608	1.6936
Financial friction and monetary response parameters			
χ	Elasticity of risk premium to leverage ratio	0.0322	0.0310
ϑ	Risk premium response to M0 via quantitative easing	0.0430	0.0446
ϑ_1	Elasticity of M0 to M2 (nocrisis regime)	0.0550	0.0529
ϑ_2	M0 responses to risk premium (crisis regime)	0.0653	0.0628
Other parameters			
σ_c	Coefficient of relative risk aversion	1.6696	1.6059
σ_L	Elasticity of labour supply with respect to the real wage	2.6826	2.5803
α	Share of capital in production	0.1780	0.1848
Wald (Y, π, R)		31.6553	16.4556
Transformed t-statistic		1.9794	0.9576

Table 3.2.2: Starting calibration and estimates of structural parameters (1986Q1 - 2016Q4)

In the bottom section of Figure 3.2.2, the t-statistic conditional on calibrated parameters of 1.9794 (last but one column) clearly exceeds the threshold of 1.645. This necessitates the model estimation with simulated annealing algorithm, for which the procedure is partly reported in Table A2.1 of appendices.

The model departs from the real business cycle (RBC) and most New-Keynesian models in that it incorporates numerous nominal and real rigidities, e.g., Calvo-type pricing, indexation to past wages and inflation, habit persistence, investment adjustment cost and autocorrelated disturbance terms. Through introducing sluggishness to variables and allowing for long-lasting influences of stochastic processes, these "bells and whistles" help match the persistence seen in data by "throwing sand in the wheels".

The DSGE model is perturbed by a total of 15 structural shocks that provide fundamental source of volatility. What we do now is fit the model as estimated above to the historical data of the UK, and derive from them the shocks that constitute the stochastic part of the model.[3] Table 3.2.3 summarises the degrees of persistence and standard deviations of their innovations. Model implied shock histories are plotted in Figure 3.2.2.

Symbols & Descriptions		**AR coefficients**		**Standard deviations**	
ϵ_t^g	Government spending shock	ρ_g	0.7922	σ_g	0.8663
ϵ_t^g	Response of exogenous spending to productivity development	ρ_{ga}	0.1141	–	—
ϵ_t^b	Preference shock	ρ_b	0.3826	σ_b	0.2568
ϵ_t^i	Investment specific shock	ρ_i	0.5789	σ_i	1.8350
ϵ_t^r	Taylor rule shock	ρ_r	0.2164	σ_r	0.3648
ϵ_t^a	Productivity shock	ρ_a	-0.4086	σ_a	0.8125
ϵ_t^p	Price mark-up shock	ρ_p	-0.3750	σ_p	0.6507
ϵ_t^{wnk}	NK wage mark-up shock	ρ_{wnk}	-0.0522	σ_{wnk}	0.6852
ϵ_t^{wnc}	NC wage mark-up shock	ρ_{wnc}	0.8589	σ_{wnc}	3.2368
ϵ_t^{pm}	Risk premium shock	ρ_{pm}	0.9289	σ_{pm}	0.1469
ϵ_t^n	Net worth shock	ρ_n	0.3728	σ_n	9.1866
ϵ^{m_0}	Quantitative easing shock	ρ_{m_0}	0.0270	σ_{m_0}	0.0721
ϵ_t^{ex}	Export demand shock	ρ_{ex}	0.8633	σ_{ex}	2.1275
ϵ_t^{im}	Import demand shock	ρ_{im}	0.8672	σ_{im}	2.7494
r_t^f	Foreign interest rate shock	ρ_{rf}	0.9839	σ_{rf}	0.0785
c_t^f	Foreign consumption shock	ρ_{cf}	0.9923	σ_{cf}	0.5812

Table 3.2.3: Statistical properties of shocks (1986Q4 - 2016Q3)

[3] To derive the model implied shock histories, we first plug the estimated coefficients into the model to obtain the differences (residuals) between data and equations. The residuals are then regressed on their past values to derive the shocks (errors) that hit the economy each period. Foreign interest rate and consumption shocks are the errors from the AR regressions of data.

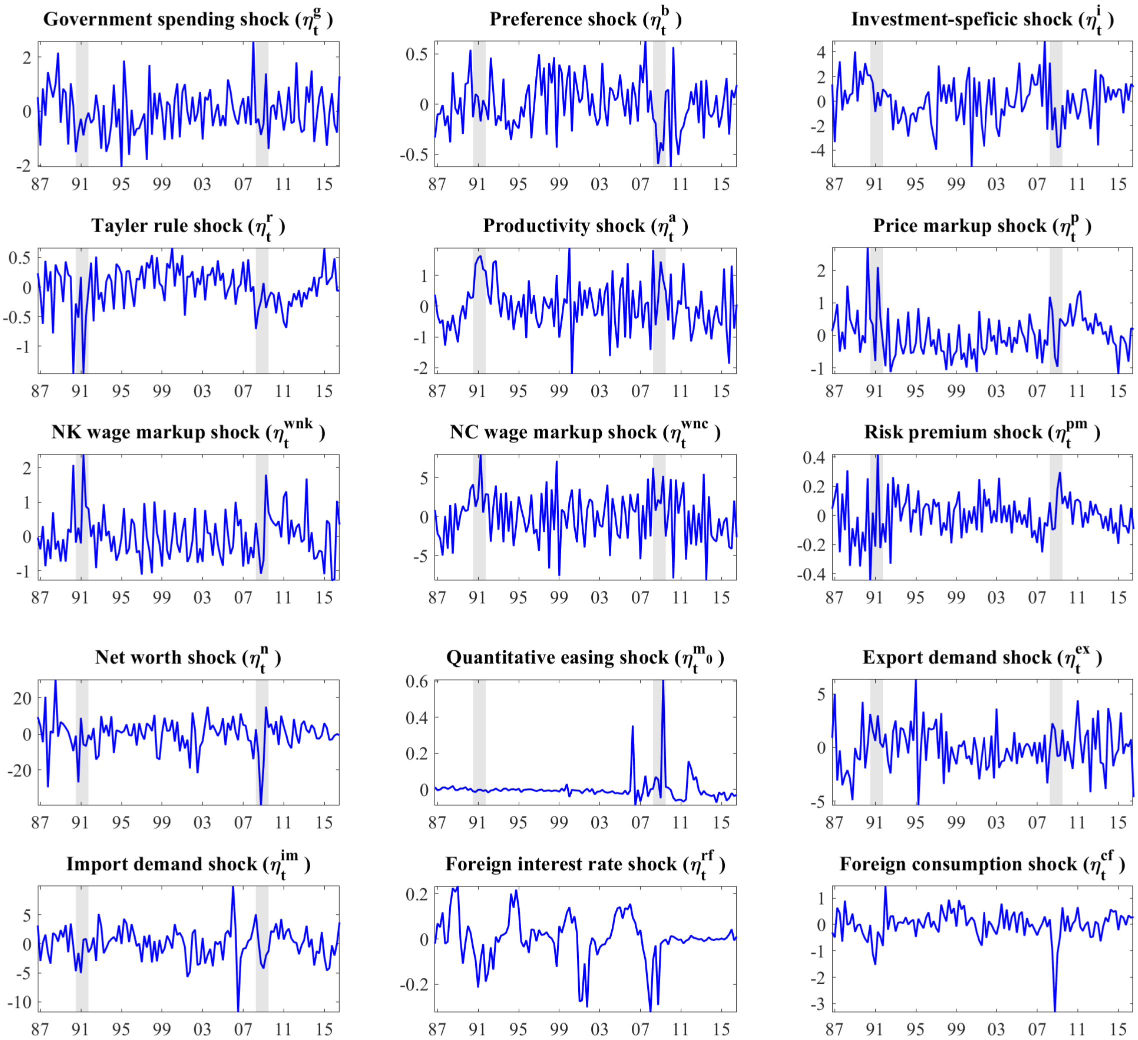


Figure 3.2.2: Model implied shock histories (1986Q4 - 2016Q3)

NOTE: Data spans the period 1986Q4 - 2016Q3 because we lost three periods at the beginning from lags and innovations of productivity shock, and one at the end from expectations. Grey shaded bands indicate UK recessions.

3.2.3 Properties of residuals

The residuals calculated as the difference between the data (LHS) and the equation (RHS) are plotted in Figure 3.2.3. Unlike the shocks series (innovations) that fluctuate around zero, the residuals are the accumulation of shocks over time.

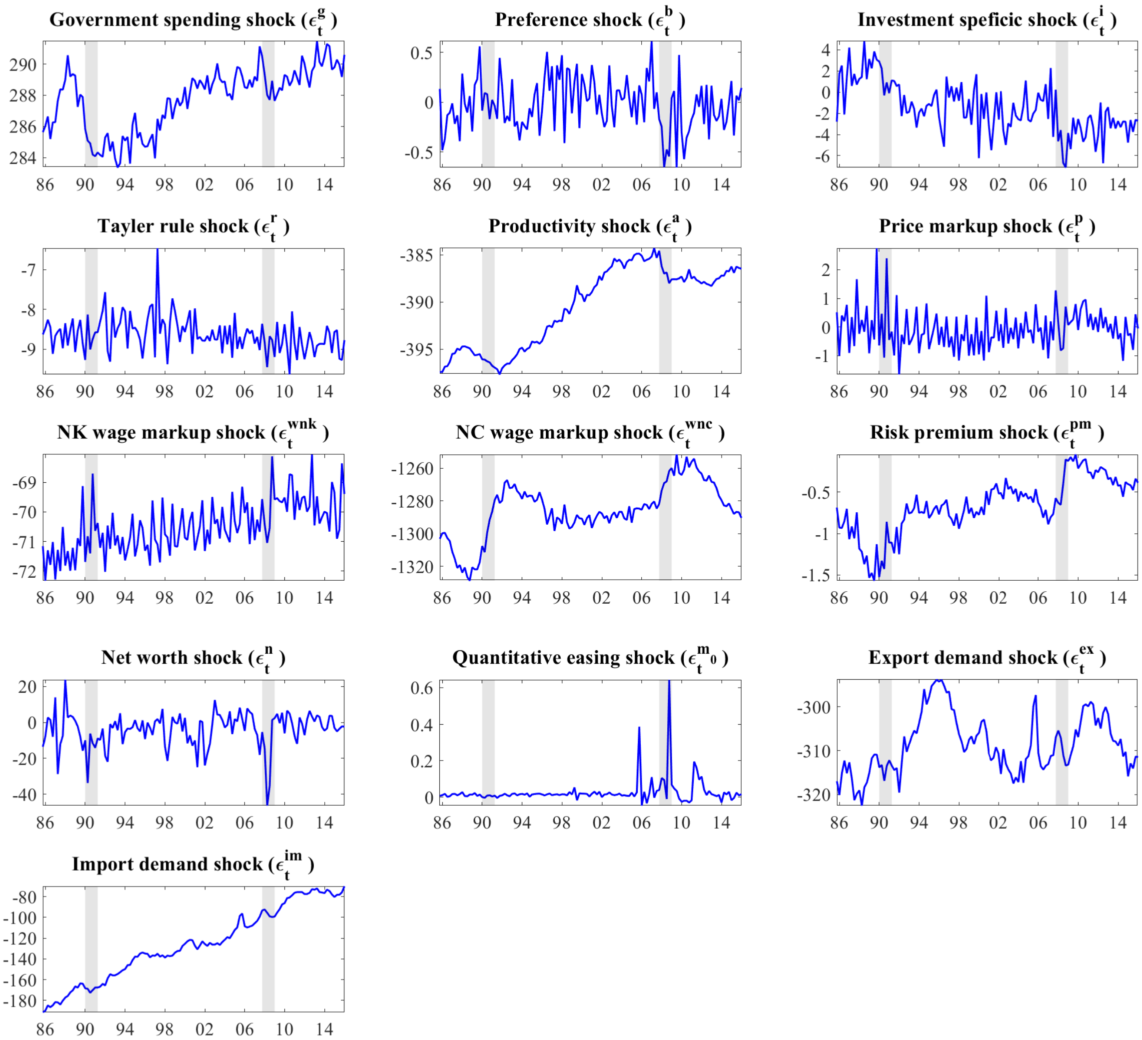


Figure 3.2.3: Model implied residual histories (1986Q2 - 2016Q3)

NOTE: Residuals spans the period 1986Q2 - 2016Q3 because we lost one at the beginning from lags and one at the end from expectations.

	Augmented Dickey-Fuller t-stats				**Phillips–Perron t-stats**				**KPSS LM-stats**			
	Level (c)	Level (c,t)	Difference (c)	Conclusion	Level (c)	Level (c,t)	Difference (c)	Conclusion	Level (c)	Level (c,t)	Difference (c)	Conclusion
Government spending shock	-1.900	-3.596^{**}	-10.228^{***}	TS (5%)	-2.130	-3.500^{**}	-14.045^{***}	TS (5%)	0.863^{+++}	0.114	0.041	TS (1%)
Preference shock	-9.955^{***}	-9.944^{***}	-10.633^{***}	S (1%)	-10.350^{***}	-10.322^{***}	-38.446^{***}	S (1%)	0.188	0.142^{+}	0.057	S (1%)
Investment shock	-3.499^{***}	-5.467^{***}	-8.788^{***}	S (1%)	-7.304^{***}	-10.023^{***}	-77.161^{***}	S (1%)	1.020^{+++}	0.097	0.234	TS (1%)
Taylor rule shock	-11.552^{***}	-12.627^{***}	-11.326^{***}	S (1%)	-11.692^{***}	-12.546^{***}	-85.779^{***}	S (1%)	0.912^{+++}	0.237^{+++}	0.282	I(1) (1%)
Productivity shock	-1.348	-1.070	-12.447^{***}	I(1) (1%)	-1.351	-1.067	-12.346^{***}	I(1) (1%)	1.122^{+++}	0.217^{+++}	0.241	I(1) (1%)
Price mark-up shock	-2.746^{*}	-2.739	-22.025^{***}	S (10%)	-15.071^{***}	-15.030^{***}	-66.737^{***}	S (1%)	0.155	0.150^{++}	0.091	S (1%)
NK wage mark-up shock	-2.023	-3.813^{**}	-17.051^{***}	TS (5%)	-9.849^{***}	-12.696^{***}	-37.900^{***}	S (1%)	1.169^{+++}	0.057	0.048	TS (1%)
Labour supply shock	-1.798	-1.340	-12.987^{***}	I(1) (1%)	-1.899	-1.952	-12.813^{***}	I(1) (1%)	0.591^{++}	0.076	0.111	S (10%)
Risk premium shock	-1.882	-4.666^{***}	-4.193^{***}	TS (1%)	-2.511	-5.197^{***}	-19.348^{***}	TS (1%)	0.972^{+++}	0.056	0.072	TS (1%)
Net worth shock	-7.603^{***}	-7.654^{***}	-10.990^{***}	S (1%)	-7.605^{***}	-7.764^{***}	-37.415^{***}	S (1%)	0.165	0.034	0.069	S (1%)
Quantitative easing shock	-10.325^{***}	-10.564^{***}	-8.443^{***}	S (1%)	-10.390^{***}	-10.564^{***}	-59.450^{***}	S (1%)	0.412^{+}	0.083	0.236	S (5%)
Export demand shock	-2.716^{*}	-2.642	-11.412^{***}	S (10%)	-2.723^{*}	-2.651	-11.567^{***}	S (10%)	0.182	0.133^{+}	0.098	S (1%)
Import demand shock	-1.028	-3.571^{**}	-9.281^{***}	TS (5%)	-1.045	-3.251^{*}	-9.143^{***}	TS (10%)	1.298^{+++}	0.078	0.071	TS (1%)
Critical values (1%)	-3.485	-4.036	-3.491		-3.485	-4.036	-3.486		0.739	0.216	0.739	
Critical values (5%)	-2.885	-3.447	-2.888		-2.885	-3.447	-2.886		0.463	0.146	0.463	
Critical values (10%)	-2.580	-3.149	-2.581		-2.580	-3.149	-2.580		0.347	0.119	0.347	

Tests in levels are conducted with model “level (c)” with a constant, and “level (c,t)” with both constant and linear trend. Tests in first difference are conducted using model “difference (c)” with a constant only. For ADF and PP tests, asterisks denote rejection of the unit root null at 10% (*), 5% (**) and 1% (***) significance levels. The KPSS test evaluates the null of stationarity. Plus signs indicate rejection of the stationarity null for KPSS test at 10% ($^{+}$), 5% ($^{++}$) and 1% ($^{+++}$) significance levels.

Table 3.2.4: Stationarity of the model implied residuals

To analyse the time series properties of model implied residuals, we apply three stationarity tests, namely Augmented Dickey-Fuller (ADF, 1979), Phillips–Perron (PP, 1988) and Kwiatkowski–Phillips– Schmidt–Shin (KPSS, 1992) tests. Results from them are reported in Table 3.2.4. Both ADF and PP test for the null of unit root process. In recognition of their potential drawbacks e.g., having low power to reject the null if redundant trend terms are included in regressions, we also conduct KPSS test to complement our analysis. The KPSS test, on the other hand, tests for the null of stationarity. However, it should be noted that the nulls of ADF and PP tests are not identical to the alternative of KPSS; and because of the non-equivalence , the triple testing cannot offer a panacea. Moreover, disparity in results might arise due to factors like lag length selection, difference in finite sample performance (Maddala and Kim, 1998).

Under the null of unit root process, the alternative of stationary or trend stationary is favoured by ADF and PP tests in eleven out of thirteen cases. The only two exceptions are TFP and NC wage mark-up shock which appear to be I(1) processes. Also in most cases, the ADF and PP tests reach the same conclusion (about nature of the process, significance level) albeit some minor differences in NK wage mark-up and import demand shocks. On the other hand, the KPSS test confirms the non-stationarity of TFP shock, but there is less unanimity regarding Taylor rule and NC wage mark-up shock (labour supply shock), where KPSS test offers contradictory results. In sum, the TFP shock is the only I(1) process out of thirteen upon which three tests reach unanimous agreement, while the others all show evidence of stationarity in at least one test. Our assumption (TFP shock is treated as ARIMA(1,1,0), while the rest are assumed to be AR(1)) hence cannot be rejected by the data.

3.3 Simulated behaviour of the model

3.3.1 Occasionally binding ZLB constraint

As noted previously that not only do we consider the possibility of nominal interest rate hitting the zero lower bound but we also permit routes out of it. Figure 3.3.1 shows some examples of simulation.

Model-generated pseudo histories are created by feeding re-ordered shocks back to the model to allow for alternative trajectories to be modelled. We put the time scale that the sample spans along the horizontal axis, so the simulation can be seen as the "rerun" of the history. Inspection reveals that among 121-period simulation, the nasty periods in which the the ZLB constraint binds can be relevant quite often. Simulation #84 and #419 provide examples of interest rate hitting the ZLB not just once but repeatedly. The model also allows for flexibility in the duration of ZLB situation, as for extreme scenarios like simulation #396, the ZLB constraint can be binding for more than half of the time. The protracted stay at the ZLB might occur if the model was perturbed by a sequence of adverse shocks.

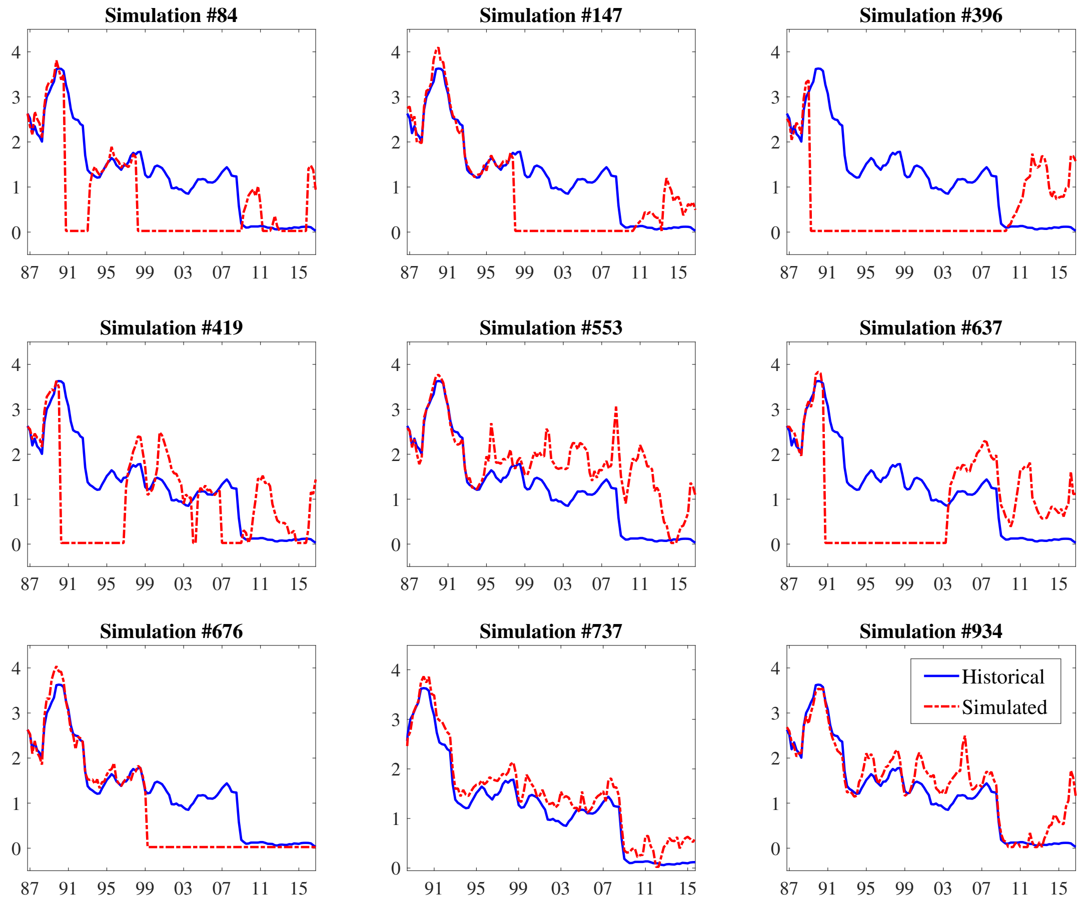


Figure 3.3.1: Interest rate simulations

Our results corroborate those of Kiley and Roberts (2017) in that the frequent encounters with ZLB can place a serious constraint on monetary policy. The pseudo histories we have created under bootstrap simulation emphasize the frequency and severity of the ZLB episodes that could occur in UK economy; and this is in line with the findings in Le et al. (2016a) about crises being a normal part of the US economy - which bears certain resemblances to its UK counterpart.

3.3.2 Monetary responses under the regime switch

Nowadays, in most New-Keynesian models the Taylor rule has become the standard way of setting CMP. Nevertheless, since 2008 the policy rates in most advanced economies were slashed to near zero and no longer responded to any developments in economy. if it calls for a zero or even negative rate, the ZLB constraint will binds, leaving actual rate to deviate from the target prescribed by the rule. The suspended Taylor rule makes monetary authorities lose one key instrument and calls for the deployment of QE, which becomes the main policy tool that brings temporary liquidity effect and, more importantly, compresses the risk premium artificially. Figure 3.3.2 presents three chosen simulations side by side to illustrate how monetary responses shift under the regime switch.

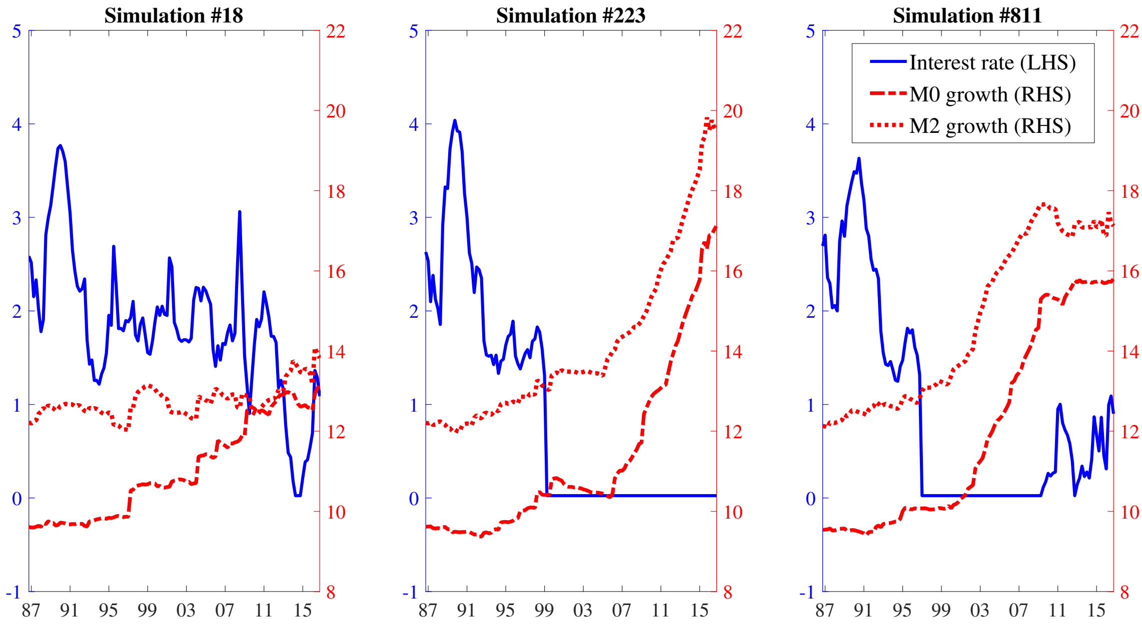


Figure 3.3.2: Occasionally binding ZLB constraint triggers QE operation

Simulation #18 depicts the case where interest rate had stayed out of the ZLB over the entire sample. In the absence of ZLB situations, Taylor rule was operating at all times and M0 (cash) only acted to accommodate the broad money supply M2. By contrast, in simulation #223 the ZLB constraint bound in 1998 and had stayed there ever since, so the central bank resorted to QE by injecting more M0 to the economy. As such, M0 becomes the main tool in operation with the aim of bringing down the risk premium and the cost of external financing. The structural break in M0 growth captures the effect of gilt purchases and liquidity injection when the traditional monetary policy is enforcedly inactive. Finally, simulation #811 shows the routes in and out of ZLB and materially different monetary responses under regime switch. The ZLB bound in 1996 and triggered QE operation, which led to a sharp rise in the supply of M0 and M2. However at a later date in 2010 the nominal interest rate escaped from ZLB, so the QE was unwound with M0 growth subsequently levelling off and being only accommodative. Nominal interest rate R once again became the primary instrument for monetary policy, as was the case in pre-QE days.

Chapter 4

Transmission Mechanism and Variance Decomposition (DSGE Model)

To shed light on some of the key transmission mechanisms at work in model's equilibrium, in this chapter we employ both impulse response analysis and variance decomposition to investigate the shocks that perturb the economy.

4.1 Responses to a government spending shock

Figure 4.1.1 shows the effect of a fiscal expansion shock (ϵ_t^g) under both regimes. In the standard non-crisis context (blue solid), we see the rise in government spending boosts the labour and wage, and raises the consumption and output. This generates mild inflationary pressure that is kept in check by a rise in nominal interest rate R (Deposit rate). With the rising output and employment, entrepreneurs' net worth goes up and drives down the credit spread via the BGG financial accelerator mechanism. However, as the rise in deposit rate outweighs the drop in credit spread, the commercial lending rate still goes up, absorbing the economy's lending capacity and crowing out private investment. The negative relationship between the fiscal expansion and the money supply indicates that monetary responses tend to offset rather than accommodate the expansionary fiscal policy. Uncovered real interest rate parity is violated owing to the rise in real interest rate, and thus must be restored by a domestic currency appreciation (a drop in real exchange rate Q), in anticipation of future depreciation (a rise in Q). This leaves the domestic production less competitive in the global market, which in turn encourages import while discouraging export.[1]

In the crisis regime (red dash-dotted) where the Taylor rule is rendered inoperative, monetary authority cannot cool down the economy by raising the nominal interest rate.

[1]Note that the change in export should be proportional to the change in real exchange rate, holding the foreign variables constant.

The drop in the real interest rate (zero nominal interest minus positive inflation) hence stimulates consumption, labour, wage and output more compared to the normal regime. The significant growth in IG producers' net worth reduces credit spread and lending rate, boosting the investment. In the absence of monetary response, the rise in inflation results in a depreciation of home currency (a rise in Q) and increases export. Import is discouraged by the devalued home currency, but encouraged by the elevated domestic consumption; overall, it rises slightly.

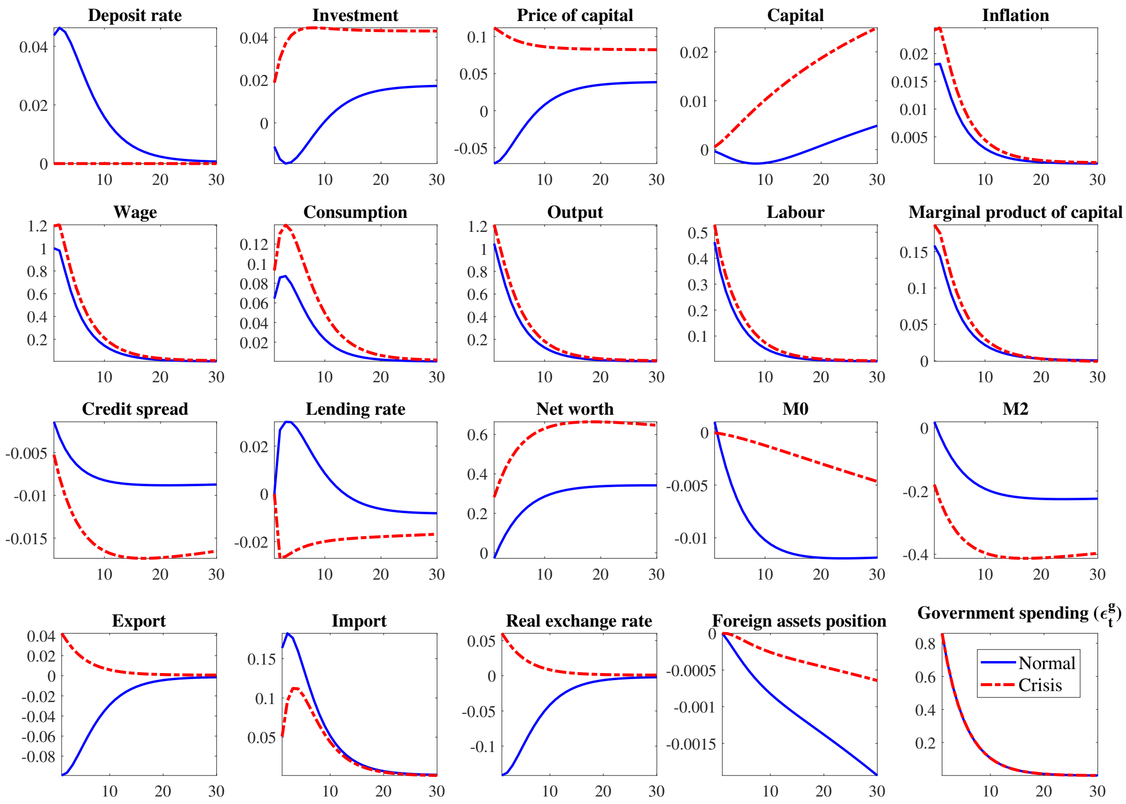


Figure 4.1.1: Impulse responses to a positive government spending shock

NOTE: deposit rate, lending rate, credit spread and inflation are expressed in percentage points (pps). The rest variables are reported in percentage deviation (%) from their steady states. Plotted along x-axis are quarters.

For the recent years, expansionary fiscal policy has been widely employed to combat economic contraction. One of the associated issues concerns the size of fiscal multiplier. Some studies are particularly relevant as they feature the widening credit spreads and low interest rates which were commonly observed in advanced economies since 2008. Christiano et al. (2011), Eggertsson (2011) and Woodford (2011) emphasize that the government spending multiplier can become substantially greater (relative to the non-ZLB situation) when the ZLB constraint is binding. Fernández-Villaverde (2010) and Eggertsson and Krugman (2012) argue for a role of credit friction in explaining the larger-than-normal fiscal multiplier. Carrillo and Poilly (2013) outline a model very similar to ours and show that the BGG type financial friction can greatly enlarge the size of fiscal multiplier in the ZLB situation. In addition, their paper investigates how adjusting monetary response (e.g., reducing policy inertia or response to output growth for Taylor rule) may affect fiscal multiplier. Later work of Hills and Nakata (2018) reconfirms the existence of greater fiscal multiplier at the ZLB compared to the non-ZLB case; besides which, they show that in the non-ZLB situation, introducing the policy inertia increases the multiplier. Here we conduct analogous experiments to study the size of multipliers in our model, which is fully equipped to deal with all these aforementioned factors.

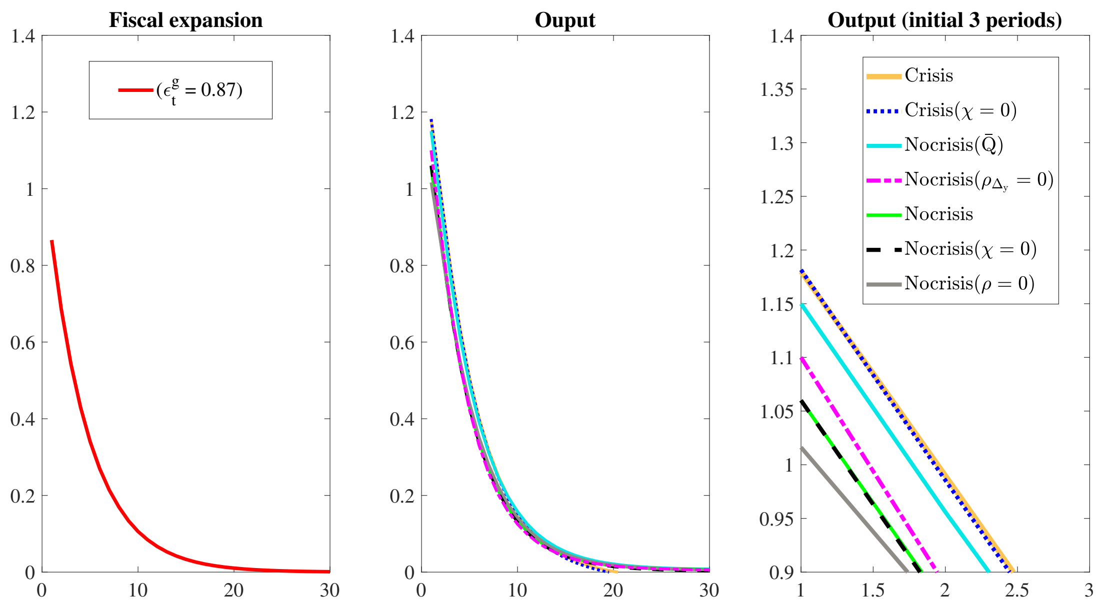


Figure 4.1.2: Impact of fiscal expansion on output

NOTE: The responses in the middle panel figure are difficult to disentangle from each other, so we plot the initial 3 periods only for the right panel figure. $\chi = 0$, $\bar{Q}$, $\rho_{\Delta_y} = 0$, and $\rho = 0$ correspond to zero financial friction, fixed exchange rate, no response to output growth (Taylor rule) and no policy inertia (Taylor rule), respectively.

Regime	**Crisis**	**Crisis**	**Nocrisis**	**Nocrisis**	**Nocrisis**	**Nocrisis**	**Nocrisis**
Specification		$(\chi = 0)$	$(\bar{Q})$	$(\rho_{\Delta_y} = 0)$		$(\chi = 0)$	$(\rho = 0)$
Impact fiscal multiplier	1.36	1.36	1.33	1.27	1.22	1.22	1.17

Table 4.1.1: Comparison of fiscal multipliers under various model specifications

Inspection of Figure 4.1.2 reveals that fiscal multipliers under all specifications remain above unity and less than 1.4. The output effect in response to a temporary fiscal expansion (persistence =0.79) vanishes within 20-30 quarters, almost the same length of time it takes for the shock itself to return to the steady state. We choose the impact multiplier rather than the cumulative multiplier to keep our design simple and close to the prior work. The fact that the rise in output follows the same shape of time path as that in government spending ensures that our choice of impact multiplier is meaningful (Woodford, 2011). In contrast to some earlier findings, our model shows that the maximum impact on the output occurs in the first quarter and then declines in a quasi-linear way.[2]

Table 4.1.1 ranks fiscal multipliers under various specifications from the largest to the smallest. The multiplier gets to be the largest (1.36) in the ZLB regime (all else equal). However, compared with the non-ZLB regime (1.22), the ZLB constraint only raises the fiscal multiplier by a small margin. Contrary to the findings of Carrillo and Poilly (2013), we find no differentiation in the size of multipliers with or without financial friction, irrespective of regimes. Removing the policy inertia in Taylor rule (ρ=0) reduces the multiplier to 1.17. The intuition behind is that with policy inertia absent, the nominal interest rate responds more promptly to the exogenous change in government spending, which dampens the output expansion. On the other hand, removing the monetary response to output growth raises the fiscal multiplier very slightly from 1.22 to 1.27. Unsurprisingly, fixing the exchange rate increases the multiplier to 1.33, as exchange rate cannot adjust freely to offset the impact arising from fiscal expansion. In general, there are only minor variations under alternative specifications relative to the baseline case.

4.2 Responses to a monetary policy shock

The New-Keynesian sticky price models with inflation-targeting have become the workhorse in monetary policy analysis nowadays. These models would typically feature Taylor-type rules that adjust nominal interest rates in reaction to the development in inflation and output; this mechanism is dubbed “lean against the wind” (Gourio et al., 2018).

Figure 4.2.1 shows the effect of a positive (contractionary) Taylor rule shock (ϵ_t^r) under the normal regime. The real interest rate rises, which reduces consumption and output. Confronted with a lower aggregate demand, entrepreneurs cut back on workforces and wages. Net worth drops in accordance with the fall in output and employment. This drives up the credit spread and commercial lending rate, discouraging investment. There is a significant currency appreciation (a drop in Q) to restore the uncovered interest rate parity, which in turn reduces the demand for export and raise the demand for import.

[2]Studies by Batini et al. (2012), Baum et al. (2012) and Coenen et al. (2012) report a hump-shaped impact on output, with the second-year multiplier being 10-30 percent higher than in the first year.

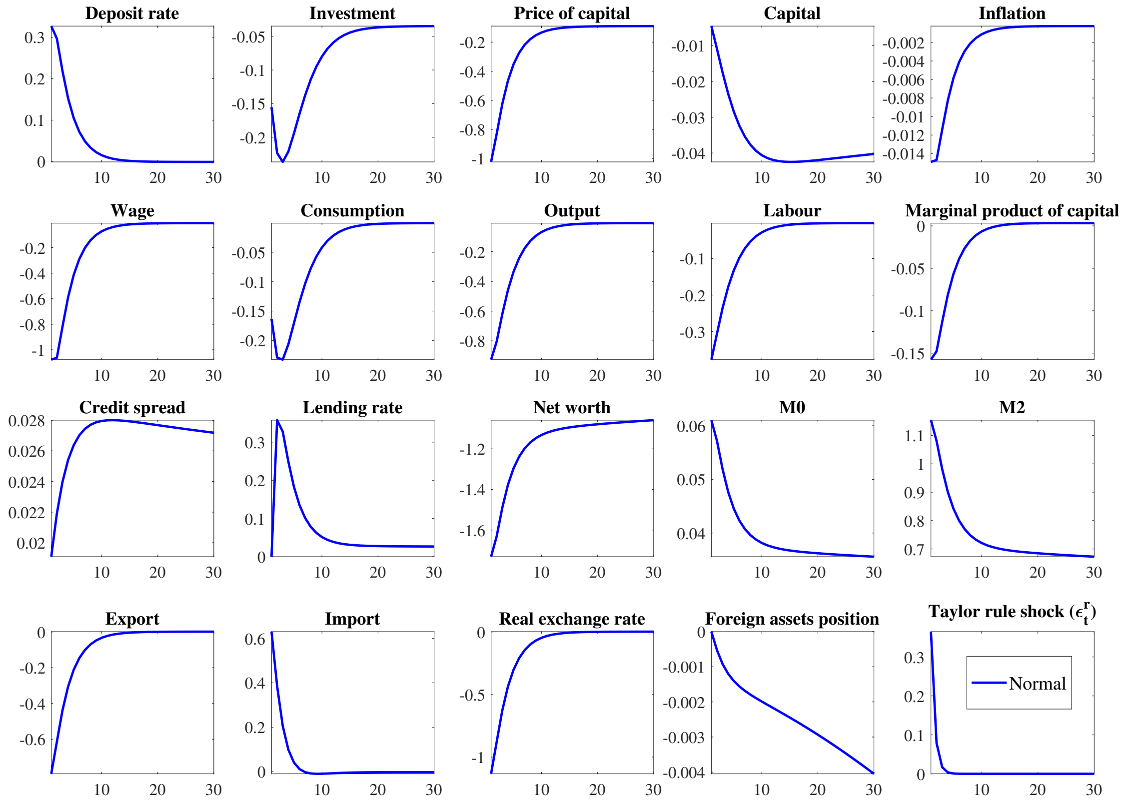


Figure 4.2.1: Impulse responses to a positive monetary policy shock

4.3 Responses to a regulatory shock

We model macroprudential regulation by directly injection into the premium equation an regulatory instrument. The intuition behind is that financial regulation aims to contain excessive risk taking and avoid reckless lending. This can be achieved by raising the credit spread, which would be translated into a rise in the commercial lending rate that reflects banks' growing unwillingness to lend.

Figure 4.3.1 shows the effect of a positive credit spread shock (ϵ_t^{pm}) under both regimes. The rise in credit spread approximates a tightening of the financial regulation that pushes up the lending rate and keeps it lifted in the following years. This increases the difficulty for the capital purchase and results in the long-lasting reduction in investment and output, with the trough occurring around 5 quarters (1.25 years) after the impulse. It also brings about a prolonged reduction in consumption, net worth, capital, labour and wage. The dampened economic activity implies downward pressure on inflation, and reduces the nominal interest rate (deposit rate). Note that the positive co-movement between inflation and output suggests that the regulatory shock behaves more like aggregate demand than supply shock.[3]

[3] Shocks are identified as demand (supply) shocks if they cause inflation and output to move in the same (opposite) direction (Barnett and Thomas, 2013).

The responses under the crisis regime appear to be more pronounced. This is because with Taylor rule response absent, the adverse impact on economy are not counteracted by any rates cut. The permanent interest rate peg leads to a rise in the real interest rate. This increases the value of domestic currency (a drop in Q) and discourages export. Reduced consumption and appreciated currency push the import from two opposite directions. The decrease in import is muted compared with the normal regime.

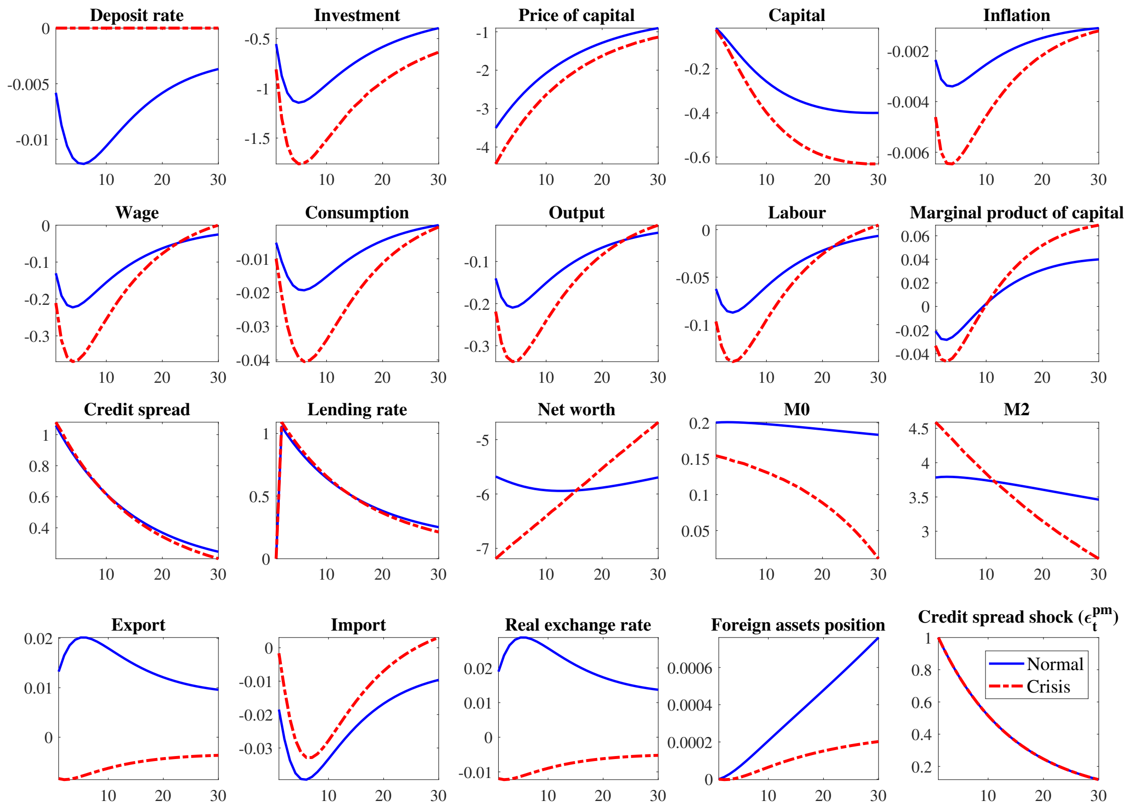


Figure 4.3.1: Impulse responses to a macro-prudential shock

4.4 Variance decomposition

Table 4.4.1 summarises the variance decomposition of the key variables under the null that shocks are independent from each other.[4] The nominal interest rate is mainly dominated by the Taylor rule shock (63%), while the price mark-up (14%) and foreign interest rate (7%) shock together accounts for another 21% variation. Inflation is entirely dominated by the price mark-up shock, which constitutes almost 88% of the total variation. Productivity shock accounts for more than 20% variation for both wage and output, although the world

[4]Considering that when bootstrapping our process in effect preserves the correlation between shocks, we see variance decomposition as the allocation for the parts of variation which is not explained by other shocks. Meenagh et al. (2010) point out that there is no basis on which for us to allocate variances between correlated shocks, unless we have built another model for the shocks themselves.

shocks play a more significant role (46%) in explaining the output variation. Quantitative easing, NK wage markup, and government spending shocks play very limited quantitative role, and contribute to less than 5% of fluctuations for any variables listed. Real exchange rate's behaviour is predominately explained by the productivity shock (45%) and foreign interest rate shock (45%), which is largely in conformity with the findings in Meenagh et al. (2010).

	R	π	W	C	Y	Q
Government spending shock	0.58	0.16	2.32	1.16	4.99	0.21
Preference shock	0.05	0.03	1.25	23.28	0.34	0.01
Investment shock	2.00	0.78	3.63	1.46	6.19	1.54
Taylor rule shock	62.09	2.01	17.45	49.90	1.72	1.34
Productivity shock	5.40	3.14	21.39	9.78	27.24	44.73
Price markup shock	14.52	87.56	1.47	2.01	1.84	3.21
NK Wage markup shock	0.00	0.00	0.05	0.00	0.00	0.00
NC Wage mark shock	2.83	2.36	25.36	2.78	0.34	1.15
Risk premium shock	0.03	0.00	0.11	0.06	0.26	0.01
Net worth shock	2.39	0.67	5.44	1.66	11.30	1.19
Quantitative Easing shock	0.00	0.00	0.00	0.00	0.00	0.00
Domestic shocks subtotal	89.87	96.71	78.48	92.09	54.23	53.39
Foreign interest rate shock	7.02	2.57	9.52	1.89	19.24	45.68
Foreign consumption shock	0.90	0.12	4.13	2.44	9.95	0.13
Export demand shock	0.76	0.21	2.74	1.25	5.78	0.28
Import demand shock	1.45	0.39	5.12	2.33	10.80	0.53
World shocks subtotal	10.13	3.29	21.52	7.91	45.77	46.61
Total	100	100	100	100	100	100

Table 4.4.1: Variance decomposition of key variables

Chapter 5

Developing a Narrative: From the Lawson Boom to the Recovery From the Global Financial Crisis (DSGE Model)

In this chapter, we employ shock decomposition to examine the historical impact of structural shocks on the UK macroeconomic aggregates. In doing so, we start off by feeding histories of individual shocks one by one back to the model (stripped of all shocks). There are fifteen exogenous processes in our model, hence we repeat this process fifteen times till the marginal effect of each shock is recorded. The path of total effects (sum of all shocks' marginal effects) is expected to approximate the detrended data. We label in the figure the well-known economic events and periods of boom and bust in business cycle, in an attempt to trace out their impacts on the output.

5.1 How have domestic shocks contributed to the UK output development?

Figure 5.1.1 shows the historical decomposition for UK output over the whole sample. The contribution from major domestic shocks are highlighted in non-grey colours, and the rest ones are in grey. The total contribution of all shocks, which somewhat resembles the data with trend removed, is depicted in red solid line. Although it is not possible to directly read off the scale of shocks from the chart, their relative contribution to the GDP fluctuation and evolution over time can still offer insights as to which shocks have mattered the most, and when.

The effect of government spending (in yellow) and investment specific shocks (in pink) have fallen over time, which possibly reflects the muted volatility on the demand side. In contrast, productivity shocks (in blue) are playing an increasing important role in explaining output fluctuations. It is worth emphasizing that even in boom periods leading up to the crisis: 2003-2007, the UK economy was nonetheless haunted by the productivity slump. This is in line with the existing evidence that the UK had experienced a more dramatic fall in the productivity growth than any other leading western economies. It then appears that any revisions since 2008 would not be able to get the economy back to its 2.5% pre-crisis growth trend unless this "productivity puzzle" gets solved. Finally, the waning impact of net worth shocks (in green) and the negligible influence of premium shocks (not big enough to be shown in the figure) suggest that financial shocks are of little relevance to the protracted and feeble recovery from the recession.

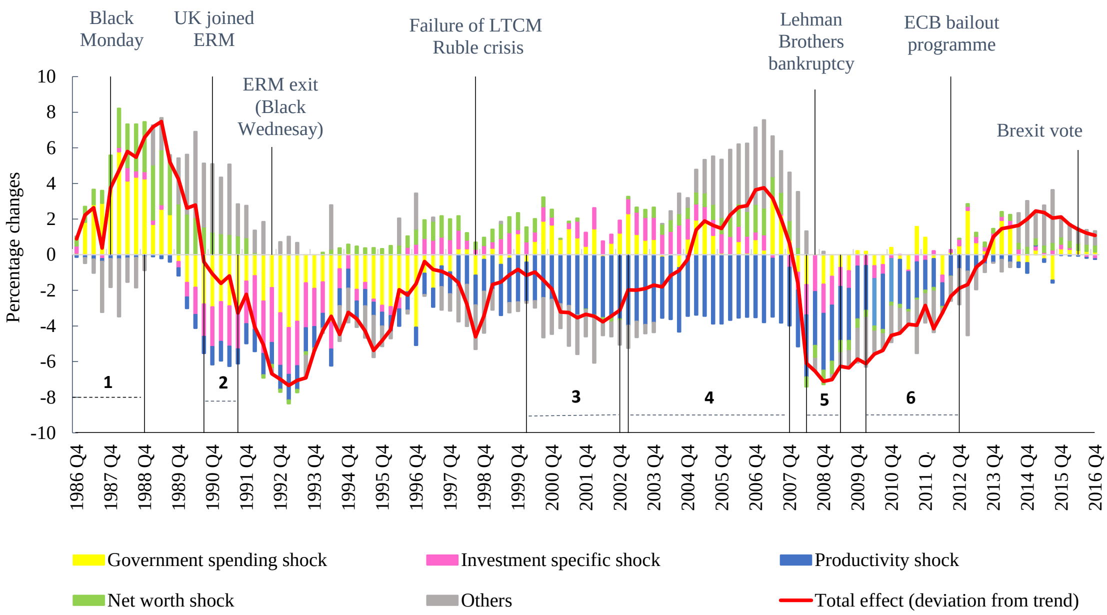


Figure 5.1.1: Historical decomposition of output - contribution from domestic shocks

Sources: decomposition results and author's calculations. The sample spans the period 1986Q4 -2016Q4 because the simulation starts from the 4th period with first three periods dropped. The periods marked in the figure are: 1. Lawson boom 2. Early 1990s recessions 3. Dot-com crash 4. Pre-crisis credit boom 5. Great Recession 6. Eurozone debt crisis.

5.2 How have world shocks contributed to the UK output development?

During the ongoing process of globalisation, UK has been trading extensively with the rest of the world relative to its size in goods, services and financial assets.[1] High levels

[1]Lane and Milesi-Ferretti (2007) reveal that UK's trade openness (calculated as the ratio of trade to GDP) amounts to more than 60%, and its financial openness (measured as the sum of its stocks of assets and liabilities) accounts for 1400% of GDP.

of openness imply that the UK economy tends to exhibit co-movement with the RoW, especially those with which it trades most or with which it is closely financially integrated. The explanations for this can be that shocks originating from UK's major trading partners can transmit to the UK, or, in another scenario, both UK and its partners are exposed to common shocks that originate elsewhere.

Figure 5.2.1 plots the annual GDP growth of UK versus that of the RoW. Estimated at around 0.52, the high correlation between the two justifies the influence of global environment on UK economic performance.[2] Moreover, there has been increasing co-movement between the two since 2005 and since then their growth trajectories have become more alike. They both managed to maintain a 2.5% annual growth rate before having downward shifts and reaching the nadir in 2009. The RoW, however, experienced a stronger recovery compared to the UK in the earlier 2010s.

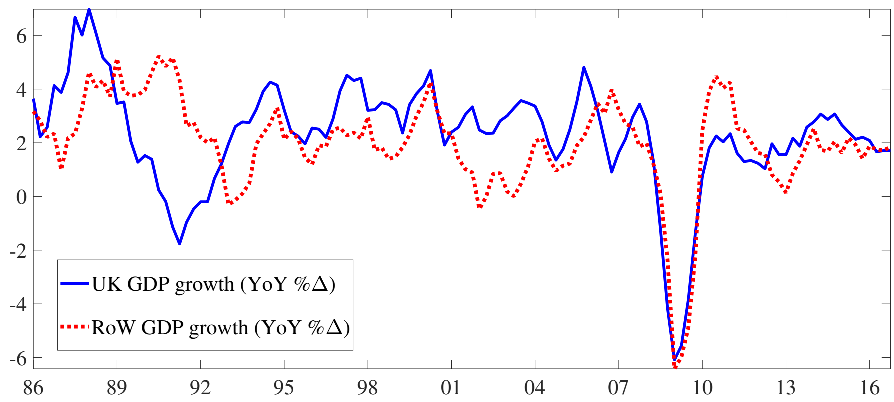


Figure 5.2.1: GDP growth: UK versus the rest of the world

NOTE: The RoW is the weighted sum of GDP growth in Germany (0.62), US (0.23), and Japan (0.15).

5.2.1 Literature on channels through which world shocks propagate to the UK

Chowla et al. (2014) classify the channels whereby world shocks affect the UK macroeconomic environment into two main categories: the trade and financial channels.

1. Trade channel

The trade channel captures the exchange of goods and serves across borders that results from global influence. Estimates from COMPASS - the main forecasting tool employed by the BoE, suggest that around 2% of the shortfall in the UK output relative to its previous trend by 2013 was due to the adverse world shocks transmitted via the trade channel (Domit and Shakir, 2010). World shocks of different sources can propagate to the

[2] Table A4.1 in our appendices lists the GDP growth in G7 countries since 2008.

UK, causing changes in its trade volume with the RoW. For example, the budget cuts in UK's major trading partners, or a shift in foreign consumers' preference for UK-produced goods, could suppress the demand for UK exports, and place downward pressure on the UK manufacturing.

Moreover, interruption (improvement) in the global supply chain might drive up (down) the commodity prices, which would ultimately be felt by the UK, because of its heavy reliance on energy imports. One example of this kind is the UK's digest of crude oil. Since 2005 world oil price has exhibited an increasing co-movement with the UK price level and was thought to have contributed to the temporary overshooting (undershooting) of the 2% inflation target, which complicated the MPC's task.

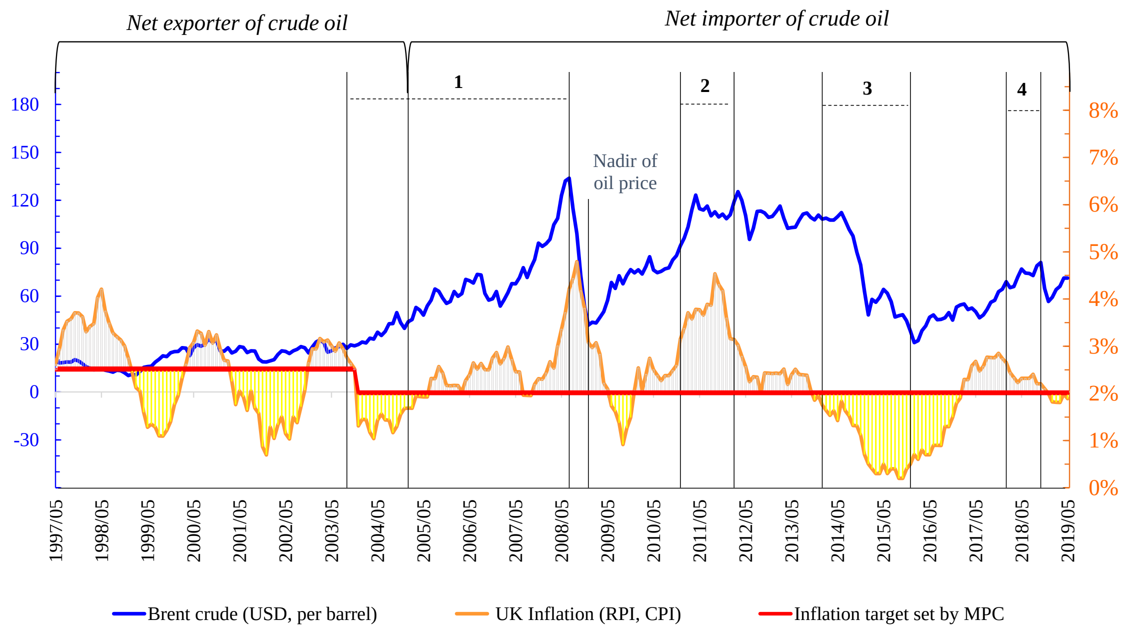


Figure 5.2.2: Fluctuations in world commodity price contribute to UK inflation overshooting (undershooting)

Sources: Datastream, ONS and author's calculation. All data are monthly. For the measure of the UK inflation, given the switch from RPI inflation target of 2.5% to CPI inflation target of 2% in December 2003, we employ the RPI index to calculate YoY (Year-over-Year) inflation before this date and CPI index for those after. Since 2005, the UK has transitioned from a net exporter to a net importer of crude oil. Periods labelled in the figure are : 1. Higher oil demand in emerging economies 2. Arab Spring 3. Steady oversupply of oil 4. Deterioration in Venezuela and threat of sanction against Iran.

Figure 5.2.2 plots the world crude oil price, UK's inflation and MPC's price target with the key periods in the global oil supply highlighted. In line with Millard et al. (2013), we find the evidence of increasing co-movement between the global oil price and UK's inflation since mid 2000s, which coincides with UK's transition from the net exporter to the net importer of oil in 2005. The higher demand in emerging markets such as China and India boosted oil price to a record high of $145.85 per barrel in July 2008, which generated upward pressure on UK inflation (period 1), causing a spike a few months later. However, as the 07/08 financial crisis broke out, the oil price had experienced a dramatic fall until it reaches it nadir in December 2008 since the crisis. Later, encouraged by the swift and robust recovery in emerging economies, the market had observed a strong recovery in oil prices between 2010 - 2012 (period 2), which again squeezed the real income of UK households and businesses. To make it worse, disrupted oil production as a result of Arab Spring further drove up the energy prices, which caused the inflation overshooting in 2011. According to Chowla et al. (2014), the high energy prices are considered the factors behind UK's sluggish recovery in early 2010s. It was not until 2014 that the positive oil supply shocks due to rising output from OPEC led to a persistent drop in oil price (period 3), thereby raising the available income of UK consumers that would otherwise has been spent on energy. Having plunged to the bottom level in January 2016, the escalation in the Venezuela crisis and threats of sanctions against Iran again put the global energy price on a upward trend again (period 4). Overall, we find clear evidence of co-movement between the oil price and UK inflation, especially from 2005 onwards.

2. Financial channel

The ongoing process of financial integration reflected in the fast-growing financial assets exchange across borders has benefited the world economy for effectively managing the funding flows globally. But, on the flip side, the same financial linkages can propagate adverse shocks from one to another, especially during times of uncertainty. When globally operating banks suffered loss abroad (outside of the UK), they might cut back loans made available globally including those to the UK, causing a tightening of the UK credit condition.[3] Conversely, the increasing profits obtained abroad might positively affect the UK credit condition - with sufficient capital retained in their balance sheets, banks are tend to extend their loans worldwide.

Apart from the banking channels, statistics show that roughly half of UK's assets and liabilities held abroad are in the forms of portfolios and foreign direct investments (FDIs), through which external shocks could propagate to the UK via the "non-banking" channel. Despite the relatively scant empirical research in this field, theoretical literature suggests the existence of "wealth effect" whereby declining (increasing) net wealth of the households due to investment losses (gains) abroad or falling (rising) asset values might slow down (speed up) households spending and borrowing in the UK. Likewise, foreign agents' loss (gain) from their investments outside UK could potentially affect UK's asset prices depending on if they view the UK financial markets as safer (riskier) choices for further investment. Inflows (outflows) of capital in the UK market could drive up (push

[3] Losses from the bad loans reduce banks' capital ratio calculated as the share of capital in total assets. To rebuild this capital ratio, banks may resort to shrinking their balance sheets by cutting supply of new loans. See alsoFarag et al. (2013).

down) the capital prices, leaving asset holders better off (worse off).[4]

5.2.2 Decomposition results - contribution from world shocks

Assessing the role that global developments have played in the recent decades allows monetary authorities to set policies in a way that takes into account the expected influence from world shocks. And doing so would assist MPC in its aim to achieve the best outcome of welfare enhancing of the entire society.

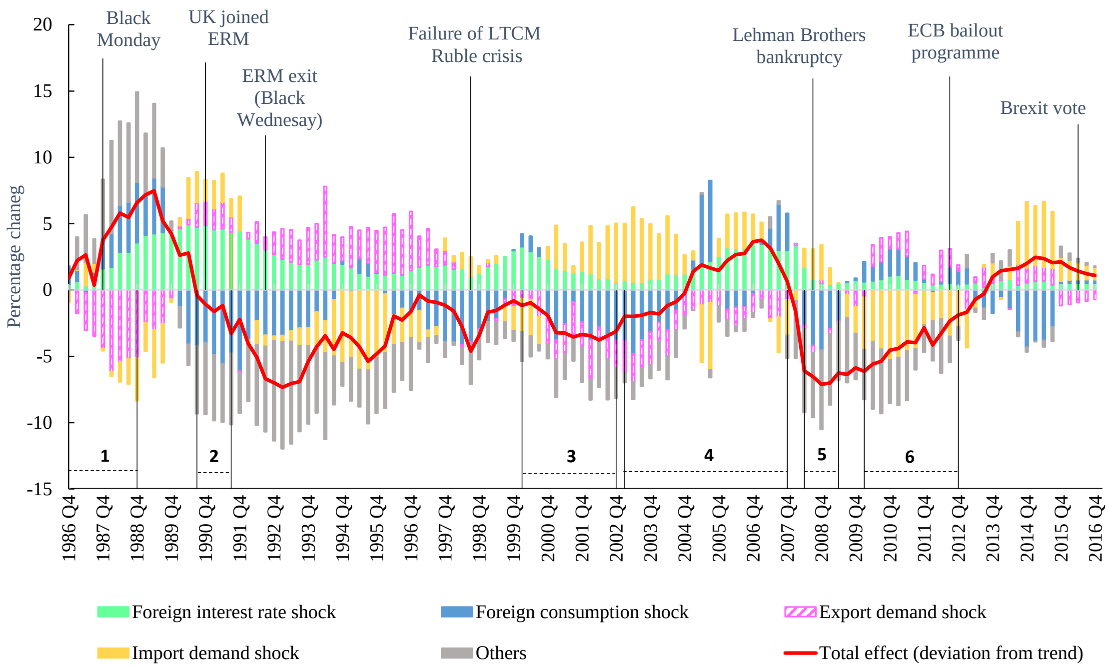


Figure 5.2.3: Historical decomposition of output - contribution from world shocks

Figure 5.2.3 shows the evolution of the world shocks that accounts for the UK output fluctuations. The influence of foreign interest rate shocks (in green) have waned over time. Visual inspection reveals that since 2008 they are about one-fifth the size they were at their peak in the early 1990s. Foreign consumption shocks (in blue) and import demand shocks (in orange) can explain the bulk of the dip in both the early 1990 recession following the ERM exit and the more recent Great Recession. Export demand shocks (in pink with pattern filled) contributed to significant countercyclical swings when studied in the context of the past three decades - they slowed down the GDP growth in the Lawson Boom and in the 03-07 credit boom, whilst adding to the GDP growth in the early 1990s and the 07-08 recessions.

Figure 5.2.4 gives a historical view of the world shocks impact via the trade channel (in

[4] Arslanalp and Poghosyan (2014) estimate that over 2008-2012, the cross-border capital flows into the UK had bid up the price of 10-year Gilt and pushed down its yield by 20-30 bps.

orange bars), so we can track the evolution of its contribution to the UK output deviation. The blue dashed line depicts alternative scenario in which the trade impact was stripped out.

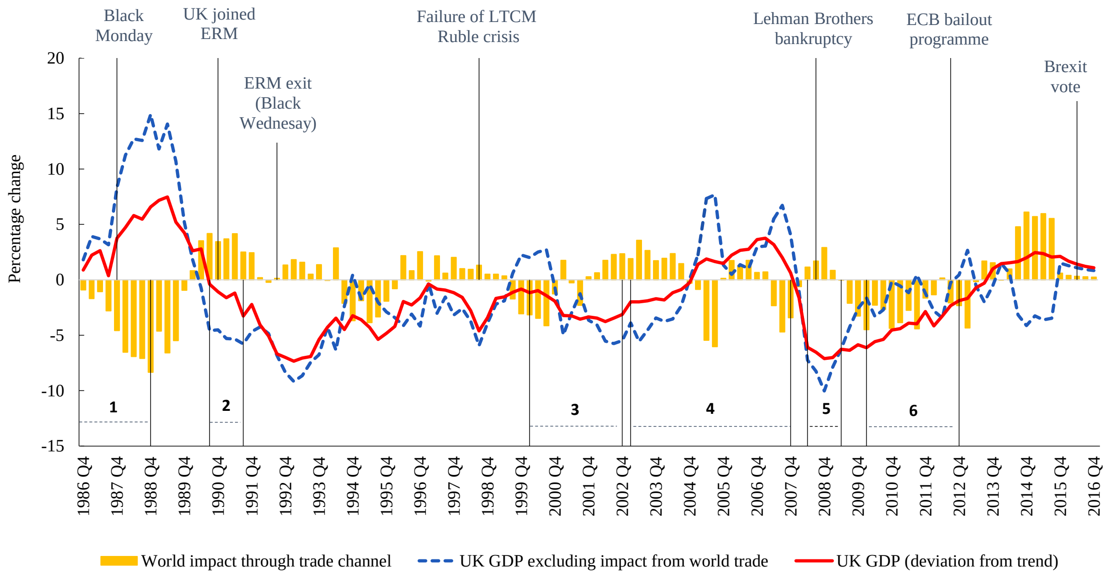


Figure 5.2.4: Impact of world shocks on UK GDP through the trade channel

Sources: decomposition results and author's calculation. The periods marked in the figure are: 1. Lawson boom; 2. Early 1990s recessions; 3. Dot-com crash; 4. Pre-crisis credit boom; 5. Great Recession; 6. Eurozone debt crisis.

The increasing co-movement between the trade impact and output deviation corroborates the statement in Chowla et al. (2014) - the trade linkage between the UK and the RoW has been strengthened in the late 1990s to the extent that economic environment in the UK was partly shaped by developments in the global context. Figure5.2.4 shows that Eurozone debt crisis (period 6) put downside pressure on the EU's demand for UK-produced goods and dragged down UK's economic recovery between 2010-2012. [5] Worse still, UK banks' indirect exposure to the Euro-area, has raised concerns that the Euro-area sovereign debt crisis might spill over to the UK financial system and weigh on its economic activities.[6] To combat the potential threat from the escalating debt crisis, a series of policies had been in place in the UK since 2011, for example, the QE2 initiated in 2011Q4, and the Funding for Lending Scheme introduced in 2012Q3 with the aim of providing cheap funding to UK banks and building societies. All these measures are seen as UK policy makers' attempts to alleviate strains in the domestic credit market arising from the adverse events abroad.

[5]As the major trading partner for the UK, the EU's share in UK's exports amounts to 48%, according to the estimates in 2017 by the European Commission database.

[6]Although the direct exposure of UK banks to the worst hit southern European countries was limited, they had heavy engagement with French banks, which sustained massive losses from bad loans made to Italy and Spain.

Had these not taken place in time, the UK's economic fortunes would be considerably weaker today. Later from 2013 to the Brexit vote, the majority of the pickup in UK output growth seems to has been driven by the positive shocks from the trade channel. In general, trade shocks appear to have mixed influences on the UK economy and it is hard for us to come to the conclusion whether the UK has benefited from its trade with the RoW.

Chapter 6

Optimal Policy Rules (DSGE Model)

A broad consensus has formed since the GFC around the ideas of incorporating financial stability consideration into monetary policy analysis. This came about because the standard Taylor rule does not respond much to the credit condition. Permitted by the inflation targeting regime, credit growth in the UK was strongly elevated in the periods leading up to the crisis. In our model, the monetary authorities only actively regulate the credit market when the economy switches to the crisis regime. One lesson we draw from the recent crisis is that the government has a duty to intervene in the credit market not only when the economy is struggling, but also when it is booming. Ideally, policies are supposed to prevent crises and avoid "reacting too little too late". Hence, it would be worthwhile to investigate if reacting to financial condition in normal times could mitigate the build-up of financial instability and tame the credit cycle.

In this regard, two strands of literature have emerged. The first view states that financial stability concerns ought to be part of the second objective of monetary policy. The reason is that regulatory tools alone are unlikely to completely contain the risk-taking behaviour of financial intermediaries. Monetary policy, by contrast, is able to affect the underlying economic environment as "it gets in all of the cracks" (Stein, 2013).

Previous works that incorporate credit condition into monetary policy rules include: Taylor et al. (2008), who propose a modified rule that allows interest rate to respond to variations in credit spread (e.g. LIBOR-OIS spread); Curdia and Woodford (2010), who show that the spread-adjusted rules are conductive for maximising average expected utility under certain circumstances e.g., appropriate degree of response to spread, and limits on the nature and persistence of economic disturbance; [1] Gilchrist and Zakrajšek (2012), who examine premium-augmented and premium shock-augmented rules in response to financial sector disturbance and adverse financial news, and conclude that both rules

[1] Curdia and Woodford (2010) compare two types of augmented Taylor rules: spread-adjusted and credit volume-adjusted rules, and find the latter to be less beneficial for welfare gains and less robust to alternative assumptions, although either type of adjustment, if of an suitable magnitude, can improve equilibrium responses to financial disturbances.

substantially dampen the economic fluctuations in nominal and real variables. Moreover, shock-augmented regime in which monetary authority only responds to underlying disruption in the financial intermediation generates greater swings in real economic activities compared to the premium-augmented regime. The reason is that by responding to shock only, it fails to account for the endogenous decline in asset price and net worth that intensifies the financial accelerator mechanism.

On the other hand, some argue that monetary policy is too blunt a tool to be routinely used for containing financial risks, and instead more targeted micro/macro prudential tools should be deployed (Bernanke, 2012; Yellen, 2014; Svensson, 2015, 2018). According to them, the successful conduct of monetary and financial policy thus requires each to have their own instruments, e.g. having a separate rule to deal with financial imbalance, while keeping monetary policy focused on price stability.

Moreover, for those that favour having at least one tool for each target, relying merely on the interest rate to achieve both price and financial stability would violet the Tinbergen rule and undermine the effective implementation of policy, if the achievement of one target precludes the achievement of the other. Badarau and Popescu (2014) show that augmenting the Taylor rule with financial stability objective (credit-to-GDP ratio) brings little to no gains in maintaining a stable credit cycle, as the trade-off appears when only one instrument (nominal interest rate) is employed for multiple goals. More recently, Carrillo et al. (2017) consider three regimes: a baseline regime that uses Taylor rule to target inflation only, an augmented Taylor rule regime that responds to both inflation and credit spread, and a dual rule regime that supplements the inflation-targeting Taylor rule with an additional financial rule.[2] Their results show that compared to the baseline case, welfare costs are smaller in dual rule regime and spread-augmented Taylor rule regime, by 264 and 138 basis points respectively.

We contribute to the existing literature by specifying three alternative policy regimes in addition to the standard Taylor rule regime (STR): a premium-augmented Taylor rule regime (ATR1), a shock-augmented Taylor rule regime (ATR2), and a dual rule regime (DRR) that supplements the standard Taylor rule with a QE rule to target spread at all times. Note that the strategy of employing QE to stabilise credit supply is now extended to the normal regime when the ZLB does not binds. All regimes are then compared in terms of reducing welfare costs.

[2]The financial rule in Carrillo et al. (2017) is implemented in the form of subsidies. Lenders receive this time-varying subsidies as compensation for the extra risks they bear when making loans to entrepreneurs with less net worth. In effect, this allows financial authorities to directly intervene in the credit market and facilitate bank lending when necessary.

6.1 Augmented Taylor rule regimes (ATRs) - Should the conventional monetary policy lean against the credit?

6.1.1 Spread-augmented Taylor rule regime (ATR1)

In the ATR1 regime, we inject into the Taylor rule as in SW(07) an additional term that responds to the risk premium. So the central bank adjusts nominal interest rate in reaction to developments in inflation, output and premium as follows:

$$\hat{r}_t = \rho \hat{r}_{t_1} + (1-\rho)(r_p \hat{\pi}_t + r_y \hat{y}_t - r_{pm} \hat{pm}_t) + r_{\Delta_y}(\hat{y}_t - \hat{y}_{t-1}) + \epsilon_t^r \qquad (6.1.1)$$

where $0 < r_{pm} < 1$ is the parameter governing the speed of spread adjustment. The negative sign before the term reflects the idea that nominal interest rate should be lowered (raised) relative to what the baseline policy rule would prescribe when the credit spread is higher (lower) than normal. Naturally, $r_{pm} = 0$ corresponds to the baseline case where monetary authority does not directly respond to variation in financial market. In the previous section, we have studied the model-based responses to a premium shock (financial disturbance) under the baseline Taylor rule $r_{pm} = 0$, now continue to examine the impulse response under alternative values of r_{pm}.

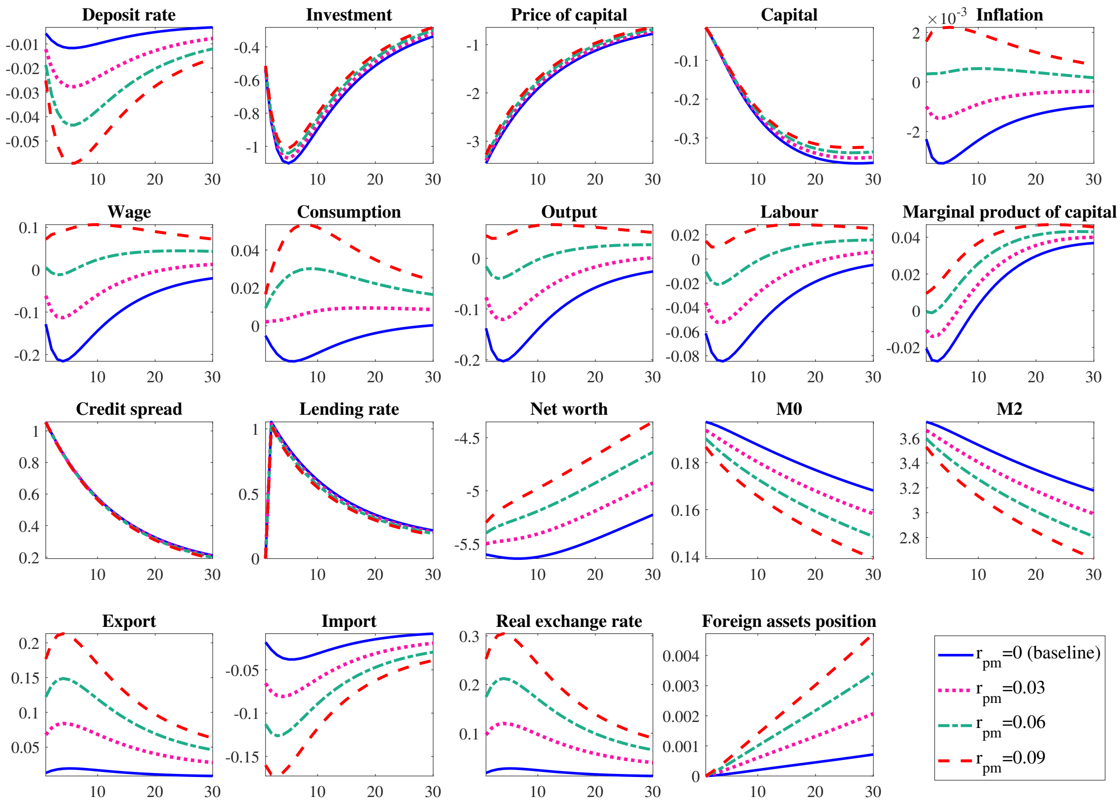


Figure 6.1.1: Responses to a premium shock under varying degrees of premium adjustment (*Baseline vs. Premium-augmented Taylor rule (ATR1)*)

Figure 6.1.1 shows the responses of variables to a one-standard-deviation premium shock ϵ_t^{pm}. As we increase r_{pm}, the equilibrium nominal interest rate (R) is reduced more compared to $r_{pm} = 0$. This is consistent with the rational that the spread-adjusted rule implies a lower interest rate relative to the level prescribed by the standard rule. Note that when r_{pm} is increased to 0.09, output and inflation no longer decline, but rise. The contraction in investment, capital and price of capital are virtually the same regardless of the value of r_{pm}.

To find the optimised policy elasticities, we perform a three-dimensional grid search over r_p, r_y and r_{pm}, and keep the remaining parameters fixed.[3] The search involves creating a grid for all the parameters to be varied and evaluating the welfare costs for each possible combination. The search algorithm randomly goes through points (combinations) that may or may not improve our objectives. We assume monetary authority can act optimally in the sense that they choose the elasticities that yield the best outcome. Through bootstrap simulations, the best ATR1 specification that minimises the variance of inflation and output takes the following form:

$$\hat{r}_t = 0.7092\,\hat{r}_{t_1} + (1 - 0.7092)(1.8371\,\hat{\pi}_t + 0.0271\,\hat{y}_t - 0.0414\,pm_t) + 0.0219\,(\hat{y}_t - \hat{y}_{t-1}) + \epsilon_t^r \tag{6.1.2}$$

6.1.2 Shock-augmented Taylor rule regime (ATR2)

Gilchrist and Zakrajšek (2012) show that due to the endogenous response of asset price in the financial accelerator mechanism, a positive premium shock can cause a rise in the premium variable that exceeds the size of shock itself. This raises the question of whether responding to the exogenous component of premium (i.e. premium shock) would promote stability. To this end, we consider the case in which nominal interest rate responds to premium shock (ATR2), and replace the premium variable in Equation (6.1.1) with the premium shock as follows:

$$\hat{r}_t = \rho\hat{r}_{t_1} + (1 - \rho)(r_p\hat{\pi}_t + r_y\hat{y}_t - r_{\epsilon pm}\epsilon_t^{pm}) + r_{\Delta_y}(\hat{y}_t - \hat{y}_{t-1}) + \epsilon_t^r \tag{6.1.3}$$

Likewise, we investigate the IRFs to a premium shock under shock-augmented Taylor rule regime (ATR2). For better comparison, the set of elasticities for ϵ_t^{pm} is maintained the same as for pm_t. Figure 6.1.2 shows the variable responses with reaction coefficients of different sizes. In contrast to Gilchrist and Zakrajšek (2012) that reports a significantly larger fluctuations for this shock-augmented Taylor rule relative to the premium-augmented one, our results show little to no disparity between the two. The only notable difference lies in the speed at which the disturbance-perturbed variables return to their steady states. The responses under shock-augmented Taylor rule appear to be less persistent (short-lived). Bootstrap simulation shows the following specification for ATR2 yields the minimum welfare costs:

[3] Parameters ρ and r_{Δ_y} are fixed at their estimated values on the basis of mathematical restrictions. See also Bundesbank (2015) page 59 for a similar experiment.

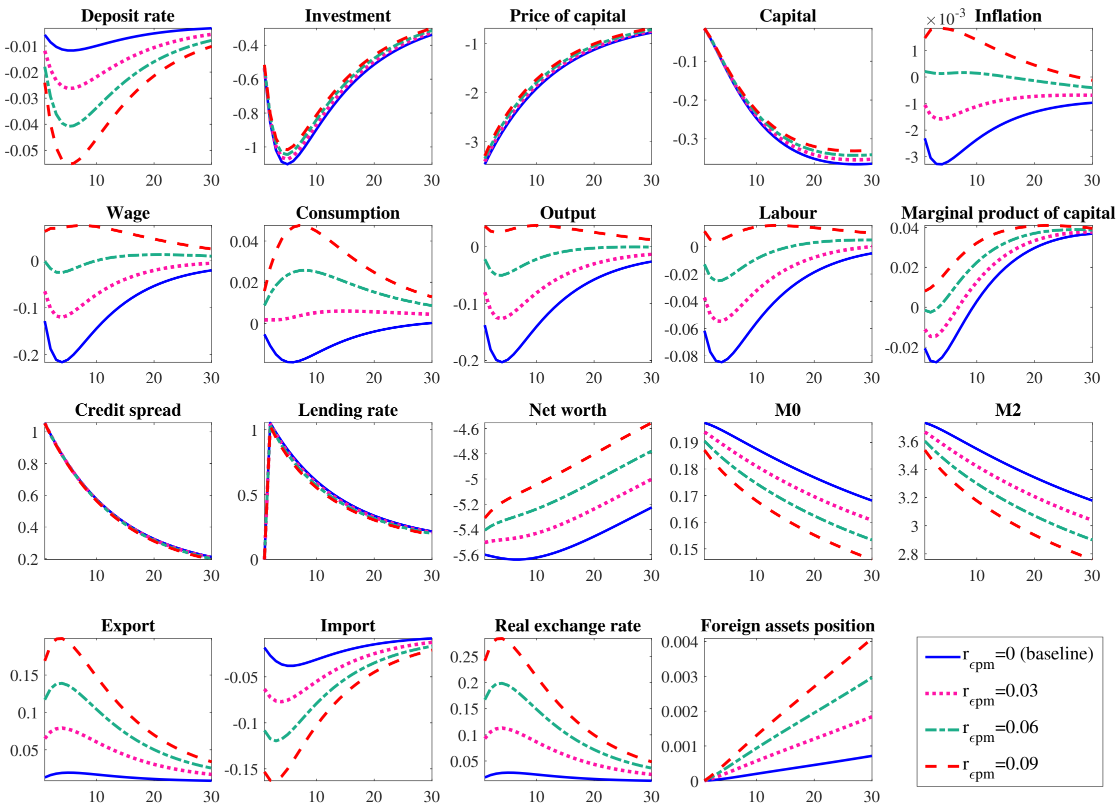


Figure 6.1.2: Responses to a premium shock under varying degrees of shock adjustment (*Baseline vs. Shock-augmented Taylor rule (ATR2)*)

$$\hat{r}_t = 0.7092\,\hat{r}_{t_1} + (1-0.7092)(3.0096\,\hat{\pi}_t + 0.0364\,\hat{y}_t - 0.0514\,\epsilon_t^{pm}) + 0.0219(\hat{y}_t - \hat{y}_{t-1}) + \epsilon_t^r \tag{6.1.4}$$

6.2 Dual rule regime (DRR) - Should the unconventional monetary policy become conventional?

Finally, we also specify a dual rule regime (DRR) by complementing the STR with a powerful M0 feedback rule that relates to credit spread (see Equation (6.2.1)). In effect, there are two instruments in the DRR during normal times with each pursuing their own objective - Taylor rule promotes price stability while M0 feedback rule targets financial stability. In the previous sections we have established that the M0 feedback rule is able to stabilise the premium via its role as the cheapest collateral in the loan contract. The DRR can be seen as a generalisation of QE, in that the UMP of bond purchase is activated at all times to facilitate the credit provision. QE is dubbed "unconventional" in the sense that it is only resorted to when the CMP of adjusting short-term interest rate becomes unavailable. By evaluating DRR, we hope to find out how policy makers should coordinate conventional and unconventional policy in the pursuit of price and financial stability.

Some previous attempts in this direction include: Ellison and Tischbirek (2014), who embed stylised financial sector and central bank asset purchase to a New-Keynesian DSGE model and find that unconventional monetary policy in the form of government bonds purchase should be kept in place even after the nominal interest rates normalize. The authors show that an appropriate coordination of conventional (that merely targets inflation) and unconventional (that responds exclusively to output) monetary policy, can minimize the volatility in reaction to shocks; Quint and Rabanal (2017) use an estimated non-linear DSGE model and find that asset purchases of government and corporate bonds should be used in conjunction with conventional monetary policy, whatever the state of the economy and not just in crises when the ZLB binds. In particular, as in our model they model the unconventional monetary policy as a feedback rule that targets credit spread, which better captures what concerns the monetary authority in crises - the stabilisation of the credit supply.

In our specification, by adjusting the supply of M0, the monetary authority can keep the credit condition in check before the crisis. The form of this normal time M0 feedback rule is the same as for the crisis regime, except that now we need to re-search the optimal value for ϑ_3:

$$\hat{m}_t^0 - \hat{m}_{t-1}^0 = \vartheta_3 \left(\hat{pm}_t - pm^* \right) \tag{6.2.1}$$

Figure 6.2.1 shows model's responses to a premium shock under varying strengths of M0 rule. It can be seen that benefits from using QE in normal times can be substantial, especially in reaction to financial shocks. Increasing the elasticity of M0 to premium (ϑ_3) brings about stronger stabilising effect. Further, we find that the variables' responses with increased reaction coefficients turn out appreciably different across regimes. In ATRs, adjusting the parameters result in notable differences in model's immediate response, whereas in DRR, different strengths of M0 rule lead to nearly identical initial responses but an increasing differentiation in the medium and long terms.

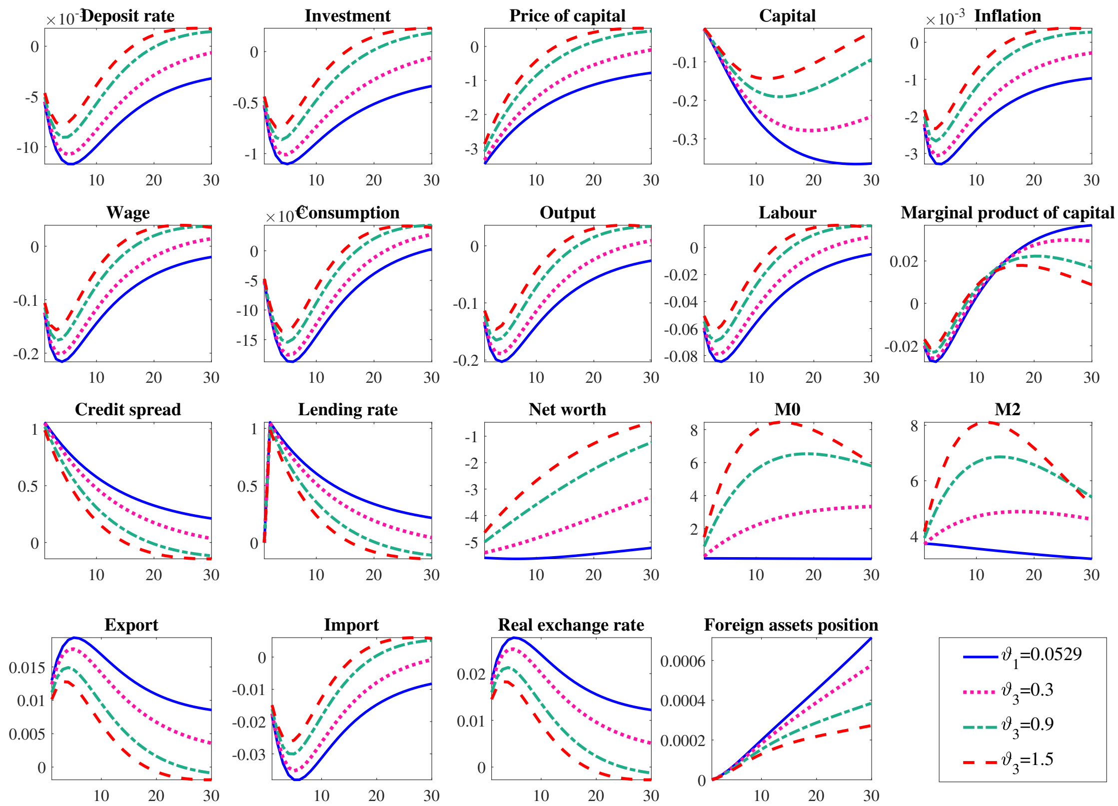


Figure 6.2.1: Responses to a premium shock under varying strengths of M0 rule (*Baseline vs. Baseline Taylor rule + M0 rule (DRR)*)

We find that the following M0 rule yields the minimum welfare losses:

$$\hat{m}_t^0 - \hat{m}_{t-1}^0 = 0.4857\left(\hat{pm}_t - pm_t^*\right) \tag{6.2.2}$$

6.3 How relevant is the Tinbergen rule?

The issue of violating the Tinbergen rule arises here as in order to tackle two sources of inefficiency: staggered pricing (associated with price instability) and costly state verification (related to financial stability), two instruments are required. However, in ATRs, only one tool - the nominal interest rate is deployed for achieving two objectives. To examine the quantitative relevancy of the Tinbergen rule, we summarise in Table 6.3.1 the optimal sets of elasticities that minimise the welfare loss for each regime. HP filter was employed to smooth the simulated data before variance calculation.

		STR	ATR1	ATR2	DRR
Optimal elasticities	r_p	2.4657	1.8371	3.0096	2.4657
	r_y	0.0261	0.0271	0.0364	0.0261
	r_{pm}	—	0.0414	—	—
	$r_{\epsilon pm}$	—	—	0.0514	—
	ϑ_3	—	—	—	0.4857
var(output)		4.9733	2.2570	2.7546	1.7424
var(inflation)		0.4846	0.4524	0.2508	0.4347
Expected welfare cost [1]		5.4579	2.7094	3.0054	2.1771

[1] Welfare cost takes the sum of var(output) and $var(\pi)$.

Table 6.3.1: Comparison of policy regimes

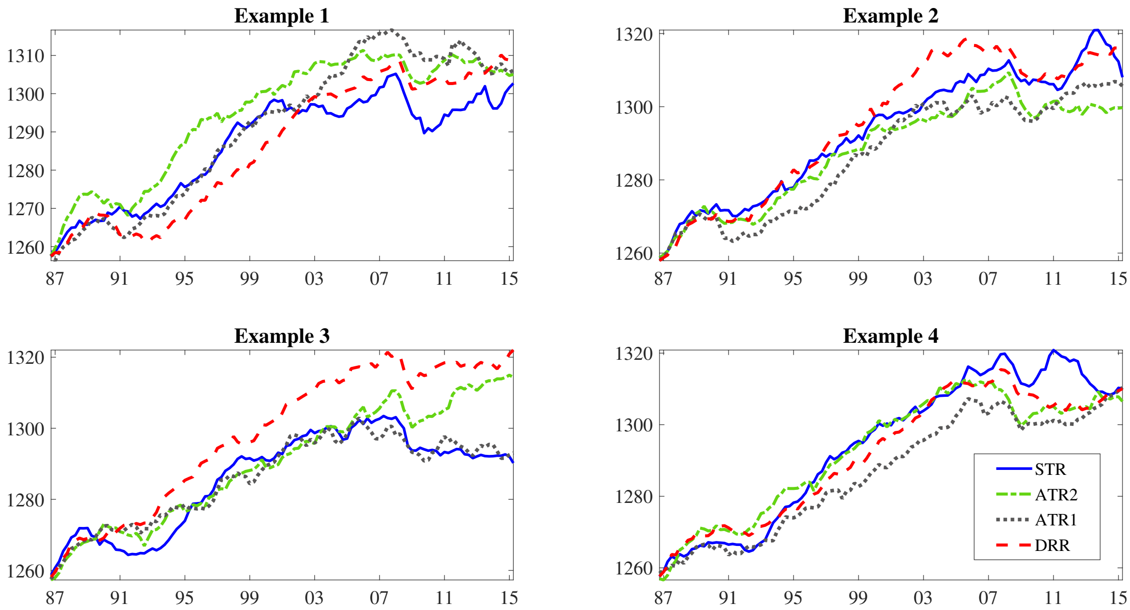


Figure 6.3.1: Simulations of output across regimes

Policy regimes are ranked in terms of the evenly weighted variances of the output and inflation. Instability is reduced under any alternative regimes - DRR leads to the minimum welfare cost, followed by ATR1, ATR2, and finally the baseline regime (STR). More importantly, violation of the Tinbergen rule appears to be costly. Welfare costs are 24.45% and 38.05% greater under AR1 and ATR2 respectively than under DRR. While "leaning against the credit" (ATR1 and ATR2) is definitely welfare-improving compared to not responding to credit condition at all, using a separate financial rule to target credit condition proves better at taming macroeconomic fluctuations. To conclude, one-instrument regimes (ATR1 and ATR2) cannot perform as well as the two-instrument regime (DRR) in reducing welfare loss from two inefficiencies.

Simulations of output (Figure 6.3.1) yield qualitatively similar results across regimes, the reason being that in all regimes policy makers adjust policy stances according to some feedback rules which react to certain measures of current state of the economy before bringing them closer to the targets.

Chapter 7

Conclusion (DSGE Model)

7.1 Results and implications

In this study we take a retrospective look at the expansions and contractions in the UK business cycle over 1986-2016 with a special focus on the GFC. In doing so, we introduce credit friction, ZLB constraint and unconventional monetary policy into an otherwise standard DSGE model with nominal and real rigidities. The occasionally binding ZLB constraint divides the model into two regimes. In the non-ZLB situations (normal regime), the CMP in the form of adjusting nominal interest rate (safe deposit rate) is not neutral under nominal rigidities and hence plays a role in stabilization. At the ZLB (crisis regime), the UMP of QE substitutes for conventional interest rate policy as the latter is hindered by the ZLB. In our model, central bank's purchases of short-term bonds are equivalent to compressing the risk premium (indicates the degree of financial friction) and so commercial lending rate via M0's role in providing the cheapest collateral in BGG-type contracts. In the same vein, macroprudential policy instrument is also injected into the risk premium equation and included as part of the premium shock that alters premium and lending rate.

The simulated behaviour of the estimated model over 1986-2016 shows that the crisis episodes can be much more relevant to the UK economy than previously thought. The shock decomposition result reaffirms the long-standing issue of "productivity puzzle", as the continuing weakness of the productivity has weighed on UK growth since the late 1990s, which remained subdued even during the recovery. In contrast to the US economy, financial shocks (premium and net worth shocks) are not the dominant forces behind fluctuations in the UK. On the other hand, world influences also held back UK economic development, especially in the early stage of the Great Recession, although the effects of their drag have waned since around 2013.

We also consider three alternative scenarios in which the standard monetary policy in non-ZLB situation can be augmented to react to credit condition: by adding a response to risk premium (ATR1) or premium shock (ATR2) in Taylor rule; or by additionally specifying a feedback rule that targets premium exclusively alongside standard Taylor rule (DRR). The simulation results are unambiguous, that is, a dual rule regime (DRR) that employs two instruments to deal with two inefficiencies excels at minimising welfare loss compared to either augmented Taylor rule regimes (ATR1 and ATR2) or the baseline regime (STR). The results call for central banks to coordinate conventional and unconventional monetary policy. In our model, this means the former should remain focused on inflation and output whilst the latter should target risk premium only. Besides, the UMP of QE merits a place in the toolkit of monetary authorities even in the non-ZLB situation when the conventional interest rate policy is still available.

7.2 Model limitations and directions of future research

Admittedly, there are limitations in our analysis that ought to be acknowledged. Building a model, as almost always, requires assumptions, simplifications and approximations, which would potentially create research gap.

1. Potential drawbacks in model set-up

Although our model implicitly assume a role for financial intermediaries that 1) absorb deposits for loan provisions 2) require cash collateral from IG producers before signing CSV type contracts, it does not fully take address their role in cyclical fluctuations, e.g. their interaction with central bank is left unmodelled. As noted in BGG paper, one way to do so is by allowing the financial intermediaries which lend to IG producers to face financial friction themselves when raising funds from other commercial banks or central banks. As a result, financial intermediaries' net worth (e.g. cash collateral held in their vaults) will work along with net worth of entrepreneurs, both of which contribute to model's dynamics.

Turning to the modelling of financial friction, there has been mixed evidence on how a shift in credit provision would interfere with the real economy with some studies showing powerful and permanent influences whereas others only finds mild and transitory impacts. Barnichon et al. (2018) find a way to accommodate two views by assuming asymmetry in its effect: in an upturn, adverse financial shocks would cool the economy by disturbing the process of financial intermediation. With good opportunities missed, firms' profitability worsens. However, the converse does not necessarily hold. In a downturn, there is no guarantee that favourable financial shocks would heat up the economy by triggering any investment boom if there are not enough opportunities present. In short, shifts in credit market mean more pain than gain. By the same token, macroprudential regulation appears more effective in tightening than in easing phases.[1] In our model, financial friction is introduced à la BGG, wherein credit tightening and loosening are expected to work in a rather symmetric way: if the investment is inhibited by a certain amount when regulatory authority raises the premium, it would be boosted by the similar amount when the premium gets compressed. The impact on the broader economy should be symmetric as well. The failure to account for asymmetries in credit friction might undermine our model as a fair representation of the actual economy.

[1] Altunbas et al. (2018) discuss this asymmetry in more detail by analysing how banks with different characteristics might react to different macroprudential tools.

Concerning the extension to the SOE framework, our assumption that the UK only exchanges final goods with the RoW is clearly at odds with the actual situation - the UK economy is closed integrated with most advanced economies, in particularly the Eurozone. In markets characterised by the increased globalisation and competition, these trade links enable the UK manufacturers to import raw materials and intermediate goods to gain advantage over their competitors. It would be necessary to allow for imported goods to play a non-trivial role in wider fields of the UK manufacturing.

Regarding the QE operation, as in Le et al. (2016a), we model it as the government's injection of M0 in exchange for short-term bonds held by households; this M0 eventually ends up as the most liquid collateral required in BGG contracts that narrows the spread. However, in practice, QE typically involves buying long-term bonds while selling short-term bills; Portfolio rebalancing effect bids up the price of long-term bonds (lowers their yields) and pushes down the price of short-term bills (raises their yields). Allowing for bonds of different maturity seems better suited for capturing its actual implementation.

Finally, the macroprudential regulation in our study is modelled as the exogenous component of the credit spread (external financing premium), in the sense that a widening spread would raise the commercial lending rate and restrain the banks from overlending. As of today, there have been various instruments deployed for the purpose of macroprudential regulation, e.g. the mostly widely used counter-cyclical capital buffer, reserve requirements, caps on loan-to-value and loan-to-income ratios, liquidity coverage ratio, and taxation. Each of them regulates the supply (or demand) of credit through its channel and has its own merit. Dealing with it in such a reduced form limits the scope for further discussion.[2]

2. Other flaws common to DSGE modelling

Compared with the aforementioned model-specific drawbacks, the following limitations are more entrenched in DSGE modelling exercises and apply to a wider range of studies.

All our simulation and impulse response functions presented here conditional on estimated parameters, which are prone to estimation uncertainty. Moreover, the proper handling of the parameter estimates uncertainty, at some point, calls for considering the uncertainty in model structure. For example, instead of fixing the parameters at their estimated values throughout the entire sample which lasts for decades, we might as well allow for time-variation in them. As such, the structure we have postulated for the economy is not fixed, rather it evolves over time and makes gradual adjustments to the shifts in model structure.

Finally, our empirical work is carried out with the macroeconomic aggregates revised and released afterwards, usually with a few months' time lag. The issue arises here as the policy makers in real life act on constantly updating real-time data which may differ from the final aggregates that are later made available to the public. This is particularly

[2]The goal of macruprudential regulation includes but is not restricted to preventing the procyclicality of financial system and smoothing the credit cycles (time dimension), e.g. to overcome banking system's tendency to amplify and propagate the cyclical fluctuations through sudden credit booms/crunches. As there exists another dimension (cross-sectional dimension) with the aim of monitoring the aggregate risks and tackling the panic contagion during bank runs or fire sales.

relevant when sudden disturbances precipitate unforeseen crisis whose consequences are hard to predict in the first place. Given data availability, it would be interesting to consider alternative scenarios wherein monetary authorities react to the real-time data and assess the difference between the two.

Abstract (Institutional Model)

Abstract: In the following study, policy makers act as welfare-maximising market participants who prioritise their own benefits rather than the society's. Regulation is assumed to only promotes stability up to a certain point, beyond which it undermines stability as the distortions it creates outweigh the stabilising effect of tighter credit. Due to the theoretical contradiction in the institutional design, macroprudential policy is unlikely to yield the best feasible outcome - where regulation is kept to the minimum necessary to maintain stability. Using indirect inference testing and estimation, we find a set of coefficients that can generate the observed behaviour for the UK central bank and government over 1993-2016. Moreover, we show that in the presence of well-conducted monetary policy, macroprudential regulation at best contributes little, at worst destabilises the economy. The overly rigid regulation since the crisis has prevented the necessary growth in credit for recovery. The results are consistent across a series of robustness checks.

How does the institutional model complement the DSGE model?

So far, we have built and estimated an open economy model for the UK for the period 1086-2016. We treated the central bank and the government as equivalents that both act to maximize the social welfare (reducing economic fluctuations) via conducting conventional and unconventional monetary policies. The macroprudential policy was modelled as an exogenous process. In the following chapters we are going to present an institutional model for the UK that investigates the interaction between monetary and macroprudential policies subject to political constraint. Our focus is on the post-crisis episode (2008-2016) which is characterized by increasingly aggressive regulation. The institutional model complements the DSGE model in the following aspects: 1) the DSGE model used historical shock decomposition to elaborate on the causes behind the sluggish recovery since 2008, attributing it to the productivity slump. The institutional model, on the other hand, attempts to explain it from the political economy perspective; the model takes the stand that it is the regulators (central bank)'s self interest that leads to overly aggressive regulation that prevents the necessary credit growth for economic recovery. 2) The institutional model distinguishes between the government and the central bank by their career concerns. The former (government or politicians) is held accountable by the voters at the election time and thus acts to maximize the voters (society)'s interests, while the latter (central bank or bureaucrats) only wants to fulfil the stated goal of their organization. 3) Regarding the modelling of macroprudential policy, we modify the risk premium equation to identify the regulatory and structural shocks such that the regulators can adjust the regulatory intensity via raising the sizes of risk premium and its associated errors.

Chapter 8

Introduction (Institutional Model)

The 07/08 financial crisis has reinvigorated the interests in studying monetary and macroprudential policies and their impacts on the macroeconomic stability. In the decades prior to the crash, macroeconomic management revolves around assigning a primary role to the price stability. The UK has adopted inflation targeting since 1992Q4 after its exit from the European Exchange Rate Mechanism (ERM). The strategy to stabilise both the real economy and the financial system has been corroborated by the muted volatility observed in the "Great Moderation" over 1992-2007.[1] Nevertheless, the Global Financial Crisis (GFC) has amply demonstrated that inflation-targeting regime alone does not ensure economic stability. As in such a regime, financial imbalance can keep building up although the inflation is kept close to the target. With some hindsight, the actions of policy makers who acted as firefighters were necessary but too little and too late. Having realised that the risks originating in the financial sectors can be contagious and even endanger the real economy (in the presence of low and stable inflation), central banks worldwide have deployed a range of macroprudential tools. Examples include but are not limited to: counter-cyclical capital buffer (CCyB), loan-to-value caps (LTV's) on mortgage loans, and taxations on commercial banks, all of which aim to strengthen the resilience of the banking system. (Bundesbank, 2015).

Notwithstanding their separate goals - monetary policy targets price stability while macroprudential regulation is geared towards financial stability, both tools are supposed to regulate the banking sector. The interaction between the two is thus inevitable and this raises the question of what "side effects" the conduct of one will have on the objective of the other. Ideally, two measures should complement each other, e.g. macroprudential policy attenuates the financial stability sides effects of monetary policy, leaving more room for the latter to maneuver. However, in some situations two goals might clash. For instance, during the crisis, central banks tend to boost the demand by maintaining an accommodative monetary policy ("loose money" stance) at the zero lower bound, whereas from the regulatory viewpoint, a tightening of the macroprudential policy is needed in

[1] The "Great Moderation" in the UK context refers to the period 1993-2007 throughout which the country had experienced 63 consecutive quarters of GDP growth - the longest expansion on record.

order to curb the credit growth ("tight credit" stance). Moreover, since in practice the conduct of both policies would face the political constraint, it appears necessary to account for the institutional design when studying the policy coordination. This is the focus of our study.

We apply the ideas of political economy and policy mandates, to a standard Macro-DSGE mode in the analysis of policy coordination. The institutional framework we present here consists of the government, the central bank and the general public. Government first chooses the monetary policy and then delegates the management of macroprudential policy to the central bank. We argue that it is the private interest that dominates the regulatory policy-making process, and plays a part in shaping the policy decision. Regulators makers act to maximise their bureaucratic size.

We posit a policy function whose shape resembles that of the Laffer curve, so that stability first improves then deteriorates as regulation gets progressively tighter. The key point here is that two levels of regulation can deliver the same stability, albeit with noticeably different social costs. The silent majority can observe the regulatory outcome only in terms of output stability, but there is no way they could find out at what costs this result is obtained. So this leaves open the possibility of grabbing more power and applying more regulation than necessary without being noticed, and as a result, the central bank proceeds to the *right* side of the Laffer curve and imposes more regulation than necessary, with the common good sacrificed for the political self-interests.

Our research reflects on the UK monetary and macroprudential policies since 1993, when the Bank of England officially established the inflation-targeting framework. Specifically, we argue that in the episodes leading up to the GFC, neither the government nor the central bank did its job properly. The government implemented insufficiently stabilising Taylor rule that failed to adjust the nominal interest rate as much as it should whist the central bank applied minimum regulation characterised by the inadequate liquidity requirements and severely deficient capital standards. In short, policy makers did little to lean against the expansionary economic cycle before the crash. Yet since then, things have gone in the opposite direction. The UK government has put extra effort into kick-starting the economy by deploying unconventional monetary policy tools such as QE. Meanwhile, the central bank has tightened macroprudential regulation via increasing bank capital requirement as per agreed international standards established in Basel III, imposing higher liquidity ratios and, most notably, the regulatory structural reforms such as the split of FSA (Financial Services Authority) into PRA (Prudential Regulatory Authority) and FCA (Financial Conduct Authority) in 2013.[2] It should be noted that there is mixed evidence regarding the impact of regulatory measures on economic activities. Questions arise as to how to measure the costs and benefits of higher lending rates resulted from higher capital requirements (or liquidity ratios), and whether more regulation leads to more stability. Here we draw upon empirical evidence from the previous studies and question the appropriateness of rigid

[2] For the evolution of the UK financial regulators, see https://www.bankofengland.co.uk/knowledgebank/what-is-the-prudential-regulation-authority-pra

and intrusive financial control and argue this, at least in part, has hindered the economic recovery since 2008.

Chapter 9

Model Setup (Institutional Model)

9.1 Does regulation really serve the public interests?

The recent financial crisis demonstrates the need to establish a coherent and well-articulated regulatory control framework at the national and global level.[1] So it should come as no surprise that the term macroprudential regulation finds itself back in favour. At its heart, macroprudential regulation is aimed at identifying the potential causes of system-wide risks and developing proactive policy tools to forestall them. The development of new structures and policies in regulation reflects the emerging consensus that financial instability (bank failures) are politically intolerable and the stakes in macroprudential regulation are high. Central banks have been tasked with the management of regulation within the system of finance capital. The focus of this study is not the technical/practical issues concerning macroprudential regulation, e.g., whether the systemic risk can be properly identified and quantified, which policy tools should be deployed to prevent the credit and asset bubbles, and at precisely which stage of the business cycle should tools be deployed? Rather the emphasis is laid on the political economy side, e.g. whose interests the policy is trying to maximise, and to what extent these policy decisions made by a small group of bureaucrats can serve the general interests of a society.

Traditionally, if we followed the public interest theory, we would believe that regulators would implement rules that improve the social welfare as a whole. Banks act as intermediaries because they stand between depositors (savers) and investors (borrowers). Regulatory rules are meant to protect the public (savers and borrowers) from banking failures by offsetting market failures caused by information externalities and inform asymmetries (Le et al., 2018). In practice, financial institutions do not lend out all of the money they take from depositors, rather they keep some of the money as reserves. The central bank sets the standard on the minimum percent of their deposits they have to keep in their possession. Tightening the reserve requirement implies less money to lend out as excessive reserves and subsequently drives up the lending rate that reflects the banks' growing unwillingness to

[1] See speech by Vítor Constâncio, Vice-President of the ECB at the Sixth ECB Statistics Conference, Frankfurt am Main, 17 April 2012 https://www.ecb.europa.eu/press/key/date/2012/html/sp120417_1.en.html

lend. However, one might doubt if we should take for granted that central bankers would prioritise the public preference when choosing this ratio, and if it is possible that their stance on regulation actually comes about as a result of maximising their self-interests.

Stigler (1971) provides an alternative view of regulation from the perspective of political economy. Besides emphasizing that regulation is neither designed nor carried out in a vacuum, it highlights that regulation emerges in a political environment populated by self-interested actors. Regulators are nothing but an interest group motivated to embrace the strategy of maintaining their power. When their narrow interests are able to influence and control the strength of regulation, chances are regulatory outcomes end up advancing the entrenched interests at the expense of the general welfare. Of course the regulatory bodies would never be explicit about their intention - to possess as much power as possible to coerce people to do as they say. It would be naive to assume that regulation rules are completely designed with public interest in mind, as this neglects the nature of policy makers. The introduction of regulatory authorities creates source of power for policy makers to manipulate the regulatory process and outcome. By abusing their power and forcing banks to divert the flow of credit, regulators might make ordinary citizens worse off. For the arguments along this line, see Levine and Barth (2001), Quintyn and Taylor (2003) and Barth et al. (2008) who highlight the positive effect of regulatory burden on corruption in the lending process; they state that the structure of banking regulation in most of the world attracts an array of government officials and central bankers who seek to shape regulation for their own good.

Having established that regulators have their own interest in grabbing as much power as possible, we move on to look into the indicator of the strength of their regulatory power. When serving as civil servants, policy makers are unlikely to pass laws to raise their own income. Instead they pursue non-pecuniary goals, e.g., feeling of control, greater financial budget and expansion of power and authority, most of which are related to the size of the agency. Regulatory agency provides public goods (regulation) whose explicit price is more or less fixed. To maximise the revenue they can only resort to selling more quantities - to impose as many regulations rules as possible. These rigid and redundant rules inevitably lead to a net loss of welfare for the society. In the case of central banks, the size of bureaucracy is best captured by the number of its employees. John Taylor in his book Taylor (2016) employed the number of federal workers engaged in regulatory activities as a metric of the regulation intensity. [2]

[2] Besides the employee number, he also touched upon the establishment of new regulatory laws such as Dodd-Frank Act (2010) that is seen as a signal of the tightened supervision in the financial sectors since the crash.

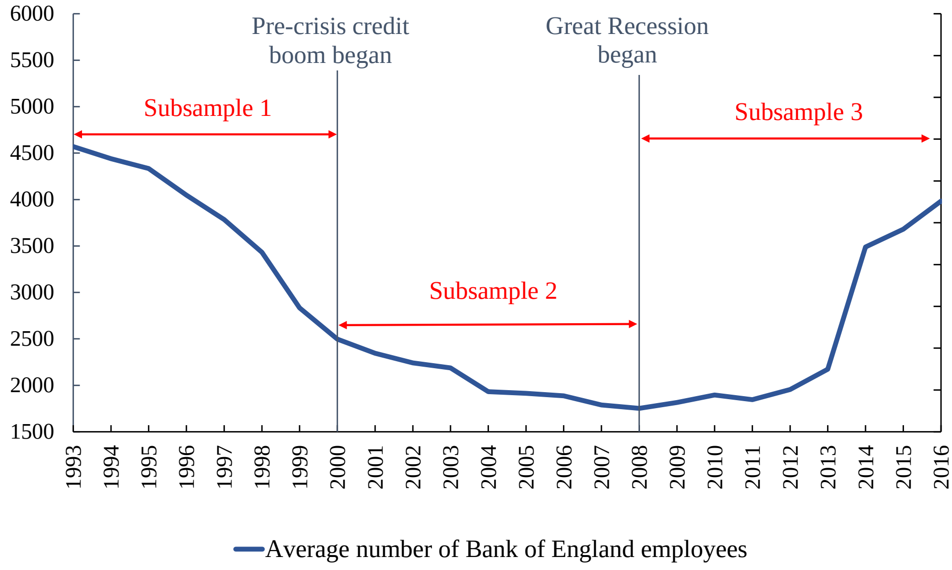


Figure 9.1.1: Fluctuations in BoE staff numbers

Sources: Bank of England annual reports. Data are annual and exclude printing works staff. Two metrics in BoE's reports - average number of employees during the year, and number of employees at the end of financial year (end of February) provide slightly different numbers. Here we employ the former, as the data for the latter in 2003 is missing.

Figure 9.1.1 plots the changes in Bank of England employees over 1993-2016. The full-sample was split into 3 subsamples. Subsample 1 starts from 1993 when the regime shift occurred, i.e, the adoption of inflation-targeting has made the monetary policy more predictable and rule-like. It ends in 2000 when the pre-crisis credit and asset-price boom began. Subsample 2 starts in 2000 and ends at the end of 2007, when the financial crisis hit the world. Subsample 3 refers to the post-crash episodes characterised by frequent unrule-like policy interventions e.g. unconventional monetary policy, and unprecedented level of regulation.

Inspection of the trend in Figure 9.1.1 reveals there has been a continuous drop in the BoE employees between 1993 and 2007 over the "Great moderation" - the combined subsample 1 and 2. The number of employees then reaches the bottom over subsample 2, which is consistent with what we have observed in the early noughties - the financial deregulation that was initiated in the 1980s had largely run its course, and its influence was fully reflected in capital growth with more risky projects undertaken. This seems to justify our choice for the indicator of regulation. Starting from 2008, the BoE staff number grew significantly from 1759 to nearly 4000 in 2016. In other words, it has more than double the size of its workforce in less than a decade. Noticeably, the staff number rise was the steepest in decades since 2012, which might suggest that more intrusive regulation has been in place since the outbreak of the Eurozone debt crisis.

In general, there was a trend of deregulation throughout subsamples 1 and 2. When financial crisis struck the economy in 2008 the regulation was considered “light-touch”. Later, it was the realisation that the laxity in regulation was to blame for the crisis that urged the central bankers to implement more stringent measures. The re-regulation hence became the new tend the other way. Trends swinging back and forth resemble the motion of a pendulum. But the issue raised here, is whether the pendulum has already swung too far towards overregulation that the compliance burden has become unduly onerous. Peltzman (1976) expands Stigler’s theory, and considers the cycle of regulation an inherent part of the political process. Regulation and deregulation are intrinsic to politics just like ebbs and flows to the nature. He stressed that in addition to the desires of industry, regulators have tendency to lean toward reforms that are mostly likely to gain support from political groups. This explains how the public outcry since the crash has pushed the regulators, who were haunted by their previous mistakes, to impose more restrictions than are strictly and sensibly necessary.

9.2 Does more regulation imply more stability?

Over the years, the macroprudential regulation has been the source of considerable controversy. Ideally, regulation that is designed with the aim to stabilise the banking system should reduce not only the likelihood but also the magnitude of bank failures. Nevertheless, there have been concerns over the efficacy of regulatory controls, many of which are deemed costly and even counterproductive. For example, many argue that the enforcement of higher capital ratio gives banks greater incentives to invest in risky but more profitable projects. This in partly or even fully offsets the effect of more restrictive capital ratio on default risk. Another widely used form of regulation - deposit insurance scheme has been criticized for inducing extra risk-taking behaviours of banks due to moral hazard, especially in the case when banks are perceived as “too-big-to-fail”.

There is ample literature on both sides. Furlong and Keeley (1989) examine theoretically the relationship between bank capital regulation and risk-taking, concluding that banks’ incentives to increase asset risk decline as capital standard gets raised. Therefore, regulators’ efforts in restraining risk-taking proves valid. See also (Brunnermeier and Sannikov, 2016) for more theoretical evidence in favour of regulation. Empirically, Gropp and Vesala (2004) test a sample of EU banks during the 1990s. Their results show that for smaller banks with low charter values or/and high shares of non-insured liabilities, the imposition of deposit insurance causes a remarkable decline in their risk-taking. Andries et al. (2017) analyse an international sample from 21 advanced economies in Europe and North America spanning the period 2008-2014, and find that tightening the capital requirements in general sense significantly reduce banks’ risk-taking. Altunbas et al. (2018) investigate the effects of macroprudential tools on bank risk through a sample of banks from 61 developed and emerging economies, and suggest that these tools are effective in mitigating bank risk, although the individual response of banks might differ depending on the sizes of their balance sheet. Using a sample across fourteen developed and emerging markets, Jumreornvong et al. (2018) also confirm the positive roles of deposit insurance and capital adequacy ratio in curbing potential systemic risks during crises if used jointly.

Conversely, Koehn and Santomero (1980) theoretically assess the impact of an increase in capital requirement on the portfolio behaviour of individual banks and report a rise in the probability of intra-industry dispersion of failure. Berger et al. (1995) discuss the relevant issues surrounding capital requirement, and questions if higher capital requirement can indeed achieve the desirable result. They further highlight that capital requirement is too blunt a tool for protecting the system. Specifically, there exist practical difficulties in defining, measuring and monitoring capital. Failure to set the requirement at its optimal level may cause price distortion and allocative inefficiencies. The authors blame the tougher regulation implemented in the US banking industry for the credit crunch in the early 1990s. Rather than disciplining banks' risk-taking, the problems in setting regulator requirement creates additional incentive for banks to take extra risks. Blum (1999) demonstrates in a theoretical dynamic model with incentives for asset substitution, tightening capital adequacy rules may increase banks' riskiness because harsher regulation indirectly reduces banks' profits and hence incentive to avoid default. Besanko and Kanatas (1996) provide empirical evidence consistent with the recognition that higher capital standards result in asset-substitution moral hazard, but also stress the time-inconsistency issue. See also Thies and Gerlowski (1988), Grossman (1992), and Demirgüç-Kunt and Detragiache (2002) for the mounting evidence that the introduction of deposit insurance actually encourages risk-taking and increases the likelihood of crises.

Interestingly, Calem and Rob (1999) reconcile two strands of literature by identifying a U-shaped relationship between bank capital and risk-taking. Using data from the US bang industry for 1984-1993, the paper assesses quantitatively the impact of more stringent capital-based regulation rules on risk-taking and shows the risk-taking first declines and then increases with capital position. When banks are severely undercapitalised (light regulation), raising the ratio (tightening the regulation) reduces risk-taking (financial instability). Nevertheless, as capital continues to rise (with regulation further strengthened), banks begin to take more risks again. Overall, capital ratio first discourages, then encourages risk-taking. Clerc et al. (2014) examine the role of capital regulation in a DSGE model with three layers of default and verify the existence of an optimal level of capital requirement ratio. The social welfare gains exhibit an inverse U-shape (hump-shaped, or bell-shaped) relationship with the capital requirement, the reason being that imposing too much regulation comes with the cost of unduly restricting the credit availability. More recently, Huang (2018) employs the macro-finance framework proposed by Brunnermeier and Sannikov (2014) and stresses again the U-shaped relationship between banking regulation and financial instability in a theoretical model where regular banks circumvent regulation via sponsoring shadow banking. Huang (2018) models shadow banking as the regular banks' off-balance-sheet financing and assumes regulation takes the form of a tax on regulator banks' debt. The author further shows that with or without shadow banking, tightening the regulation would eventually undermine the stability, despite their different underlying mechanisms.[3]

We follow the aforementioned evidence and generalise it to a broader concept of macroprudential policy. The assumption we make in what follows is that regulation only reduces risk-taking (increases stability) up to a certain point, beyond which it increases risk-taking (reduces stability). The relationship between regulation and stability is represented by an inverted U-shaped function that resembles the well-known Laffer curve. Considering that the UK has long stood as the world's leading fintech centre, it seems particularly necessary to avoid excessive regulation that might hamper the innovation within the financial sectors and undermine the industrial competitiveness.

9.3 Macroprudential regulation in the UK: more pain than gain?

To model the impact of regulation on macroeconomic stability, we consult a macro-DSGE model set out for the UK. The Model is built upon the work of Smets and Wouters (2007) with various extensions to incorporate financial friction, zero lower bound constraint, unconventional monetary policy (QE), and the trade with the rest of the world. The model was found to fit adequately the UK data for 1993-2016. From this DSGE model we would like to construct an institutional model that captures the behaviours of the government and the central bank.

We start by reviewing the risk premium equation in the underlying DSGE model (Equation (9.3.1)). The risk premium given by the spread between risky rate (commercial lending rate) - cy_t and risk-free rate (deposit rate) - r_t indicates the stress in the financial market. The wider the spread, the harder it is for the entrepreneurs to obtain the funds. Regardless of the specific type of the instrument, macroprudential regulation is always meant to constrain banks' willingness to lend (reflected as a rise in commercial lending rate), so as to reduce the supply of loans. Recall from the IRFs in our DSGE paper in which a positive premium shock drives up the commercial lending rate, increase the cost of borrowing for entrepreneurs (intermediate goods producers), and contributes to the contraction in investment and output. Thus, we model financial regulation through the channel of risk premium in studying macroprudential policies.

$$pm_t = cy_t - (r_t - \mathbb{E}_t\,\pi_{t+1}) = \chi(pk_t + k_t - n_t) - \vartheta m_t^0 + \xi_t + \epsilon_t^{pm} \tag{9.3.1}$$

Above expression states that the credit spread is positively dependent on the leverage ratio of entrepreneurs (capital price pk_t, capital k_t, net worth n_t), the effect of quantitative easing m_t^0, the impact of financial regulation ξ_t, and an error term ϵ_t^{pm}. To let the regulatory

[3]Huang (2018) concludes that in an economy without shadow banking, the overly-stringent regulation depresses the wealth growth, whereas in the presence of shadow banking, it is the higher leverage in shadow sector driven by the larger opportunity cost of default that leads to this result.

authorities have control over the regulatory strength via altering the risk premium, we re-express the regulatory impact on premium as:

$$\xi_t = \kappa\big[\zeta \cdot pm_t + \eta_t\big] \tag{9.3.2}$$

where κ is the strength of regulation ($0 \leq \kappa < 1$), ζ measures the response size of regulatory policy to premium which is set at unity as in Le et al. (2018), and η_t represents the regulatory errors with certain variances σ_η^2. Substituting Equation (9.3.2) into Equation (9.3.1) yields:

$$pm_t = \chi(pk_t + k_t - n_t) - \vartheta m_t^0 + \kappa\zeta \cdot pm_t + \kappa \cdot \eta_t + \epsilon_t^{pm} \tag{9.3.3}$$

We further relate the regulatory errors to the existing noises in premium equation by assuming that:

$$\kappa \cdot \eta_t = g(\kappa) \cdot \epsilon_t^{pm} \tag{9.3.4}$$

where $g(k)$ is a function of κ whose shape will be chosen to yield the assumed relationship between regulation and stability. This way the regulatory errors (social costs induced by imposing regulation) are transformed into the extra noises included in the premium equation. All together Equation (9.3.3) becomes:

$$\begin{aligned}
(1-\kappa\zeta)\cdot pm_t &= \chi(pk_t + k_t - n_t) - \vartheta m_t^0 + g(\kappa)\cdot\epsilon_t^{pm} + \epsilon_t^{pm} \\
pm_t &= \left(\frac{1}{1-\kappa\zeta}\right)\Big\{\chi(pk_t + k_t - n_t) - \vartheta m_t^0 + \big[g(\kappa)+1\big]\cdot\epsilon_t^{pm}\Big\} \\
pm_t &= \underbrace{\left(\frac{1}{1-\kappa\zeta}\right)\Big[\chi(pk_t + k_t - n_t) - \vartheta m_t^0\Big]}_{\text{direct effects}} + \underbrace{\left(\frac{1}{1-\kappa\zeta}\right)\big[g(\kappa)+1\big]\cdot\epsilon_t^{pm}}_{\text{indirect effects}}
\end{aligned} \tag{9.3.5}$$

The first part of Equation (9.3.5) captures the intended effects that regulation has on premium, and the second part captures the side-effects as regulation results in shifts in financial sectors environment that eventually affect the premium. We assume that changes in regulation are not directly related to the responses in premium size, would result in extra noises in the markets and hence instability. Extra noises here could be interpreted as the red tape such as having multiple committees approve decision, obtaining licenses and filling out paperwork that not only slows decision-making but creates hotbeds for corruption.

Note that setting out $0 \leq \kappa < 1$ and $\zeta = 1$ ensures that $0 < 1 - \kappa\zeta \leq 1$ and $1 \leq \frac{1}{1-\kappa\zeta} < \infty$. It can be easily shown that macroprudential authority can scale up the regulation by raising κ from 0 to 1. This increases the size of premium via $\frac{1}{1-\kappa\zeta}$ but also that of the noise via $\left(\frac{1}{1-\kappa\zeta}\right)[g(\kappa)+1]$ - the undesired side-effects. The function form we have chosen for $g(\kappa)$ must satisfy that i) $g(0) = 0$ - when regulation is at the minimum ($\kappa = 0$), there is no extra noises induced by regulation; ii) the g function should be able to generate the presumed inverted U-shaped relationship between regulation and stability - a rise in κ amplifies both the premium and its error variances, and the stability (inverse of output variance) first rises as the stabilising effort outweighs the noises, then declines as the error variances get scaled up so drastically that they dominate the stabilising effect. Through simulation experimenting, we have chosen $g(\kappa)$ to be $\kappa^2 + 10\kappa$. The assessment results are summarised in Table 9.3.1:

Regulation level	Raise the premium	Raise the error variances	Stability
κ	$\times \frac{1}{1-\kappa\zeta}$	$\times \left(\frac{1}{1-\kappa\zeta}\right)(\kappa^2 + 10\kappa + 1)$	$\frac{1}{var\left[\text{HP-filtered(output)}\right]}$
0	1	1	0.6132
0.1	1.11	2.23	0.9783
0.2	1.25	3.80	0.9421
0.3	1.43	5.84	0.8288
0.4	1.67	8.60	0.4834
0.5	2	12.5	0.3206
0.6	2.5	18.4	0.1742
0.7	3.33	28.3	0.0828
0.8	5	48.2	—

Table 9.3.1: How different regulative intensity affects stability in standard regime (STR)

NOTE: Results are obtained through 1000 simulations. "—" refers to non-converging case.

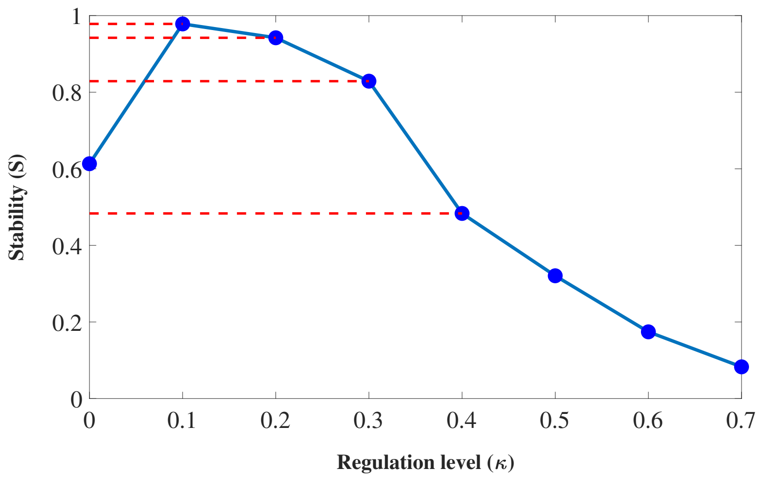


Figure 9.3.1: Raising regulation in standard regime (STR)

NOTE: in the standard regime (STR), monetary policy is conducted according to a Taylor rule which responds to movements in inflation and output gap with interest rate smoothing as in SW(07).

Table 9.3.1 shows that, at the minimum level of regulation ($\kappa = 0$), the premium and its error variances remain at levels determined by the aggregate state of the economy. However, once we deviate from this minimum, both the premium and the ambient noises get scaled up by times listed in the second and third columns. e.g., increasing κ from

0 to 0.1 amplifies the premium 1.11 times, the error variances 2.23 times. Overall, it improves stability to 0.9783 - the maximum level achieved in our simulations. However, more regulation beyond this level (raising κ above 0.1) does not bring more stability. As we keep strengthening the regulation, stability worsens progressively; in particular, raising kappa above 0.4 even destabilises the economy compared to the zero regulation case (See Figure 9.3.1).

With this experiment in mind, we are now convinced that this Macro-DSGE model can generate the quadratic policy function we assume for the institutional model. It opens downwards with a peak of stability at $\kappa = 0.2$.

9.4 An institutional model to account for the choices of monetary and macroprudential stances

9.4.1 Policy constraint

Having obtained the Laffer curve effect from regulation (P) to stability (S), we now proceed to take account of the monetary policy (M) before formalizing how the conduct of monetary and macroprudential policy jointly affects stability. Despite the differences in their primary objectives: monetary policy pursues price stability whereas macroprudential targets financial stability, two policies tools share the same ultimate goal of reducing instability (volatility) in the macroeconomy. (Figure 9.4.1).

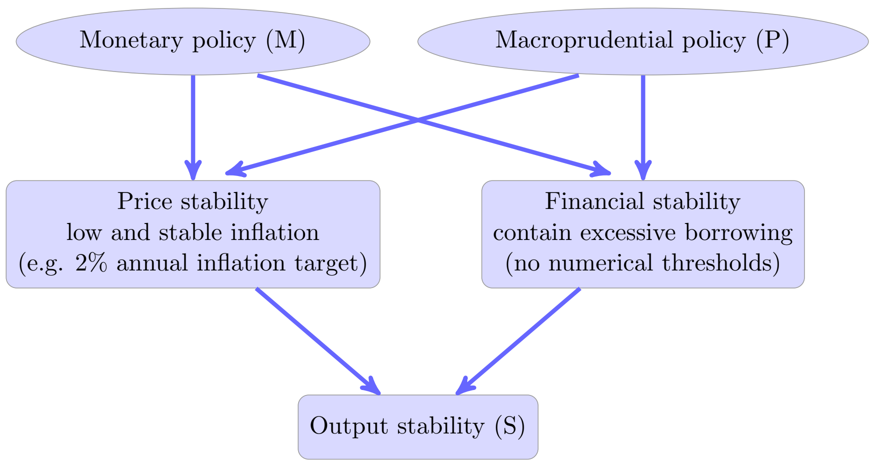


Figure 9.4.1: Interactions among policies and objectives

Unlike monetary policy that has an explicit goal to achieve - low and stability inflation (e.g. 2% annual inflation rate in the UK), knowledge on macroprudential policy's goal - financial stability is incomplete. Factors such as the changing nature and interactions across financial distortions, the degree of financial development and the exchange rate regime that affect the types of risks that arise are hard to account for. Numerical thresholds are considered premature at this stage, and it is not yet possible to assess the financial stability to the same degree as price stability. Gauging the efficiency of the conduct of macroprudential policy hence appears difficult for the politicians and the society alike. In practice we can only base our judgement on whether the regulation has achieved the observable outcome - output stability.

Given that both policies eventually contribute to the overall stability calculated as the volatility of output in response to shocks, we now formally set up the policy function as follows:

$$S = a + bM + cP - 0.5dP^2 - \sigma_E^2 \tag{9.4.1}$$

Note that the amount of regulatory power (P) in the institutional model corresponds to κ (regulation intensity measure) in the DSGE model. The rationale behind is that macroeconomic stability is determined by authorities' monetary stance (M), macroprudential policy stance or amount of power (P), and error variances or ambient noises (σ_E^2) that shift upwards during booms and downwards during busts.

The general public do not get directly involved in policy making, nor can they gauge the efficiency of authorities' operation. However as voters they can observe and assess the aggregate policy outcome reflected in output stability. As emphasized by Peltzman (1976), while pursuing their power, regulators must consider the influence of voters. In countries with free markets and democratic forms of government like the UK, political parties would face serious backlash from the society, if they have failed to do their job properly. To accommodate these facts, we interpret policy making as a political process and assume that it must be subject to the constraint in Equation (9.4.1). What this implies is that due to moral principles and election concerns, policy makers must take account of the potential influence their actions would have on stability before any decision-making.

9.4.2 Political preference of the government

So far we have established how macroprudential policy and monetary policy will jointly affect the output stability, now we move on to look at how these policy decisions are chosen in the first place. Under the assumption that policy makers maximise their own utility subject to the political constraint and institutional arrangement, we model their sequential decisions as the outcome of some constrained maximisation. Specifically, the government first chooses the monetary stance M_0, and targets regulatory power P an stability S - what it thinks P and S should be according to the policy function constraint ($\hat{P}$ and $\hat{S}$ in Figure 9.4.2).

However, more clarity is still required about which variables would enter their separate utility function, and in which ways. Without this information we cannot reach agreement on the costs and benefits of specific policies. The government's preference is introduced as:

$$U_G = S^\mu - M^\nu - lP \tag{9.4.2}$$

where S, M and $P > 0$, and for the parameters that govern the preference, we have $0 < \mu < 1$, $\nu > 1$ and $l > 0$. S enters positively of course as one of government's main responsibilities is to maintain output stability. M enters negatively because the more stabilising the monetary stance, the greater effort required for the government to adjust it to some more interventionist levels (e.g. the binding ZLB constraint during the crisis has forced the government to deploy QE in addition to the conventional rates cutting, and this required extra stabilising effort by the monetary authority). The regulatory power P also enters negatively since the government considers regulation as the resource cost that it wishes to reduce wherever possible. Quite often, we see from the government propaganda the expression "cutting of red tape" when it attempts to circumvent bureaucratic obstacles deemed to have fuelled corruption.

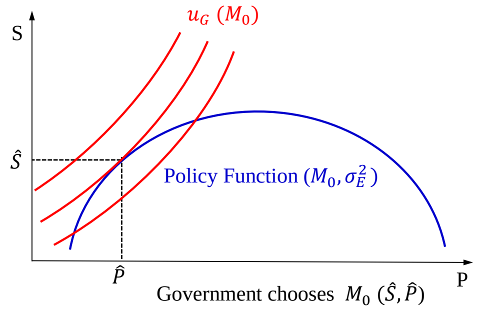


Figure 9.4.2: Choice of the government

The government maximises its utility as assumed in Equation (9.4.2) subject to the policy function for stability:

$$S = a + bM + cP - 0.5dP^2 - \sigma_E^2 \tag{9.4.3}$$

where $a > 0$, $b > 0$, $c > 0$, $d > 0$. Maximising the Lagrangian $\mathcal{L}_1 = U_G - \Lambda_1 S$ with respect to S, M, and P leads to the following first order conditions:

$$\begin{aligned} \frac{\partial \mathcal{L}_1}{\partial S} &= \mu S^{\mu-1} - \Lambda_1 = 0 \\ \frac{\partial \mathcal{L}_1}{\partial M} &= -\nu M^{\nu-1} + \Lambda_1 b = 0 \\ \frac{\partial \mathcal{L}_1}{\partial P} &= -l + \Lambda_1(c - dP) = 0 \end{aligned} \tag{9.4.4}$$

The solutions for M and P are:

$$M = (\frac{\mu b}{\nu})^{\frac{1}{\nu-1}} S^{-(\frac{1-\mu}{\nu-1})} \tag{9.4.5}$$

$$P = \frac{c}{d} - \frac{l}{\mu d} S^{(1-\mu)} \tag{9.4.6}$$

It follows that:

$$\frac{dM}{dS} = \left[-\frac{(1-\mu)}{\nu-1}\right]\left(\frac{\mu b}{\nu}\right)^{\frac{1}{\nu-1}} S^{\left(\frac{\mu-\nu}{\nu-1}\right)} < 0 \quad (9.4.7)$$

Therefore, as S rises (more stability) , M declines (less interventionist monetary rule is needed). We then assume that the government can pass a law to ensure that central bank will pursue the chosen monetary stance M. Furthermore, the government is able to monitor central bank's policy actions so that in the next step the central bank must take M as given while pursuing its power. Note that only M is determined by this stage.

9.4.3 Political preference of the central bank

The organisation of the macroprudential regulation (P), however, is delegated by the government (politicians) to the central bankers who are essentially a group of bureaucrats. The central bank is forced to follow the chosen monetary stance (M) but subject again to the political constraint (policy function) in its welfare maximisation. The preference of the central bank is written as:

$$U_{CB} = S^{\varepsilon} + \varpi P \quad (9.4.8)$$

where $\varepsilon > 1$ and $\varpi > 0$. We assume that central bank values both stability and power (budget size) and it maximises its utility subject again to the policy function - Equation (9.4.3). Maximising the associated Lagrangian $\mathcal{L}_2 = U_{CB} - \Lambda_2 S$ results in the following first-order-conditions:

$$\frac{\partial \mathcal{L}_2}{\partial S} = \varepsilon S^{\varepsilon-1} - \Lambda_2 = 0$$
$$\frac{\partial \mathcal{L}_2}{\partial P} = \varpi + \Lambda_2(c - dP) = 0 \quad (9.4.9)$$

The solution for P is :

$$P = \frac{c}{d} + \frac{\varpi}{\varepsilon d} S^{-(\varepsilon-1)} \quad (9.4.10)$$

It then follows that:

$$\frac{dP}{dS} = \frac{\varpi}{\varepsilon d}(1-\varepsilon)S^{-\varepsilon} < 0 \quad (9.4.11)$$

which implies that the less stabilised the economy is, the more regulatory power it requires. Moreover, the marginal utility generated from more power outweighs the marginal disutility from instability. Under the assumption that the central bank's action cannot be monitored by the government as the latter has no idea of the former' production function, i.e., in which size it delivers the required amount of stability. In its pursuit of regulatory power (P), the central bank in effect goes over the maximum point of the policy function onto the other side where it achieves the same stability but with much more power (bigger size of bureaucracy and larger budget). The situation is illustrated in Figure 9.4.3 where out of this model first comes a choice of M ($\overline{M_0}$) by the government, then the subsequent choices of power (P_0) and stability (S_0) by the central bank given $\overline{M_0}$.

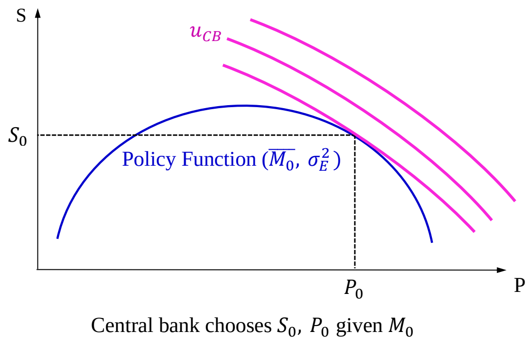


Figure 9.4.3: Choice of the central bank

The justification for the delegation of the regulatory activities arises from the hypothesis that government cannot carry out the necessary regulatory actions without delegating them to bureaucrats, who are are pointed as central bankers with a certain degree of specialized knowledge. Due to the information advantage (or information asymmetry), the central bankers can always convince the government that it is impossible to achieve the same stability with less power. The existence of the time to time shifting error variance σ_E^2 allows the bureaucrats the room to raise power beyond what is necessary. The government does not know which side of the Laffer curve the central bank is on and hence cannot gauge its efficiency or prove in the public domain that the same stability can be obtained with smaller budgets.

We appeal here to the politics of delegation: due to information asymmetry, the politicians find it difficult to keep the bureaucrats within the budget or force them to be as efficient as possible. The government has no better way to limit the size of budget than choosing the best monetary policy M. Because a good M that shifts the policy function upwards, which in effect limits the central bank's use of power. Or to put it another way, the better the monetary policy alone can stabilise the economy, the less need there is to resort to regulatory intervention and the less chance for the bureaucrats for exploit the situation for a huge budget.

Note that P is only determined after the central bank's maximisation. Substituting the solution for P into the policy function yields the total differential (evaluated at $S = P = 1$):

$$dS = -\frac{1}{1 + b\left(\frac{\mu b}{\nu}\right)^{\frac{1}{\nu-1}} \frac{1-\mu}{\nu-1} + (c-d)\frac{\varpi}{\varepsilon d}(\varepsilon - 1)} d\sigma_E^2 \tag{9.4.12}$$

This implies that once both government and central bank have chosen their monetary and macruprudential stances, the rise in the volatility of the general environment raises M and P and of course reduces S. This can be represented by the following first-order derivatives:

$$\frac{dM}{d\sigma_E^2} > 0, \quad \frac{dP}{d\sigma_E^2} > 0 \text{ and } \frac{dS}{d\sigma_E^2} < 0 \tag{9.4.13}$$

For the indirect inference estimation in the next section, these functions will form the auxiliary model to be observed in data moments. The signs of these first order derivatives would be checked in the robustness tests.

Chapter 10

Model Testing and Estimation (Institutional Model)

10.1 Actual data

We consider the data sample: 1993Q1-2016Q4 for the UK. The estimation coefficients for the underlying DSGE model are obtained by the indirect inference method. The model list and estimated coefficients are provided in appendix. The data is divided into three subsamples, depending on the strength of regulation and the stabilising property of the monetary policy, as identified in our DSGE model (Figure 9.1.1). For the construction of correlations between three variables S, M and P over different subsamples, we need to first gather the actual data. Stability (S) is calculated as the inverse of the output variance. Output is HP-filtered so as to remove the trends. The results are plotted in Figure 10.1.1.

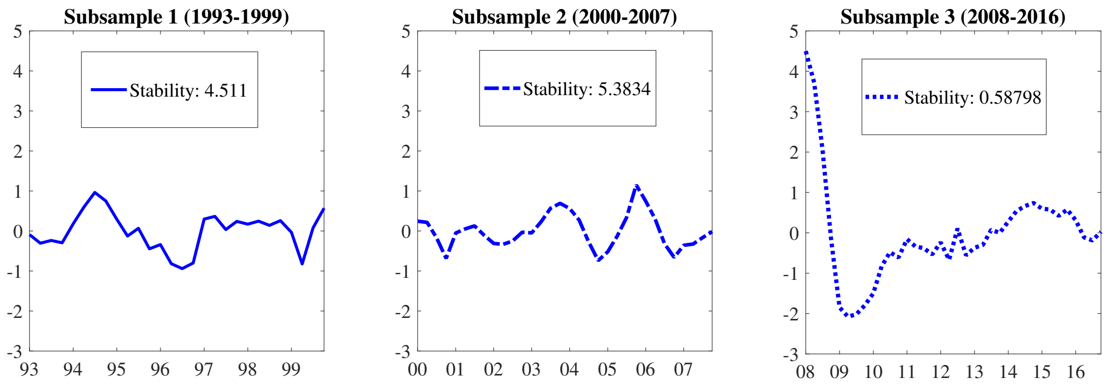


Figure 10.1.1: Output stability (S) for subsamples

The monetary regimes (M) for each episode are identified as in Taylor (2016). Although Taylor's original speech was mainly about the US economy. The UK economy, however, bears certain resemblances to its US counterpart in terms of policy tendencies. The problems observed in the US in the run-up to the GFC seem to apply to the UK as well.

This view was backed up by some UK economists: for example, the former deputy governor of the Bank of England Charles Bean, argued that around 46% of the UK housing boom price bubble observed in the early noughties was due to policy makers not following the Taylor rule; the interest rate at the Bank of England was below the level prescribed by the policy rule (Bean et al., 2010). Patrick Minford in his comments on Taylor (2016), also blamed the less stabilising monetary policy in the early 2000s for the build-up of debt and risk-taking. The post-2008 era, on the other hand, is the period when the BoE deployed both conventional and unconventional monetary tools to inject the liquidity into the economy. We have verified from the simulation of underlying DSGE model that a "monetary reform regime" in which QE was used extensively has achieved the most stability for major economic indicators (output, consumption). The monetary policy stance from 2008 onwards can be seen a deviation from the Taylor rule and characterised by the monetary authority's extra efforts in stabilising the economy. So if we rate the subsample 1 (93-99) as the standard Taylor rule period (M=1) for which central bank carried out the moderately stabilising monetary rules, then subsample 2 (00-07) refers to the poor (half) Taylor rule period (M=0.5) when the BoE responded little to output and inflation and this created an inflationary credit boom. Finally, in subsample 3 (08-16), the BoE aggressively reacted to low liquidity with the tools of both Taylor rule and QE; so we rank M=1.5 for it. Notice that we do so based on the simulation results for different monetary regimes (See Figure 11.0.1). The Dual rule regime where QE is employed extensively delivers the maximum stability across all regimes, whereas the half Taylor rule regime achieves the minimum.

For the measure of regulation level (P), we divide the number of BoE employees at the end of each episode by 10000. The idea is that regulative burden takes time to show up in employment as the central bank eventually hires all the staff it needs. This would give us 0.2833 for 93-99, 0.1789 for 00-07 and 0.3983 for 08-16, which are in line with what we have observed for the regulation: moderate in the 1990s, relaxed in the early 2000s, and intrusive since 2008.

Having gathered the observable data moments, we construct a number of correlations across subsamples in Figure 10.1.2. There are essentially 3 data points for each variable. S is negatively correlated with both M and P, while S and P seem to be in line with one another. We now proceed to find out if this data behaviour can be generated from our institutional model.

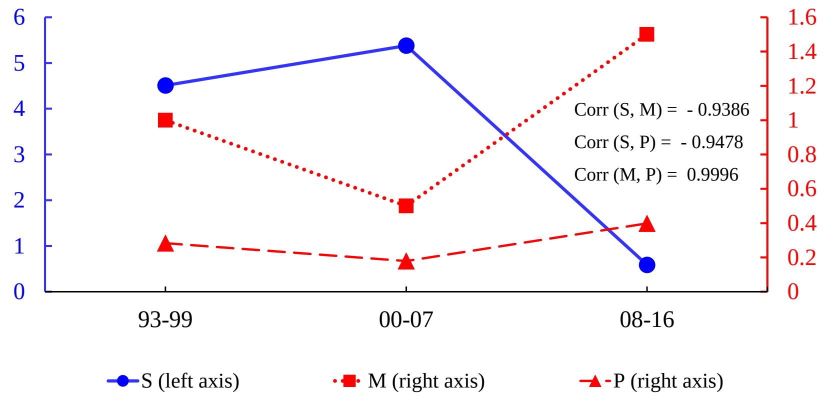


Figure 10.1.2: Subsample correlations in actual data

10.2 Simulated data

To generate the simulated data, we start by bootstrapping the DSGE model for each subsample to find the distribution of S. The macro-DSGE model was tested already for its fit to the UK data. Now we need to create a corresponding version for each subsample. As with most DSGE models with banking sector and financial friction, we assume that monetary policy targets the risk-free interest rate, whereas the macroprudential policy controls the risk premium. It is through adjusting these equations that we model the shift in policies.

The number of BoE employees has gradually declined to 2833 by 1999 - the end of subsample 1. We assign for this period $\kappa = 0.2$, which implies some moderate and limited banking regulation. The number hit the bottom at 1789 in 2007 just prior to the crisis. Hence, we rate pre-crisis episode (00-07) as having very light regulation ($\kappa = 0$). It is also the period with the most risky projects undertaken by financial institutions in the background of benign macroeconomic prospect. The post-crisis episode has seen the sharp increase in the central bank employees. We see this as a signal that the BoE has put in the extra effort to tighten the regulation and assign $\kappa = 0.4$ for it.

For the modelling of monetary policy, we stick to the standard Taylor rule for the period 93-99 where the BoE responded appropriately to the output and inflation. For the early 2000s we halve the Taylor ruler coefficients for output and inflation to reflect the fact that the BoE did not react as much as it should to curb the lending that fuelled asset-price bubbles. For the post-2008 era, we supplement the standard Taylor rule with a powerful QE rule. The idea is that besides adhering to the good rule coefficients, the BoE was doing extra stabilising action via the QE response. The way we model the monetary policy for each episode with DSGE model is consistent with how we assign the M values for the actual data.

10.3 Indirect inference estimation

Testing and estimating the institutional model involves comparing correlations across actual data subsamples with their counterpart joint distribution of correlations across simulated sabsamples; from calculating where in the distribution of the latter the former lies we then obtain the transformed P-value. A P-value exceeding the threshold of 0.05 indicates the model passes the past, which in turn suggests the institutional model could be the data-generating one.

The estimation proceeds as follows: First, by bootstrapping the innovations 1000 times in simulation we obtain 1000 sets of S values (measured as the inverse of the variance of the output gap) in each of the 3 episodes. This generates for each subsample the distribution of S because we want to "animate" the institutional model as realistically as possible with sufficient exogenous noises. From combining these S values randomly we create 1000 pseudo histories for 3 episodes that could have occurred. As noted in Le et al. (2018), the institutional model's reliance on the underlying macroeconomic model is limited to obtaining the S distribution from simulations. Given that the underlying macro model has been tested already, we are now in effect only testing the accuracy of institutional model. The histogram (left panel) in Figure 10.3.1 shows that the post-crisis episodes (subsample 3) experience the most volatility in output with most simulations out of 1000 falling into the low stability bins (left side of horizontal axis). Scatter plot (right panel) presents the results in a different way and also shows that compared to subsamples 1 and 2, more simulations from subsample 3 (green dots) end up in the bottom (low stability range).

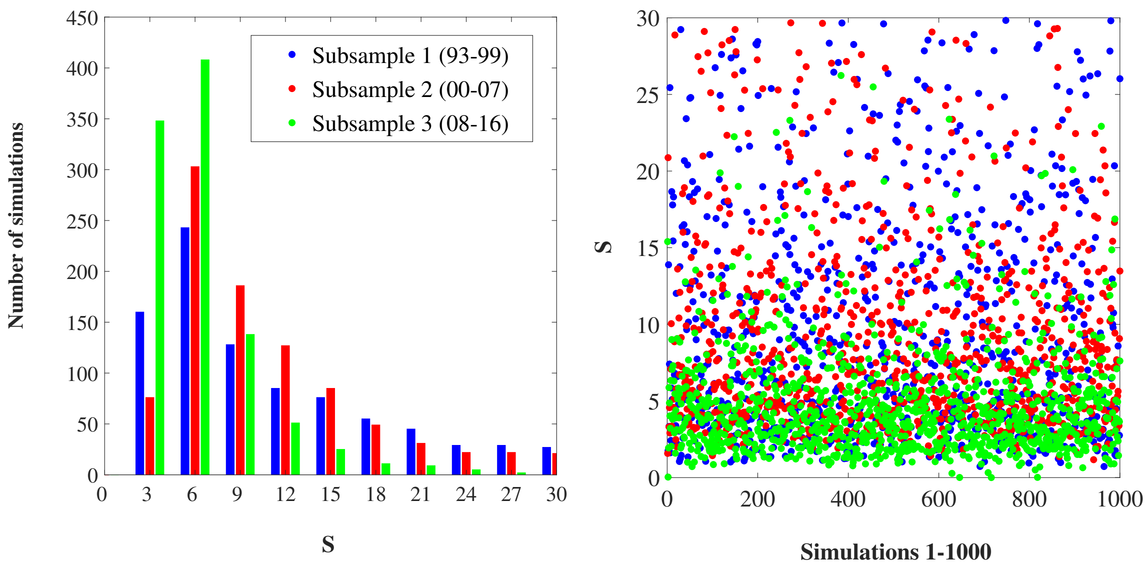


Figure 10.3.1: Distribution of Ss from subsample simulations

Second, we inject the S values into the parameterised institutional model to derive the corresponding 1000 sets of Ms and Ps based on the solution: $M = (\frac{\mu b}{\nu})^{\frac{1}{\nu-1}} S^{-(\frac{1-\mu}{\nu-1})}$, $P = \frac{c}{d} + \frac{\varpi}{\varepsilon d} S^{-(\varepsilon-1)}$, and also the implied σ_E^2 which are not directly observable. The general environmental volatility σ_E^2 is produced by different shocks in the underlying model and cannot be aggregated into a single measure of volatility. Up to this point we have accumulated 1000 sets of three S, M, P and σ_E^2, one for each episode. What we have found is that S and σ_E^2 are perfectly correlated; so we exclude σ_E^2 and consider only the correlations between S, M and P. We end up with 1000 sets of $corr(S_{sim}, M_{sim})$, $corr(S_{sim}, P_{sim})$ and $corr(M_{sim}, P_{sim})$.

Finally, we compute from these correlations their joint distribution, which is to be compared with the moments we constructed from the actual data. The Wald-percentile that determines where in the distribution the actual data correlations lie is then transformed into a p-value. For the model estimation, we carry out the simulated annealing algorithm across the calibration parameter space to find one set of coefficients that minimises the Wald-statistic (or equivalently, maximises the p-value). Table 10.3.1 reports the coefficient set that delivers a p-value of 0.741 (> 0.05), which means the model easily passes the test.

Coefficients	ε	ϖ	μ	ν	b	c	d
Starting calibration	1.5	0.5	0.5	1.5	0.5	0.5	0.5
Estimation	1.5634	8.1662	0.6674	3.1481	5.9214	4.7975	4.6804

Table 10.3.1: Estimated coefficients

NOTE: parameter a (policy function) and l (government utility function) do not enter the solutions for M or P, and hence cannot be identified from the estimation.

Moreover, Figure 10.3.2 summarises the procedure as described in texts. Figure 10.3.3 visualises the simulated distribution of Ms and Ps across subsamples conditional on estimated parameters. Inspection reveals that subsample 3 observes the highest frequency of large Ms and Ps (strong efforts in monetary and regulatory stabilising), which is followed by subsamples 1 and 2. Our simulation is hence capable of accommodating the fact that monetary and regulative stances were moderate in the late 1990s, relaxed before the crisis and aggressive since the crisis. Figure 10.3.4 plots five randomly selected correlations in the simulation. As expected, we find that Ss are negatively correlated with Ms and Ps, while the latter two are positively correlated. Figure 10.3.5 and Table 10.3.2 compare the actual correlations with the simulated correlations by finding where in the distribution of the latter the former lie. We find that the actual correlations lie within the upper and lower 25th percentiles of the simulation and are close to its mean.

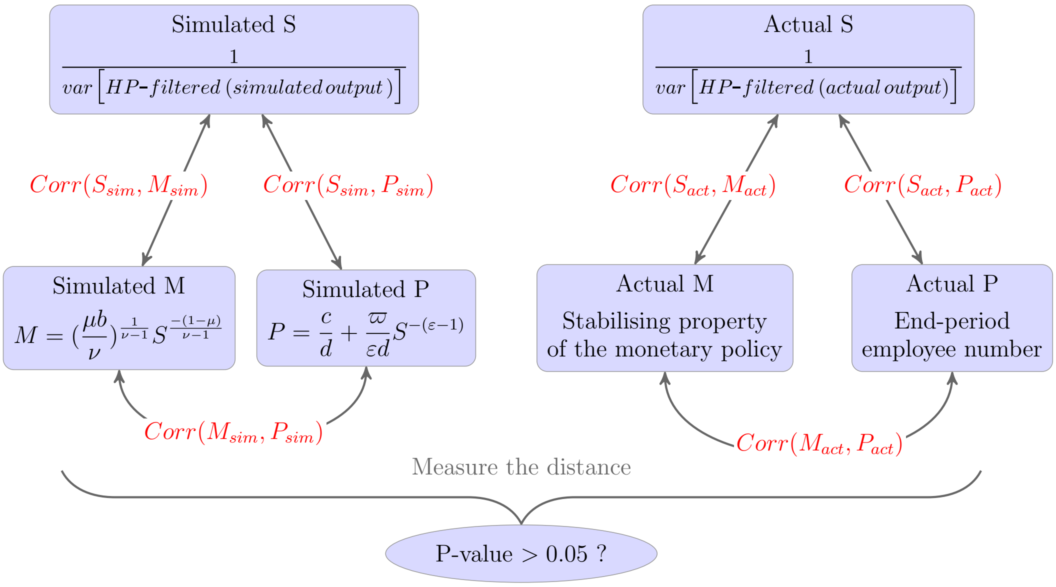


Figure 10.3.2: Procedure of II estimation

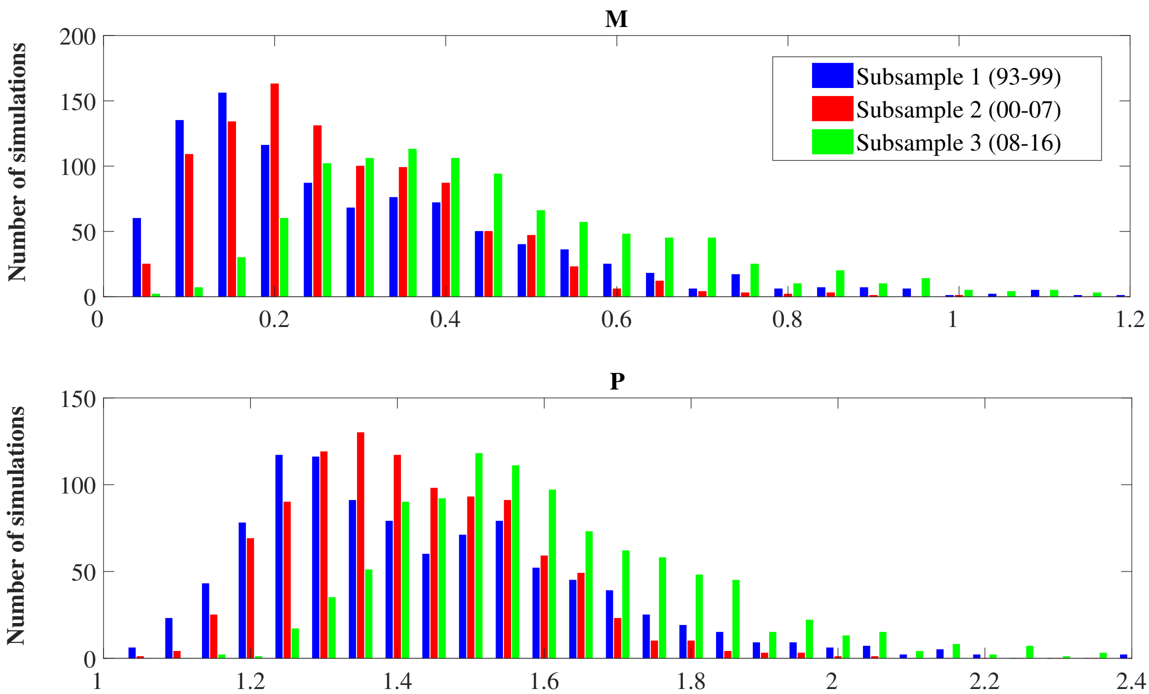


Figure 10.3.3: Distribution of Ms and Ps conditional on the estimated model

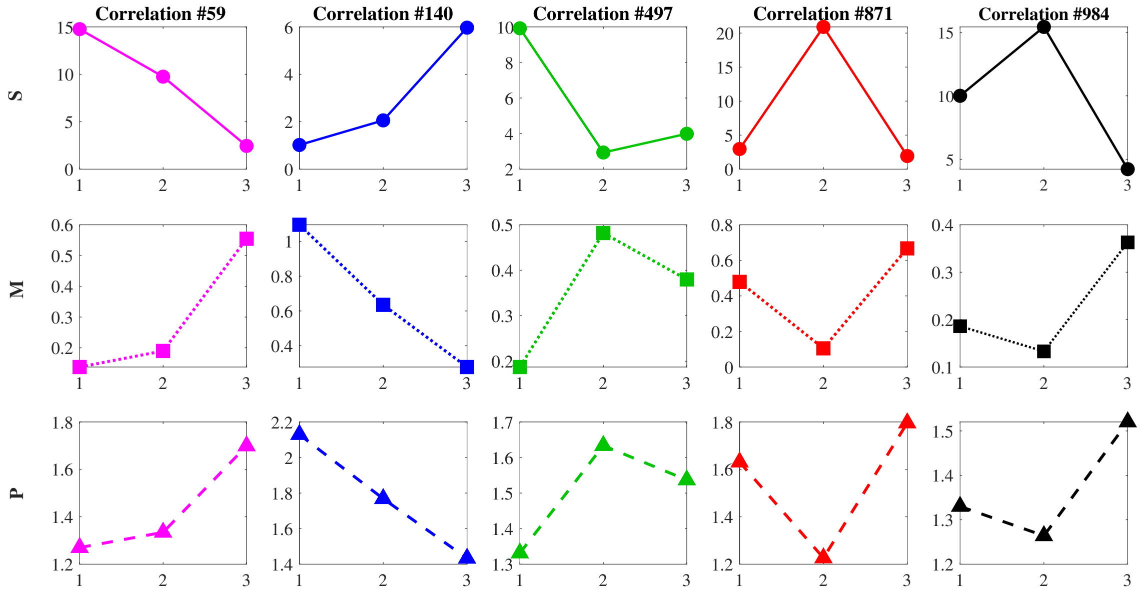


Figure 10.3.4: Examples of simulated correlations across subsamples (estimated model)

NOTE: on the x-axis, 1 - subsample (93-99), 2 - subsample (00-07), and 3 - subsample (08-16).

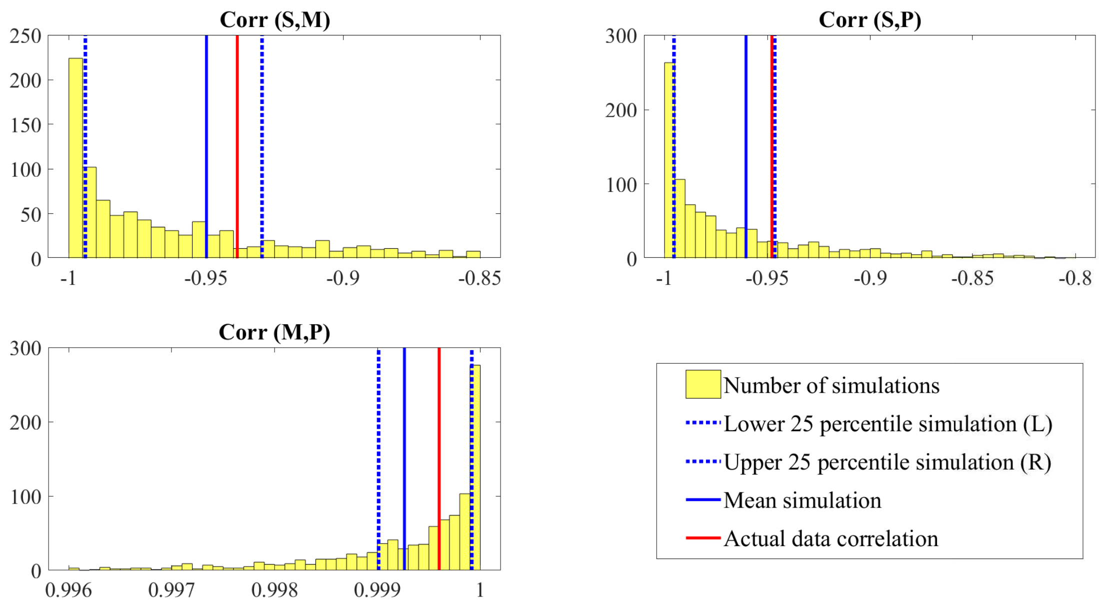


Figure 10.3.5: Correlations in actual data *vs.* Correlations in simulated data

	Corr (S,M)	Corr (S,P)	Corr (M,P)
Actual data correlation	-0.9386	-0.9478	0.9996
Mean simulation	-0.9498	-0.9604	0.9993
Lower 25% percentile	-0.9940	-0.9954	0.9990
Upper 25% percentile	-0.9296	-0.9464	0.9999

Table 10.3.2: Correlations in actual data *vs.* Correlations in simulated data

10.4 Robustness checks

10.4.1 How powerful is our test?

The first robustness check is concerned with the power of our estimation. To check the accuracy of our estimated results, we perform a Monte Carlo experiment to examine the test power. To begin with, we take the estimated model as the true one and create a series of false models by altering each estimated parameters by + or - x% randomly. We also make sure that x must comply with the bounds restrictions we put on parameters to guarantee that the model is always correctly identified. Table 10.4.1 summarises how raising the degree of falseness (top row) leads to the increasing frequency of rejection (bottom row). It shows that the rejection rate rises slowly till the falseness reaches 65% (29.7% rejection), then it jumps to 57.7% with 68% falseness. When the falsified model is seriously mis-specified and gets really close to the parameter bounds (e.g. 70%), we see a 99.9% rejection.

Degree of Falseness in %	5	10	20	30	40	50	60	65	68	70
Rejection rate in %	7.5	9.7	14.7	18.1	21.8	24.6	27.4	29.7	57.7	99.9

Table 10.4.1: Power of estimation

Anther check is concerned with the private interest assumption upon which the model is built, as we want to find out if a model in which the central bank would not be dominated by its power-seeking but prioritise the society's welfare would be rejected at all times. In doing so, we set the parameter that governs central bank's preference for regulatory power - ϖ to negative values. This implies central bank would dislike P and aim to reduce the size of bureaucracy wherever possible; its choice of power will not proceed over the maximum point of Laffer curve, but stay on the left-hand side. Our test results show that regardless of the absolute size of this negative ϖ, we end up with the 99.9% rejection rate. We argue that this gives us reasonable confidence that our private interest assumption can be validated from the data.

10.4.2 Does the estimated model fit into political theories?

Figure 10.4.1 depicts the Laffer curve effect from raising power to stability. The tangency points between the indifference curves and the policy function locate the welfare maximising points for the government (square markers in the left subplot) and the central bank (round markets in the right subplot). Central bank values power and the quadratic form of the policy function allows room for it to purse more power while delivering the same stability. Besides, a good monetary rule (more stabilising M policy, and hence bigger M) shifts the policy function upwards. Hence, with the same level of regulation, better monetary rules deliver more stability.

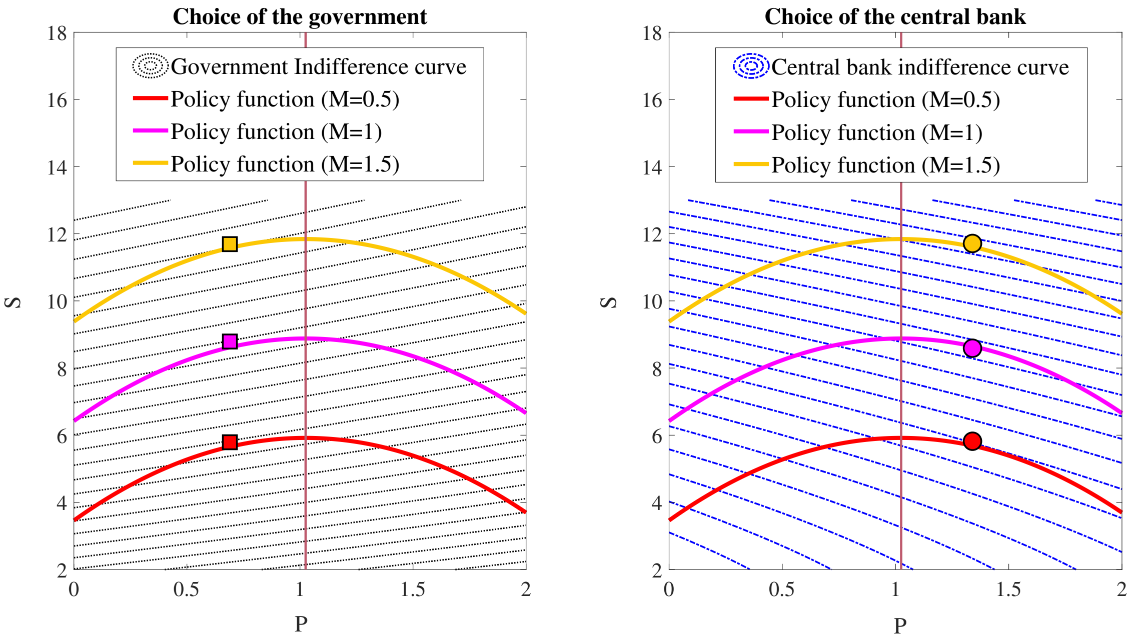


Figure 10.4.1: Choices of the government and the central bank

NOTE: parameter l (the government's preference for power) is calibrated at 0.4; parameter a (which shifts the policy function upwards/ downwards) is calibrated at 0.5. The rest ones are set as in estimation.

The solutions for M and P conditional on the estimated parameters are plotted in Figure 10.4.2. It is clear that the more stable the economy is (greater S), the less need there is for either M or P policy intervention. Finally, the last check is concerned with the effect of environmental volatility σ_E^2 on S, M and P. As shown by Figure 10.4.3, S decreases in σ_E^2 and drops to zero when σ_E^2 rises above 18; this is straightforward as general volatility contributes to stability negatively on top of monetary (M) and regulatory (P) stances. On the other hand we see that the rising σ_E^2 causes a steady and slow rise in M as the government chooses more aggressive monetary rules in reaction to higher volatility. Clearly the gains from stability outweigh the administrative costs as implied by government's utility function. The response of P to σ_E^2 remains positive but quite muted before σ_E^2 reaches around 10, then P rises much more sharply in σ_E^2 (while S approaches 0); this is because for the central bank, gains from raising P will no longer be offset by the loss in utility from smaller S, when the latter is constrained by the zero bound (in this model stability is calculated as variance and thus cannot be negative). So we have verified from our estimated model that: $\frac{dS}{d\sigma_E^2} < 0$, $\frac{dM}{d\sigma_E^2} > 0$ and $\frac{dP}{\sigma_E^2} > 0$.

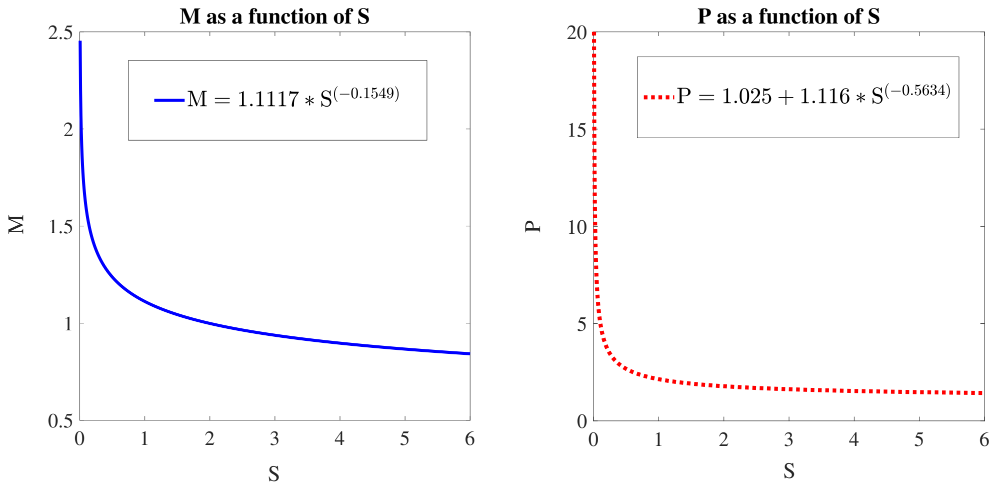


Figure 10.4.2: M and P as functions of S

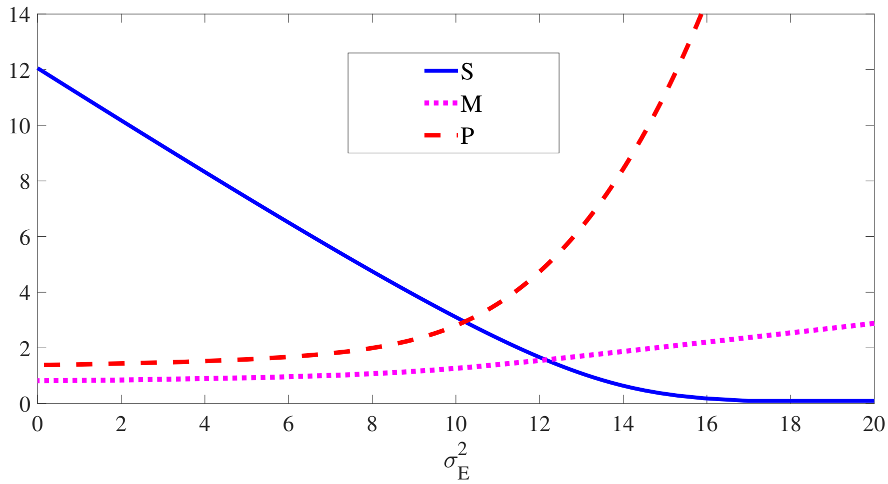


Figure 10.4.3: Responses of S, M and P to environmental volatility σ_E^2

Given the simplicity and limitations in our auxiliary model and data - the model only involves the correlation between three variables and with three data points, it is only when the estimated model survives a series of robustness checks that we can be confident that the conclusions are qualitatively robust.

Chapter 11

Reformed Monetary Regimes: A Way Out of This Impasse? (Institutional Model)

In the previous chapters, we have built and estimated an institutional model for the UK wherein macroprudential policy at best contributes little, at worst destabilises the economy. Now we move on to explore if there are better alternatives to burdening the economy with cumbersome regulation.

Recall that besides macroprudential policy, monetary policy in the form of Taylor-type feedback rules has been employed commonly in advanced economies for stabilising the output. Admittedly, the painful experience from the recent financial crisis reveals the inability of standard monetary regime (which adjusts the nominal interest rate in reaction to the inflation and output only) to perform efficiently to prevent financial turmoil. This, on the other, opens the discussion about if any augmented/reformed monetary regimes can achieve better stabilising result. In the DSGE model, we have already explored this possibility by comparing output stability across a few monetary regimes. Now we conduct a similar experiment with the addition of different regulatory intensity (different values of κ). In doing so, we are attempting to find a way out of this dilemma.

The alternative regimes we consider are: premium augmented Taylor rule regime (ATR1) which modified the STR and adds a response to premium, premium shock augmented Taylor rule regime (ATR2), which adds to the STR a response to premium shock, Dual Rule Regime (DRR) which supplements the STR with a QE rule to target premium, and half Taylor rule regime for which we cut the Taylor rule response to inflation and output in half. In the underlying DSGE model we have established a clear ranking of monetary rules and found that in terms of reducing the welfare loss, DRR > STR1 > STR2 > STR. The poor (half) Taylor rule regime is analysed additionally to capture the monetary stance in the pre-crisis episodes when the authority did little to curb the credit and housing boom.

The results are summarised in Table 11.0.1.[1]

Regulation level (κ)	DRR	ATR1	ATR2	STR	Half
0	0.9845	0.9097	0.8545	0.6132	0.5166
0.2	1.3371	1.0018	0.8961	0.9421	0.8262
0.4	0.6771	0.5634	0.5728	0.4834	0.3773
0.6	0.4412	0.4478	0.2760	0.1742	0.1899
0.8	0.0311	—	—	—	—

Table 11.0.1: Raising regulative intensity for different regimes

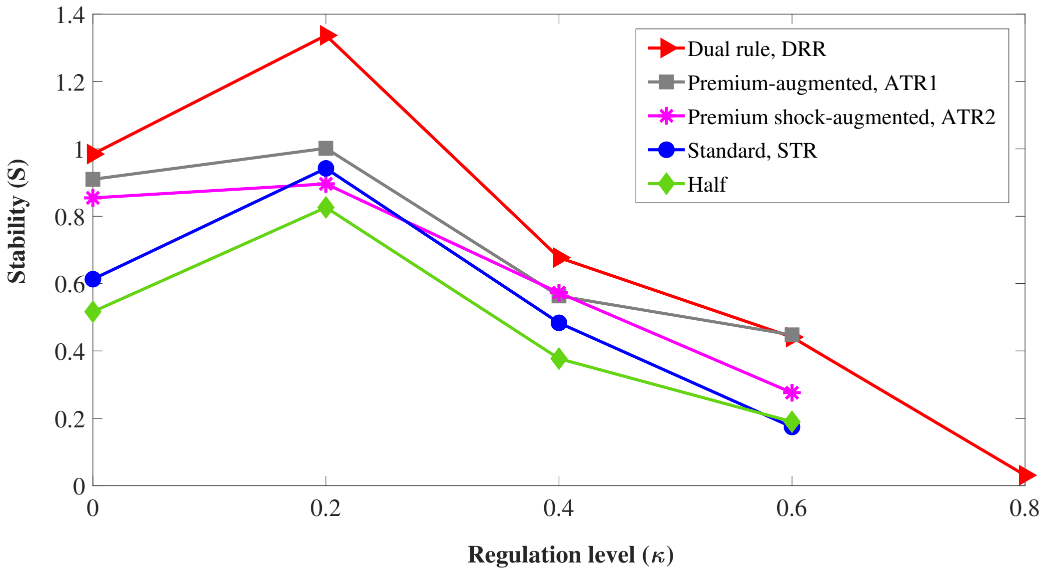


Figure 11.0.1: Comparison of stability across regimes

The results are plotted in Figure 11.0.1 for visual comparison. Stability under different monetary regimes is distinguished by a combination of marker symbols and line colors. We find that there is a Laffer curve effect from P to S for all regimes. When there is moderate regulation, say $\kappa = 0.2$, the stability improves compared to the minimum regulation case $\kappa = 0$. Nonetheless, raising κ beyond this optimal level delivers more volatility (instability). The DRR regime which we associate with the monetary authority's extra-stabilising effort in the post-crisis episodes (by using QE extensively to keep the credit condition in check) achieves the best outcome for any levels of regulation; it is followed by premium and premium shock augmented regimes (denoted by ATR1 and ATR2, respectively) which also improve stability compared to the baseline case (STR), but their stability property appears to be less pronounced than that of DRR. Unsurprisingly, half regime which we relate to the least-stabilising monetary stance (by not adjusting interest rate as much as it should) in the pre-crisis episodes, performs the worst across all regimes. Notice that all but one

[1]We increase the interval for κ to 0.2 as this yields consistent results for all regimes.

regime (DRR), fail to converge with extreme regulation $\kappa = 0.8$. However, before that all regimes are destabilised already for any $\kappa \geq 0.4$.

As indicated by Figure 11.0.1, virtually the same stability was obtained under standard regime (STR) when $\kappa = 0.2$ and premium-augmented regime (ATR1) when $\kappa = 0$. What this suggests is that stability crucially depends on the choice of monetary regime. Raising M by adopting more stabilising monetary rules shifts the Laffer curve upwards systematically. Hence, the best way for the government to mitigate instability (e.g., frequency, length and severity of crises) is to select a good monetary regime that systematically enhances the system resilience to adverse financial shocks. This should be preferable to distorting the economy with regulation which proves not only inefficient but can be harmful to stability if imposed at high intensity.

Chapter 12

Conclusion and Policy Implication (Institutional Model)

This study examines the re-emergence of an emboldened concept of macroprudential regulation since 2008 and takes issue with it on several fronts. First, regulation is assumed to only promote stability up to a certain point, beyond which it undermines stability as the distortions it creates outweigh the stabilising effect of tighter credit. Second, departing from the idealised perspective that policy makers have public interests in mind when designing regulatory rules, we raise the possibility that policy makers might prioritise advancing their own interests, not necessarily those of the general public. Third, at the current juncture, analyses of the effectiveness of macroprudential instruments, their impact on financial stability, and their interaction with monetary policy tools are still rather limited. Here we resort to an estimated Macro-DSGE model for the UK and build on top of it an institutional model wherein the government first chooses the monetary stance, and then delegates the organisation of regulation to the central bank. Using indirect inference estimation, we find a set of coefficients that can generate the observed moments for the UK economy over 1993-2016. Moreover, we show that by committing to an aggressive stabilisation monetary regime that supplements the standard Taylor rule with a QE rule to keep the credit condition in check at all times, the monetary authority can achieve stability without resorting to the excessive regulation that clearly brings more pain than gain.

We attribute the post-crisis sluggish recovery partially to the faulty institutional arrangement that leads to the failure in setting appropriate economic policy. By highlighting the drawbacks intrinsic to the regulatory framework, it is envisaged that the findings of our study may offer new insights into the policy delegation and management.

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Appendices

A1 Data construction

Most data series used in the model are readily available from the Bank of England (BoE), Office for National Statistics (ONS) and Federal Reserve Economic Data (FRED). The construction of variables and data sources are summarized in Table A1.1.

We choose FTSE 250 rather than FTSE 100 because the former involves fewer companies that are internationally focused and thereby a better indication of the UK economy. While the revenues of FTSE 100-listed companies are more susceptible to exchange rate movements and barely indicative of how the UK economy is faring. See also https://en.wikipedia.org/wiki/FTSE_100_Index

Symbol	Variable	Definition and description	Source
R	Nominal interest rate	Quarterly average rate of discount, 3 month Treasury, Sterling	BoE
I	Investment	$\frac{Total\ gross\ fixed\ capital\ formulation}{GDP\ Deflator * Total\ population}$	ONS
PK	Price of capital	Derived from capital arbitrage equation	Calculation
K	Capital stock	Derived from capital accumulation equation	Calculation
π	Inflation	$\frac{CPI_t - CPI_{t-1}}{CPI_{t-1}} * 100$	FRED
W	Wage	$\frac{Wages\ and\ salaries + employers'\ social\ contributions + income\ from\ self-employment}{Total\ hours\ worked * Total\ employment}$	ONS
C	Consumption	$\frac{Final\ consumption\ of\ households + Final\ consumption\ of\ NPISHs}{GDP\ Deflator * Total\ population}$	ONS
Y	Output	$\frac{Gross\ domestic\ product:\ chained\ volume\ measures}{Total\ population}$	ONS
L	Labour	$\frac{Total\ hours\ worked}{Total\ employment}$	ONS
RK	Marginal product of capital	Derived from labour demand equation	Calculation
PM	Risk premium	3-month LIBOR - 3-month Treasury bills	FRED
CY	Commercial lending rate	3-month LIBOR	FRED
N	Net worth	FTSE 250 index	Yahoo Finance
$M0$	Monetary base	M0 Monetary base in the UK	FRED
$M2$	Broad supply of money	M2 Monetary stock in the UK	FRED
EX	Export	Exports of goods and services in the UK	FRED
IM	Import	Import of goods and services in the UK	FRED
Q	Real exchange rate	Inverse of sterling effective exchange rate $* \frac{P^F}{P}$	BoE
P^F	Foreign price level	Weighted average CPI in Germany, US and Japan [1]	FRED
P	Domestic price level	UK CPI	FRED
R^F	Foreign interest rate	Weighted average 3-month discount rates in Germany, US and Japan [2]	FRED
π^F	Foreign inflation level	Weighted average inflation in Germany, US and Japan [3]	FRED
C^F	Foreign consumption demand	World import in goods and services	IMF
B^F	Foreign assets position	BoP: Ratio of nominal net foreign assets (NFA) to nominal GDP [4]	ONS

[1] Weights: Germany (0.62), US(0.23), Japan (0.15). Germany proxies EU.
[2] Weights as foreign price level.
[3] Weights as foreign price level.
[4] Nominal NFA is accumulated current account surplus, taking the balance of payments international investment position as the starting point.

Table A1.1: Data construction and sources

A2 Indirect inference estimation

We adopt the simulated annealing algorithm as developed by Ingber (60) and later Le et al. (73). The estimation process mimics the optimization method employed when cooling the steel with a degree of reheating at randomly chosen moments, during which the progressive reduction in the atomic movement effectively minimises the density of lattice defects until the cooling process is completed. While the algorithm applies to the metal cooling process that guarantees the defects are minimised, it could be considered apt also for the parameter estimation. Starting from the initial calibrated parameters, the simulated annealing algorithm searches around the chosen range. The search algorithm randomly goes through points that may or may not improve our objectives, and this way it helps prevent the algorithm being trapped in local minima, which ensures our objectives are globally minimised.

The criteria we use to test sets of parameters are standard: Using the LIML method, we extract the resulting residuals for each set of parameters given the actual data, before finding the implied AR(1) coefficients and bootstrapping their implied innovation to obtain the Wald statistic. Simulated annealing algorithm is then applied to find the global minima.

Part of our Indirect Inference estimation is reported in Table A2.1 below. The last three columns correspond to Wald statistic, transformed t-statistic and number of sensible simulations out of 1000. We only keep groups with more than 900 meaningful simulations and pick the set that yields the smallest t-statistic (Wald), conditional on its not reaching the threshold of 1.645.

φ	σ_c	λ	ξ_w	σ_L	ξ_p	ι_w	ι_p	ψ	ϕ_p	r_p	ρ	r_y	r_{Δ_y}	α	ω^w_{NK}	ω^p_{NK}	χ	ϑ_2	ϑ_1	ϑ	Wald stats	t-stats	No.of sensible sims
6.7234	1.6908	0.7276	0.6711	2.6458	0.8817	0.3571	0.1646	0.1142	1.9148	2.5989	0.6637	0.0255	0.0193	0.1624	0.4478	0.0813	0.0292	0.0661	0.0502	0.0468	29.89076	1.9597	991
7.6433	1.9221	0.6281	0.7629	3.0078	1.0023	0.406	0.1421	0.0986	1.6528	2.2433	0.7545	0.029	0.0167	0.1402	0.3865	0.0924	0.0332	0.0571	0.0433	0.0404	38.04965	3.4667	1000
6.378	1.9368	0.6218	0.6366	2.5099	1.01	0.409	0.1407	0.1201	2.0132	2.2208	0.6296	0.0242	0.0165	0.1388	0.3827	0.0771	0.0277	0.0565	0.0528	0.04	35.54908	3.0246	1000
6.3522	1.9371	0.6301	0.6419	2.5306	1.0101	0.4049	0.1406	0.1192	1.9982	2.2204	0.6271	0.0244	0.0167	0.1387	0.3826	0.0778	0.0279	0.0565	0.0524	0.0405	37.67682	3.112	1000
5.9411	1.6076	0.6196	0.593	2.338	1.0126	0.4101	0.1727	0.1275	2.1376	2.2131	0.7177	0.0276	0.0202	0.1383	0.3813	0.0718	0.0316	0.0694	0.056	0.0491	40.99235	3.6311	1000
6.5512	1.7224	0.6936	0.6539	2.578	1.0131	0.4103	0.1784	0.1288	2.1595	2.2117	0.7332	0.0256	0.0209	0.1548	0.4269	0.0709	0.0323	0.0649	0.0515	0.0507	38.69101	3.5636	1000
7.6389	1.446	0.6185	0.5716	3.0061	1.0139	0.3091	0.1884	0.0987	1.6541	2.9484	0.7609	0.0292	0.0221	0.1842	0.508	0.0924	0.0252	0.0757	0.0576	0.0536	38.8487	3.3641	1000
7.0739	1.6059	0.7409	0.5933	2.5803	0.9357	0.368	0.1614	0.1084	1.6936	2.4657	0.7092	0.0261	0.0219	0.1848	0.4589	0.0931	0.031	0.0628	0.0529	0.0446	16.4556	0.9576	943
5.7999	1.5013	0.6189	0.5789	2.7778	1.0134	0.3436	0.1831	0.1299	1.8193	2.2106	0.7461	0.0287	0.0179	0.1381	0.3809	0.0701	0.0328	0.0611	0.0477	0.0433	35.78383	3.2865	1000
6.0763	1.4921	0.65	0.6065	2.7021	1.0135	0.3532	0.1839	0.1301	1.874	2.3219	0.7486	0.0288	0.0185	0.1381	0.4001	0.07	0.0329	0.0633	0.047	0.0448	37.29114	3.1898	1000
5.8462	1.4571	0.7689	0.5835	2.9189	1.0138	0.3216	0.1559	0.1309	1.7171	2.7464	0.7579	0.0242	0.0172	0.1691	0.3877	0.0694	0.0333	0.0714	0.0538	0.0505	42.17317	3.7571	1000
5.8868	1.5005	0.8172	0.5962	2.9425	0.773	0.4023	0.1874	0.1286	2.1953	2.2709	0.5659	0.0218	0.0169	0.1404	0.499	0.0933	0.0253	0.0744	0.0577	0.0404	42.26735	3.2578	915
6.8404	1.9326	0.7091	0.7391	2.26	0.9462	0.3385	0.1691	0.1137	2.1582	2.6138	0.5753	0.0222	0.0195	0.1537	0.4102	0.0881	0.0291	0.0653	0.0577	0.0441	35.6168	3.2707	1000
7.6761	1.4592	0.693	0.6232	2.8113	0.9707	0.3158	0.1481	0.1093	1.9472	2.3286	0.7253	0.023	0.0176	0.144	0.4369	0.0824	0.0307	0.0668	0.0525	0.0425	38.43748	3.3412	1000
7.702	1.449	0.6584	0.6921	2.9187	0.9908	0.3598	0.1672	0.1036	1.7988	2.2731	0.7429	0.0259	0.0197	0.1638	0.4731	0.0762	0.032	0.0711	0.0549	0.0412	36.85036	3.0148	1000
7.7248	1.44	0.628	0.5995	2.4089	0.8071	0.317	0.1464	0.0986	2.1057	2.8178	0.7584	0.0285	0.0172	0.1813	0.4027	0.0894	0.0265	0.0597	0.0571	0.0401	28.90318	1.9524	955
7.7266	1.5708	0.6255	0.6442	2.5733	0.8607	0.3413	0.1447	0.1071	2.1307	2.7169	0.708	0.0287	0.0185	0.1701	0.4318	0.0904	0.0261	0.0588	0.0572	0.04	33.69086	2.5452	996
7.7295	1.7761	0.6216	0.6037	2.8312	0.9449	0.3794	0.1421	0.1204	1.8542	2.4379	0.7384	0.0291	0.0173	0.1525	0.4037	0.0921	0.0302	0.0574	0.0575	0.0399	38.28959	3.4208	1000
7.7311	1.5486	0.6195	0.5814	2.4404	0.8137	0.3285	0.1738	0.1047	1.7021	2.2843	0.6214	0.0292	0.0206	0.1755	0.4784	0.0767	0.0325	0.0566	0.0577	0.0398	35.33542	2.5505	740
7.5732	1.5796	0.6365	0.5805	2.4876	0.8087	0.3265	0.1711	0.1041	1.7413	2.2784	0.617	0.0286	0.0203	0.1764	0.4707	0.078	0.0326	0.0581	0.0577	0.0409	37.04352	2.5934	780
7.72	1.917	0.7571	0.7574	2.2669	0.9985	0.4043	0.1423	0.0976	2.1674	2.9354	0.5681	0.0293	0.0167	0.186	0.5116	0.0698	0.0254	0.0747	0.0438	0.0529	39.48338	3.2132	1000
6.1538	1.8583	0.7894	0.5728	2.9116	0.7634	0.309	0.1473	0.1249	2.0932	2.2254	0.5766	0.0292	0.0173	0.1471	0.5045	0.0898	0.0333	0.0718	0.0462	0.0508	24.91401	2.359	864
5.9869	1.458	0.6211	0.7438	2.9614	0.7581	0.3069	0.1445	0.0981	2.1346	2.2192	0.7418	0.0292	0.017	0.1852	0.3938	0.0912	0.026	0.0565	0.0449	0.0399	30.00029	2.2117	812
6.3173	1.5501	0.6619	0.7491	2.9768	0.7565	0.3063	0.1436	0.1044	2.1473	2.3649	0.7082	0.0278	0.0169	0.1855	0.4168	0.0917	0.0274	0.0602	0.0473	0.0399	24.39327	1.6128	827
7.6787	1.8285	0.7867	0.5772	2.882	0.9516	0.325	0.1876	0.0973	2.0855	2.8099	0.5696	0.0234	0.0208	0.1867	0.382	0.0886	0.0267	0.0715	0.0458	0.0533	35.70232	2.9575	1000
6.3996	1.444	0.756	0.5813	2.7836	0.7499	0.4043	0.1865	0.0975	2.0141	2.2185	0.5729	0.0292	0.02	0.1867	0.4658	0.0705	0.0332	0.0564	0.0478	0.0443	30.80451	2.4902	635
7.6788	1.4634	0.7868	0.5859	2.2763	0.9403	0.3249	0.1499	0.122	1.6471	2.8104	0.5696	0.0238	0.0167	0.1846	0.4846	0.0875	0.033	0.0572	0.0567	0.0527	38.44989	3.3798	1000
6.391	1.7936	0.7728	0.5913	2.2883	0.7498	0.3985	0.1841	0.1194	2.0181	2.7603	0.6978	0.0243	0.0168	0.153	0.4746	0.0856	0.0328	0.07	0.0468	0.0434	32.83304	3.0832	838
7.6964	1.4595	0.8033	0.7438	2.9048	0.7514	0.4043	0.147	0.1249	2.102	2.2452	0.5683	0.0231	0.0213	0.1459	0.493	0.0697	0.0261	0.0569	0.0449	0.0417	31.82661	2.3983	677
7.7124	1.4494	0.8184	0.6654	2.9672	0.7505	0.4072	0.1438	0.1123	2.1473	2.5816	0.6565	0.0259	0.0217	0.1644	0.4422	0.0694	0.0295	0.0655	0.0507	0.0472	22.98098	1.0577	748
6.7321	1.6924	0.8274	0.6188	3.0042	0.8798	0.4089	0.1661	0.1048	1.8922	2.7814	0.6112	0.0276	0.0191	0.1754	0.412	0.0812	0.0272	0.0707	0.0468	0.0504	34.34409	2.4745	981
7.1662	1.4461	0.8234	0.6945	2.9878	0.8225	0.4081	0.1427	0.1175	2.1622	2.6929	0.6312	0.0248	0.0202	0.1705	0.4253	0.0693	0.0282	0.063	0.0485	0.049	23.83222	1.4194	936
6.4067	1.4414	0.7162	0.7349	3.0165	0.9227	0.4095	0.1671	0.1068	2.1831	2.4397	0.7003	0.0272	0.0213	0.1535	0.4019	0.082	0.031	0.0698	0.0533	0.0442	35.77759	3.966	1000
6.8541	1.439	0.7836	0.6429	2.5871	0.9738	0.3502	0.1795	0.1205	2.1937	2.7469	0.6241	0.0241	0.0185	0.1449	0.39	0.0748	0.0325	0.0622	0.0474	0.0417	37.63715	3.3656	1000
6.3643	1.4382	0.8065	0.6983	2.7829	0.991	0.3301	0.1625	0.1104	2.1973	2.8509	0.6839	0.0263	0.0176	0.1419	0.386	0.0828	0.0292	0.0681	0.0518	0.0469	40.39258	3.611	1000
7.2504	1.7662	0.6847	0.6155	2.9512	1.0059	0.3823	0.1799	0.1018	1.8282	2.9402	0.6063	0.0283	0.0168	0.171	0.3825	0.0739	0.0264	0.0732	0.0557	0.0514	34.93467	2.9143	1000
7.5302	1.8698	0.6462	0.7063	2.785	0.8569	0.3365	0.1566	0.099	1.9072	2.9684	0.5818	0.0289	0.0166	0.1801	0.4595	0.0711	0.0255	0.0749	0.0481	0.0446	30.29438	2.3531	956
7.6633	1.5843	0.7719	0.7495	2.4313	0.9605	0.3148	0.1456	0.0977	1.7227	2.4674	0.5702	0.0292	0.0165	0.1845	0.4075	0.0698	0.0308	0.0756	0.0445	0.0507	35.96263	2.892	1000
7.7149	1.8551	0.8207	0.7662	2.8911	0.8018	0.3869	0.1785	0.0972	1.6512	2.8594	0.7154	0.0293	0.0164	0.1496	0.4883	0.0693	0.0263	0.0759	0.0431	0.053	44.0837	5.3418	596
7.6856	1.6358	0.793	0.7567	2.372	0.9779	0.346	0.1437	0.0975	1.8786	2.637	0.633	0.0267	0.0164	0.1694	0.3987	0.0775	0.0317	0.0693	0.0439	0.0517	37.68049	2.9496	1000
7.6937	1.6894	0.8006	0.7244	2.4768	0.9842	0.3572	0.1517	0.0974	1.9348	2.6981	0.621	0.0259	0.0164	0.1724	0.3956	0.076	0.0305	0.0705	0.0437	0.0496	36.7043	3.2671	1000
7.6989	1.7241	0.7758	0.7308	2.5538	0.9882	0.3499	0.1568	0.0974	1.893	2.6316	0.6404	0.0263	0.0172	0.1744	0.4118	0.0784	0.0297	0.0712	0.0456	0.0502	39.03246	3.2919	1000
7.5239	1.6988	0.7812	0.7344	2.5969	0.9672	0.3553	0.1597	0.1004	1.8696	2.5943	0.6427	0.0259	0.0172	0.1755	0.4091	0.0797	0.0301	0.0699	0.0467	0.0493	33.59877	2.8941	1000
7.7105	1.8014	0.7206	0.7452	2.4468	0.9044	0.3336	0.1509	0.0973	2.0015	2.7569	0.6136	0.0247	0.019	0.1616	0.4009	0.0837	0.0311	0.0659	0.0446	0.0515	26.83346	2.0541	1000
5.7717	1.9403	0.8334	0.771	3.0257	1.0108	0.4085	0.1402	0.0971	1.6382	2.2247	0.5656	0.0218	0.0165	0.1387	0.5117	0.0695	0.0335	0.0565	0.0427	0.0538	37.75615	3.1433	1000

Table A2.1: Example of simulated annealing algorithm

A3 Historical decomposition of other key variables

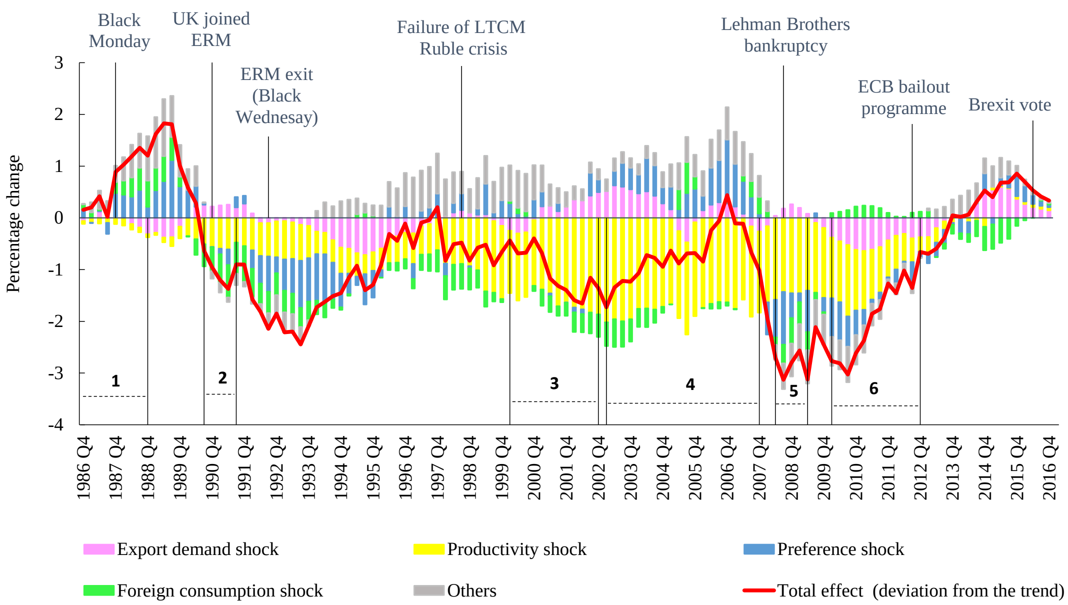

Figure A3.1: Historical decomposition of consumption

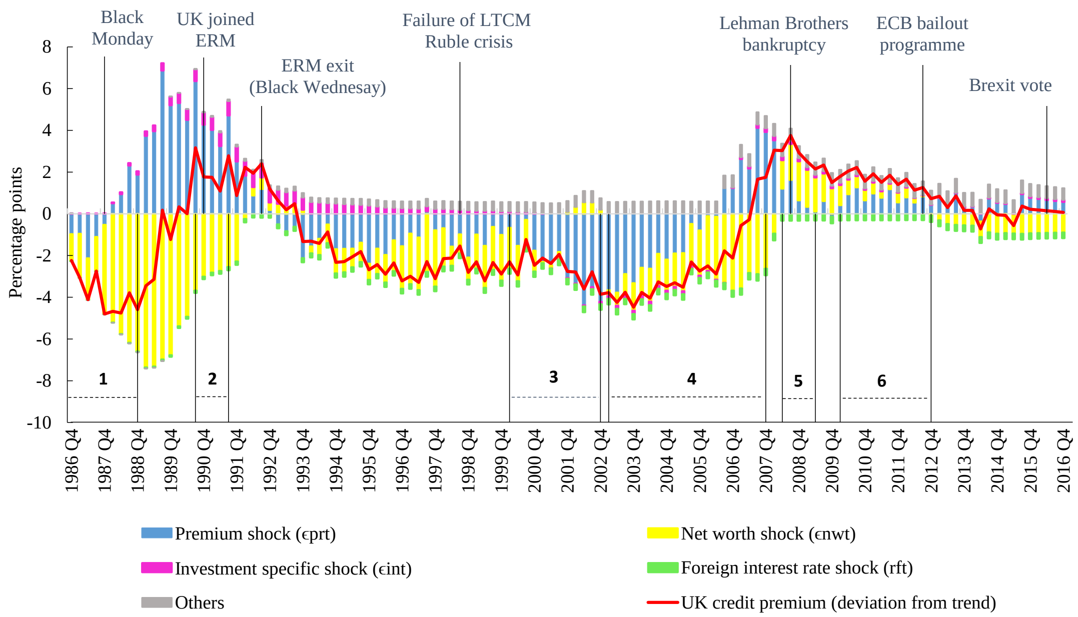

Figure A3.2: Historical decomposition of risk premium

A4 GDP growth in G7 countries

	UK	Germany	US	Japan	France	Italy	Canada
2008 Q1	2.78%	2.68%	1.10%	0.44%	1.79%	1.02%	1.59%
2008 Q2	1.29%	1.56%	1.10%	-0.16%	0.58%	-0.01%	0.97%
2008 Q3	-1.21%	0.41%	0.00%	-0.91%	-0.11%	-1.37%	1.38%
2008 Q4	-4.15%	-1.83%	-2.80%	-3.75%	-1.75%	-3.50%	0.09%
2009 Q1	-6.08%	-7.03%	-3.30%	-8.67%	-3.80%	-7.17%	-2.25%
2009 Q2	-5.56%	-6.66%	-3.90%	-6.35%	-3.45%	-6.62%	-3.66%
2009 Q3	-3.84%	-5.54%	-3.00%	-5.10%	-2.96%	-5.04%	-4.02%
2009 Q4	-1.37%	-3.28%	0.20%	-1.39%	-0.88%	-2.33%	-1.76%
2010 Q1	0.75%	2.28%	1.70%	4.44%	1.16%	0.80%	1.72%
2010 Q2	1.81%	4.42%	2.80%	3.66%	1.78%	1.86%	3.39%
2010 Q3	2.25%	4.69%	3.20%	5.51%	2.21%	1.87%	3.65%
2010 Q4	2.03%	4.77%	2.60%	3.22%	2.21%	2.15%	3.60%
2011 Q1	2.34%	5.93%	1.90%	0.89%	2.88%	2.18%	3.14%
2011 Q2	1.61%	3.72%	1.70%	-1.08%	2.42%	1.55%	2.80%
2011 Q3	1.30%	3.75%	0.90%	-0.42%	2.05%	0.58%	3.49%
2011 Q4	1.34%	2.62%	1.60%	0.23%	1.62%	-0.89%	3.15%
2012 Q1	1.24%	0.89%	2.70%	2.97%	0.65%	-2.34%	2.44%
2012 Q2	1.03%	0.96%	2.40%	2.82%	0.41%	-3.22%	2.58%
2012 Q3	1.96%	0.39%	2.50%	-0.07%	0.37%	-3.29%	1.32%
2012 Q4	1.56%	0.24%	1.50%	0.34%	0.03%	-3.21%	0.74%
2013 Q1	1.56%	-0.43%	1.60%	0.26%	-0.08%	-2.94%	1.57%
2013 Q2	2.17%	0.45%	1.30%	1.90%	0.78%	-2.17%	1.83%
2013 Q3	1.87%	0.70%	1.90%	3.12%	0.58%	-1.45%	2.52%
2013 Q4	2.58%	1.46%	2.60%	2.82%	1.11%	-0.86%	3.38%
2014 Q1	2.78%	2.93%	1.40%	2.59%	1.23%	0.10%	2.63%
2014 Q2	3.07%	1.83%	2.70%	-0.15%	0.71%	0.09%	2.97%
2014 Q3	2.87%	1.78%	3.10%	-0.88%	1.19%	0.05%	3.12%
2014 Q4	3.07%	2.31%	2.90%	-0.36%	0.82%	0.04%	2.75%
2015 Q1	2.67%	1.12%	4.00%	0.01%	1.20%	0.13%	2.02%
2015 Q2	2.40%	1.79%	3.30%	2.08%	0.98%	0.54%	0.82%
2015 Q3	2.13%	1.75%	2.40%	1.95%	0.93%	0.63%	0.22%
2015 Q4	2.21%	1.32%	1.90%	1.04%	1.05%	1.33%	-0.39%
2016 Q1	2.08%	2.33%	1.60%	0.39%	1.22%	1.44%	0.70%
2016 Q2	1.67%	2.28%	1.30%	0.28%	0.97%	1.20%	0.48%
2016 Q3	1.71%	2.03%	1.60%	0.59%	0.79%	1.54%	1.16%
2016 Q4	1.70%	1.95%	2.00%	1.19%	1.19%	1.38%	1.65%

Table A4.1: Annual GDP growth of G7 countries since 2008

Sources: leading indicators OECD reference series (FRED). Data are quarterly and GDP growth is calculated as annual percentage change.

B1 Model list for the institutional model simulation [1]

Consumption Euler equation:

$$\hat{c}_t = \left(\frac{\frac{\lambda}{\gamma}}{1+\frac{\lambda}{\gamma}}\right)\hat{c}_{t-1} + \left(\frac{1}{1+\frac{\lambda}{\gamma}}\right)\mathbb{E}_t\,\hat{c}_{t+1} + \left[\frac{(\sigma_c-1)\frac{W_*^h L_*}{C*}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}\right]\left(\hat{l}_t - \mathbb{E}_t\,\hat{l}_{t+1}\right) - \left[\frac{1-\frac{\lambda}{\gamma}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}\right]\left(\hat{r}_t - \mathbb{E}_t\,\hat{\pi}_{t+1} + \epsilon_t^b\right) \tag{B1.1}$$

Investment Euler equation:

$$\hat{i}_t = \left(\frac{1}{1+\beta\gamma^{1-\sigma_c}}\right)\hat{i}_{t-1} + \left(\frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}}\right)\mathbb{E}_t\,\hat{i}_{t+1} + \left(\frac{1}{(1+\beta\gamma^{(1-\sigma_c)})\gamma^2\varphi}\right)\hat{pk}_t + \epsilon_t^i \tag{B1.2}$$

Capital arbitrage condition:

$$\hat{pk}_t = \left(\frac{1-\delta}{1-\delta+R_*^k}\right)\mathbb{E}_t\,\hat{pk}_{t+1} + \left(\frac{R_*^k}{1-\delta+R_*^k}\right)\mathbb{E}_t\,\hat{rk}_{t+1} - \mathbb{E}_t\,\hat{cy}_{t+1} \tag{B1.3}$$

Capital stock evolves according to:

$$\hat{k}_t = \left(\frac{1-\delta}{\gamma}\right)\hat{k}_{t-1} + \left(1-\frac{1-\delta}{\gamma}\right)\hat{i}_t + \left[\left(1-\frac{1-\delta}{\gamma}\right)\left(1+\beta\gamma^{(1-\sigma_c)}\right)\right]\gamma^2\varphi\,\epsilon_t^i \tag{B1.4}$$

Aggregate resource constraint:

$$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{I}{Y}\hat{i}_t + \left(R_*^k k_y \frac{1-\psi}{\psi}\right)\hat{rk}_t + \frac{C^e}{Y}\hat{c}_t^e + \frac{EX}{Y}\hat{ex}_t - \frac{IM}{Y}\hat{im}_t + \epsilon_t^g \tag{B1.5}$$

Output is produced using capital and labour service:

$$\hat{y}_t = \phi_p\left[\alpha\hat{k}_{t-1} + \alpha\left(\frac{1-\psi}{\psi}\right)\hat{rk}_t + (1-\alpha)\hat{l}_t + \epsilon_t^a\right] \tag{B1.6}$$

Cost minimisation yields the demand for labour:

$$\hat{l}_t = \hat{rk}_t - \hat{w}_t + \hat{k}_t \tag{B1.7}$$

Hybrid price setting is the weighted average of corresponding NK and NC equations

$$\hat{rk}_t = \omega_{NK}^p\left\{\frac{\left(\frac{\iota_p}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\right)\hat{\pi}_{t-1} + \left(\frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\right)E_t\hat{\pi}_{t+1} - \hat{\pi}_t + \epsilon_t^p}{-\alpha\left(\frac{1}{1+\beta\gamma^{(1-\sigma_c)}\iota_p}\right)\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_p\right)\left(1-\xi_p\right)}{\xi_p\left((\phi_p-1)\varepsilon_p+1\right)}} + \frac{\alpha-1}{\alpha}\hat{w}_t - \frac{\epsilon_t^a}{\alpha}\right\} + (1-\omega_{NK}^p)\left\{\frac{(\alpha-1)\hat{w}_t + \epsilon_t^a}{\alpha}\right\} \tag{B1.8}$$

[1]See section 2.3 for a full description of the log-linearized equation system in the DSGE model. The stochastic processes are the same as listed in section 2.4.

Hybrid wage setting merges both NK and NC elements:

$$\hat{w}_t = \omega_{NK}^{w}\Bigg\{\left(\frac{1}{1+\beta\gamma^{(1-\sigma_c)}}\right)\hat{w}_{t-1} + \left(\frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}}\right)\left(\mathbb{E}_t\,\hat{w}_{t+1} + \mathbb{E}_t\,\hat{\pi}_{t+1}\right) - \left(\frac{1+\beta\gamma^{(1-\sigma_c)}\iota_w}{1+\beta\gamma^{(1-\sigma_c)}}\right)\hat{\pi}_t + \left(\frac{\iota_w}{1+\beta\gamma^{(1-\sigma_c)}}\right)\hat{\pi}_{t-1} - \left(\frac{1}{1+\beta\gamma^{(1-\sigma_c)}}\right)\left[\frac{(1-\beta\gamma^{(1-\sigma_c)}\xi_w)(1-\xi_w)}{\xi_w\left((\phi_w-1)\varepsilon_w+1\right)}\right]\left(\hat{w}_t - \sigma_l\hat{l}_t - \frac{1}{1-\frac{\lambda}{\gamma}}(\hat{c}_t - \frac{\lambda}{\gamma}\hat{c}_{t-1})\right) + \epsilon_t^{wnk}\Bigg\} + (1-\omega_{NK}^{w})\left\{\sigma_l\hat{l}_t + \left(\frac{1}{1-\frac{\lambda}{\gamma}}\right)\left(\hat{c}_t - \frac{\lambda}{\gamma}\hat{c}_{t-1}\right) + \epsilon_t^{wnc}\right\} \tag{B1.9}$$

Monetary policy: *for subsample 1 (93-09) and 2 (00-07), monetary rules switch between normal (Equation (B1.10)) and crisis regimes (Equation (B1.11)). During the normal regime, interest rate is set according to a Taylor type rule, and the supply of M0 is set to accommodate the supply of M2, which is determined by bank' balance sheets quantities:*

$$For\ \ r_t > 0.025\% \quad \begin{cases} \hat{r}_t = \rho\hat{r}_{t-1} + (1-\rho)(r_p\hat{\pi}_t + r_y\hat{y}_t) + r_{\Delta_y}(\hat{y}_t - \hat{y}_{t-1}) + \epsilon_t^r \\ \hat{m}_t^0 - \hat{m}_{t-1}^0 = \vartheta_1\,(\hat{m}_t^2 - \hat{m}_{t-1}^2) + \epsilon_t^{m0} \\ \hat{m}_t^2 = (1 - \frac{M0}{M2} + \frac{N}{M2})\,\hat{k}_t + \frac{M0}{M2}\,\hat{m}_t^0 - \frac{N}{M2}\,\hat{n}_t \end{cases} \tag{B1.10}$$

In the crisis regimes, interest rate is fixed at its lower bound, whereas M0 is set to target risk premium around its steady state via QE operations:

$$For\ \ r_t \leq 0.025\% \quad \begin{cases} \hat{r}_t = 0.025\% \\ \hat{m}_t^0 - \hat{m}_{t-1}^0 = \vartheta_2\,(\hat{pm}_t - pm^*) + \epsilon_t^{m0} \end{cases} \tag{B1.11}$$

For subsample 3 (08-16) where QE was employed extensively, the rules for the crises episodes remain unchanged as in Equation (B1.11), whereas for the normal times we replace the last two equations of Equation (B1.10) with the following extra stabilising M0 rule:

$$\hat{m}_t^0 - \hat{m}_{t-1}^0 = \vartheta_3\,(\hat{pm}_t - pm^*) + \epsilon_t^{m0} \tag{B1.12}$$

Macroprudential policy: *financial regulation targets the risk premium with the strength of regulatory power controlled by κ:*

$$pm_t = \left(\frac{1}{1-\kappa\zeta}\right)\left[\chi(\hat{pk}_t + \hat{k}_t - \hat{n}_t) - \vartheta\hat{m}_t^0\right] + \left(\frac{1}{1-\kappa\zeta}\right)\left[\kappa^2 + 10\kappa + 1\right]\cdot\epsilon_t^{pm} \tag{B1.13}$$

Entrepreneurs' net worth evolves according to:

$$\hat{n}_t = \frac{K}{N}(\hat{cy}_t - \mathbb{E}_{t-1}\,\hat{cy}_t) + \mathbb{E}_{t-1}\,\hat{cy}_t + \theta\hat{n}_{t-1} + \epsilon_t^n \tag{B1.14}$$

Entrepreneurs' consumption equals their net worth:

$$\hat{c_t^e} = \hat{n}_t \tag{B1.15}$$

The demand for import:

$$\hat{im}_t = \hat{c}_t^{im} = \sigma log(1-\omega) + \hat{c}_t - \sigma\hat{q}_t + \epsilon_t^{im} \tag{B1.16}$$

The demand for export:

$$\hat{ex}_t = \sigma^F log(1-\omega^F) + \hat{c}_t^f + \sigma^F\hat{q}_t + \epsilon_t^{ex} \tag{B1.17}$$

Movement in real exchange rate satisfies the real uncovered interest rate parity (UIRP):

$$(\hat{r}_t - \mathbb{E}_t\,\hat{\pi}_{t+1}) - (\hat{r}_t^f - \mathbb{E}_t\,\hat{\pi}_{t+1}^f) = \mathbb{E}_t\,\hat{q}_{t+1} - \hat{q}_t \tag{B1.18}$$

Evolution of the foreign bonds:

$$\hat{b}_t^f = (1+\hat{r}_t^f)\,\hat{b}_{t-1}^f + \frac{EX}{Y}(\hat{ex}_{t-1} - \hat{q}_{t-1}) - \frac{IM}{Y}\hat{im}_{t-1} \tag{B1.19}$$

B2 Structural parameters for subsample simulations

Symbol	Description	93-99	00-07	08-16
Taylor rule parameters				
r_p	Taylor rule response to inflation	2.6459	1.3230	2.6459
ρ	Interest rate smoothing	0.6588	0.6588	0.6588
r_y	Taylor rule response to output	0.0275	0.0138	0.0275
r_{Δ_y}	Taylor rule response to change in output	0.0219	0.0219	0.0219
Nominal friction parameters				
ξ_p	Degree of Calvo price stickiness	0.9463	0.9463	0.9463
ξ_w	Degree of Calvo wage stickiness	0.5696	0.5696	0.5696
ι_p	Degree of indexation to past inflation	0.1603	0.1613	0.1603
ι_w	Degree of indexation to past wages	0.3687	0.3687	0.3687
ω^p_{NK}	Proportion of sticky prices in hybrid price setting	0.0969	0.0969	0.0969
ω^w_{NK}	Proportion of sticky wages in hybrid wage setting	0.4599	0.4599	0.4599
Real friction parameters				
λ	Degree of external habit formation in consumption	0.7761	0.7761	0.7761
φ	Elasticity of investment adjustment cost	6.9538	6.9538	6.9538
ψ	Elasticity of capital utilisation cost to capital inputs	0.1145	0.1145	0.1145
ϕ_p	One plus the share of fixed costs in production	1.5876	1.5876	1.5876
Financial friction and monetary response parameters				
χ	Elasticity of premium to leverage ratio	0.0287	0.0287	0.0287
ϑ	Risk premium response to M0 via QE	0.0440	0.0440	0.0440
ϑ_1	Elasticity of M0 supply to M2 supply	0.0501	0.0501	—
ϑ_2	M0 response to premium (during crises)	0.0586	0.0586	0.0586
ϑ_3	M0 response to premium (monetary reform)	—	—	0.5250
Other parameters				
σ_c	Coefficient of relative risk aversion	1.6347	1.6347	1.6347
σ_L	Elasticity of labour supply to real wage	2.4533	2.4533	2.4533
α	Share of capital in production	0.1961	0.1961	0.1961

Table B2.1: Coefficients for subsample simulations

NOTE: The coefficients for the full sample over 93-16 has been re-estimated and thus are slightly different from those for 86-16 in Essay I. For subsample 2 (00-07), we halve the Taylor rule response for the inflation r_p and output r_y to accommodate the fact that monetary policy was less stabilising (M=0.5) in the periods leading up to the crisis. To be in line with the extra-stabilising property of monetary rules (M=1.5) since 2008, we supplement the standard Taylor rule with a powerful QE rule (of which the strength is governed by ϑ_3) as in Equation (B1.12) for the normal regime in subsample 3. ϑ_1 does not apply here as the supply of M0 is no longer contingent on the M2 even for the non-ZLB situation.