Financial Frictions in Macroeconomic Models

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Abstract

The purpose of this thesis is to examine the interaction between financial frictions and macroeconomic variables. A range models are used which encompasses both theoretical and empirical approaches. The thesis attempts to address several questions with the interaction between changes in borrowing constraints, and so credit markets, and their impact on macroeconomic variables the main themes throughout the chapters. The thesis explores the role of changes in borrowing limits on the amplification of shocks. Utilising the theoretical collateral constraints model it also draws together two separate literatures to examine the interaction between collateral constraints and the steady state interest rate. Finally the thesis conducts an empirical analysis of the impact of an array of financial frictions and financial stress measures on macroeconomic aggregates. The empirical approach used allows this analysis to be conducted in a multi-country setting and so allow the issue of the international propagation of shock to be taken into account.

In terms of results, from the theoretical models it is found that financial liberalisation, as modelled by a loosening of the borrowing constraint, leads to a greater amplification of financial shocks compared to conventional shocks. In relation to the steady state interest rate the results suggest that a financial disruption can lead a persistently low interest rate. It is also found that an ageing population and higher debt levels could influence the probability of an economy entering a situation of persistently low interest rates. From the empirical analysis it is found that many measures proposed in the literature are not strong transmitters of financial stress, this is particularity true of credit which is a commonly used shock measure in the literature. It is found that measures of financial frictions that are constructed from corporate bond market data have the most impact on macroeconomic variables.

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Author's Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References. Chapter 2 was presented at the University of York Macro-Finance Cluster seminar series in November 2013. Chapter 3 was presented at the 4th White Rose Doctoral Training Centre Economics Conference at Leeds University in March 2015 and at the Topics in Macro-Finance seminar at the Economic and Social Research Institute in Dublin in August 2015. Chapter 3 has also been accepted for presentation at the PhD Conference in Monetary and Financial Economics hosted by the Centre for Global Finance at the University of the West of England in June 2016. Chapter 4 was presented at the GVAR Workshop at the University of York in July 2015, in an Economics Division seminar at the Department of Finance of the Irish Government in February 2016 and at the 5th White Rose Doctoral Training Centre Economics Conference at the University of York University in March 2016.

Chapter 1

Introduction

The recent financial crisis has led to a renewed interest in, and an accelerated development of, macroeconomic models that facilitate analysis of the interaction between financial frictions and macroeconomic fluctuations (Brzoza-Brzezina et al., 2013). As stated by Chari (2011), in the pre-crisis literature, these financial market interactions had been de-emphasised due, in part, to a long period of financial sector stability in advanced economies [1]. Bernanke et al. (1999) note on a similar point to Chari (2011) that an emphasis on the role of credit market factors for explaining aggregate dynamics had fallen outside the US academic mainstream. Given this context' the most recent crisis; which was an extreme manifestation of the potential interactions between the financial sector and the real economy, has served as a reminder of the importance of understanding these linkages (Claessens et al., 2014).

From a historical perspective, recessions associated with financial factors have been found to be associated with longer, deeper and more abrupt down-

[1] In 2005 the vice Chairmans of the U.S. Federal Reserve Board stated that "recessions that follow swings in asset prices are not necessarily longer, deeper and associated with a greater decline in output and investment than other recessions" (Claessens et al., 2014).

turns than those originating from other sources, with the impact from financial crisis typically being 10-15 times larger as other disruptions (Claessens et al., 2014)[2]. A range of studies on the overall macroeconomic impact of financial crisis, over the historical record, have found substantial effects. In terms of quantifying the losses associated with these crises, Laeven and Valencia (2014) estimate that during the first 4 years after a banking crisis, the cost in terms of output lost is on average 23 per cent of GDP, and was over 100 per cent in the case of Iceland and Ireland during the most recent crisis. Specifically looking at the output loss for the United States from the 2007-09 financial crisis, Atkinson et al. (2013) suggests that, if estimated in terms of wealth, the output loss was greater than 100 percent of GDP. Of all of these financial disruptions, large asset price booms fuelled by leveraged financing from intermediaries are associated with the largest risks for the economy (Claessens et al., 2014). In relation to financial variables and downturns, it has been observed that movements in asset and credit variables during financial crises are much sharper than those observed during the normal business cycle (Claessens et al., 2014; Terrones et al., 2009), (Terrones et al., 2009).

Financially initiated crises have also been found to have a differing impact on the components of GDP. Claessens et al. (2014) notes that in recessions without financial crisis consumption growth generally slows, but in recessions following a financial crisis, consumption tends to contract. This private consumption effect is due to the need for households to restore balance sheets and is a key reason these types of recessions are worse than others (Terrones

[2]The sample for this analysis covered 23 advanced economies over the period 1960-2011.

et al., 2009). There can also be financial crisis specific effects on investment. This variable can fall further due to the tighter lending standards restricting the flow of credit, coupled with a rise in uncertainty and risk premiums (Abiad et al., 2009). This is particularly the case for investments with a long planning horizon (Terrones et al., 2009). The medium run effects of financial disruptions are also significant; output tends to be substantially and persistently depressed as the effects damage each component of the determinants of potential output (Abiad et al., 2009).

As noted, and despite the substantial and prolonged impacts of financial shocks on macroeconomic outcomes, the majority of standard macroeconomic models in the pre-financial crisis period did not incorporate structures that would have allowed analysis of many of the above mentioned issues. This is because the assumptions used in the standard models correspond to those underlying the Modigliani-Miller (1958) theorem. This theorem comprises four results from a series of papers; the first states that firms debt to equity ratio does not impact market value, secondly that firms leverage has no impact on the cost of capital, thirdly that market value is independent of dividend policy and lastly that equity holders are indifferent to firms financial policy (Villamil, 2008). This theorem thus implies that the financial structure is both indeterminate and irrelevant to real economic outcomes (Bernanke et al., 1999). Agents thus operate in perfect financial markets, and thus had immediate access to unlimited funding with no business cycle variation (Brazdik et al., 2012).

As discussed in Bernanke et al. (1999), this assumption may be problematic for macroeconomic models if substantial financial frictions exist. Specific evidence for their importance is supported by the fact that financial crises are often associated with large changes in asset prices and credit volumes, disruptions in financial intermediation and credit supply, and large scale balance sheet problems in firms, households, financial intermediaries and governments (Claessens et al., 2014). In the aftermath of financial crises it has been observed that asset prices and credit growth can remain depressed for a long time and this can have further consequences on the performance of the real economy (Claessens et al., 2014). Quadrini (2011) points to evidence that credit standards are observed to be pro-cyclical, as indicated by credit spreads and Federal Reserve Board Surveys. This cyclical behaviour is in violation of the Modigliani-Miller theorem as with complete, frictionless financial markets credit standards should not change over the business cycle.

As stated these features of the economy have led to a renewed interest in the development of macroeconomic models which incorporate financial frictions. At present, broadly speaking, there are three main strands in the theoretical literature on incorporating financial frictions, each of which is based on introducing an agency problem between borrowers and lenders (Gertler and Kiyotaki, 2010). These mechanisms are cash-flow constraints, as detailed in Bernanke et al. (1999), collateral constraints, as detailed in Kiyotaki and Moore (1997), and constraints on the supply of external funding through financial intermediaries, as detailed in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). The three approaches are differentiated by the mechanism used to generate the financial friction (Brunnermeier and Sannikov, 2014). The common feature among the models is the presence of a financial accelerator mechanism; where endogenous forces in credit markets amplify and propagate shocks to the real economy (Brunnermeier and Sannikov, 2014). These models have been applied to analyse a wide range of issues in both the academic and policy spheres.

In conjunction with an expansion in theoretical analysis of the interaction of financial frictions and macroeconomic variables, a substantial empirical literature has also developed. The result of these analyses have pointed to the importance of financial or uncertainty shocks or a combination of both as non-conventional drivers of economic fluctuations (Caldara et al., 2016). The volume of empirical research in this field is indicative of both the importance of this topic and also the many complications inherent in this type of analysis. The sources of this complexity are the array of differing theoretical models for financial and macroeconomic interactions, the difficulty in measuring financial friction and financial stresses and also the strength of financial linkages across countries and thus the strength of the international propagation of financial shocks (Claessens et al., 2014). It is particularly important to take these linkages into account in terms of the recent financial crisis, as this episode was a highly synchronised recession. These types of recessions are a special case that typically have more severe and long-lasting consequences (Terrones et al., 2009).

Within this large theoretical and empirical literature there are still a number of issues yet to be examined. In terms of the outline of this thesis, the second chapter looks at the impact of a range of shocks in a general equilibrium model with endogenous collateral constraints. The third chapter develops this collateral constraints approach in an perpetual youth model. Finally the forth chapter looks empirically at the interaction of financial friction/financial shocks and macroeconomic aggregates.

The analysis of the range of shocks in the second chapter is done to contribute to the literature on the effect of financial liberalisation on macroeconomic volatility. The second chapter outlines a particular approach in the financial frictions literature and the use of these models to analyse the connection between financial liberalisation, credit access and output fluctuations. This is of importance as financial liberalisation is a commonly proposed explanation for the Great Moderation period that abruptly ended with the recent financial crisis.

The second chapter details a basic financial frictions model and outlines how this approach to modelling financial frictions is embedded into a standard DSGE model. To contribute to the existing literature this standard DSGE model containing a basic financial frictions framework is then extended to add a broader range of shocks to the model than is contained in previous papers. Impulse response functions from the calibrated model are then used to analyse the transmission mechanism and impact of these shocks. The shocks considered in the model are a monetary sock, a technology shock, a borrowing shock and a real estate demand shock.

The effect of financial development on the amplitude of the shocks can be analysed through the loosening of the collateral constraint. It is shown that a loosening of the constraints leads to higher levels of debt in the steady state of the model, as the borrowing constrained agents can now borrow more for a given level of collateral. This approach is congruent to that employed in the broader literature where this parameter can be interpreted as a change in financial sector development. The impulse response functions for different levels of financial liberalisation are then compared. It is found that large differences in the responses are only observed for the financial shocks. The financial development effect observed in the literature is evident in the means by which technology shocks are dampened with financial development. It is however shown that higher levels of financial development result in financial shocks having a much bigger impact than in a situation of lower financial development. It has also been shown that this result is sensitive to the specification of monetary policy.

As well as highlighting these results, this chapter provides a detailed description of the collateral constraints approach. This description of the key assumptions and equations will be drawn on heavily in the subsequent chapters as it is this framework that provides the basis for the theoretical model in the third chapter and aids with the variable section process and interpretation of the empirical results of the forth chapter.

The financial frictions framework detailed and employed in the second chapter of this thesis has been used in a vast array of analyses on the impact of financial frictions. The vast majority of the models using this framework rely on an infinite horizon representative agent framework. Within this structure, the patient agents, as typically used in these models, fix the steady state rate of interest in accordance with their rate of time preference. This means that in these models although many interesting questions on the dynamics of macroeconomic variables in the presence of financial frictions can be analysed the steady state rate of interest is always a fixed constant. This feature motivates the analysis in the third chapter of this thesis.

The third chapter proposes a model that permits an endogenous steady state rate of interest and that allows an interaction between this rate and the level of financial frictions. The contribution of this chapter is that it establishes an analytical link between the financial frictions literature and a feature of the zero lower bound literature; that of prolonged low interest rates after a crisis. It does this with an extension of a benchmark macroeconomic model.

In order to analyse this credit constraints and interest rate interaction, the third chapter presents a perpetual youth overlapping generations model, which is extended to incorporate an endogenous financial friction in the form of a collateral constraint. The chapter outlines a basic overlapping generations structure and then embeds the financial friction framework into this model. A key issue in implementing a financial frictions element in this type of overlapping generations model is that the steady state rate is not fixed. This is because it is a function of other variables aside from the fixed rate of time preference. The technical steps required to solve this issue, thereby ensuring a binding borrowing constraint in the model, are presented in this chapter.

As in the second chapter a change in a borrowing constraint parameter is utilised to represent financial liberalisation. Analytical expressions and elementary diagrams are presented to illustrate the results of the model. It is found that a tightening of the financial friction reduces the steady state rate of interest, and that non-linearity's exist in this relationship. This result occurs endogenously in the model subsequent to a change in the constraint. The model demonstrates that shocks to agents borrowing capacity push down the economy's natural rate of interest, and that an economy with a looser friction will experience a larger fall as a result of the shock. The model also suggests support of hypotheses from the secular stagnation literature by way of illustrating that population ageing and higher debt levels could possibly leave an economy more likely to encounter episodes of persistent low interest rates.

The forth chapter is empirical and draws on the theoretical propositions of the previous chapters. The chapter aims to examine the international impact of shocks to a large array of measures of financial frictions and financial stress. The chapter contributes to the literature by employing an empirical approach that seeks to provide a means of distinguishing the most influential measures of financial disruptions in the global economy.

Quantifying this question involves a considerable degree of complexity. The chapter outlines how the issues of an intensification of global linkages, the uncertainty about the nature of the linkages between macroeconomic and financial variables and the difficulty in measuring financial frictions and financial stress engender a particular approach in estimation. The chapter articulates how an approach which is flexible and uses a minimal amount of structural assumptions is of particular relevance for this question.

The methodology employed in this chapter is twofold; it firstly utilities the Global VAR (GVAR) approach, and then employs a set of Generalized Connectedness Measures (GCM) to summarise the results of this analysis. These two methodologies provide a way to rank the relative importance of different measures of financial shocks both on countries and on macroeconomic variables.

The GVAR approach was originally developed both as a way of analysing global interactions and as a way of analysing the impact of foreign variables on national and regional economies. This approach was developed as a standard macroeconometric approach to these types of questions quickly becomes infeasible due to the large number of parameters to be estimated. The Global VAR model proposes a solution to this dimensionality problem while maintaining a country level structure. Each country is modelled individually as a VAR model. This is then combined to produce the final global model. This country level structure allows the chapter to examine the effects of financial shocks on different types of countries, such as emerging versus advanced economies. As the GVAR approach links countries, this approach also allows a quantification of some aspects of the concept of systemic risk, such as the importance of different countries and variables. The GCM approach uses the estimated generalised impulse response functions from the GVAR model to construct a number of index measures. These index measures allow quantification of the concepts of influence, dependence and connection between countries, between variables, or between variables and countries. Given that the GVAR approach maintains a country level structure in estimation, combining this approach with the GCM approach allows a new stratum between individual variables and system wide aggregates in the presentation of the results such that the influence of financial variables on particular countries or block of countries. Applying this type of analysis to this question is a novel contribution to the literature.

The methodologies are initially applied to a data set of 17 countries, over the period 1981Q1 to 2013Q1, with 12 separate measures of financial frictions and financial stress. The chapter outlines the proliferation of measures of financial stress since the financial crisis, and part of the novelty of this chapter is it attempts to quantify the most influential of these measures. Utilising connectedness index measures, it is found that financial stress measures constructed from the corporate bond market are the most influential on global macroeconomic variables and that this result is also consistent across individual countries. It is found that many proposed measures of financial stress are not net transmitters of influence, but are more dependent on external factors. The chapter finds little evidence to support the use of credit as a financial shock variable as is common in the literature. This variable is found to be a weak transmitter of shocks and highly influenced by shocks to other variables. In an extension to include a number of emerging market economies, it is found that the impacts are mixed with some emerging economies displaying little reaction and while some display a high degree of sensitivity to financial shocks.

With respect to the approach used in modelling financial frictions the thesis focuses on the collateral constraints approach. Motivation for this choice is similar to that of Gerali et al. (2010) who also use a collateral constraints mechanism. The reason for this choice is that other frameworks, such as the costly state verification approach of Bernanke et al. (1999), emphasize the demand side of the credit market as the source of the financial friction. In the costly state verification approach frictions arise because management of capital by the entrepreneurs in the model is risky and lenders only learn about the shocks once they are realised (Brzoza-Brzezina et al., 2013). The cost of monitoring the loan applicant is costly thus driving a wedge between the lending rate and the risk free rate. As stated, this all arises on the demand side with frictions affecting the economy via the price of loans (Brzoza-Brzezina et al., 2013). In contrast the the collateral constraints approach emphasises the supply side of the credit market via the quantity of loans which is explicitly modelled. In this case the financial friction directly affects the quantity of loans made (Brzoza-Brzezina et al., 2013). In terms of this thesis in the chapter looking at financial liberalisation, the second chapter, whereby there is a substantial increase in the supply of credit, this framework where the quantity of credit available can be directly modelled and analysed was seen as more appropriate. Also in terms of the chapter looking at the interaction between persistently low interest rates and financial frictions, the third chapter, in order to examine this link it is important that the quantity of credit is explicitly measured in relation to the financial friction, such that it can enter into the aggregate consumption function and thus influence the level of the steady state interest rate.

Through analysing these issues this thesis makes a number of contributions to both the theoretical and empirical literature dealing with the interaction between financial frictions and macroeconomic aggregates. Chapter two contains a set of contributions from an analysis that presents a comparison between different states of financial liberalisation, of the impact of various shocks on an array of macroeconomic and financial variables in a calibrated and simulated benchmark model with financial frictions. This is a contribution to the literature as this result has not been previously shown in this type of benchmark financial frictions model. This chapter also shows that a loosening of the constraints leads to higher levels of debt and a greater amplification of borrowing shocks compared to that of standard shocks. This is a novel result in this modelling framework and lends itself to a Great Moderation type narrative in which aggregate volatility is seen to decline with increases in an indicator of financial development. The analysis of this chapter also contributes a novel explanation for the lack of appreciation of the risks leading up to the financial crisis as even in models with a financial friction mechanism conventional macroeconomic shocks usually considered in projections and policy experiments do not show a substantial difference between initial conditions of high as opposed to low debt.

Another set of contributions in the thesis comes from chapter three which establishes a link between two strands of macroeconomic literature that have become prominent since the financial crisis; the financial frictions literature and the zero lower bound literature. This chapter describes the interaction between credit constraints and persistently low real interest rates. This is a novel contribution as by building on two strands of literature it expands a benchmark macroeconomic model and establishes results in relation to credit market disruptions and persistently low real interest rates. This link is important given the monetary policy environment following the financial crisis. This link is also uncommon in the literature given that other papers that contain this result involve the construction of much more complex models. The model is also novel relative to other papers looking at the zero lower bound issues as it does not employ ad-hoc changes to inter-temporal preferences in order to push the economy into this situation. In addition to these features from a technical perspective the chapter provides a novel solution to ensuring the credit constraint binds in the steady state of these models.

The model developed in this chapter also supports hypotheses from the secular stagnation literature by way of illustrating that population ageing and higher debt levels could possibly leave an economy more likely to encounter episodes of persistent low interest rates. The model quantifies a novel explanation contrary to the view held prior to the financial crisis that episodes of zero lower bound would be relatively infrequent and short lived. The model does this by highlighting a non-linearity in the relationship between financial shocks and the fall in the interest rate. This relationship suggests that different characteristics of economies can lead to higher probabilities of experiencing problems of persistently low interest rates after financial crises.

The thesis, in chapter four, also contributes to the empirical literature by applying a flexible framework for analysing and distilling the results of a multi-country model containing a large array of financial frictions and financial stress measures. Some of the measures used are displayed in Figures 1.1 to 1.3. The TED spread[3] in Figure 1.1 shows considerable volatility across countries and over time. The Great Moderation period can clearly be seen as well as the financial crisis. In particular, in the series for Germany, the subsequent crises in the Eurozone are also visible. Figure 1.2 displays a variety of measures of the corporate bond spread in the United States [4]. Each of these measures is evidently capturing a different aspect of the corporate bond spread and therefore contains different information. Figure 1.3 shows a stock market volatility index for a number of countries[5]. As in the TED spread

[3]This data is taken from the IMF's Financial Stress Index (One unit equivalent to one standard deviation of standardized variable).

[4]The FSI Corporate variable is taken from the IMF's Financial Stress Index (One unit equivalent to one standard deviation of standardized variable). The GZ EBP and GZ Spread are decompositions of the corporate bond spread and are taken from Gilchrist and Zakrajsek (2012). The Aaa-Baa spread is Moody's corporate bond spread measure.

[5]This data is taken from the IMF's Financial Stress Index. One unit is equivalent to one standard deviation of standardized variable.

variable, the Great Moderation and the financial crisis are clearly visible. In comparing this figure to that for the TED spread, it is also clear that although the general pattern is similar, these two index measure are capturing different information about the condition of financial stress.

The empirical chapter, chapter four, articulates the applicability of the multi-country framework to analysing the international impact of shocks to measures of financial frictions and financial stress, and presents this in the context of the existing literature. From the array of existing measures of financial frictions and financial shocks, this chapter contributes to the literature by ranking the relative importance of different measures of financial shocks on countries and macroeconomic variables. This is a contribution to the literature as the application of this methodology to this question is novel as well as being of considerable policy relevance. This chapter finds that financial stress measures constructed from the corporate bond market are the most influential on global macroeconomic variables and that this result is consistent across individual countries. It is also found that many proposed measures of financial stress are not net transmitters of influence, but are more dependent on external factors. Of particular importance is the finding that there is little evidence to support the use of credit as a financial shock variable as is common in the literature. This variable is found to be a weak transmitter of shocks and to be highly influenced by shocks to other variables. Finally, the chapter extends the analysis to a number of emerging market economies. Extending this framework of analysis to this group of countries is also a novel contribution.

Finally the fifth chapter of this thesis draws together a set of general conclusions, policy implications and future research issues.

Figure 1.1: The TED Spread Financial Stress Index Measure

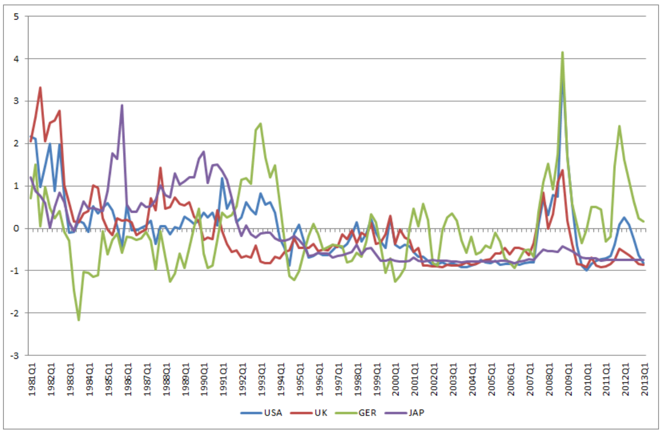


Figure 1.2: United States Corporate Bond Spread Measures

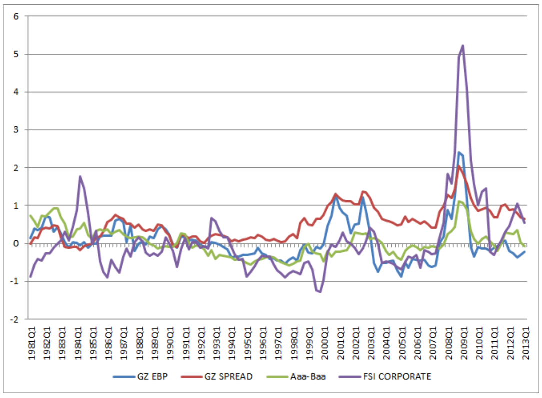
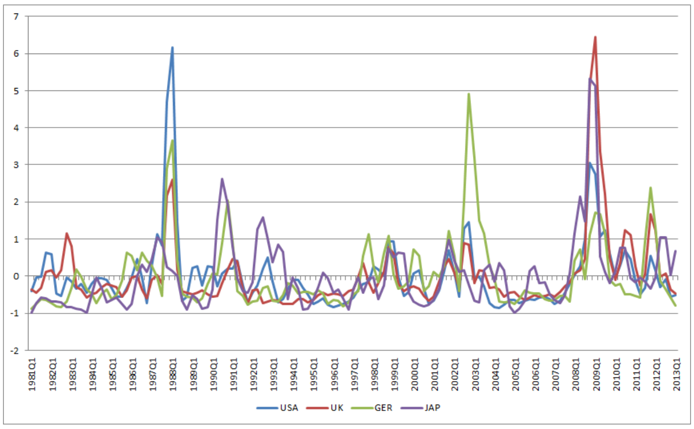


Figure 1.3: Stock Market Volatility



Chapter 2

Collateral Constraints and Shocks in a Basic Financial Frictions Model

2.1 Introduction

The standard tool for macroeconomic analysis is the dynamic stochastic general equilibrium model (DSGE). In the run up to the financial crisis most DSGE models did not include the interaction of financial markets with the rest of the economy (Brazdik et al., 2012). These interactions were not included despite there being a separate and established literature on adding financial market frictions into macroeconomic models (Quadrini, 2011).

The contribution of this chapter is that it will add financial frictions and financial variables to a standard DSGE model. The resulting model is the benchmark model from Iacoviello (2005). In this chapter this model is extended to encompass a broader range of shocks and is utilised to study the effect of financial liberalisation on macroeconomic volatility. In Iacoviello (2005) this model was used in the context of house prices and monetary policy the application to volatility and financial liberalisation was not considered. The use of this type of financial frictions model is also a contribution to the existing literature on financial liberalisation and macroeconomic volatility.

This is important in relation to the 2008 crisis which was marked by a large accumulation of liabilities in the government, household, and corporate sectors (Ahearne and Wolff, 2012), (Cecchetti et al., 2011). The years preceding the crisis had seen a large expansion in household debt to GDP ratios; increasing 40 percentage points in the OECD from 1985 to 2005 (Ahearne and Wolff, 2012). Furthermore, asset price fluctuations were an important part of this dynamic both before and after the crisis (Iacoviello, 2005). Real estate assets were of particular importance to the household sector, typically comprising a large part of the household wealth portfolio (Cussen et al., 2012). As detailed in Brunnermeier and Sannikov (2014), a number of papers focusing on violations of the the Modiglian (1958) assumptions found that it lead to models that feature a bound on agents borrowing capacity and restrictions on risk sharing. This also leads to a situation where adverse price movements affect borrowers net worth, and resultantly, their financial constraint (Brunnermeier and Sannikov, 2014). Bernanke et al. (1999) also points to a large empirical literature on consumption and investment that emphasises the importance of financial factors on these variables and the importance of incorporating these features into theoretical models.

A large literature has thus developed on the incorporation of financial frictions into DSGE models and at present, there are three main strands in this literature. These mechanisms are cash-flow constraints, as detailed in Bernanke et al. (1999), collateral constraints, as detailed in Kiyotaki and Moore (1997), and constraints on the supply of external funding through financial intermediaries, as detailed in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). In this chapter, the focus is on the collateral constraints approach of Kiyotaki and Moore (1997) and Iacoviello (2005)[1].

In addition to providing a framework in which financial shocks can be analysed these financial frictions models can be used to analyse the effect of financial liberalisation on macroeconomic volatility. As discussed in Mitra (2012) many explanations have been put forward for the Great Moderation, financial liberalisation, better monetary policy, improved inventory management and good luck. In relation to the financial liberalisation explanation Bernanke and Gertler (1995) state that access to credit may decrease output fluctuations as credit demand contains a significant countercyclical component. Bezemer and Grydaki (2013) use GARCH and VAR models to analyse the period of the Great Moderation. This is seen as the period from the mid 1980's when macroeconomic volatility declined strongly until the financial crisis of 2007 (Bezemer and Grydaki, 2013). They state that during this period borrowing by the US non-financial sector structurally exceeded GDP growth with a more that threefold rise in the annual rate of real sector credit-to-GDP in the period 1984-2008 compared to 1952-1983. Bezemer and Grydaki (2013) test the hypothesis that this measure of debt build up lead to lower

[1]This modelling approach has been developed by a number of other authors, with Monacelli (2009) analysing co-movements between durable and non-durable spending following a monetary shock, and Gerali et al. (2010) in developing a dynamic general equilibrium model involving banks and bank capital based on this framework.

volatility. Excluding the finance, insurance and real estate sectors in order to focus on the real sector Bezemer and Grydaki (2013) conclude that the changes in excess credit caused the decline in output volatility during the great moderation and that the causality was bidirectional.

Campbell and Hercowitz (2005) use a theoretical model to study the relationship between the decline in macroeconomic volatility and household credit market reforms in the 1980's. This follows the view of Stock and Watson (2002) that because the stabilisation of residential investment was so marked the equity requirement reforms may have been a contributing factor. The borrower saver model employed in Campbell and Hercowitz (2005) predicts a substantial reduction of macroeconomic volatility following a lowering of equity requirements in response to a technology shock. Jermann and Quadrini (2006) state that the financial volatility of firms has increased over the period of the Great Moderation and develop a model with a borrowing constraint where financial innovations allow for both greater financial flexibility and so volatility at the firm level while at the same time resulting in lower aggregate volatility in response to technology shocks and shocks the firm's ability to generate profit. The model of Jermann and Quadrini (2006) is different to that of Campbell and Hercowitz (2005) in that they investigate the possibility of the reduction in aggregate volatility from changes in the financial structure of firms as opposed to changes originating in the household sector's credit market interaction. As in Bezemer and Grydaki (2013), Jermann and Quadrini (2006), point to the large build up in outstanding debt in the business sector over the period of the Great Moderation and to recent developments in financial markets that make it easier for firms to pledge assets to lenders and so increase leverage.

Pinheiro et al. (2013), Quadrini and Perri (2008) and Mitra (2012) also analyse financial development and macroeconomic volatility using models based on Kiyotaki and Moore (1997). In Pinheiro et al. (2013) it is found in a general equilibrium model with exogenously varying collateral constraints it is found that volatility in response to a technology shocks can rise or fall depending on the degree of financial development and so the relationship between financial development and volatility is non-monotonic with high and low levels of development reducing volatility and intermediate levels increasing it. Quadrini and Perri (2008) employ a Kiyotaki and Moore (1997) based open economy business cycle model with financial frictions to analyse the international Great Moderation observed in many OECD countries. Quadrini and Perri (2008) find using Bayesian estimation and calibration to simulate the model that financial liberalisation lowers volatility if country specific technology and credit shocks are not perfectly correlated across countries. Mitra (2012) analyses the same question as Jermann and Quadrini (2006), a rise in firm volatility when aggregate volatility is falling using a model that follows more closely that of Kiyotaki and Moore (1997) with the addition of productivity differences. Mitra (2012), although not able replicate the magnitudes observed in the data, finds that in response to technology shocks the model generates lower aggregate output volatility as the economy becomes more financially developed.

The contribution of this chapter is that it will add a broader range of shocks to the standard collateral constraints financial friction model than is contained in previous papers. This will allow an analysis on the interplay of macroeconomic volatility and financial frictions within a benchmark model. The remainder of the chapter is structured as follows Section 2 outlines the basic Kiyotaki and Moore (1997) financial frictions model. Section 3 outlines the basic Iacoviello (2005) model which embeds the framework outlined in Section 2 into a standard DSGE model and provides some comparison between the models. Section 4 discusses the equilibrium and linearisation of this model. Section 5 extends the model adding a broader array of shocks. Section 6 presents the results of shocks to the model and analyses the effect of financial development on the response of the model to shocks. Section 7 concludes.

2.2 The Financial Frictions Model

The financial frictions model used is that proposed by Kiyotaki and Moore (1997). This theoretical model is built to demonstrate how endogenously determined credit constraints cause an amplification and an increased persistence of economic shocks. The basic model contains two goods; durable (land) and non-durable (fruit), two agents with different discount factors; patient agents (gatherers) and impatient agents (farmers), and three markets; a credit market, a competitive spot market, where the durable and non-durable good can be exchanged, and a market for the durable good, which is in fixed supply. Both the farmers and gatherers seek to maximize expected utility. They produce and consume the non-durable good with the non-durable good being the factor of production. The gatherers production, $y'_{+1} = G(k'_t)$, is subject to decreasing returns to scale, while farmers production , $y_{+1} = (a+c)k_t$, is subject to constant returns to scale. There are four assumptions made in the model that give rise to the condition in steady state that one agent will be highly leveraged and credit constrained. These are:

Assumption 1: $\beta < \beta'$

Assumption 2: $c > (1/\beta - 1)\, a$

β and β' are the discount factor of the farmer and gatherer respectively. The third assumption is that the farmers technology is idiosyncratic, given inputs at date t, only the farmer can produce an output once production has started. Fourthly, it is assumed that the farmer cannot be pre-committed to work; they can withdraw labour at any time.

The third and fourth assumption together mean that if a farmer is in debt, there is a threat of repudiation, as in a high debt situation with the prospect of withdrawal of labour, it could be advantageous for the farmer and gatherer (creditor) to negotiate down the debt. The creditors in this model know this threat exists and don't allow the size of the debt to exceed the value of the collateralizable asset; in this model the durable good. This introduces the borrowing constraint to the model, and given the perfect foresight on land prices it takes the form: $Rb_t \leqslant q_{t+1}k_t$. This constraint states that the amount of debt plus the interest payment on that debt due at date $t+1$ cannot exceed the $t+1$ value of the date t land holding.

In analysing the impact of assumption 1, it is necessary to analyse the first order optimization conditions of the two agents. The farmers optimize utility subject to a budget constraint and a borrowing constraint. Gatherers optimize utility subject to a budget constraint only. Gatherers optimize:

$$E_0 \left(\sum_{t=0}^{\infty} \beta'^s x'_{t+s} \right) \tag{2.1}$$

subject to:

$$G(k'_t) + b'_t = q_t k'_t - q_t k'_{t-1} + R_t b'_{t-1} + x'_t \tag{2.2}$$

Farmers optimize:

$$E_0 \left(\sum_{t=0}^{\infty} \beta^s x_{t+s} \right) \tag{2.3}$$

subject to:

$$(a + c)k_t + b_t = q_t k_t - q_t k_{t-1} + R_t b_{t-1} + x_t \tag{2.4}$$

$$R_t b_t \leqslant q_{t+1} k_t \tag{2.5}$$

Where x_t is consumption, b_t is borrowing/lending, k_t is land and R_t is the interest rate. Gatherers optimization leads to the result, $R_t = 1/\beta'$, which indicates that the interest rate always equals the patient agent's rate of time preference. This is important with respect to the rest of the model as it fixes a value for the interest rate. Farmers' optimization involves an equality and inequality constraint. The first order condition with respect to borrowing yields an expression for the multiplier on the borrowing constraint, $\lambda_t = \beta' - \beta$. Using assumption 1, this is positive, and thus the borrowing constraint holds with equality. Therefore, through assumption 1, 3 and 4, there is a borrowing constraint, and it binds eternally. Assumption 2 is used along with solving forwards the utility for an additional unit of consumption, investment and savings to show that the farmer will always want to invest in the steady state (Kiyotaki and Moore, 1997). These assumptions differ from a standard model as it creates a heterogeneous as opposed to a representative agent environment

(Cordoba and Ripoll, 2004). The difference in agent's time preference creates differing borrowing and lending motivations absent in representative agent models. Also in standard models financial markets are assumed to be frictionless with no risk of repudiation and so no roll for collateral in borrowing.

With the borrowing constraint holding, through the farmer's budget constraint, there is a gap between the price of a unit of land and the amount the farmer can borrow to purchase a unit of land. This gap is financed by farmers' net worth, and can be thought of as a down payment on a unit of land. The market for land clears in the model, as this down payment is increasing in proportion to the farmer's acquisition of land, whilst the gatherer's user cost of the land is increasing in proportion to the down payment.

In the steady state of the model, the first order conditions result in the expression, $(R-1)B* = aK*$.[2] The credit constrained agent; the farmer, borrows up to the maximum, such that interest on their debt just covers tradable output. This situation of high leverage in the steady state creates an increased amplification and persistence of shocks in the model. When a shock occurs in the model, it reduces the net worth the credit constrained agents have borrowed against their asset value, and thus must reduce their investment expenditure and resultantly, their durable asset holding. This reduction in demand reduces the asset price. In the next period, this reduction in asset price further reduces the farmers' net worth, which again decreases the asset demand and thus the asset price. This one period multiplier and dynamic multiplier, of which the latter is more powerful in the Kiyotaki-Moore model, both cause an amplification and increased persistence of shocks and

[2] K and $B*$ refer to the steady state levels of landholding and borrowing

give rise to a financial accelerator mechanism in the model. This breaks with the Modigliani-Miller theorem, as through a costly enforcement mechanism, there is no longer a frictionless flow of assets between agents and there will be a pro-cyclical credit cycle endogenous to the model (Bernanke et al., 1999).

2.3 The Basic Model

The model used here is based on that of Iacoviello (2005). This is a similar model to the Kiyotaki-Moore model in which there are two types of agents; a borrower and a lender. The basic assumptions to yield a steady state where financial factors can be analysed are the same. As outlined below, the same assumptions regarding repudiation and impatience ensure a borrowing constraint that binds. The model is a discreet time, infinite horizon model, containing patient households, entrepreneurs, retailers and a Central Bank. The patient household consumes output, holds real estate and money balances and supplies labour to the entrepreneur's sector. The entrepreneurs combine labour with real estate to produce output. The entrepreneurs also consume in the model. In addition to this standard set up, there is a credit constraint which impacts the entrepreneur and creates a friction in the borrowing/lending relationship between households and entrepreneurs. A retail sector is added to provide a source of nominal rigidity through a sticky price mechanism. The behaviour of each of these sectors is outlined in the following subsections, beginning with the patient households.

2.3.1 A. Patient Households

The household sector will maximize lifetime utility. Typically, the functional form chosen for the utility function is the most general form available that satisfies the conditions of the balanced growth path[3]. To satisfy these restrictions, one period utility takes the form of a constant relative risk aversion utility function:

$$U_t = (\ln c'_t + j \ln h'_t - (L'_t)^\eta/\eta + \chi \ln(M'_t/P_t)) \quad if\; p = 1 \tag{2.6}$$

$$E_0 \sum_{t=0}^{\infty} \beta^t (\ln c'_t + j \ln h'_t - (L'_t)^\eta/\eta + \chi \ln(M'_t/P_t)) \tag{2.7}$$

In equation 2.7 E_0 is the expectation operator, $\beta \in (0,1)$ is the discount factor, c'_t is consumption at time t, h'_t is the households holding of real estate, L'_t are the hours of work, and L'_t will be equal to the hours used in entrepreneurial production. M'_t/P_t are money balances divided by the price level. χ and j are taste parameters on money balances and real estate. In this functional form the term η is interpreted as labour disutility (Farmer, 1999).

In equation 2.6 the coefficient of relative risk aversion , p, is assumed to be equal to 1, this gives rise to separability[4]. With the property of separability the variables in the utility function can be partitioned such that preferences can be described independently of the quantities of other variables (Deaton

[3]Namely a constant rate of growth of output per worker and a constant savings to output ratio (King et al., 1988),(Heer and Mauner, 2009).

[4]Given that the function is undefined at p=1, employing l'hopital's rule results in an expression of the utility function in logs as is shown in equation 2.6.

and Muellbauer, 1980)[5].

The flow of funds of the household sector is given as:

$$c_t^{'} + q_t \Delta h_t^{'} + R_{t-1} B_{t-1}^{'} / \pi_t = B_t^{'} + w_t^{'} L_t^{'} + F_t + T_t^{'} - \Delta M_t^{'} / P_t^{'} \tag{2.8}$$

In equation 2.8 q_t is the real house price, $w_t^{'}$ is the real wage, Δ is a difference operator, F_t are lump sum profits received from the retailers, $b_t^{'}$ is household net borrowing/lending, and R_{t-1} is the nominal interest rate on loans between $t-1$ and t. The last two terms are net transfers received from the Central Bank that are financed by printing money.

The patient household optimizes expected utility with respect to the choice variables and subject to the flow of funds constraint. The patient household can choose the level of consumption, real estate holdings, lending/borrowing, money assets and labour hours. The first order conditions for this constrained optimization problem are:

$$\frac{1}{c_t^{'}} = \beta E_t \left(\frac{R_t}{\pi_{t+1} c_{t+1}^{'}} \right) \tag{2.9}$$

$$w_t^{'} = (L_t^{'})^{\eta - 1} c_t^{'} \tag{2.10}$$

$$\frac{q_t}{c_t^{'}} = \frac{j}{h_t^{'}} + \beta E_t \left(\frac{q_{t+1}^{'}}{c_{t+1}^{'}} \right) \tag{2.11}$$

$$\frac{M_t^{'}}{P_t^{'}} = \chi c_t^{'} (1 - R_t) \tag{2.12}$$

[5]The marginal utility from a good will depend on the level of consumption of that good alone. The assumption regarding p has other implications in the model; both in an intra and inter-temporal context. In the intra-temporal case, $-p$ is the elasticity of marginal utility (Novales et al., 2010), and using the assumption regarding p we get a diminishing marginal utility for all variables. The inter-temporal property follows, as with diminishing marginal utility, the inter-temporal indifference curves for the variables in the utility function will be convex; specifically, the elasticity of inter-temporal substitution will be equal to 1.

Equation 2.9 is the inter-temporal consumption optimizing decision; the Euler equation. This states that the household cannot shift consumption across time to increase overall utility. Equation 2.10 shows the household optimal labour supply decision[6]. Taking logs, and the derivative with respect to the wage of this expression, yields the Frisch labour supply elasticity, $(1/\eta - 1)$. This quantifies the substitution effect of wage changes on labour supply (Christiano et al., 2010). Real estate optimization is shown in equation 2.11[7]. The utility from real estate has two components; the utility at time t, and the expected resale value in terms of consumption utility. This is because real estate is a durable good and lasts longer than a single period (Monacelli, 2009).

Equation 2.12 is the standard money demand equation (Galí, 2008). Money demand is decreasing as the interest rate increases which increases the opportunity cost of holding money. Money demand is also increasing with consumption, due to a change in the level of transactions[8]. In this model money will not have a majour role in the analysis [9].

[6]Whereby the household supplies labour until the per unit of currency marginal utility gain is equal to the per unit of currency marginal utility loss from increased labour.

[7]This equation states that the per unit of currency marginal utility should be equal between real estate and consumption at the optimum.

[8]Contrary to many other models, this is not a cashless economy model, and the approach used to incorporate money is that of assuming that money yields direct utility (Galí, 2008). This generates the demand for money equation from household optimization (equation 2.12).

[9]As Iacoviello (2005) states, in the model, money supply will always meet money demand, and thus the money demand equation has no implication for the rest of the model.

2.3.2 B. Entrepreneurs

Entrepreneurs use real estate and labour to produce an intermediate good Y from a Cobb-Douglas, constant returns to scale production function[10]:

$$Y_t = A(h_{t-1})^{\nu}(L_t)^{1-\nu} \tag{2.13}$$

A is the technology parameter. The entrepreneurs use the previous periods' real estate to produce output, as this is what is available at the beginning of period t. The parameter ν is the output elasticity of real estate. As constant returns to scale have been assumed, $(1-\nu)$ is the output elasticity of labour[11].

Entrepreneurs seek to optimize lifetime utility and their utility is a function of their own consumption c. The functional form of utility is consistent with balanced growth path restrictions, and with the coefficient of relative risk aversion equal to 1, the function is given by:

$$E_0 \sum_{t=0}^{\infty} \gamma^t \ln c_t \tag{2.14}$$

The parameter $\gamma \in (0,1)$ is the entrepreneur's discount factor, and is assumed to be lower than the patient household sectors discount rate, $\gamma < \beta$, and thus entrepreneurs are more impatient than households. The entrepreneur's flow

[10]This production function is used again to comply with the restrictions on functional form implied by a balanced growth path (Herr and Maussner 2009).

[11]Both inputs display decreasing returns to scale, and, therefore, the production isoquants will be convex. The elasticity of substitution is constant, complying with a balanced growth path, and equals to 1.

of funds constraint is given by:

$$Y_t/X_t + b_t = c_t + q_t \Delta h_t + R_{t-1}B_{t-1}/\pi_t + w_t^{'}L_t \tag{2.15}$$

X_t is the mark up; the price per unit of the composite final good divided by the price per unit of entrepreneur's output. Y_t is divided by this in the flow of funds constraint to yield entrepreneur's output in terms of units of the final composite good. b_t is the entrepreneur's net borrowing/lending. The constraint states that income from production plus borrowing must equal expenditure plus accumulated debt. Accumulated debt is divided by inflation, P_t/P_{t-1}, as it is assumed that debt contracts are set in nominal terms, and thus changes in the price level will affect realized real interest rates (Iacoviello, 2005).

In the model, entrepreneurs are also assumed to face a borrowing constraint that is tied to the value of their collateral; in this case the expected value of their next period real estate holdings[12]. Lenders will only lend up to the value of the asset that can be repossessed, and, in this way, set a limit on what the entrepreneur can borrow[13]. The borrowing constrain is given as:

$$b_t \leqslant mE_t(q_{t+1}h_t\pi_{t+1}/R_t) \tag{2.16}$$

$(1 - m)$ is taken as a transaction cost on repossession. As m increases, the transaction cost falls, thus the constraint is decreasing in m. The expected value of real estate is divided by the interest rate R_t in the borrowing con-

[12]This is the same borrowing constraint concept as detailed in Kiyotaki and Moore (1997).

[13]As in the Kiyotaki and Moore (1997) model this again breaks with the Modigliani-Miller theorem as a credit cycle is introduced.

straint to take into account the interest payment. The total amount that can be borrowed is then the expected value of real estate less the interest payment and the repossession transaction cost.

Entrepreneurs in the model optimize expected utility with respect to one equality constraint and one inequality constraint. The choice variables for the entrepreneur are their level of consumption, net lending/borrowing, labour demand and real estate demand. The first order conditions for the entrepreneur are as follows:

$$\frac{1}{c_t} = \gamma E_t\left(\frac{R_t}{\pi_{t+1}c_{t+1}}\right) + \lambda_t R_t \tag{2.17}$$

$$\frac{q_t}{c_t} = E_t\left(\frac{\gamma}{c_{t+1}}\left(\nu\frac{Y_{t+1}}{X_{t+1}h_t} + q_{t+1}\right) + \lambda_t m\pi_{t+1}q_{t+1}\right) \tag{2.18}$$

$$w_t^{'} = (1-\nu)Y_t/(X_tL_t) \tag{2.19}$$

The inequality constraint that arises from the borrowing constraint in optimization gives rise to the standard complementary slackness condition:

$$\lambda_t[mE_t(q_{t+1}h_t\pi_{t+1}) - b_tR_t] = 0 \tag{2.20}$$

λ_t, in this expression, is the multiplier on the borrowing constraint. This condition states that either the constraint binds with equality, or it does not, and drops out of the optimization condition. As stated in Kiyotaki and Moore (1997), it is the assumption regarding the relative impatience of agents; as represented by their discount factors, that ensures a binding borrowing constraint. In Kiyotaki and Moore (1997) this assumption results in a borrowing constraint that binds eternally for the impatient agent. In the Iacoviello (2005) model, the constraint is analysed in the steady state condition. From the entrepreneurs Euler equation the steady state borrowing constraint multiplier is given as:

$$\lambda = \frac{\beta - \gamma}{c} \tag{2.21}$$

Given we have assumed entrepreneurs are more impatient, $\gamma < \beta$, this expression is positive, and thus by complementary slackness, the borrowing constraint will bind with equality. It is assumed then to bind with equality eternally in the model (Brzoza-Brzezina et al., 2013)[14]. In this model as opposes to that of Kiyotaki and Moore (1997) the assumption of linear utility is not made and so the borrowing constraint can be shown to bind in steady state only. With the linear utility assumption Kiyotaki and Moore (1997) can prove the borrowing constraint binds in all states.

Equation 2.17 gives the entrepreneurs Euler equation. The imposition of a borrowing constraint changes the first order optimization conditions. There is an additional term as opposed to the non-credit constrained case. When optimizing consumption over time, entrepreneurs should reach a standard Euler equation condition, however, with a credit constraint, entrepreneurs cannot optimally smooth consumption over time (Monacelli, 2009), (Andrés et al., 2013). The credit constraint in 2.17 implies that:

$$u^{'}(c_t) > \gamma E_t \left(\frac{R_t u^{'}(c_{t+1})}{\pi_{t+1}} \right) \tag{2.22}$$

[14]It is noted in Iacoviello (2005) that, due to uncertainty in the stochastic steady state, agents may self-insure by borrowing less than the credit limit to provide a buffer against the probability of adverse shocks, and the credit constraint may not bind in this situation. In this chapter, as per Iacoviello (2005), it is assumed that uncertainty is small enough, allowing us to rule out this possibility.

The marginal utility of consumption in period t is greater than the marginal utility of consumption in $t+1$. This is as a result of the financial friction which means that resources cannot be shifted across time to optimize utility (Monacelli, 2009). Without the friction, entrepreneurs would increase consumption in period t and reduce it in period $t+1$. The variable λ_t is the multiplier on the borrowing constraint. This is interpreted as the increase in expected lifetime utility that would result in relaxing the constraint by one unit (Zeldes, 1989). In equation 2.17 it is equal to the increase in lifetime utility that would occur from borrowing an extra $1/R_t$ of currency, consuming that in the current period, and reducing consumption by one unit in the next period. This is consistent with the definition in Zeldes (1989), however, it should be noted that this is a slightly different interpretation of λ_t in the optimization condition compared to many other papers using the same mechanism[15].

The optimization condition for real estate is also changed with the imposition of the financial friction. In equation 2.18, the first two terms on the right hand side are standard for a durable good, in that the utility from real estate, which the entrepreneur uses for production, is equal to the consumption utility value of the discounted marginal product in terms of the composite final good, plus the consumption utility value of the resale value in the next period. These first two terms and the left hand side of 19 yield the standard result of equalised marginal utility between the two variables at the optimum. The difference with the presence of the financial friction is that real estate has a collateral value, as shown in the borrowing constraint.

[15] This is due to a difference in the specification of the inequality constraint, whether the interest rate in on the left hand side or right hand side of equation 2.16.

There is now an additional benefit to acquiring real estate in that it allows a relaxation of the binding borrowing constraint and thus allows entrepreneurs to smooth consumption to a greater extent (Monacelli, 2009), (Cerletti and Pijoan-Mas, 2012). In this optimization condition, λ_t is interpreted as the increase in utility from borrowing and consuming an extra $(m\pi_{t+1}q_{t+1})/R_t$; as facilitated by an increase in h_t, minus the utility gain from the increase in real estate holding. The constraint implies, again, due to the impediment on consumption smoothing, the following:

$$q_t u^{'}(c_t) > \gamma E_t u^{'}(c_{t+1}) \left(\nu \frac{Y_{t+1}}{X_{t+1}h_t} + q_{t+1} \right) \tag{2.23}$$

Therefore, this collateral effect gain will be positive with a binding constraint. It can be seen that the tighter the constraint, the greater the marginal utility of real estate, as this increases the gain in total utility from expanded borrowing and a reallocation of consumption across time.

The last optimization condition for the entrepreneur, equation 2.19, yields the standard labour demand condition. At the optimum, the wage will equal the marginal product of labour in terms of the composite final good.

There is a difference in the reaction to a relaxation of the borrowing constraint between the model of Iacoviello (2005) and of Kiyotaki and Moore (1997). In the Kiyotaki and Moore (1997) model, utility optimization of the credit constrained agent is closely linked to output optimization. In this model, the farmer cannot borrow enough to optimally invest in land, and their holding of land; the only factor of production, is below that of the non-credit constrained level. In the model of Iacoviello (2005), the credit constraint again binds, but in a different way; entrepreneurs want to borrow more to smooth consumption, the fixed capital is only one factor of production, and entrepreneurs over-invest in this asset to smooth consumption such that their holding is above that of the non-credit constrained case. A relaxing of the borrowing constraint in the Iacoviello (2005) model would lead to a reduction in demand for the durable asset, whereas it leads to an increase in the Kiyotaki and Moore (1997) model.

2.3.3 C. Retail Sector

Sticky prices are added to the model to increase the temporal persistence of shocks. In models without the sticky price mechanism, the adjustment from shocks and return to equilibrium is too fast when compared to the empirical data (McCandless, 2008). The addition of sticky prices uses the method of Calvo (1983). Monopolistic competition is allowed so firms have a degree of market power, and thus can charge prices that are higher than their marginal cost. This monopolistic competition occurs in the retail sector. Not all firms in this sector are allowed to set prices in every period, so the price adjustment is non-synchronous. In each period a random and independently chosen fraction of intermediate goods firms can set their prices. The rest of the firms keep prices unadjusted from the last period. This results in a staggering of price setting in the model.

There is a continuum of retailers of mass 1, indexed by z. They purchase the intermediate good produced by the entrepreneurs at a price P_t^w in a competitive market. The good is then differentiated at no cost into $Y_t(z)$. This good is then sold at a price $P_t(z)$ to a final goods firm. Final goods are given by $Y_t^f = (\int_0^t Y_t(z)^{(\varepsilon-1)/\varepsilon} dz)^{\varepsilon/\varepsilon-1})$ with $\varepsilon > 1$. ε is the elasticity of demand for the final goods. This is a constant elasticity of substitution (CES) production function. In it we take a weighted sum of all intermediate goods firms output to arrive at final output[16]. The assumption regarding the elasticity of demand, $\varepsilon > 1$, means that there is a degree of complementarity in the production inputs in final goods. As long as $\varepsilon < \infty$ the retailers inputs to final goods are imperfectly substitutable, and thus they have a degree of market power (McCandless, 2008). The final goods firm optimizes profit with respect to the output they receive from the retailers. Their profit expression is given as:

$$P_t[\int_0^1 y_t(z)^{\varepsilon-1/\varepsilon} dz]^{\varepsilon-1/\varepsilon} - \int_0^1 P_t(z) y_t(z) dz \tag{2.24}$$

Taking equation 2.24, the individual demand curve faced by each retailer is given as $Y_t(z) = (P_t(z)/P_t)^{-\varepsilon} Y_t^f$. Demand for each good z is then an increasing function of total production, and a decreasing function of the relative price. It should be noted that $-\varepsilon$ is the elasticity of demand for each retailer. This downward sloping demand curve allows prices above marginal cost (McCandless, 2008).

Each retailer chooses a sale price $P_t(z)$ taking the cost of purchase from the entrepreneurial sector P_t^w and the demand curve as given. As mentioned, not all firms can change their prices in every period. The probability that a firm can change their price in a period is given by $(1 - \theta)$. $P_t^*(z)$ denotes the reset price, and the corresponding demand is given by $Y_{t+k}^*(z) = (P_t^*(z)/P_{t+k})^{-\varepsilon} Y_{t+k}$. The optimal reset price; the price that firms

[16]This production function formulation for the final good firm allows for the elasticity of substitution to vary from perfect complements to perfect substitutes (Varian, 1992).

set when free to choose, will maximize the market value of the firm. This is different when compared to profit maximization, as future profits are also taken into account through the probability of being able to change prices in the future (McCandless, 2008). In a single period, each firm will maximize profit as follows:

$$[(P_t^*(z) - P_t^w)/P_t]Y_t^*(z) \tag{2.25}$$

Adjusting this to take account of retailers in period t, and that these retailers may not be able to optimally adjust prices with probability θ, the expression for expected discounted profit in period t becomes:

$$\sum_{k=0}^{\infty} \theta^k E_t\{\Lambda_{t,k} \left(\frac{P_t^*(z) - P_{t+k}^w}{P_{t+k}}\right) Y_{t+k}^*(z)\} \tag{2.26}$$

In equation 2.26, $\Lambda_{t,k} = \beta(c_t^{'}/c_{t+k}^{'})$ is the discount factor relevant to the patient household. This is in the expression as, in this model, households own the retail firms, and thus in valuing future profits a discount factor is needed, and the relevant rate will be that of the household sector. This discount factor is weighted for inter-temporal differences in household marginal utility. The optimal price will be the gross mark-up price per unit over the discounted stream of costs per unit. This can be derived from equation 2.26 as:

$$P_t^*(z) = \frac{\varepsilon}{(\varepsilon - 1)} \sum_{k=0}^{\infty} \theta^k E_t\{\Lambda_{t,k} P_{t+k}^w\} \tag{2.27}$$

The mark-up is given by X_t, which is $X = \varepsilon/(\varepsilon - 1)$ in the steady state. Profits of the retail sector can be derived from equation 2.26, and are given by $F_t = (1 - 1/X_t)Y_t$. The profits are rebated to the patient household as seen in the patient household budget constraint. Given that a fraction of prices, θ, remains unchanged, the aggregate price level evolves according to:

$$P_t = (\theta P_{t-1}^{\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon})^{1/(1-\varepsilon)} \tag{2.28}$$

2.3.4 C. The Central Bank

Central Bank behaviour is described by a Taylor type rule of the form:

$$R_t = (R_{t-1})^{rR}(\pi_{t-1}^{1+r\pi}(Y_{t-1}/Y)^{rY}\overline{rr})^{1-rR}e_{R,t} \tag{2.29}$$

In this expression $\overline{rr}$ and Y are the steady state real rate and output respectively. This is a backward-looking Taylor rule in that monetary policy responds to past inflation and past output. The interest rate will rise above its desired level if inflation or output are above their desired level, as an interest rate rise will eventually reduce both inflation and output. The parameters $(1 + r_\pi)$ and r_y determine how much the Central Bank cares about inflation versus output/employment in setting monetary policy[17].

The parameter r_R allows for the possibility of interest rate inertia if positive. This is included, as it is widely observed that the level of the interest rate in the recent past is an important determinant of where the Central Bank will set the level of the present (Woodford, 1999). This implies that Central Banks do not change their interest rate once and for all in response to observed changes in inflation or the level of economic activity (Woodford, 1999), $e_{R,t}$ is a white noise shock process with zero mean and variance σ_e^2.

[17] Both coefficients will be positive (Blanchard, 2005).

2.4 Equilibrium

There are four markets in the model; a labour market ($L_t = L_t^{'}$), a real estate market that has a fixed supply ($h_t + h_t^{'} = H = 1$), a goods market in which total consumption must equal total output ($c_t + c_t^{'} = Y_t$), and finally a credit market in which total borrowing must equal total lending ($b_t = b_t^{'}$). The model can be linearised using the techniques described in Uhlig (1995). This is done around a zero-inflation steady state. Letting variables without subscripts denote steady state values and hatted variables denote per cent changes from the steady state, results in a model with nine equations and nine variables: $(\widehat{Y}_t, \widehat{c}_t, \widehat{c}_t^{'}, \widehat{q}_t, \widehat{h}_t, \widehat{b}_t, \widehat{\pi}_t, \widehat{X}_t, \widehat{R}_t,)$[18]. The nine linearised equations (2.30-2.38) are:

Aggregate Demand

$$\widehat{Y}_t = (c/Y)\widehat{c}_t + (c'/Y)\widehat{c}_t^{'} \tag{2.30}$$

$$\widehat{c}_t^{'} = E_t\widehat{c}_{t+1}^{'} - \widehat{rr}_t \tag{2.31}$$

$$c\widehat{c}_t = b\widehat{b}_t + Rb(\widehat{\pi}_t - \widehat{R}_{t-1} - \widehat{b}_{t-1}) + (vY/X)(\widehat{Y}_t - \widehat{X}_t) - qh\Delta\widehat{h}_t \tag{2.32}$$

Real Estate Market Dynamics

$$\widehat{q}_t = \gamma_e E_t\widehat{q}_{t+1} + (1-\gamma_e)E_t(\widehat{Y}_{t+1} - \widehat{h}_t - \widehat{X}_{t+1}) - m\beta\widehat{rr}_t - (1-m\beta)E_t\Delta\widehat{c}_{t+1} \tag{2.33}$$

$$\widehat{q}_t = \beta E_t\widehat{q}_{t+1} + \iota\widehat{q}_t + \widehat{c}_t^{'} - \beta E_t\widehat{c}_{t+1}^{'} \tag{2.34}$$

Borrowing Constraint

$$\widehat{b}_t = E_t\widehat{q}_{t+1} + \widehat{h}_t - \widehat{rr}_t \tag{2.35}$$

[18] The deterministic steady state of the model defines a starting point for the model (Heer and Mauner, 2009).

Aggregate Supply

$$\widehat{Y}_t = \frac{\eta\nu}{\eta-(1-\nu)}\widehat{h}_{t-1} - \frac{1-\nu}{\eta-(1-\nu)}(\widehat{X}_t - \widehat{c}'_t) \tag{2.36}$$

$$\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} - \kappa \widehat{X}_t \tag{2.37}$$

$$\widehat{R}_t = (1-r_R)((1+r_\pi)\widehat{\pi}_{t-1} + r_y \widehat{Y}_{t-1}) + r_R \widehat{R}_{t-1} + \widehat{e}_{R,t} \tag{2.38}$$

Definitions are: $\iota = (1-\beta)h/h', \kappa = (1-\theta)(1-\beta\theta)/\theta, \gamma_e = m\beta + (1-m)\gamma$ and $\widehat{rr}_t = \widehat{R}_t - E_t\widehat{\pi}_{t+1}$.

Equation 2.30 is derived from the market clearing condition. Equation 2.31 is derived from the household Euler equation. The deviation in present consumption is positive in future consumption, as this reduces the marginal utility in the next period, and consequently in order to maintain the Euler condition, $\widehat{c}'_t$ must rise. The expression is positive in inflation, as this increases the cost of next period consumption, and thus $\widehat{c}'_t$ rises. A rise in the interest rate increases the incentive to save, and thus reduces current consumption.

Equation 2.32 is taken from the entrepreneurial budget constraint. Within this equation, the parameter on the hatted variables depends on the steady state ratio of the variables to consumption. The deviation in their consumption is negative with a deviation in the mark-up as this increases the margin between the price they receive and the final composite good price. This parameter is increasing in ν, as labour is a cost in the entrepreneur's budget constraint. As ν rises, the marginal product of labour falls, and in optimization, the wage equals the marginal cost. Therefore, labour utilisation will be decreasing in ν.

Equation 2.33 is derived primarily from the entrepreneur's first order condition for real estate, but also households' and entrepreneurs' consumption first order condition. The parameters γ_e and $(1-\gamma_e)$ are positive due to the assumptions regarding the discount factors. An increase in the price of real estate in $t+1$ increases the resale value and collateral effect, and thus raises the demand for real estate in period t. Given a real estate market with a fixed supply and a downward sloping demand curve, this leads to an increase in the price of real estate in period t. The parameter on this variable accounts for these effects. It is increasing in γ as this increases entrepreneurs' valuation of future consumption and, accordingly, the resale value. It is also increasing in m; allowing more borrowing per unit of real estate and an increase in the collateral value. Finally, the parameter increases in $\beta - \gamma$, as this gap determines the tightness of the borrowing constraint, and thus increases the collateral value of real estate. The price of real estate increases in the marginal product of real estate. The parameter on the marginal product is $(1-\gamma_e)$. In a model with no durable good or collateral aspect the price of real estate would equal the discounted marginal product, and aside from the discount factor, a deviation would have a one to one impact on price. The presence of the durable good aspect and the collateral effect reduce the parameter value of the marginal product on the price. This can be seen in the decrease in the parameter in γ and $c\lambda m$. These parameters increase the resale utility value and the collateral effect value. The price is negative in R_t as the friction increases the price, and the size of the friction is reducing in R_t as it affects borrowing and lending incentives. The parameter on this variable is increasing in β and in m, because they impact the size of the friction. The deviation in price is negative in the deviation in the change in consumption, as this change in marginal utilities between periods reduces the consumption utility from real estate output and durable good resale value, and thus reduces demand for real estate. The parameter is reduced by $m\beta$, as there is a collateral effect whereby an increase in consumption in $(t+1)$ increases the utility value of relaxing the constraint.

Equation 2.34 is derived from the household's first order condition for real estate. The price increases with the deviation of entrepreneurs holding, as this implies a demand increase and consequent price rise. The parameter on this effect is less than 1 as with a resale effect the price will not adjust one to one with a fall in marginal utility of real estate, as this is only one component of the utility from real estate.

Equation 2.35 is the linearised borrowing constraint. Equation 2.36 is derived from the production function combined with both the first order condition for labour supply and the first order condition for labour demand. The deviation is negative with household consumption as when household consumption rises labour supply falls. The parameter on real estate is increasing in ν as a higher ν will mean that real estate is a bigger component of the input mix for every level of output, and, therefore, a steady state deviation will have a bigger impact on output. This parameter is falling in η as the Frisch labour supply elasticity falls in η and, consequently, there will be a higher steady state wage required for each labour hour. This will move the firm onto a lower isoquant, and lower overall output.

Equation 2.37 is derived by combining the retailers' optimal pricing equation and the aggregate price level equation. The summation term is removed from the equations by the method of quasi-differencing using a polynomial lead operator (McCandless, 2008). The expression is decreasing with the mark-up as this is the reciprocal of the marginal cost of production in terms of the final composite good. The coefficient on this variable is increasing in the probability that firms can adjust prices; as if more firms can adjust prices the impact will be greater. Equation 2.38 is derived from the backward-looking Taylor rule.

2.5 Extensions

This basic model of Iacoviello (2005) is extended by adding in three further stochastic processes. These processes will allow the impulse response functions of a household real estate demand shock a technology shock and a borrowing shock. To model the real estate demand shock a subscript is added to the fixed parameter j in the household optimization decision. The variable j_t will follow an AR(1) process. This allows a shock that directly affects house prices, and, consequently affects demand. The household sector now optimizes:

$$E_0 \sum_{t=0}^{\infty} \beta^t (\ln c'_t + j_t \ln h'_t - (L'_t)\eta/\eta + \chi \ln(M'_t/P_t)) \tag{2.39}$$

The technology shock is added through an AR(1) process in the formerly fixed technology parameter A, production is now given by.

$$Y_t = A_t (h_{t-1})^{\nu} (L_t)^{1-\nu} \tag{2.40}$$

Similarly to analyse a borrowing shock an AR(1) process is added to the borrowing constraint, which becomes:

$$b_t = g_t m E_t(q_{t+1} h_t \pi_{t+1}/R_t) \tag{2.41}$$

The shock processes are given by:

$$\widehat{j}_t = \rho_j \widehat{j}_{t-1} + e_{jt} \tag{2.42}$$

$$\widehat{A}_t = \rho_A \widehat{A}_{t-1} + e_{At} \tag{2.43}$$

$$\widehat{g}_t = \rho_g \widehat{g}_{t-1} + e_{gt} \tag{2.44}$$

Where the shock processes, e_{At}, e_{gt}, e_{jt} are white noise with mean zero and variance σ_e^2. These additional variables will alter a number of the linearization equilibrium conditions; namely the household and entrepreneurial real estate first order condition, the borrowing constraint and the production function. These changed conditions are given as:

$$\widehat{q}_t = \gamma_e E_t \widehat{q}_{t+1} + (1-\gamma_e) E_t(\widehat{Y}_{t+1} - \widehat{h}_t - \widehat{X}_{t+1}) - m\beta \widehat{r}r_t - (1-m\beta) E_t \Delta \widehat{c}_{t+1} + m(\beta-\gamma)\widehat{g}_t \tag{2.45}$$

$$\widehat{q}_t = \beta E_t \widehat{q}_{t+1} + \iota \widehat{q}_t + \widehat{c}_t^{\prime} - \beta E_t \widehat{c}_{t+1}^{\prime} + \widehat{j}_t (1-\beta) \tag{2.46}$$

$$\widehat{b}_t = E_t \widehat{q}_{t+1} = \widehat{h}_t - \widehat{r}r_t + \widehat{g}_t \tag{2.47}$$

$$\widehat{Y}_t = \frac{\eta}{\eta - (1-\nu)} \left(\widehat{A}_t + \nu \widehat{h}_{t-1} \right) - \frac{1-\nu}{\eta - (1-\nu)} (\widehat{X}_t - \widehat{c}_t^{\prime}) \tag{2.48}$$

House prices are positive in the shock to borrowing as real estate has a collateral value, and if more borrowing is allowed, more real estate will be purchased to smooth consumption. The coefficient is increasing in the tightness of the constraint, as this increases the potential utility gain from relaxing the constraint. The deviation in price is positive in the real estate preference variable equation 47. A positive deviation in j_t increases the marginal utility of real estate for the household sector and so increased demand and thus price. The parameter on this variable is negative in β as the optimization condition does not depend on the marginal utility of real estate alone but also the expected resale value (Monacelli, 2009). The higher the β, the higher the utility value of resale in optimization, and so the lower will be the demand response to a deviation in j_t.

In the borrowing constraint the shock is positive and its parameter value is one as it increases the amount that can be borrowed for any expected value of real estate held by the entrepreneur. The deviation in output is positive in the technology shock as it increases output for any level of inputs. The parameter on this variable is increasing in the Frisch labour supply elasticity as a higher value means a lower wage in steady state, and so output will be higher. The solution to the model using Uhligs method (Uhlig, 1995) is outlined in Appendix B. The values of the calibrated parameters are also given in Appendix B.

2.6 Shocks and the Transmission Mechanism

The impulse response functions of the model are used to analyse the transmission mechanism of the shocks. Four shocks are considered; a monetary shock, a technology shock, a borrowing shock and a real estate demand shock. In order to conduct the impulse response analysis, values must be set for the 11 deep parameters in the model; ($\beta, j, \eta, \nu, m, \gamma, \epsilon, \theta, r_R, r_\pi$ and r_Y). We follow Iacoviello (2005) in setting these parameter values. The discount factors are set as $\beta = 0.99$ and $\gamma = 0.98$. The parameter m on the repossession transaction cost is set to 0.89. The output elasticity of real estate ν is set to 0.03. The household taste parameter on real estate is $j = 0.1$. For the sticky price model, the probability that a firm will not be able to adjust prices is given as $\theta = 0.75$, and the gross mark-up $\epsilon/(\epsilon - 1)$ is set to 1.05. The parameters of the Taylor rule are set as $r_R = 0.53, r_\pi = 1.4$ and $r_Y = 0.4$.

The choice of parameter values determines the steady state values as shown in appendix A, where the steady state of the model is outlined. The parameter values lead to the entrepreneurs holding 20 per cent of the real estate stock. The assumptions employed in the model were made to yield a steady state in which the entrepreneur is leveraged. This occurs as the ratio of entrepreneurial borrowing to aggregate output is 2.1 in steady state. The choice of values also leads to households accounting for the vast majority of consumption. The consumption to output ratio is 0.994. The small share of entrepreneurial consumption in overall consumption means parameter changes have a substantial impact on the percentage change in entrepreneurial consumption, but not in relation to other variables in the model.

Changes in the parameters lead to changes in the steady state values. An increase in the value of m, which reduced the repossession cost, increases the amount of borrowing by the entrepreneur in steady state and their holding of real estate. This change in m reduces entrepreneurial consumption in the steady state, as from their steady state budget constraint increased borrowing reduces consumption. An increase in m from 0.89 to 0.92 increases the steady state ratio of borrowing to output by 6.2 per cent. An increase in the elasticity of real estate output ν also increases entrepreneurial real estate holding and borrowing in steady state.

2.6.1 A. Monetary Shock

The impulse response functions for all shocks are shown in appendix C. We first consider a contractionary monetary shock. The impulse response functions for this shock are shown in Figure 2.1. The presence of the sticky price mechanism is important in analysing this shock, as sticky prices allow unexpected monetary shocks to cause real variables to change in the short run. The shock occurs in the Taylor rule equation and increases the nominal interest rate. This translates into an increase in the real interest rate when prices are sticky, and thus inflation is slower to adjust (Ireland, 2005). This increase in the real interest rate leads to a fall in household consumption due to the inter-temporal substitution effect of the interest rate rise. This effect is seen in the linearised household Euler equation. In the Phillips curve equation; which is the linearised version of the monopolistically competitive retail firms pricing rule, the fall in demand from households leads to deflationary pressure and prices fall (Ireland, 2005). The entrepreneur's consumption also falls in the model. The mark-up moves in a counter cyclical way as is the case in almost all new Keynesian models (Nekarda and Ramey, 2013). This occurs as with the decrease in demand the optimal price falls, but with a sticky price adjustment some firm's prices remain at an elevated level.

The additional effects in the model from the addition of the borrowing constant can be seen in the response of the variables for borrowing, entrepreneurial real estate holding and the price of real estate. Households hold 80 per cent of the real estate stock in steady state and so a change in their holding has the potential to have a large impact on prices. Taking the households optimal real estate equation; the price of real estate fails to satisfy the optimization condition when the marginal utility of consumption increases. Taking the entrepreneurs linearised real estate first order condition; the rise in the nominal interest rate reduces the price of real estate. This occurs as the financial friction is decreasing in the real interest rate, because it increases household lending and reduces entrepreneurial borrowing. Consequently, the collateral value of real estate is reducing in R_t. The fall in output also reduces the marginal product of real estate, and the mark-up rise reduces the real value of output. The price of real estate is also negative in the rise in the interest rate, because this reduces the collateral value of the real estate.

The overall effect on real estate is a fall in the entrepreneurs holding. This fall, combined with the rise in the real interest rate, results in a fall in borrowing from the monetary contraction.

The financial accelerator mechanism is a factor in the model. The fall in the price of real estate reduces the value of the asset that the entrepreneur uses against which to borrow collateral. This causes a reduction in borrowing which was used to invest in real estate to smooth consumption. Therefore, when borrowing falls, investment in real estate falls. This reduction in the demand for real estate further reduces the price of this asset, again impacting the value of collateral and borrowing accordingly. These effects on borrowing can be seen in the linearised borrowing constraint.

2.6.2 B. Technology Shock

The results of a technology shock are shown in Figure 2.2. The technology shock raises entrepreneurial output for any combination of inputs, and therefore, in the retail firms pricing rule the optimal price falls and the mark-up rises. In the optimal pricing rule the mark-up is the reciprocal of the marginal cost and thus there is a marginal cost fall in response to the shock. From the Phillips curve this creates deflationary pressure. The Central Bank responds via the Taylor rule by reducing the nominal interest rate. This occurs as even though the initial shock raises output this is weighted lower in the Tylor rule relative to inflation and so the interest rate falls. This fall in the interest rate along with an expectation change means household consumption increases (Galí, 2008). This also raises household demand for real estate and accordingly the price of real estate. The overall effect on entrepreneur's real estate holding is a decrease, as the price rise and mark-up rise out-weigh any marginal product effect. The mark up rise directly reduces entrepreneurial income. Entrepreneurial borrowing also falls as a result of this shock. This is a demand driven change and occurs as with the fall in the price of the non-durable consumption good the households expand their purchases of real estate, this raises the price. The net impact is a fall in the entrepreneurs holding of the real estate and this in turn brings down their capacity to borrow.

It should be noted that the response of entrepreneurial real estate holding and borrowing is sensitive to the parameter choice in the Taylor rule. With a lower weighting on output and a higher weighting on inflation, the borrowing and real estate response will be positive. This occurs as with a higher Taylor parameter on output the Central Bank responds more to the output rise, and household consumption does not rise as high and consequently real estate prices don't rise as strongly. There is an impact on the mark-up which rises according to an increased Taylor parameter. This occurs because the rise in demand should lead to a fall in the mark-up, but this demand rise is lower with a stronger Taylor response.

2.6.3 C. Borrowing Shock

The shock to borrowing enters in the linearised borrowing constraint and the entrepreneur's real estate optimization and is shown in Figure 2.3. The contraction in borrowing allows the entrepreneurial sector to hold less real estate. As real estate is a factor of production this reduces output and therefore, household consumption. There is also a household consumption impact from the fall in the price of real estate that occurs as demand reduces. This causes households to reduce consumption. Once the shock impacts, the real interest rate slightly rises initially as inflation begins to rise, as an contraction of entrepreneurial output would imply a rise in the retailer's optimal price. However, after this initial rise, the real rate falls as the expected future prices falls with the demand fall. This fall in the real rate further increases consumption and, accordingly, output. As with the other shocks in the model, the financial accelerator mechanism is present and can be seen in the convergence back to steady state after the shock. There is an oscillation around steady state as the accelerator mechanism pushes the model past steady state upon convergence.

2.6.4 D. Real Estate Demand Shock

A shock to the marginal rate of substitution allows modelling of disturbances that affect real estate demand such as tax changes or expectation changes (Iacoviello, 2005). The impulse responses of a 1 unit standard deviation negative shock to the preference variable on the marginal utility of real estate for the household sector is shown in Figure 2.4. The shock enters the linearised household optimization condition with respect to real estate. The shock reduces the marginal utility of real estate, and therefore, the demand for and the price of real estate. As stated previously, households hold the majority of real estate in the steady state.

This reduction in the price of real estate initiates the accelerator effect. The price fall impacts the entrepreneu's ability to borrow also as their demand for real estate had three components in terms of its utility benefit; increased output, a resale value and a collateral value. The price fall reduces the two latter benefits. Therefore, even though the price falls, the amount of real estate held by the entrepreneurs also falls. This further reduces the price.

The initial impact of the price fall is to reduce the cost of production and through firms' optimal price setting inflation falls. The fall in inflation increases the real rate. There are thus two effects on consumption; the decrease in inflation reduces current consumption as seen in the Euler equation, and the rise in the real interest rate also has a negative impact on consumption. This consumption fall reduces output further reducing inflation.

2.6.5 E. The Repossession Cost

To look more closely at the impact of the borrowing constraint and the financial accelerator mechanism, the impulse responses are calculated with a change in parameter value. The parameter m is changed from 0.89 to 0.92. As $(1-m)$ is the transaction cost, if m is increased the transaction cost falls and so entrepreneurs can borrow more for any given increase in the value of their collateral. An increase in m is associated with a higher steady state level of debt in the model and, as in Pinheiro et al. (2013), a higher level of consumption and so output. Therefore an increase in m will have the effect of loosening the credit constraint and increasing the financial accelerator mechanism. As in Pinheiro et al. (2013) changing this parameter can be interpreted as a change in financial sector development, the variable can be seen as summary of potential factors that constrain the borrowing and lending between agents. In terms of the entrepreneurs first order conditions, the term m enters in the first order condition with respect to real estate. In steady state this equation in terms of the multiplier is given as:

$$\lambda = 1/cm - \gamma\nu y/cqxhm - \gamma/cm \tag{2.49}$$

As the right hand side of the equation is positive, the derivative with λ is decreasing in an increase in m and thus the constraint is relaxed with a fall in the repossession cost. It can be seen from equation 2.49 that a fall in the constraint increases the steady state consumption of the entrepreneur. The impulse response of output to borrowing shocks for the different values of m are shown in Figure 2.5. It can be seen that with a relaxation of the borrowing constraint in the model that borrowing shocks have a higher amplitude and deeper trough upon return to steady state.

It is of interest to compare the impulse response functions of the model for different variables and for different shocks for different values of m. The responses of the variables output, inflation, the interest rate borrowing and real estate prices in response to shocks to the interest rate, technology and borrowing. Figure 2.6 contains the comparison of responses for the first four quarters after a shock, given the timing convention of the calibrated parameters this is thus the response for 1 year after a shock. The columns in the figures show the per cent difference in the absolute value of the response between models with, $m = .89$, and, $m = .92$,. With the constrain relaxed and a higher steady state level of debt it can be seen from the figure that for standard variables, output, inflation and the interest rate there is not a large difference in the responses between the two states.

The large differences in the impulse response are only seen for financial shocks. This is also true of the response of real estate prices. The response of borrowing however is not very different in response to the same shocks for the different values of the borrowing constraint. As seen the reaction of output to the shocks is much larger for the borrowing shock as opposed to the monetary shock or the technology shock. This occurs as the initial impact of the latter two shocks impact the model directly through the borrowing constraint and real estate prices, so changes in m have more of an impact on the strength of these shocks, the monetary and technology shock however impact output primary through the real rate and so m is of less importance in the propagation of these shocks.

It is of interest to note from Figure 2.6 that with financial development the effect of a technology shock is damped for many of the variables. This is a result see in Mitra (2012), Quadrini and Perri (2008), Campbell and Hercowitz (2005) and partially in Pinheiro et al. (2013). Mitra (2012) notes that aggregate volatility declines with an increase in an indicator of financial development up until the point of the financial crisis at which point even with small increases in financial development aggregate output becomes much more volatile. This observation is consistent with Figure 2.6, with a financial shock having a larger impact on volatility at high levels of financial development. The mechanism is similar to that of Pinheiro et al. (2013) whereby with high levels of borrowing there is a bigger impact from the reduction in borrowing that occurs with a technology shock and this dampens the response of other variables. As noted previously the response of borrowing and entrepreneur's real estate holding are sensitive to the specification of the Taylor rule. Figure 2.6 shows the pre cent difference in the absolute value of the response of output with change in parameter values for the monetary policy rule. The weighting on output and interest rate inertia is reduced and the weighting of inflation is increased. The new values are shown in appendix B. As can be seen aggregate volatility is greater in the second period after a shock with more financial development compared to the model with less development and so the clear result in previous papers does not occur with a changed monetary policy. It should be noted Pinheiro et al. (2013), Quadrini and Perri (2008) and Mitra (2012) who use a Kiyotaki and Moore (1997) based framework to analyse volatility do not include a monetary policy aspect.

2.7 Conclusions

Iacoviello's basic financial frictions model adds collateral constraints and nominal debt contracts to a standard macroeconomic model (Iacoviello, 2005). In this chapter this model was extended to include not only a monetary policy shock but also a technology shock, a real estate shock and a borrowing shock. We have shown that the sign of the response of borrowing and real estate prices to a technology shock in the model is sensitive to the specification of the Taylor rule and the weighting on output relative to inflation. A positive shock to borrowing or real estate demand raised output and asset prices and both were characterised by an oscillatory movement back to steady state for most variables.

In relation to financial development the results were consistent with other papers in the literature that focused on technology shocks and financial development and showed a reduction in volatility from this type of shock at higher levels of financial development. It was however shown that higher levels of financial development resulted in financial shocks having a much bigger impact than in a situation of lower financial development. This finding can be seen as a rationale for the absence of concern for high debt levels prior to the financial crisis. In models with a financial friction present conventional shocks did not show a substantial quantitative difference between initial conditions of high as opposed to low debt. It was also shown that this result is sensitive to the specification of monetary policy.

2.8 Chapter 2 Appendix

2.8.1 Appendix A. The Steady State

The steady state of the model, assuming zero inflation, ($\pi = 1$), and constant technological progress ,($A = 1$), and is given by equations 2.50-2.55

$$R = 1/\beta, \lambda = (\beta - \gamma)/c \tag{2.50}$$

$$h = \frac{\gamma\nu(1-\beta)}{\gamma\nu(1-\beta) + j[(X-\nu)(1-\gamma-(\beta-\gamma)m) + \gamma\nu(1-\beta)m]} \tag{2.51}$$

$$\frac{qh}{Y} = \frac{\gamma\nu}{1-\gamma-(\beta-\gamma)mX} \tag{2.52}$$

$$\frac{b}{Y} = \frac{\gamma\nu m\beta}{1-\gamma-(\beta-\gamma)mX} \tag{2.53}$$

$$c = \frac{\nu}{X}Y - (1-\beta)mqh \tag{2.54}$$

$$c' = \frac{X-\nu}{X}Y + (1-\beta)mqh \tag{2.55}$$

From these steady state conditions it can be seen that in the deterministic steady state, the interest rate is equal to the rate of time preference and the multiplier on the borrowing constraint is positive.

2.8.2 Appendix B. Solution Method

The solution method relies on dividing the endogenous variables into endogenous variables and endogenous state variables. The result will be an endogenous state vector, a list of other endogenous variables (jump variables) and exogenous stochastic processes (Uhlig, 1995). The log linearised equations are divided into those that contain expectations and those that do not, and the structure of the equations without expectations will be exploited to find a solution (Uhlig, 1995). The model will be written as:

$$0 = Ax_t + Bx_{t-1} + Cy_t + Dz_t \tag{2.56}$$

$$0 = E_t[Fx_{t+1} + Gx_t + Hx_{t-1} + Jy_{t+1} + Ky_t + Lz_{t+1} + Mz_t] \tag{2.57}$$

Along with the stochastic processes what is required is a recursive equilibrium law of motion of the form:

$$x_t = Px_{t-1} + Qz_t \tag{2.58}$$

$$y_t = Rx_{t-1} + Sz_t \tag{2.59}$$

The future values of the endogenous state vector x_t and the endogenous vector y_t are functions of past values of the endogenous state vector and the stochastic processes (Uhlig, 1995). P, Q, R and S are interpreted as elasticities. In dividing the model into two sets of equations, the matrix C should be kept of full rank (Uhlig, 1995). As is often the case, the aggregate monetary policy function; although not involving expectations, is included in the expectational equation set to satisfy the rank condition of matrix C (McCandless, 2008). The extended model written in Uhligs method is given as:

$$x_t = [\widehat{Y}_t, \widehat{b}_t, \widehat{\pi}_t, \widehat{R}_t, \widehat{h}_t, \widehat{q}_t]' \tag{2.60}$$

$$yt = [\widehat{c}_t, \widehat{c}'_t, \widehat{X}_t]' \tag{2.61}$$

$$zt = [\widehat{e}_{jt}, \widehat{e}_{At}, \widehat{e}_{Rt}, \widehat{e}_{gt}]' \tag{2.62}$$

A

$$\begin{pmatrix} 0 & 0 & 0 & 0 & -1 & 0 \\ -s7 & s4 & s5 & s6 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 \end{pmatrix}$$

B

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ -s7 & -s5 & 0 & -s5 & 0 & 0 \\ s19 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

C

$$\begin{pmatrix} s1 & s2 & 0 \\ -s3 & 0 & -s6 \\ 0 & s14 & -s14 \end{pmatrix}$$

D

$$\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & s22 \end{pmatrix}$$

F

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -s10 & 0 & s9 & s8 \\ 0 & 0 & 0 & 0 & 0 & s12 \\ 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & s12 & 0 & 0 \end{pmatrix}$$

G

$$\begin{pmatrix} 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 \\ -s9 & 0 & 0 & -s10 & 0 & -1 \\ 0 & -s13 & 0 & 0 & 0 & -1 \\ 1 & -1 & 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 \end{pmatrix}$$

H

$$\begin{pmatrix} 0 & 0 & s16 & s18 & s17 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

J

$$\begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ -s11 & 0 & -s9 \\ 0 & -s12 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

K

$$\begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ s11 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -s15 \end{pmatrix}$$

L

$$\begin{pmatrix} 0 \end{pmatrix}$$

M

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & s20 & 0 & 0 \\ 0 & 0 & s21 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

$s1 = (c/Y), s2 = (c'/Y), s3 = c, s4 = b, s5 = Rb, s6 = (\nu Y/X), s7 = qh, s8 = \gamma_e, s9 = (1-\gamma_e), s10 = \beta m, s11 = (1-\beta m), s12 = \beta, s13 = (1-\beta)h, s14 = \dfrac{1-\nu}{\eta-(1-\nu)}, s15 = \kappa, s16 = (1-Rr)(1+r\pi), s17 = r_y, s18 = r_R, s19 = \dfrac{\eta\nu}{\eta-(1-\nu)}, s21 = (1-\beta), s22 = \dfrac{\eta\nu}{\eta-(1-\nu)}$

Calibrated Parameters[19]

$\beta = 0.99, \gamma = 0.98, \nu = 0.03, \theta = 0.75, \eta = 1.01, j = 0.1, m = 0.89, \rho_y = 0.40, \rho_\pi = 1.4, R_r = .053, X = 1.1$

Calibrated Parameters with a changed Taylor rule

[19] The timing convention set so that one period equals a quarter.

$\rho_y = 0.30, \rho_\pi = 1.6, R_r = .053$

2.8.3 Appendix C. Model Solution

As stated in Adjemian et al. (2011), the main algorithm for solving stochastic models in Dynare is a Taylor approximation up to the third order of the expectation functions. It is also stated that this method is outlined in Schmitt-Grohe and Uribe (2004) in which the method uses the approach of Klein (2000). Following the outline in DeJong and Chetan (2007), to apply this approach for solving the model the system of equations must be written as:

$$AE_t(x_{t+1}) = Bx_t + Cf_t \tag{2.63}$$

$$f_t = Pf_{t-1} + \varepsilon_t \tag{2.64}$$

A distinction is made between predetermined and non-predetermined variables in the model with a variable being predetermined if at any time t its' $t+1$ is certain (DeJong and Chetan, 2007). A variable is non-predetermined if its' on $t+1$ value is an expected value (DeJong and Chetan, 2007). The extended model written in the Klein form is given as:

$$x_t = [\widehat{Y}_{t-1}, \widehat{\pi}_{t-1}, \widehat{R}_{t-1}, \widehat{b}_{t-1}, \widehat{h}_{t-1}, \widehat{Y}_t, \widehat{pi}_t, \widehat{c}_t, \widehat{c}'_t, \widehat{q}_t, \widehat{x}_t]' \tag{2.65}$$

$$\varepsilon_t = [\widehat{e}_{Rt}, \widehat{e}_{jt}, \widehat{e}_{At}, \widehat{e}_{gt}]' \tag{2.66}$$

$$f_t = [\widehat{e}_{Rt}, \widehat{j}_t, \widehat{A}_t, \widehat{g}_t]' \tag{2.67}$$

A

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -s4 & -s7 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -s10 & 0 & s9 & -s9 & s10 & s11 & 0 & -s8 & s9 \\ 0 & 0 & 0 & 0 & -s13 & 0 & 0 & s12 & 0 & -s12 & 0 \\ 0 & 0 & 1 & 1 & -1 & 0 & -1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -s12 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

B

$$\begin{pmatrix}
0 & 0 & 0 & 0 & 0 & -1 & 0 & s1 & s2 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & -s5 & -s5 & s7 & s6 & s5 & -s3 & 0 & 0 & -s6 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & s11 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & s19 & -1 & 0 & -s14 & 0 & 0 & -s14 \\
0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & -s15 \\
s17 & s16 & s18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0
\end{pmatrix}$$

C

$$\begin{pmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & s20 \\
0 & s21 & 0 & 0 \\
0 & 0 & 0 & 1 \\
0 & 0 & s22 & 0 \\
0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0
\end{pmatrix}$$

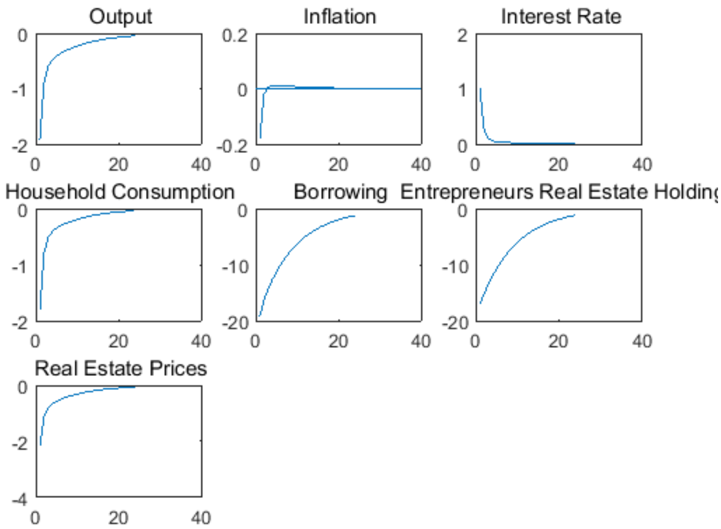
P

$$\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & \rho_j & 0 & 0 \\ 0 & 0 & \rho_a & 0 \\ 0 & 0 & 0 & \rho_g \end{pmatrix}$$

$s1 = (c/Y), s2 = (c'/Y), s3 = c, s4 = b, s5 = Rb, s6 = (\nu Y/X), s7 = qh, s8 = \gamma_e, s9 = (1-\gamma_e), s10 = \beta m, s11 = (1-\beta m), s12 = \beta, s13 = (1-\beta)h, s14 = \dfrac{1-\nu}{\eta-(1-\nu)}, s15 = \kappa, s16 = (1-Rr)(1+r\pi), s17 = r_y, s18 = r_R, s19 = \dfrac{\eta\nu}{\eta-(1-\nu)}, s21 = (1-\beta), s22 = \dfrac{\eta\nu}{\eta-(1-\nu)}$

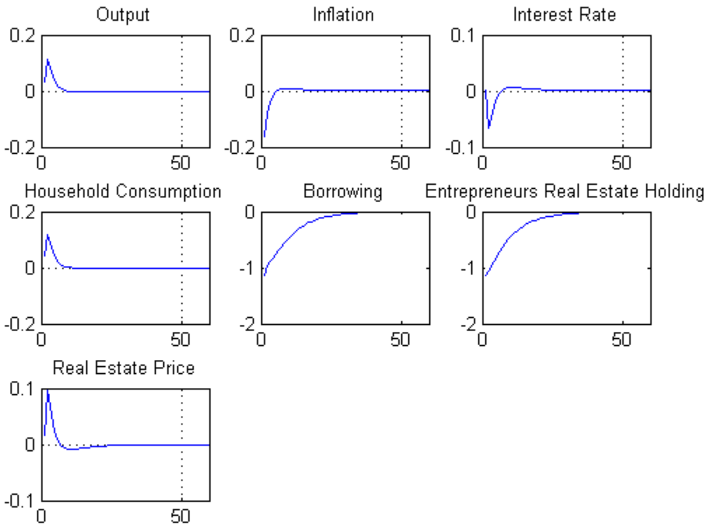
2.8.4 Appendix D. Figures

Figure 2.1: Monetary Shock



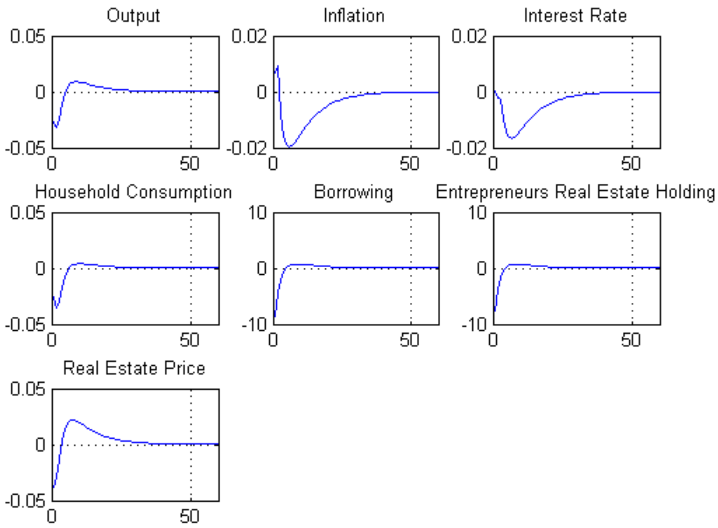
This Figure shows the impulse response functions of a selection of the models variables to a shock to the interest rate.

Figure 2.2: Technology Shock



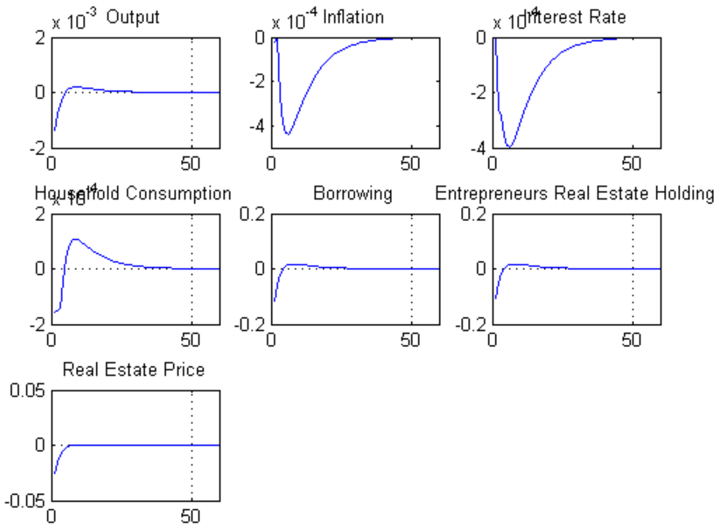
This Figure shows the impulse response functions of a selection of the models variables to a shock to technology, from the entrepreneurs production function.

Figure 2.3: Borrowing Shock



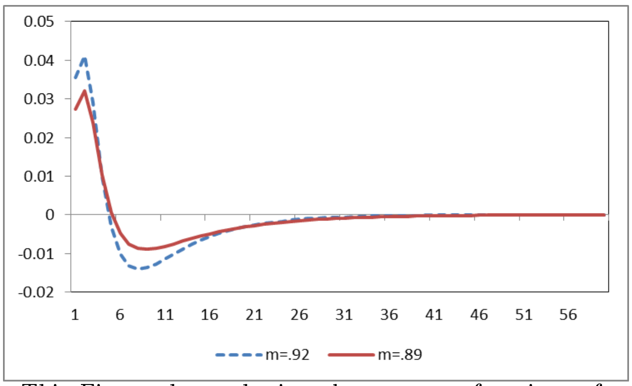
This Figure shows the impulse response functions of a selection of the models variables to a shock to the level of borrowing from the entrepreneurs borrowing constraint.

Figure 2.4: Real Estate Demand Shock



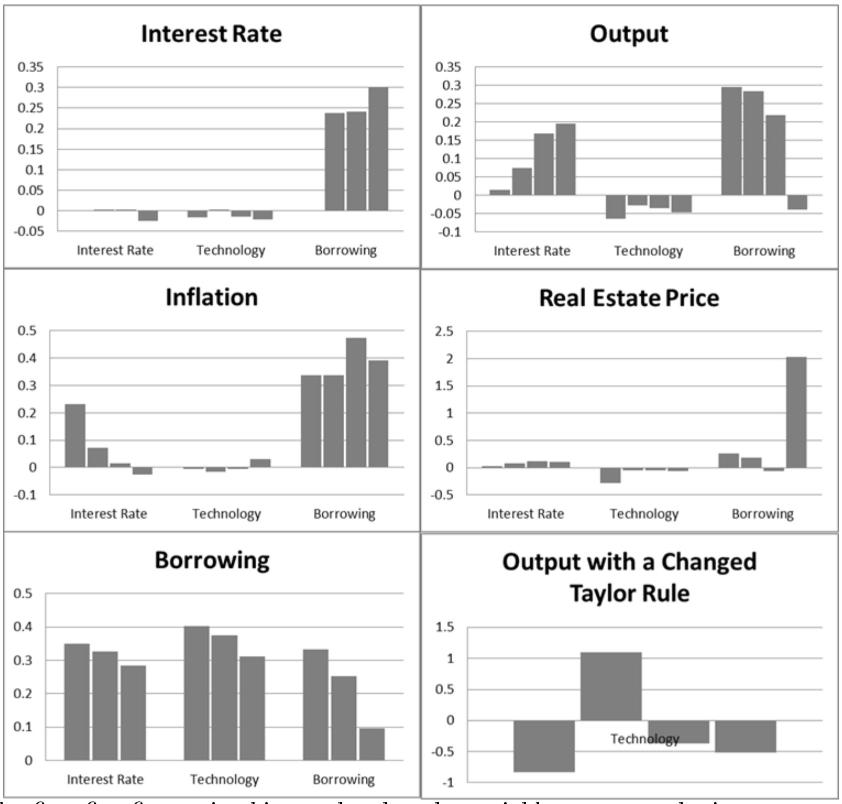
This Figure shows the impulse response functions of a selection of the models variables to the preference parameter for households utility from holding real estate.

Figure 2.5: Impulse Response of Output with a Change in Transaction Cost



This Figure shows the impulse response functions of output to borrowing shocks for the different values of the repossession cost. Changing this parameter can be seen as a relaxation of the borrowing constraint.

Figure 2.6: Absolute Value of the Difference in the Impulse Response with Relaxation of the Collateral Constraint



The first five figures in this graph takes the variables; output, the interest rate, inflation, real estate prices and shows the per cent difference in the absolute value of response of these variables, averaged over 1 year, to a shock to the interest rate, technology and borrowing. This is done to illustrate the difference in the response to shocks between situation of different levels of financial constraint. As can be seen the response of most variables to standard shocks is not drastically different between the two states considered, however for o borrowing shock the response is amplified. The final Figure shows the pre cent difference in the absolute value of the response of output to a technology shock for different parameter values for the monetary policy rule.

Chapter 3

Collateral Constraints and the Interest Rate

3.1 Introduction

The substantial impact of the 2008 financial crisis and the subsequent prolonged period of adverse conditions, which prevailed across a wide range of economies, have motivated an expansion of research on a broad range of topics in macroeconomics. This chapter focuses on the potential connection between two of the main strands of this research; the financial frictions literature and the zero lower bound (ZLB) literature. By linking these two strands of literature, this chapter derives a model that will seek to explain one of the salient features of many economies in the years after the financial crisis; that of persistently low interest rates. This will be done by building an analytical framework which permits the real steady state interest rate to be influenced by changes in the credit market. In addition to this, the resultant model can also be used to look at the factors that may influence the probability of an economy experiencing episodes of persistently low interest rates following a disruption to the credit market, due to disparate features of the economy, such as financial liberalisation and ageing. Specifically this is done by embedding a collateral constraints based financial friction in a perpetual youth overlapping generation's model. This provides both a financial friction and an endogenous steady state interest rate. The model will be used to show that a credit market dislocation causes a fall in the steady state rate of interest. This thus provides an explanation for this observed post-financial crisis phenomenon. The paper arrives at this important result through a benchmark macroeconomic which contains a standard financial frictions framework. The paragraphs that follow will detail the aforementioned first and second strands of literature which are employed in developing the model.

The interaction of financial factors on macroeconomic aggregates, although outside the academic mainstream, has been the subject of a long established literature, thus providing a natural framework for the research motivated by the 2008 crisis. This broad financial frictions literature developed from a "credit view" of the economy which stressed the importance of credit market imperfections and variables, such as, net worth, debt and asset prices in enhancing the explanation of economic fluctuations (Iacoviello, 2005). In this literature, the presence of imperfect information between agents results in credit market imperfections, leading to a distinct credit channel (Walsh, 2010). A large number of papers have developed microfounded partial equilibrium models capturing the sources of imperfections. In order to quantify the macroeconomic impact of these credit market imperfections, some of these concepts were incorporated into general equilibrium macroeconomic models, with the imperfections being termed, "financial frictions" (Brunnermeier and Sannikov, 2014). The resulting macroeconomic financial frictions literature has developed in line with a number of theoretical frameworks[1]. In Bernanke et al. (1999), it is found that agency costs in credit markets vary counter-cyclically due to the effect on firms' balance sheets, and this exacerbates the initial impact of a shock. This amplification effect, termed the "financial accelerator mechanism", is a key result that is found in the financial frictions literature and across the modelling approaches mentioned. The financial accelerator in these models adds to the amplification and persistence of shocks, and provides a theoretical basis for explaining the substantial movements in macroeconomic variables during the financial crisis (Bernanke et al., 1999), (Iacoviello, 2005). Much of the focus of the financial frictions literature has had as its subject the magnitude and persistence of variables in response to shocks in the short run. This literature has recently expanded to cover a wide range of issues, such as the effect of financial frictions on open economy models, Taylor rules, risk premiums, macroprudential policy and in fitting models to national and regional data[2].

With respect to the second strand of research that is the subject of this chapter, the zero lower bound literature has sought to explain the characteristics of an economy and the policy options in a situation where the policy interest rate is close to zero, or at zero. This is the situation which has prevailed in a number of economies for a prolonged period since the 2008 crisis (Williams, 2014). The literature on the ZLB expanded rapidly in the 1990's

[1] Notably the costly state verification approach of (Bernanke et al., 1999), the collateral constraints approach as per Kiyotaki and Moore (1997) and the financial intermediaries approach of Gertler and Karadi (2011).

[2] For an overview, refer to Walsh (2010) and Brunnermeier and Sannikov (2014).

due to the Japanese zero interest rate policy, and also later in the 2000's due to the low interest rates experienced in Europe and the US after the technology bubble (Buiter (2009), Eggertsson and Woodford (2003)). The general conclusion of this earlier literature was that episodes of ZLB would be relatively infrequent and generally short lived; with estimates that monetary policy would be constrained by the ZLB five percent of the time, and that the typical episode would last just one year (Williams, 2014). A broad literature review of this pre-financial crisis research on the ZLB is found in Yates (2004), and in summary states, "Overall the risks of being trapped at the zero bound of interest rates are probably small, and probably overstated". As stated in Buiter (2009), the existence of the ZLB has long been acknowledged, but was, however, viewed mainly as a purely theoretical concern with, as mentioned above, a low probability of practical relevance.

In the period after the 2008 financial crisis, this situation changed sharply, with The Federal Reserve, The Bank of England, The Bank of Japan and the European Central Bank all lowering their policy rates to their effective lower bounds (Williams, 2014). The ZLB has thus been a binding constraint on Central Bank interest rate setting across a large number of economies. The tightness of this binding constraint is estimated to be substantial[3]. This condition of the post-crisis economy called into question much of the predictions of the previous ZLB research; in particular the predictions that these episodes had a very low probability of occurrence, thus instigating a new wave of research. The ZLB is now seen as an issue that will constrain policy options

[3]Buiter (2009) notes that a number of studies have shown that by following the Taylor rule principal and abstracting for the existence of the ZLB, the official policy rate in the US in early 2009 would have been negative and in the range of -5 to -7.5 percent.

well into the future (Williams, 2014). The ZLB literature has also extensively analysed the policy options for further stimulus, such as quantitative and credit easing.[4]

Despite this large expansion in research in these two closely aligned fields, there have been comparatively few papers which integrate elements of these two literatures. The contribution of this chapter is that it establishes an analytical link between the financial frictions literature and a feature of the zero lower bound literature; that of prolonged low interest rates after a crisis. It does this by building a model with endogenous collateral constraints; as per the financial frictions literature, into a benchmark macroeconomic model, which permits an endogenous steady state interest rate. In this model low interest rates occur endogenously as a result of a change in the strength of the financial friction. This is different too much of the financial frictions literature wherein the models' steady state rate of interest is generally fixed, and much of the zero lower bound literature wherein the interest rate fall is initiated by an exogenous change in the rate of time preference. As will be discussed in the subsequent section, the link between these two features of the crisis has been explored in some other papers; however, in this chapter the result is shown analytically in a more standard benchmark model with an endogenous friction. The model that is derived also has implications for hypotheses on secular stagnation, as the relationship between the credit constraint and the steady state rate of interest is shown to be non-linear. The link between the model developed in this chapter and this literature will also be explored. The remainder of the chapter is structured as follows; section 3.1.1 reviews the

[4]Refer to Buiter (2009), Eggertsson and Woodford (2003) and Williams (2014) for an overview.

literature relevant to the development of the model. Section 3.2 describes the basic perpetual youth model with heterogeneous agents. Section 3.3 details the borrowing constraint in this model. Section 3.4 analyses the equilibrium and steady state of the model. In Section 3.5, the interaction of the financial friction and the interest rate is examined. Finally, Section 3.66 summarises the results, and Section 3.7 concludes.

3.1.1 Existing Literature

This potential link between the interest rate and financial frictions has been explored in some papers. In Guerrieri and Lorenzoni (2011), a Bewly-Huggett-Ayagari model is used which features an exogenous borrowing constraint and a fixed quantity of bonds. This model is used to examine the economic response to an unexpected tightening of the credit constraint and the way the economy adjusts from an easy credit regime to a situation of tight credit. They find that a tightening of the constraint leads the economy to adjust to a lower steady state interest rate. This occurs as a tightening of the constraint increases deleveraging and increases savings, and thus the supply of lending in the economy increases. Equilibrium in the asset market means the interest rate falls (Guerrieri and Lorenzoni, 2011). Guerrieri and Lorenzoni (2011) argue that the interest rate dynamics modelled in the paper are linked to the idea of the liquidity trap. They define the liquidity trap as, "a situation where the economy is in recession and the nominal interest rate is zero" (Guerrieri and Lorenzoni, 2011). Guerrieri and Lorenzoni (2011) state that their model demonstrates that shocks to agents' borrowing capacity are precisely the type of shocks that push down the economy's natural rate of interest, and thus trigger a liquidity trap situation. This provides an alternative to the ad-hoc changes to intertemporal preferences commonly used in the literature to push the economy into a liquidity trap (Guerrieri and Lorenzoni, 2011). They further argue that, historically, liquidity trap episodes have typically followed disruptions in the banking system, and that their model establishes a natural connection between credit market shocks and the emergence of a liquidity trap (Guerrieri and Lorenzoni, 2011)[5]. Empirical evidence of this fall is found in the natural rate in crisis periods has been documented in Laubach and Williams (2003) and Cùrdia et al. (2015).

Eggertsson and Mehrotra (2014) also examine the link between financial frictions and the interest rate using an endowment economy three stage overlapping generations model with exogenous collateral constraints. This model attempts to explicitly construct a situation in which unemployment is high due to a permanent drop in the natural rate of interest. Eggertsson and Mehrotra (2014) referred to this as a secular stagnation. As per the collateral constraints literature, Eggertsson and Mehrotra (2014) state that much of the analysis in the literature on the financial crisis is based on models with a representative agent framework and, therefore, a fixed steady state interest rate. This creates a problem in these models, as changing the steady state interest rate to a new lower level can only be done by permanently changing the rate of time preference, with the resultant effect that the maximization problem of the household is no longer well defined (Eggertsson and Mehrotra, 2014). It is found that by using an alternative to the representative agent structure, the natural rate of interest can become negative in response to a

[5]In relation to liquidity traps and the 2008 crisis, Hall (2013) notes, that the crisis saw a sharp decline in the safe interest rate.

shock to the debt limit of the household sector, and this gives rise to secular stagnation (Eggertsson and Mehrotra, 2014). In terms of the methodology employed, in the Guerrieri and Lorenzoni (2011) paper, the model is solved by numerical simulation and the credit constraint is tightened through calibration. Eggertsson and Mehrotra (2014) present a three stage model with an exogenous credit constraint. In the current chapter, a model is constructed that attempts to capture the result of these other models in an analytical way using a benchmark model with an endogenous constraint.

The model will need to contain two elements; a framework that permits an endogenous steady state interest rate and a financial frictions element. With respect to the financial frictions element, this chapter utilises the collateral constraints approach. The collateral constraints literature has been used in a number of macroeconomic models to analyse a variety of questions on the role of financial frictions[6]. Across the range of questions addressed, in all of these applications of the collateral constraints literature, the impact of the collateral constraint on a number of key variables in varying modelling specifications is explored. However, due to the modelling choices in these papers; specifically the infinite horizon representative household, the potential impact of a change in the financial friction on the steady state interest rate cannot be analysed.

With respect to the second element required in the model; the variation in the steady state rate of interest, a perpetual youth model is utilised. This model provides a straightforward synthesis of representative-agent and overlapping generations models, thus allowing features of both models to be

[6] See Kiyotaki and Moore (1997), Iacoviello (2005), Iacoviello and Neri (2010), Monacelli (2009), Gerali et al. (2010), Brzoza-Brzezina and Makarski (2011) and Campbell and Hercowitz (2005)

employed in the analysis (Obstfeld and Rogoff, 1996). These models have long been used in macroeconomic analysis, but this has been motivated by other questions unrelated to financial frictions. As stated in Ascari and Rankin (2007), the perpetual youth framework, like other overlapping generations models, implies that "Ricardian Equivalence" does not hold, and thus it has been used extensively in analysing government debt and deficits, and growth and capital accumulation in the long run, such as in Blanchard (1985). Recently, this framework has become much more popular in short run models and models of monetary and fiscal interactions, as it allows a departure from the representative agent framework (Ascari and Rankin, 2007) [7].

Another advantage of the perpetual youth structure and a reason for its recent popularisation in short run macroeconomic models, is that in open economy models with a representative agent the level of net foreign assets is not restricted to a long run equilibrium level (Harrison et al., 2005). The perpetual youth structure avoids this, as it ensures consumption will be stationary and thus net foreign assets will also be stationary (Harrison et al., 2005). This feature has been used widely, especially in large models of particular economies that have been developed predominantly by Central Banks [8].

In relation to the topic of this chapter, some of the aforementioned papers, such as Laxton et al. (2010) and Almeida et al. (2013), do introduce a concept

[7] See, Devereux (2011), Barbara et al. (2008),Leith and Wren-Lewis (2000) and the coordination of monetary and fiscal policy in Chadha and Nolan (2003). Ascari and Rankin (2013) use this model to show the sensitivity of the Ricardian equivalence result to the monetary policy rule.

[8] Examples include; the LSM model for Luxembourg, Deák et al. (2011), The Bank of England Quarterly Model (Harrison et al., 2005), the PESSOA model of Portugal in Almeida et al. (2013), the JEM model of the Japanese economy in Fujiwara et al. (2005), Elbourne et al. (2009) for the Dutch economy, the Euro area model of Smets and Wouters (2002) and the GIMF model of the global economy Laxton et al. (2010).

of credit constraints into their models. This is done through having a subset of households that behave as "Rule of Thumb" consumers (Gali et al., 2004). As discussed in Beaton (2009), Campbell and Mankiw (1990) justify the use of this type of consumer by appealing to credit market imperfections and thus they can be thought of as credit constrained agents. For the purposes of this chapter, however, these types of agents do not engage in borrowing and lending and don't possess an endogenous borrowing constraint that can be relaxed. In the model of Laxton et al. (2010) and Almeida et al. (2013), they are included mainly to enhance the non-Ricardian features of the models.

There is a limited literature which uses overlapping generation's models that do contain specific financial frictions. In the Kiyotaki and Moore (1997) paper, an overlapping generation's version of the basic financial frictions model is outlined in an Appendix. This model contains two productive sectors differing in their production technologies. This basic model has been applied to study international asset market dynamics in Kasa (1998). In our model, however, the approach of Iacoviello (2005)) is adopted. Iacoviello (2005)) translates a simplified version of the Kiyotaki-Moore model into a standard macroeconomic model with one production sector and one household sector. A version of this approach is presented in Andrés et al. (2013) who adopts the heterogeneous producers overlapping generations model of Kiyotaki-Moore to a perpetual youth setting with households and entrepreneurs. This paper looks at the effect of the presence of collateral constraints and banking competition on the trade-off between stabilization goals. Its structure does not, however, permit analysis of the financial friction and interest rate link as, given the structure used; the steady state interest rate is fixed. Some papers in the perpetual youth literature do present models that explore factors changing the interest rate aside from the standard increases in government debt[9]. These papers do not, however, look specifically at financial frictions.

In terms of the zero lower bound literature, large number of recent papers have been motivated by examining the size of fiscal multipliers when interest rates are very low[10]. Devereux (2011) presents the interest rate and multiplier interaction in a perpetual youth setting, and in Christiano et al. (2011) this interaction is presented in an infinite-horizon setting. In both papers, as in other papers in this literature such as Eggertsson and Woodford (2003), the concept used to lower the steady state of interest is a temporary, unanticipated rise in agents' discount factor (Christiano et al., 2011). As already stated; Eggertsson and Mehrotra (2014) state that this mechanism is problematic when modelling a prolonged slump in the interest rate.

In order to analyse the link between financial frictions and the rate of interest, this chapter constructs a discrete time, perpetual youth model with durable goods and an endogenious financial friction in the form of a collateral constraint. We translate the friction into the model in a simplified way, as in Iacoviello (2005). The model developed in this chapter has a link to the financial frictions models of Hall (2012) and Chari et al. (2007), which will be detailed in Section 5.

[9]Vila and Vayanos (1999) find that when the transaction cost on financial assets falls, the interest rate for the illiquid asset rises in the perpetual youth model.

[10]Refer to Christiano et al. (2011) and Devereux (2011) for an overview.

3.2 The Basic Model

The model constructed in this chapter draws on a number of papers from different strands of literature. The financial frictions mechanism in the model is based on Iacoviello (2005). As stated previously, the Iacoviello (2005) model uses a simplified version of the Kiyotaki and Moore (1997) model, and it is this version of the Iacoviello model that is used for the friction in this chapter. The model is simplified on the financial frictions side to the extent that, as in Iacoviello (2005), the borrowing constraint can be proved to bind in steady state only. However, without the additional assumptions of Kiyotaki-Moore, it cannot be proved to bind outside of the steady state[11].

In the model in this chapter there is a population of consumers whose size is normalized to 1. This population will consist of two types of agents; a fraction $(1-\omega)$ of perpetual youth households and a fraction (ω) of entrepreneurs. The perpetual youth households will evolve according to a Blanchard-Yaari overlapping generations scheme. Agents are subject to stochastic finite lifetimes, and face a probability of dying $(1-\gamma), \gamma \in (0, 1]$ at the end of each period. To make aggregation possible it is assumed that the probability of death is independent of age (Frenkel and Razin, 1992). $(1-\gamma)$ can be interpreted as the relevant economic horizon behind agents' decisions where the future is a period of lower economic relevance (Almeida et al., 2013). The probability of death is the only source of uncertainty in the model. In each period a new cohort of agents v will be born. The cohort is assumed to be

[11]Another advantage of taking the approach of Iacoviello as opposed to using two productive sectors (as in Kiyotaki and Moore (1997) and Kasa (1998)) is that it does not necessitate the use of the "net wealth net worth relation" employed in these papers, which requires restrictive assumptions on functional form.

large enough so that the probability of death $(1-\gamma)$ is also the rate at which the cohort size decreases through time. With this assumption each individual is still uncertain about their time of death, but the size of each cohort will decline deterministically through time (Almeida et al., 2013). The population of households is held constant, implying that the number of agents born in each period is the same as the number of agents that die.

The financial frictions structure in the model differs from that used in Andrés et al. (2013); where the credit flow relationship is between infinitely lived households, which are the patient agent, and perpetual youth entrepreneurs; the impatient agent. The patient agent in Andrés et al. (2013), as in Kiyotaki and Moore (1997), fixes the interest rate in the model. This occurs because the patient agent in these models is an infinitely lived household. Therefore, the standard result; that the steady state interest rate is fixed by the rate of time preference of the households, holds. Within a borrower-lender financial frictions model, this situation can be thought of in terms of supply and demand in a credit market. The suppliers of credit, which in collateral constraints financial frictions models are typically households, have a perfectly elastic supply curve, and therefore, any changes in credit demand do not change the market clearing interest rate. In this chapter, the households have a perpetual youth structure and the entrepreneurs are infinitely lived, and thus the steady state rate of interest in the model will not be determined by the rate of time preference alone. This facilitates an analysis of the potential effect of a change in the financial friction on the steady state interest rate as per Eggertsson and Mehrotra (2014). The change in structure allows the steady state rate to vary. In the remainder of this section the household sector is described, and then the aggregation procedure and the aggregate Euler equation are shown. Finally the entrepreneurs sector is presented.

3.2.1 Households

In the perpetual youth household sector a new cohort of agents are born in each period of time. The timing convention that is adopted for the model is that of Frenkel and Razin (1986). Using this timing convention, the expected lifetime utility function of an agent alive at period t who was born in period s is:

$$E_t U_{s,t} = E_t \sum_{v=t}^{\infty} (\beta)^{v-t} U_{s,v} = \sum_{v=t}^{\infty} (\gamma\beta)^{v-t} U_{s,v} \tag{3.1}$$

In the equation above E_t is the expectation operator, $\beta \in (0,1)$ is the discount factor and $U_{s,v}$ is the flow utility in period v. Utility is in the form of expected utility to take account of the probability of survival from one period to the next[12]. The expression adopted for utility on the left hand side of equation 3.1 follows Frenkel and Razin (1992), and is termed the "certainty equivalent utility function" as it takes into account the probability of survival[13]. The presence of the survival probability, with $\gamma < 1$, has the effect of reducing the utility of future consumption, and thus it makes individuals more impatient relative to the infinite horizon model (Frenkel and Razin, 1992). Households will optimize utility with respect to consumption of durable and non-durable goods, and leisure. The form of instantaneous utility $U_{s,v}$ is assumed to be:

$$U_{s,v} = ln(c_{s,v}^{1-\theta} X_{s,v}^{\theta} (1 - H_{s,v})^k) \tag{3.2}$$

[12]In this modelling structure the probability of surviving any n periods will be a joint probability (Wickens, 2012).

[13]It can be seen that the infinite horizon utility function is a special case of the perpetual youth model when ($\gamma = 1$).

In the equation above κ, is a taste parameter on leisure and $H_{s,v}$ is hours worked as a fraction of the total time endowment in each period [14]. That the utility function is homothetic is a property that is required for aggregation across cohorts[15]. In line with Deák et al. (2011) and Ascari and Rankin (2007), θ, is a taste parameter related to the expenditure share of durable and non-durable consumption [16]. Using this formulation the parameter can change the marginal rate of substitution between durable and non-durable consumption, but not the elasticity of substitution. $c_{s,v}$ is consumption of cohort s in period v in real terms. $X_{s,v}$ is the stock of the durable good held by cohort s in period v.

Households' maximization is subject to the following budget constraint which is expressed in nominal terms:

$$P_v c_{s,v} + B_{s,v} + Q_v X_{s,v} = W_v H_{s,v} + \frac{1}{\gamma}\left((1+i_{v-1})B_{s,v-1} + Q_v X_{s,v-1}\right) \quad (3.3)$$

In this equation, P_v is the price level in period v, $B_{s,v}$ is the stock of households' financial assets, W_v is the money wage in period v, Q_v is the price of the durable good and (i_{v-1}) is the nominal interest rate on loans between periods $(v-1)$ and v.

It can be seen from the budget constraint that, in addition to the nominal interest rate on bonds, each individual agent also receives an additional pay-

[14] As discussed in Ascari and Rankin (2007) this formulation means that the labour supply will not be wealth independent.

[15] The function used for utility is a constant relative risk aversion utility function (CRRA) with the coefficient of relative risk aversion equal to one. The CRRA utility function is homogeneous, and any function that is homogeneous is also homothetic Varian (1992).

[16] The durable good in this model is a dual purpose good that households get utility from and that firms use as a factor of production. It is a perfect substitute on the sellers side and heterogeneous on the buyer's side. It is thought of as land in Kiyotaki and Moore (1997) and as real estate in Iacoviello (2005)

ment equal to a fraction of their total asset level. This occurs because in the Blanchard-Yaari model the existence of a non-profit life insurance company is assumed (Frenkel and Razin, 1992)[17]. This chapter follows the approach to insurance of Hu (1994). The Hu (1994) paper describes the case of both assets and durable goods. In the perpetual youth situation, the insurance contract stipulates that the individuals' wealth; which includes both financial assets and the durable stock, are transferred to the life insurance company. The insurance company agrees in return to pay a fraction of each agent's wealth to them, in the form of a premium payment, whilst the agent is still alive. This allows households to increase utility to a level higher than if there were no insurance company[18]. Free entry of insurance companies is assumed, and therefore, with zero profits the fraction of wealth which forms the premium payment is actuarially fair and is equal to $1/\gamma$[19].

As this is a heterogeneous agent model with production controlled by entrepreneurs, and is also without nominal rigidities, households do not gain profit receipts from firms, and thus these transfers do not enter the household budget constraint. This has the benefit of avoiding unintended household wealth effects due to some income streams being subject to insurance and

[17] In a situation in which individuals maximize expected lifetime utility with no bequest motive, and in which there is uncertainty about the time of death, and in addition to which one assumes there is a large enough number of agents born in each new cohort such that the frequency of those who survive is equal to the survival probability $\gamma < 1$, there is no aggregate uncertainty about the time of death, and thus insurance is possible (Blanchard and Fischer, 1989).

[18] The assumption that the conditional expectation of future life is independent of wealth and the large population turnover ensures that income receipts and payouts for the insurance company will match in every period (Acemoglu, 2009).

[19] In this chapter, credit allocation is of interest and this institutional arrangement for insurance in the form of a premium payment does not impact the credit market, as all agents will borrow and lend at the same rate. It should be noted that the alternative institutional arrangement of insurance companies; that of modelling their presence in the form of a direct surcharge on loans as outlined in Frenkel and Razin (1992), is not suitable in the presence of durable assets.

others being uninsured, as discussed in Harrison et al. (2005).

Households optimising utility subject to the flow budget constraint with the choice variables as $C_{s,v}$, $H_{s,v}$, $X_{s,v}$ and $B_{s,v}$ yield the following first order conditions:

$$\frac{1}{c_{s,v}} = \gamma\beta\left[\frac{(1+i_v)P_v}{c_{s,v+1}P_{v+1}\gamma}\right] \tag{3.4}$$

$$\frac{\kappa}{(1-H_{s,v})} = \frac{W_{s,v}}{C_{s,v}P_v} \tag{3.5}$$

$$\frac{\theta}{X_{s,v}} = \frac{q_v}{c_{s,v}} - \gamma\beta\left[\frac{q_{v+1}}{c_{s,v+1}\gamma}\right] \tag{3.6}$$

In the equation above lower-case letters indicate values in real terms with the price of the non-durable good being the numeraire.

As mentioned previously, an essential requirement of the perpetual youth model is that the agents' consumption should constitute a linear function of their lifetime wealth. This facilitates aggregation across cohorts, such that aggregate consumption can be written as a function of aggregate wealth (Ascari and Rankin, 2007). This consumption function is the key behavioural equation in perpetual youth models. To arrive at this expression, individual consumption as a function of wealth at the cohort level is first derived. Firstly, the budget constraint is written in real terms and is first solved forwards, with the no-ponzi condition imposed. The inter-temporal budget constraint is as follows:

$$\begin{aligned} WT_{s,t} = \sum_{v=t}^{\infty}\gamma^{v-t}\frac{\alpha_v}{\alpha_t}\left(c_{s,v}+f_vX_{s,v}\right) = \sum_{v=t}^{\infty}\gamma^{v-t}\frac{\alpha_v}{\alpha_t}\left(w_vH_{s,v}\right) \\ + \frac{1+r_{v-1}}{\gamma}b_{s,v-1} + \frac{q_t}{\gamma}X_{s,v-1} \end{aligned} \tag{3.7}$$

In the above $WT_{s,t}$ is the wealth of an agent in cohort s at time t. $WT_{s,t}$ is the present value of all future consumption, or equally the present value of all future income from period t onwards plus initial wealth. As in Deák et al. (2011), the variable f_v is defined as the user cost of the durable good;

$$f_v = \left[q_v - \frac{q_{v+1}}{1+r_v}\right] \tag{3.8}$$

$\frac{\alpha_v}{\alpha_t}$ is the present value factor (Frenkel and Razin, 1992)[20].

The certainty equivalent utility function is now optimized with respect to the present value inter-temporal budget constraint. The first order conditions for non-durable and durable consumption are:

$$c_{s,v} = \lambda^{-1}(1-\theta)\frac{\alpha_t}{\alpha_v}\beta^{v-t} \tag{3.9}$$

$$\frac{\theta(\gamma\beta)^{v-t}}{X_{s,v}} + \frac{\lambda}{\gamma}q_{v+1} - \lambda\gamma^{v-t}\frac{\alpha_v}{\alpha_t}f_v = 0 \tag{3.10}$$

In the above λ is the multiplier on the present value inter-temporal budget constraint. The result is the same as in a standard infinite horizon model in that agents cannot increase lifetime utility by shifting consumption across time. As in Fujiwara et al. (2005), combining the first order conditions 11 and 12 yields an expression for durable goods stock in terms of non-durable goods:

$$X_{s,v} = \frac{\theta}{1-\theta}c_{s,v}f_v^{-1} \tag{3.11}$$

Using these conditions, and combining the expression for wealth and the first order condition for durable and non-durable consumption at period $(v = t)$

[20]It is the one period rate of interest compounded from period zero up to period $t-1$, such that: $\alpha_3 = (1+r_0)^{-1}(1+r_1)^{-1}(1+r_2)^{-1}$.

results in the expressions:

$$c_{s,t} = (1 - \beta\gamma) WT_{s,t} \tag{3.12}$$

$$c_{s,t} = (1 - \beta\gamma) \left(\frac{1 + r_{t-1}}{\gamma} b_{s,t-1} + \frac{q_t}{\gamma} X_{s,t-1} + \sum_{v=t}^{\infty} \gamma^{v-t} \frac{\alpha_v}{\alpha_t} (w_v H_{s,v}) \right) \tag{3.13}$$

The above represents the consumption of an individual as a linear function of wealth. The term $(1 - \beta\gamma)$ is the marginal propensity to consume out of wealth. All individuals of the same cohort will have the same consumption as they will consume the same proportion of their total wealth in each period. This allows for aggregation, as the saving propensity is independent of age, and thus there is no within age variation for individuals born at the same time. Consumption thus depends on total wealth and the propensity to consume[21]. In line with Frenkel and Razin (1992), with respect to the second set of brackets on the right hand side of expression 15, the first two terms constitute non-human wealth and the sum of wages is termed "agents' human wealth".

3.2.2 Aggregation

Up to the present point in this chapter, the expressions derived have been at the cohort level. Aggregate consumption will now be derived. This is defined as the sum of consumption for all individual cohorts alive at date t. Given that the probability of survival is γ and the proportion of the total population of consumers that are households is $(1-\omega)$, aggregate per capita consumption

[21] As discussed in Frenkel and Razin (1992), given the assumptions made about the functional form of utility, which yield a log utility function, the consumption propensity is a constant over time.

of the household sector is given by:

$$c_t = (1-\omega)(1-\gamma)\sum_{s=-\infty}^{t}\gamma^{t-s}c_{s,t} \tag{3.14}$$

This is interpreted as a per capita expression due to the timing convention used. In the remainder of this chapter, aggregate and aggregate per capita are used interchangeably. The aggregation formulation follows that of Frenkel and Razin (1986), such that s is the period in which a cohort was born (and the cohort can be born at any time to minus infinity)[22]. Time extends back to minus infinity, therefore, in the latter case, agents' age can extend to infinity. The aggregate consumption is written as:

$$c_t = (1-\beta\gamma)\left((1+r_{t-1})b_{t-1} + q_t X_{t-1} + \sum_{v=t}^{\infty}\gamma^{v-t}\frac{\alpha_v}{\alpha_t}\left(w_v H_v\right)\right) \tag{3.15}$$

Equation 3.15 above is the optimal aggregate consumption rule of the overlapping generation's households. In perpetual youth models it expresses current aggregate consumption of households as a function of their real aggregate human and non-human wealth and their propensity to consume (Laxton et al., 2010).

3.2.3 The Aggregate Euler Equation

In deriving the aggregate euler equation, the aggregate consumption function is used along with the dynamic equation for the evolution of human capital:

$$HW_t = \frac{1}{\gamma}\left(1+r_{t-1}\right)\left[HW_{t-1} - w_{t-1}H_{t-1}\right] \tag{3.16}$$

[22] An alternative specification used in Harrison et al. (2005) is to define cohorts by age.

In the equation above HW_t is the human component of wealth at time t. The aggregate budget constraint is also required for the derivation of the aggregate Euler equation. The main difference between the aggregate and cohort level budget constraint is that there is no stream of payments from the insurance company in this budget constraint as these payments are between individuals and so on aggregate payments will cancel with losses (Piergallini, 2004). Combining the expression for wealth, the aggregate budget constraint and then using the equation for the evolution of human capital yield an expression for the aggregate Euler equation. After some manipulation the aggregate Euler equation can be written as[23].

$$c_t = \beta(1 + r_{t-1})c_{t-1} - \left(\frac{(1-\theta)(1-\beta\gamma)(1-\gamma)}{\gamma}\right)\left(\tilde{b}_{t-1} + q_t X_{t-1}\right) \quad (3.17)$$

This euler equation will collapse into a standard Euler equation if ($\gamma = 1$), and thus the probability of death is zero and agents have an infinite horizon. As discussed in Heijdra and Ligthart (2000) and Ascari and Rankin (2007), the aggregate Euler equation contains additional terms which are not present in the individual Euler equation. These additional terms will be an important driver of the dynamic behaviour of the model. The Euler equation now contains a term that is negatively related to financial wealth and the stock of durable goods. This is due to the generational turnover effect. As can be seen from the aggregate Euler equation, the interest rate will be greater than the discount factor, and therefore, it can be seen from the individual Euler equations that each cohort will have an increasing path of

[23]As in Ascari and Rankin (2007), the level of debt is set in real terms inclusive of the interest rate: $\tilde{b}_{t-1} = (1 + r_{t-1})b_{t-1}$.

lifetime consumption. Agents in the perpetual youth model are thus always saving and accumulating assets (Leith et al., 2011). This occurs as agents use financial assets to fill the gap between their income profile and their desired level of consumption (Ascari and Rankin, 2007). As outlined in Heijdra and Ligthart (2000), this means that the share of human wealth in total wealth of a cohort is decreasing in the age of the cohort, which is to say very old agents will have a large stock of financial assets. Given the conditions of cohorts consuming out of their wealth, new agents having no wealth (apart from their human wealth) and given the death of a random sample of agents in each period, aggregate consumption between dates t and $t+1$ will be reduced. This is termed the "generational turnover effect" (Heijdra and Ligthart, 2000). Therefore, aggregate consumption will have a negative term, and will be lower than the infinite horizon case. This will be in proportion to the size of the stock of wealth, the propensity to consume and the probability of death.

As can be seen from the aggregate Euler equation, the generational turnover effect also affects the interest rate. In the individual Euler equation the interest rate is at a level that makes individuals unable to increase utility by shifting consumption across time, given preferences. The death of a random sample of agents that have higher consumption than the newly born agents will increase this interest rate. The aggregate interest, in line with the individual case, must be so that agents can't shift consumption across time and increase utility, and thus with the probability of death and the higher consumption of older agents it is higher than in the infinite horizon.

3.2.4 Entrepreneurs

The fraction $(1-\omega)$ of entrepreneurs in the population use the durable good and labour to produce a composite good y from a Cobb-Douglas, constant returns to scale production function:

$$y_t = A(X^{'}_{t-1})^{\nu}(H^{'}_{t})^{1-\nu} \tag{3.18}$$

In the above A is the constant technology parameter, $X^{'}$ is the entrepreneurs holding of the durable good and $H^{'}$ is their labour demand. The parameter $\nu \in (0,1)$ is the output elasticity of the durable good. As constant returns to scale have been assumed, $(1-\nu)$ is the output elasticity of labour. There is a one period lag on the production of output from the durable good.

Entrepreneurs seek to optimize lifetime utility and their utility is a function of their level of consumption c'. The functional form of deterministic utility at time t is given by:

$$U'_t = \sum_{t=0}^{\infty} \varphi^t \ln c'_t \tag{3.19}$$

The parameter $\varphi \in (0,1)$ is the entrepreneurs discount factor and c' is their level of consumption. In line with the collateral constraints literature of Kiyotaki and Moore (1997) and Iacoviello (2005), an assumption will be required for the value of φ so that financial frictions play a role in the model. This assumption will be outlined in Section Three. The entrepreneurs flow of funds constraint in real terms is given by:

$$y_t + b'_t = c'_t + q_t \Delta X'_t + (1+r_{t-1})b^{'}_{t-1} + w_t H^{'}_t \tag{3.20}$$

b'_t is the entrepreneur's net stock of financial liabilities. The constraint states that income from production plus borrowing must equal expenditure plus accumulated debt[24].

In the model in this chapter, entrepreneurs are also assumed to face a borrowing constraint that is tied to the value of their collateral; in this case the value of their durable goods holdings for the next period. This is the same borrowing constraint concept as detailed in Kiyotaki and Moore (1997) and Iacoviello (2005). As in Kiyotaki and Moore (1997), it is assumed that there is a threat of debt repudiation, and thus there is the possibility of mutually beneficial debt write-down negotiations between the agents. Creditors in the model know that this threat exists, and so will not allow the size of borrowing to exceed the collateral value of the durable good. Lenders will only lend up to the value of the asset that can be repossessed. The borrowing constraint is thus given as:

$$b'_t \leqslant \frac{m(q_{t+1}X'_t)}{R_t} \tag{3.21}$$

It is assumed, as in Iacoviello (2005), that there is a proportional transaction cost $(1-m)$ on lenders repossessing borrowers' assets. The parameter $m \in (0,1)$ enters the borrowing constraint, as this scales the value of the durable goods stock that can be used as collateral. An increase in m is a reduction in the transaction cost. This parameter change, that can be interpreted as a loosening of the borrowing constraint, will be used later in the analysis[25]. The total amount that can be borrowed is thus the value of the durable good

[24] Accumulated debt is divided by inflation, P_t/P_{t-1}, as it is assumed that debt contracts are set in nominal terms, and thus changes in the price level will affect realized real interest rates, as per Iacoviello (2005).

[25] The value of the durable good holding is divided by the interest rate $R_t = (1 + r_t)$ in the borrowing constraint to take account of interest payments.

holding less the interest payment and the repossession transaction cost.

Entrepreneurs in the model optimize utility with respect to the budget and collateral constraints. The first order conditions for the entrepreneur are as follows:

$$\frac{1}{c_t'} = \varphi\left(\frac{R_t}{c_{t+1}'}\right) + \Lambda_t R_t \tag{3.22}$$

$$\frac{q_t}{c_t'} = \left(\frac{\varphi}{c_{t+1}'}\left(\nu\frac{y_{t+1}}{X_t'} + q_{t+1}\right) + \Lambda_t m q_{t+1}\right) \tag{3.23}$$

$$w_t^{'} = (1-\nu)y_t/H_t^{'} \tag{3.24}$$

The inequality constraint that arises from the borrowing constraint in optimization gives rise to the standard complementary slackness condition:

$$\Lambda_t[m(q_{t+1}X_t') - b_t'R_t] = 0 \tag{3.25}$$

Λ_t is the multiplier on the borrowing constraint. The conditions under which the borrowing constraint binds will be outlined in Section 3. For now, a binding credit constraint is assumed. For the entrepreneur this implies that:

$$u^{'}(c_t') > \varphi\left(R_t u^{'}(c_{t+1}')\right) \tag{3.26}$$

As is standard in the collateral constraints literature, the marginal utility of consumption in period t is greater than the marginal utility of consumption in $t+1$. The financial friction means resources cannot be shifted optimally across time (Thornton, 2009).

The optimization condition for the durable good is also changed with the imposition of the financial friction. In equation 3.23, the first two terms on the right hand side are standard for a durable good, in that the utility from the durable good; which the entrepreneur uses for production, is equal to the consumption utility value of the discounted marginal product in terms of the composite final good, plus the consumption utility value of the resale value in the next period. These first two terms and the left hand side yield the standard result of equalised marginal utility between the two variables at the optimum level. The difference caused by the presence of the financial friction is that the durable good has a collateral value, as shown in the borrowing constraint. There is now an additional benefit to acquiring the durable good; in that it allows a relaxation of the binding borrowing constraint (Andrés et al., 2013).

This collateral effect gain for the durable good will be positive with a binding constraint. It can be seen that the tighter the constraint, the greater the marginal utility of the durable good. The last optimization condition for the entrepreneur, equation 3.24, yields the standard labour demand condition.

3.3 The Borrowing Constraint

As discussed in Leith et al. (2011), in a non-Ricardian economy, such as in an overlapping generation's model, the steady state rate of interest will be above the rate of time preference. This gap between the steady state real rate of interest and the rate of time preference is positively related to the ratio of financial assets to consumption (Ascari and Rankin, 2013)[26]. This general

[26]In a typical perpetual youth model, this feature gives the model the property of a failure of Ricardian equivalence, as an increase in government debt increases the household stock of financial assets. Thus there is a consumption response from the households and so

feature of overlapping generations models in which the steady state real interest rate is not fixed has implications for the lender borrower framework as presented in this chapter. As discussed, in the models of Kiyotaki and Moore (1997) and Iacoviello (2005), the rate of time preference of the most patient agent in the model fixes the level of the real interest rate. As a result of the impatient agent/entrepreneur having a higher discount factor, the real interest rate required for this agent to be indifferent between consumption now and consumption in the future is higher than that of the patient agent, and thus that which prevails in the model. This difference creates the motivation to borrow in these models. The other assumption regarding repudiation provides a basis for a borrowing constraint.

In order for the complementary slackness condition of the borrowing constraint to bind, it must be the case that $\Lambda_t > 0$. The expression for Λ in steady state is derived from the entrepreneurs Euler equation:

$$\Lambda = \frac{1}{c'}\frac{1}{R} - \frac{1}{c'}\varphi \tag{3.27}$$

In a typical infinite horizon collateral constraints model this expression would depend on the relative rates of time preference of the agents. However, in the overlapping generations framework R is a function of variables and is not fixed by the rate of time preference alone. What is required for a binding constraint is an implied R for the impatient agent that is higher than that of the patient agent. This should be possible as given $\varphi \in (0,1)$, the implied R for the entrepreneur can be calibrated to be arbitrary large. However, in order to provide an analytical solution for the conditions required

the increase in debt is non-neutral (Ascari and Rankin, 2013).

to guarantee that the borrowing constraint binds in the steady state of the model an expression for an upper bound value for R is employed. In order to obtain this upper bound, the discrete time version of a result derived in continuous time in Rankin (2014) is utilised. The result in Rankin (2014) is stated as a Lemma and it states that in a closed economy version of the perpetual youth model, a steady state equilibrium cannot exist unless the interest rate is less than a critical value; a ceiling value. This ceiling is determined by the pure rate of time preference and the probability of death of the household sector. This result is derived under the condition that aggregate consumption in steady state is finite; that aggregate consumption cannot be increasing in time. This is because a high interest rate implies consumption increases rapidly with age. In aggregate, this increase would be offset by the death rate and aggregate consumption would be finite. However, if R is too large, aggregate consumption would explode with time.

The result is derived by solving the cohort level household Euler equation. The household Euler equation at $v = t$ is given as[27]

$$C_{s,t} = \beta^{t-s} C_{s,s} \prod_{k=s}^{t-1} R_k \tag{3.28}$$

This is consumption of an individual born in period s at time t. Aggregate consumption is thus:

$$c_t = (1-\gamma) C_{s,s} \sum_{s=-\infty}^{t} (\gamma\beta)^{t-s} \prod_{k=s}^{t-1} R_k \tag{3.29}$$

As in Rankin (2014), it is assumed that $C_{s,s}$ is independent of s. It can

[27] As noted in Mallik (1998), the closed form solution to a first order difference equation with variable coefficients is known.

be seen that the first three terms on the right hand side of this formulation of aggregate consumption are finite, and thus whether aggregate consumption is finite in t, or not, will depend on the second two terms. Aggregate consumption will be finite in steady state if:

$$R < \frac{1}{\gamma\beta} \tag{3.30}$$

Therefore, under the condition of finite aggregate consumption in the steady state R has a ceiling. In order for the borrowing constraint to be binding in steady state is sufficient to assume that:

$$\varphi \leqslant \gamma\beta \tag{3.31}$$

This result can be summarised by:

Proposition 1. *In a Kiyotaki and Moore type collateral constraints model the borrowing constrain will only bind in steady state if the inverse of the steady state interest rate is greater than the rate of time preference of the impatient agent. In a closed economy perpetual youth model, a steady state equilibrium cannot exist unless the interest rate is less than a critical value. Therefore in a model of perpetual youth with a collateral constraint given that a maximum value the interest rate for the existence of steady state can be defined there is a minimum value for its inverse. Given this the rate of time preference of the most impatient agent can be set such that the borrowing constrain will always bind in steady state.*

Proof. The complementary slackness condition for the borrowing constraint yields the steady state condition: $\Lambda = \frac{1}{c'}\frac{1}{R} - \frac{1}{c'}\varphi$. It can be shown that in a closed economy version of the perpetual youth model there is a upper bound on the value of R such that a steady state exits. This is determined by the rate of time preference and probability of death and is given as: $R < \frac{1}{\gamma\beta}$. Substituting this in to the complementary slackness condition it is sufficient to assume $\varphi \leqslant \gamma\beta$ to yield a binding borrowing constraint in steady state. □

This expression contains the condition, as noted in Kiyotaki and Moore (1997), wherein, unlike in the infinite horizon case, in an overlapping generations model, it is not necessary to assume a difference in the rate of time preference between agents in order for the borrowing constraint to bind in steady state. The entrepreneurs will then always want to borrow more at the prevailing interest rate in the model[28]. Taking this assumption; which implies an imposition on the rate of time preference of the entrepreneur, the borrowing constraint will bind with equality in the steady state. The subsequent section will analyse the steady state of the model, as it is the long run effects of a permanent change in the model that are of interest.

3.4 Equilibrium and Steady State

To determine the general equilibrium of the model market clearing is imposed. In the labour market, the wage rate will clear the market, the supply wage from household optimization will equal the demand wage from entrepreneurs'

[28] This is the condition used in the financial frictions models of Kiyotaki and Moore (1997) and Iacoviello (2005).

optimization and labour supply will equal labour demand.

$$H_t = H_t^{'} \tag{3.32}$$

In the goods market the supply of goods is equal to the demand for goods, and equilibrium is given as:

$$y_t = c_t + c_t^{'} \tag{3.33}$$

The stock of the durable good is fixed, and its size is normalised to one:

$$\bar{X} = 1 = X_t + X_t^{'} \tag{3.34}$$

To achieve equilibrium in the credit market, total borrowing must equal total lending:

$$b_t = b_t^{'} \tag{3.35}$$

The steady state occurs when all variables in the model are at their stationary value. It is assumed that in the steady state of this model that there is a constant rate of technological progress, $(A = 1)$. The steady state equations in the model are given as [29]:

$$c + b = wH + Rb \tag{3.36}$$

$$c = \beta Rc - \left(\frac{(1-\theta)(1-\beta\gamma)(1-\gamma)}{\gamma}\right)\left(\tilde{b} + qX\right) \tag{3.37}$$

[29]The equations are the aggregate household budget constraint, the aggregate Euler equation, the first order condition for aggregate household labour supply, the aggregate household first order condition for durable goods holding, the production function, the borrowing constraint, the entrepreneurs consumption Euler equation, the entrepreneurs durable goods first order condition and the entrepreneurs demand for labour condition respectively.

$$\frac{\kappa}{1-H} = \frac{w}{c} \tag{3.38}$$

$$\frac{\theta}{X} = \frac{q}{c} - \beta\left[\frac{q}{c}\right] \tag{3.39}$$

$$y = A(X^{'})^{\nu}(H^{'})^{1-\nu} \tag{3.40}$$

$$\tilde{b}' = mqX' \tag{3.41}$$

$$\frac{1}{c'} = \varphi\left(\frac{R}{c'}\right) + \Lambda R \tag{3.42}$$

$$\frac{q}{c'} = \left(\frac{\varphi}{c'}\left(\nu\frac{y}{X'} + q\right) + \Lambda mq\right) \tag{3.43}$$

$$w' = (1-\nu)y/H' \tag{3.44}$$

$$\tilde{b} = (1+r)b \tag{3.45}$$

3.5 The Borrowing Constraint and the Interest Rate

The change in the interest rate resulting from a change in the tightness of the borrowing constraint is analysed through the steady state of the model. Following on from the entrepreneurs steady state first order condition with respect to the durable good, the multiplier on the borrowing constraint can be written as:

$$\Lambda = \frac{1}{c'm} - \frac{\varphi\nu y}{c'mqX'} - \frac{\varphi}{c'm} \tag{3.46}$$

Given the presence of the assumptions regarding the discount factors, the borrowing constraint binds, $\Lambda > 0$, it can be seen that in terms of a partial derivative the change in Λ with respect to m is negative. As $(1-m)$ is the transaction cost, an increase in m reduces this cost, thus loosening the borrowing constraint, and thus it would be expected that the financial friction in the model would be reduced. Following Pinheiro et al. (2013), a change in the parameter m is interpreted as a summary of potential factors constraining borrowing and lending between agents. From the borrowing constraint below it can be seen that borrowing rises with a change in m in proportion to the value of the entrepreneurs' holding of the durable good:

$$\tilde{b}' = mqX' \tag{3.47}$$

From market clearing as the entrepreneurs' borrowing increases, the lending of the household sector will also increase. Also, combining the entrepreneurs' first order condition for the durable good, with their first order condition for non-durable consumption, it can be shown using the assumptions regarding the maximum value of R and the entrepreneurs' discount factor, that the value of the entrepreneurs' holding of the durable good is decreasing in m[30]. When m increases and the constraint is loosened, the durable goods collateral value is reduced, and thus entrepreneurs reduce their holding of the good.

In terms of the context in the broader literature it is worth noting that this result of a reduction in the holding of a production input with a relaxation of the borrowing constraint is in contrast to another strand in the financial frictions literature, as outlined in Hall (2012) and Hall (2013) which follows Chari et al. (2007). In this literature the concept used for the financial friction is one of combining frictions from a number of potential sources and the entering of these frictions into the model as a wedge between the return to businesses from the use of physical capital and the risk free interest rate (Hall,

[30] This result is noted in Andrés et al. (2013); that in the presence of a collateral constraint entrepreneurs over-invest in the durable goods in order to smooth consumption.

2013). In Hall (2012) and Hall (2013), this concept is modelled as a tax. This is on the same conceptual basis as the investment wedge approach as used in Chari et al. (2007). In Hall (2012) and Hall (2013), the analysis in relation to the financial friction is empirically focussed, and borrowing limits and the investment wedge are assumed and are exogenous. It can, however, still be compared to the model in this chapter. If, in the entrepreneur's sector, utility from consumption is assumed to be linear and the friction is set to zero, $\Lambda_t = 0$, then the optimization conditions yield:

$$R_t = \frac{\varphi}{q_t}\left(\nu \frac{y_{t+1}}{X_t'} + q_{t+1}\right) \tag{3.48}$$

This, aside from the absence of depreciation, is the same as one of the key expressions in the model with financial frictions set equal to zero, as presented in Hall (2012). The difference in the dynamics of the productive asset to a relaxation of the borrowing constraint in the Hall (2012) and Hall (2013) papers and the model in this chapter, is that due to the differing effect of a positive financial friction between the two models in the above expression. In Hall (2012) and Hall (2013), the friction, as defined by an investment wedge, means that the return to capital is higher than the real interest rate. In this chapter, as stated, and as in Iacoviello (2005) and Andrés et al. (2013), the presence of the friction adds to the value of the productive asset in the form of a collateral value, and thus the return to capital will be lower than the interest rate. Therefore, the holding of this asset will respond in opposite directions to a relaxation of the constraint in each modelling approach. It will be shown that, given the assumptions of the model, this difference is not relevant to the interest rate analysis.

In relation to other approaches to modelling financial frictions, another finding of Chari et al. (2007) is that financial frictions, as modelled by a costly state verification approach in Bernanke et al. (1999) or a credit market frictions model such at Carlstrom and Fuerst (1997), are equivalent to their model; a growth model with an investment wedge. This finding links these approaches to the Hall (2012) and Hall (2013) approach and the collateral constraints framework employed in this chapter.

3.5.1 The Interest Rate

Turning to the interest rate, the aggregate euler equation gives an expression for its steady state level.

$$R = \frac{1}{\beta} + \frac{1}{\beta}\left(\frac{(1-\theta)(1-\beta\gamma)(1-\gamma)}{\gamma}\right)\left(\frac{\tilde{b}}{c} + \frac{qx}{c}\right) \tag{3.49}$$

As already noted in the infinite horizon case, with the probability of survival equal to one, this equation reduces to the standard condition that the steady state interest rate is equal to the reciprocal of the discount factor. From this equation, it can be seen that the steady state interest rate will depend on the real amount of borrowing and the holding of durable goods per unit of consumption. With the presence of a durable good the intercept value is different from that found in more standard perpetual youth models. The intercept will be larger for a positive holding of the durable good, and will be a function of more parameters than just the household discount factor.

From the aggregate version of the households' first order condition for the durable good, it can be shown that:

$$\frac{qx}{c} = \left(\frac{\theta}{1-\beta}\right) \tag{3.50}$$

The ratio of the value of durable to non-durable consumption is fixed by the preference parameter and the discount factor. Substituting this result into the aggregate Euler equation simplifies the analysis of a change in the financial friction on the steady state level of the interest rate. As has been shown, the entrepreneurs' holding of the durable good changes in the parameter m, and this change could have introduced another dynamic to the aggregate Euler equation, through the market for durable goods, that would have changed the interest rate. This fixed ratio simplifies the analysis.

Another implication of this feature of the model is related to another concept of the financial friction as used by Hall (2014) and Chari et al. (2007). As already noted, this literature gives the opposite prediction for the change in a factor of production in response to a change in the financial friction. That the ratio between the value of durable and non-durable consumption is fixed also avoids this complication, and allows a focus on the change in borrowing only. This permits the result to be thought of in more general terms as the main impact of a tightening of the borrowing constraint in a broad range of financial frictions models is that borrowing will decrease, the issue of changes in the holding of the durable good is abstracted from.

The change in the steady state interest rate in the model from a change in m will, therefore, be determined by the ratio of households' financial assets to consumption only. From the steady state conditions:

$$c = wH + mqX'\frac{\omega}{1-\omega}(1 - 1/R) \tag{3.51}$$

$$\tilde{b} = mqX'\frac{\omega}{1-\omega} \tag{3.52}$$

In the model, households cannot hold negative amounts of the durable good, and will not on aggregate borrow in steady state. Therefore, the lower bound value on R in steady state is the reciprocal of the discount factor, $\beta < 1$. Given that the ratio of the real level of borrowing to consumption in steady state will increase in m, this suggests that R will increase with an increase in m.

3.6 Results

In analysing the results of the model the strategy that is adopted it to reduce the steady state equations of the model into two curves and to illustrate diagrammatically the relationship between assets and the interest rate. With the key relationships illustrated in this way the response of the model to changes in key parameters is then outlined graphically again with assets and the interest rate on the respective axies. We begin by combining equations 3.51 and 3.52 with the other steady state equations. This yields an expression for the ratio of households' financial assets to consumption as a function of the interest rate:

$$\frac{\tilde{b}}{c} = \frac{m}{\left(\frac{1-\nu}{\varphi\nu}\right)(1 - \varphi - m(1/R - \varphi)) + m(1 - 1/R)} \tag{3.53}$$

From this equation, it can be shown that the change in the ratio of households' financial assets to consumption is negative with respect to an increase in the interest rate R. This result, given a reasonable range of values for R[31], does not rely on any additional parameter restrictions in addition to those already stated. It is also the case that this equation confirms the positive relationship between a change in m and a change in the assets to consumption ratio. This relationship again is not reliant on any further assumptions on parameters.

In addition to analysing the sign of the relationship between the variables and parameters, it is also of interest to examine changes in magnitudes of these relationships. The relationship between $\frac{\tilde{b}}{c}$ and m is positive. Using the quotient rule, it can also be shown that given the restrictions on parameter values required to ensure a non-explosive steady state there is a positive and convex relationship between these two variables for realistic values (non-negative) of R.

The result indicates that, given the parameter assumptions made in the model, changes in m have a greater impact on the financial assets to consumption ratio at higher levels of m. Given that an increase in m reduces the financial friction, this result indicates that economies with an initial condition of a looser financial friction will experience a sharper fall in $\frac{\tilde{b}}{c}$, and thus in the interest rate with a tightening of the financial friction.

Turning again to the relationship between R and the financial assets to consumption ratio, it can be shown that this relationship; whilst negative, is strictly convex for a reasonable non-negative range of values for the interest rate. It is also of interest to note that the limit of the ratio as R tends to

[31]It should be noted that as $R = 1 + r$, this permits a broad range of values for the real interest rate. The convex relationship in m is shown in Figure 3.1.

infinity is a positive constant:

$$\lim_{R \to \infty} \frac{\tilde{b}}{c} > 0 \tag{3.54}$$

This limit result applies without any additional parameter restrictions. These results can be used along with the steady state aggregate Euler equation to sketch the relations among variables. This is shown in Figure 3.2

In Figure 3.2, the equation relating the interest rate to the financial assets to consumption ratio is labelled BC, and the aggregate Euler equation is labelled EE. In order to be consistent with a non-explosive steady state, this line (EE) will have an upper bound. It should be noted that the intercept value of the aggregate Euler equation is determined by a restricted set of parameter values, as some value choices will violate the restriction on the value of R required for steady state. In particular, it is sensitive to the choice of taste parameter on durable and non-durable consumption. While this taste parameter, θ, must not be large, the steady state condition does not restrict it to an unrealistic range of values. The restriction on the level of this variable is found to be reasonable, as selecting a value for this parameter at the calibrated value chosen in Iacoviello (2005), $\theta = 0.1$, satisfies the condition. The diagram shows a reduction in parameter m. This is interpreted as a tightening of the financial friction which will reduce the financial assets to consumption ratio for any given interest rate and thus lead to a lower interest rate. This is shown in Figure 3.2 as a shift in the curve from BC to BC^*, and a change in equilibrium from A to A^*. This result can be summarised as follows:

Proposition 2. *In a perpetual youth model with a Kiyotaki and Moore type* *collateral constraint a tightening of the financial friction reduces the demand for credit. Through credit market clearing this reduces the households holding of credit. As the interest rate in the model is a function of the holding of credit of the households this increase in the financial friction has the effect of reducing the steady state interest rate.*

This is a key result in the paper as it links a credit market disruption to a lowering of the steady state rate of interest. This is absent the population ageing or slowing productivity explanations seen in the literature in this area (Summers, 2014). It is particularly important as this "lower for longer" feature of interest rates is something that has been a very important phenomenon across a number of economies since the financial crisis (Williams, 2014). Much of the literature on episodes of persistently low interest rates to this point had indicated these were low probability events. This theoretical results provides a possible explanation as to why this "low probability event" has been observed with such persistence since the global financial crisis.

The non-linear relationship between $\frac{\tilde{b}}{c}$ and m has another implication in that for the same observed interest rate, there could be a scenario where, if there are factors which reduce the slope and intercept of the EE curve, shifting down and flattening the line, then in a situation of low financial friction, this may increase the probability of the occurrence of problems of a persistent low interest rate due to the convex relationship highlighted in Figure 3.1. This scenario is presented in Figure 3.3. In this figure, this downward shift of the EE curve to EE^* could occur due to an increase in the probability of the survival parameter. If this occurs simultaneously with a reduction in the financial friction; a shift to the right of the BC curve to BC^*, it is possible to arrive at a new equilibrium point to the right of the original equilibrium; point A, with the same interest rate, shown as R^*, but with a higher debt level. At this new point, a bigger shift in the interest rate would occur from a change in m at the same initial interest rate. This could be thought of as two different economies with the same interest rate, but one would experience a bigger fall in the steady state interest rate given an increased financial friction.

In the model presented the steady state interest rate is shown to be determined by fixed parameters and ratios of variables; household real lending/financial assets to consumption and the value of households durable goods holdings to consumption. Given the specification of the utility function and the separability of durable and non-durable consumption in the steady state, the second ratio is fixed, and thus the fact that changes in the financial friction impact the market for durable goods in the model has no effect on the household's ratio of durable to non-durable consumption. The variable ratio of interest is thus household real lending/financial assets to consumption.

With an increase in m, entrepreneurs in the model have the opportunity to borrow more, and given the assumptions made regarding discount factors, they will increase their borrowing when possible. With credit market clearing households lending/financial assets increase, and as demonstrated previously, the ratio increases. This increases the steady state interest rate. The interest rate is bounded from above under the condition of the existence of a stable steady state level of consumption. Given that the relaxation of the borrowing constraint raises borrowing in the model, and this raise in borrowing raises the interest rate, the result is similar to that found in the pertpeual youth litrature in that there are real effects in a non-Ricardian economy; although from a different source. In the aforementioned litrature, it is a government debt increase that raises the interest rate by adding to households' net wealth. The direction of the response of the steady state interest rate to the borrowing constraint also matches that in the Bewley model of Guerrieri and Lorenzoni (2011), and the three generation overlapping generations model of Eggertsson and Mehrotra (2014). A summary of the model dynamics is similar to the supply and demand, asset market equilibrium diagram presented for the basic model of Eggertsson and Mehrotra (2014). In typical collateral constraints models, the credit market, in the steady state, can be thought of as one characterised by an perfectly elastic supply curve. In the Eggertsson and Mehrotra (2014) model, as in the model presented here, there is a supply and demand for credit and a tightening of the constraint leads to a drop in demand for credit. This shifts the demand curve downwards. In equilibrium, the steady state real interest rate will be lower. This market structure is presented in Figure 3.4. The advantage of this paper over these models is that this result, which is important in the context of the financial crisis and its aftermath, is found analytically with a simple extension to a benchmark macroeconomic model without recourse to computational methods.

The model also indicates that a tightening of the financial friction leads to a bigger fall in the interest rate when the economy is in a situation where the financial friction is relatively low. This result parallels a result from a more short run analysis as in Pinheiro et al. (2013), which finds that the magnitude of the response to shocks can rise and fall depending on the level of financial frictions present.

As per Figure 3.3, the model indicates that it is possible to have a scenario where, if there was simultaneously a relaxation of the financial friction in the economy; for example from a process of financial development as in Pinheiro et al. (2013), and a process of a reduction in the probability of death; for example population ageing, this would lead to a situation of an economy with the same steady state interest rate, but with a higher debt level. This economy would be vulnerable to a greater fall in the interest rate from tightening of the financial friction. This scenario involving a change in the probability of survival holding down the interest rate is in line with a hypothesis promulgated in Summers (2014). It may also point to a factor to be considered in the literature on the probability of the occurrence of persistent low interest rates, as discussed in Williams (2014).

3.7 Conclusions

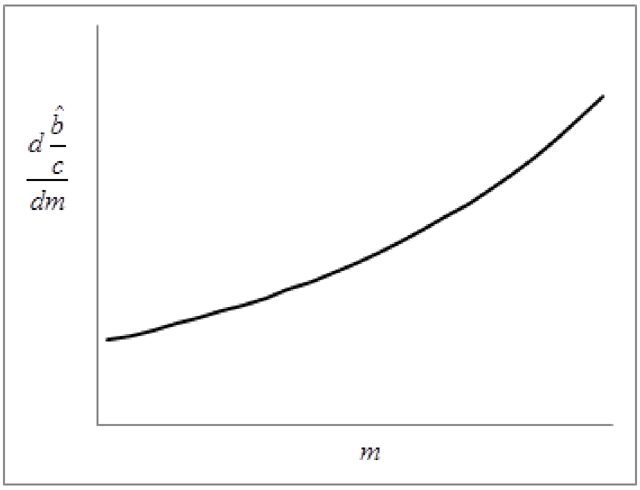
This chapter began with the observation that, although a vast literature had developed, particularly since the financial crisis, on the analyses the role of financial frictions in macroeconomic models and also on the features of macroeconomic models whereby the policy interest rate would be persistently low, there were comparatively few papers which analysed the link between financial frictions and the underlying interest rate. The main contribution of this chapter was to show that, using a basic and tractable benchmark macroeconomic model and a benchmark financial frictions model, there was an analytical link between these two phenomenon's.

To this end, in this chapter, a model was proposed that provided an endogenous theoretical framework for the impact of financial frictions on the steady state interest rate. The model presented was a perpetual youth type overlapping generation's model with financial frictions in the form of collateral constraints. This model replicated the basic result of more complex and numerically simulated models, and demonstrated that a tightening of the financial friction generated a fall in the steady state interest rate. The model also highlighted a non-linearity in this relationship, and discussed how this result had relevance for the literature on the ZLB and secular stagnation.

Guerrieri and Lorenzoni (2011) stated that this basic result may explain why recessions driven by financial market trouble are more likely to be accompanied by zero lower bound issues. Given that the model proposed in this chapter sees a fall in the interest rate from financial frictions, and that a major consideration of the zero lower bound literature is the size of fiscal multipliers in a situation where the interest rate is low, a promising direction for future research could be to provide an analytical solution to the size of fiscal multipliers in the model.

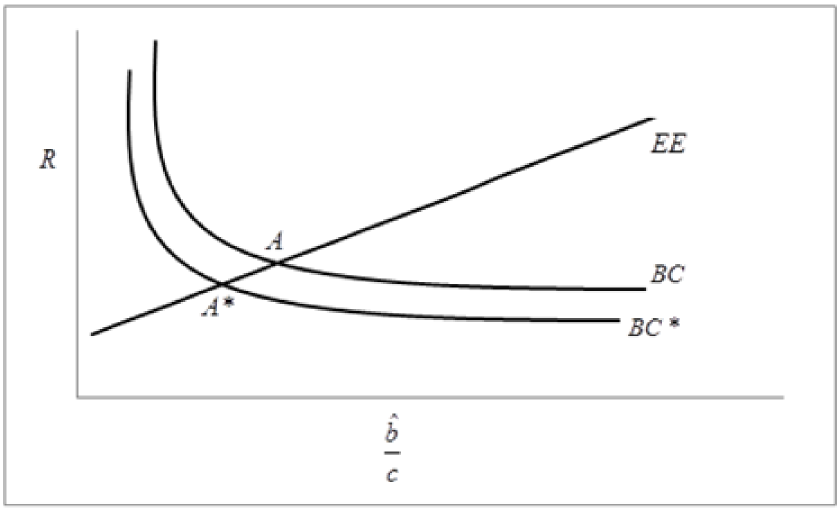
3.8 Chapter 3 Appendix

Figure 3.1: $\frac{\tilde{b}}{c}$ and m



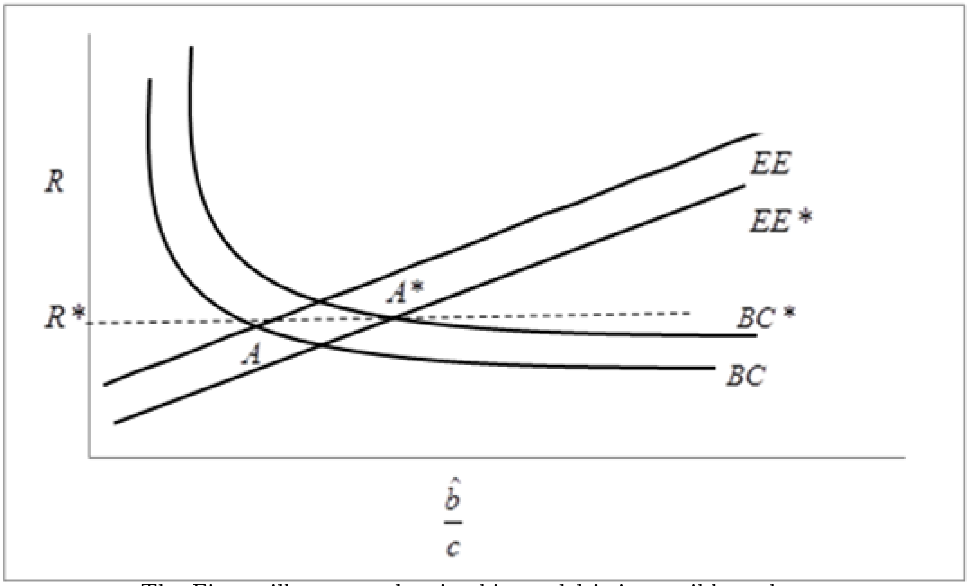
This Figure shows the convex relationship between a loosening of the borrowing constraint and the change in the ratio of borrowing to consumption per unit change in the repossession cost (m), which loosens the borrowing constraint. This derivative is increasing in the value of m.

Figure 3.2: Interest Rate and Assets



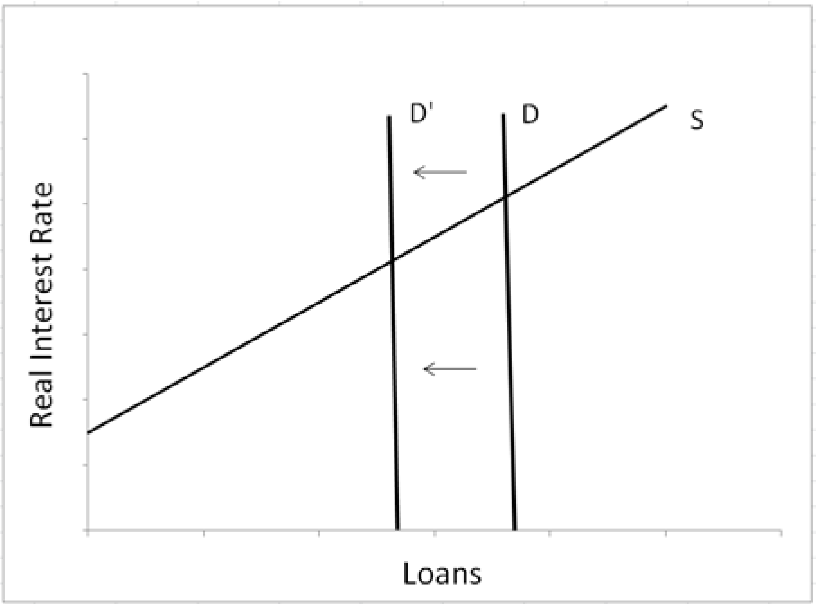
The Figure shows the impact of a tightening of the financial friction on the level of the interest rate, a move from A to $A*$. The x-axis shows the ratio of financial assets to consumption.

Figure 3.3: Change of Equilibrium



The Figure illustrates that in this model it is possible to have an economy with different parameter values but with the same observed interest rate. In this state the economy with the higher assets to consumption ratio will be move vulnerable to problems of a persistent low interest rate.

Figure 3.4: Equilibrium in the Asset Market



The Figure shows the credit market structure suggested by the model. A tightening of the constraint leads to a drop in demand for credit and so a lower steady state real interest rate.

Chapter 4

The International Impact of Financial Shocks: A Global VAR and Connectedness Measures Approach

4.1 Introduction

This chapter focuses on three prominent issues, who's importance was underscored by the 2008 global financial crisis, firstly; the intensification of global linkages, secondly the importance of credit cycles and macro-financial interactions and thirdly the recognition that better measures of stresses in the financial system were needed. The chapter will draw together the theoretical and empirical insights from these three separate research areas into a framework which will allow the interactions between global linkages, credit cycles and financial stress to be explored. The empirical approach will provide a means to distinguish the most influential measures of financial disruptions in the global economy. The methodologies that will be employed will be the GVAR framework as developed by di Mauro et al. (2007), henceforth DdPS (2007), and the Generalised Connectedness Measures framework as outlined in by Greenwood-Nimmo et al. (2015). These provide a flexible methodology and are particularly suited to the questions addressed in this chapter.

The contribution of this chapter is threefold; firstly the chapter apples the connectedness measures approach of Greenwood-Nimmo et al. (2015) to rank the global influence of an array of measures of financial frictions and financial stress. This application of the methodology is an advancement on the work of Greenwood-Nimmo et al. (2015) as they apply the connectedness measures developed in their paper to a baseline GVAR model which is absent of financial shock measures. The connectedness methodology is particularly suited to the analysis of financial frictions and financial stress as it does not require onerous structural assumptions. In addition to this the methodology allows this ranking analysis to be broken down to the country and variable level. The second contribution is that in building towards these results the analysis proceeds in a way that further reduces the number of assumptions used in the estimation. Specifically the model is based on stationary time series and generalised impulse response functions. As opposed to previous studies[1] the model is not sensitive to the identification scheme used or the co-integrating relationships specified, as these do not need to be defined in the model. The approach taken, which is a departure from the GVAR methodol-

[1]See for example, Xu (2012), Eickmeier and Ng (2011), Guarda and Jeanfils (2012), Sanjani (2014), Goodhart and Hofmann (2008) and N'Diaye et al. (2010)

ogy that is standard in the literature, is particularly advantageous given that when including financial variables in a multi-country macroeconomic model the theoretical guidance for the appropriate structure to be employed is often unclear. This is also the case in relation to the nature of the long run relationship between the vast array of financial and the standard macroeconomic variables and so would complicate a co-integration based model. Thirdly, in terms of the contribution, further to dealing with the uncertainty as regards the interactions of the variables there is also a large degree of uncertainty regarding the macro-financial relationships among countries, especially between advanced and emerging market economies. This chapter contributes to the modelling of these interactions as the methodologies employed provide a way to characterise the strength of the influence and dependence among countries without heavy reliance on structural assumptions.

The focus of this chapter is on the international impact of financial shocks. As regards the previous literature this research area contains a relatively limited number of empirical papers, this is due to the necessary high dimension of this type of analysis (Eickmeier and Ng, 2011). In the literature two broad approaches to dealing with the dimensionality issue in international economic dynamics have been developed, the GVAR approach and the factor augmented VAR (FVAR) approach (Eickmeier and Ng, 2011). In this chapter the GVAR approach, which is outlined in the next section, is used as it allows country specific dynamics to be explicitly modelled and the weights for foreign variables are data, not statistically, based (Eickmeier and Ng, 2011). The ability of the GVAR approach to model at the country level is an important feature as it allows a wider range of issues such as the strength of country specific financial linkages to be estimated (Bijsterbosch and Falagiarda, 2014). The GVAR model is built up from VAR models and in the context of the analysis in this chapter the VAR based approach is particularly advantageous when analysing financial stress as it provides a rich representation of the complex potential interactions (Borio and Drehmann, 2011). The estimation results of the GVAR model will form the basis for construction of the connectedness measures.

Our results indicate that variables which proxy for the concept financial friction as in the Bernanke et al. (1999) model are the most influential sources of financial shocks. This result holds both at the global level and at the level of most individual countries. It is also found that the credit variable is not an influential source of shocks but is more influenced by other financial shock variables, suggesting that credit is likely to be less accurate as a measure of changes in financial constraints than some of the more direct measures as outlined in this chapter. This may be because credit is likely to be influenced by a number of variables both direct financial constraints on the supply side and a number of demand side factors and so the presence of the friction could be diluted in this measure. This is contrary to much of the existing literature which gives a central role to analysing shocks to different measures of the quantity of credit in analysing the propagation of financial distress.

The remainder of this chapter is structured as follows; the next two subsections will provide firstly; an overview of the literature related to the three issues that will be analysed in this chapter and secondly; the existing empirical literature and how this literature informs the empirical approach. Section 2 will outline the empirical strategy. Section 3 will detail the empirical methodology. Section 4 will describe the data, the variables and the model used in the analysis. Section 5 will present the results and Section 6 will conclude.

4.1.1 Literature and Motivation

This chapter will draw together three important themes in the macroeconomic literature, the first theme is that of the intensification of global financial linkages. As discussed in Lane (2012) there have been substantial changes in the global financial system since at least the 1980's. A major feature is that many markets have undergone a process of financial integration (Sgherri and Galesi, 2009). One measure of the scale of cross-border financial integration is the sum of foreign assets and foreign liabilities as a ratio of GDP, the international financial integration (IFI) ratio, (Lane, 2012). This ratio has increased from 68.5 percent in 1980 to a peak of 438.2 percent in 2007, before the financial crisis (Lane, 2012). Further to this Ciccarelli et al. (2012) states that in the past quarter of a century, global trade flows have grown at a much faster rate than world output and the volume of global financial flows has grown even faster than global trade [2].

This greater degree of financial integration and the better functioning financial intermediaries have been found, in general, to be associated with improved growth opportunities (Xu, 2012). This process does, however, have potential costs as well as benefits. While it has the potential to smooth the response of income to asymmetric shocks through cross-border asset diversification, these cross-border links may also expose financial institutions to

[2] Taking world gross external assets relative to world GDP as a measure of financial flows and comparing it to world trade to GDP in 1980 global financial flows and global trade were roughly equal at approximately a quarter of world GDP (Haldane, 2014). However, by 2010 global financial flows had grown to be nine times larger than global trade (Haldane, 2014)

shocks in an array of segmented markets and countries (Metiu et al., 2015). The increase in cross-border financial linkages could potentially allow these shocks to be transmited internationally more easily such that in a situation of low global financial integration. This dynamic is termed the "international finance multiplier" in Metiu et al. (2015).

These financial shocks have the potential to spillover to the real side of the economy. This has been evidenced by the 2008 global financial crisis with sharp drops in output and employment, heavy credit losses, falls in stock markets, increased volatility and a rise in risk aversion (Stock and Watson, 2012), (Ciccarelli et al., 2012). There was also a strong transmission to emerging market economies (Ozkan and Unsal, 2012), (Adler and Mora, 2012).

In relation to the second issue highlighted by the global financial crisis, that of the importance of macro-financial linkages and credit, on the theoretical side, as noted in Goodhart and Hofmann (2008), many modern macroeconomic models contained no banks, no borrowing and no risk of default. As a result of this credit aggregates and asset prices played no role in the dynamics of these models [3]. The financial crisis changed the perception that macro-financial linkages were of a lesser importance, as observed in Stock and Watson (2012), the shocks that produced the financial crisis were primarily financial disruptions. As a result of this, the link between financial distress and real outcomes that operate through capital, credit and/or liquidity has been repositioned as a major theme in macroeconomics and this literature has rapidly developed (Brzoza-Brzezina et al., 2013). On the theoretical side this literature developed from a line of research in macroeconomics that gives

[3] Chari (2011), postulates that this is likely due to a long period of financial stability experienced in many advanced economics up until the 2008 crisis.

a central role to financial frictions and assumes that insolvency, high debt burdens, bankruptcy, asset price fluctuations, and bank failures are not just features of a declining economy, but major instigating factors (Iacoviello, 2005) [4].

The third issue that will be integrated into the analysis in this chapter is that of measuring stresses in the financial system. There is a large array of newly proposed measures of financial stress, the number of which have expanded rapidly since the financial crisis (Giglio et al., 2015). The large number of indicators that have been developed is in part in response the lack of proper indicators of financial instability available to policy makers both before and during the financial crisis (Kliesen et al., 2012). Some of these policy makers now have a legal obligation to manage financial stress; the Dodd Frank Act created a Financial Stability Oversight Council and an Office of Financial Research (Bisias et al., 2012). The directive of these institutions necessitates the prompt measurement of financial risk (Bisias et al., 2012). The large number of indicators is also due to the fact that financial stress is an unobservable latent condition and consequently there are many alternative ways to construct measures of it (Kliesen et al., 2012). Another issue in developing measures is the relative infrequency with which systemic financial shocks occur. This, coupled with the limited time span of financial data,

[4] At present, broadly speaking, there are three main strands in the literature on incorporating financial frictions; each of which is based on introducing an agency problem between borrowers and lenders (Gertler and Kiyotaki, 2010). These mechanisms are cash-flow constraints, as detailed in Bernanke et al. (1999), collateral constraints, as detailed in Kiyotaki and Moore (1997), and constraints on the supply of external funding through financial intermediaries, as detailed in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). The three approaches are differentiated by the mechanism used to generate the financial friction (Brunnermeier and Sannikov, 2014). The common feature among the models is the presence of a financial accelerator mechanism; where endogenous forces in credit markets amplify and propagate shocks to the real economy (Brunnermeier and Sannikov, 2014).

makes identifying patterns and developing useful empirical and statistical indicators of financial crisis difficult (Bisias et al., 2012). On the importance of these measures, Bisias et al. (2012) outline circumstances in which improved techniques for measuring threats can significantly reduce the likelihood of macro-prudential policy mistakes.

Many of the issues highlighted are interrelated and, given the proliferation of theoretical and empirical contributions, involve potentially complex interactions between a broad set of variables. The analysis will necessarily be cross-country in nature owing to the internationalisation of the financial system, as discussed. This chapter adopts the GVAR and GCM approach as it is particularity suited to quantify these complex and uncertain relationships.

4.1.2 Existing Empirical Literature

The traditional GVAR approach as outlined in Pesaran et al. (2004), henceforth PSW (2004), and DdPS (2007) was constructed primarily to analyse the impact of foreign influences on national and regional economies (Garratt et al., 2012). This approach was developed as analysing global interactions and the impact of foreign variables on national and regional economies with a standard macroeconometric approach quickly becomes infeasible due to the large number of parameters to be estimated relative to the data series available (Garratt et al., 2012). The GVAR approach proposes a solution to this problem of modelling an array of economies in a consistent way through the construction of separate measures of foreign variables for each national economy or region in the model. These country specific foreign variables summarise the influence of all external variables on a particular economy (Garratt et al., 2012). Each of the foreign variables is constructed by weighting, typically according to trade data, the importance of that variable in other countries to a particular economy, so all influences are contained in a single variable (Garratt et al., 2012). This approach of summarising the foreign influences substantially reduces the number of parameters to be estimated.

There have been a number of recent studies that have utilised this GVAR methodology in studies on cross country financial linkages. Sgherri and Galesi (2009) use a 27 country GVAR model to analyse the time profile of the cross-country transmission of financial shocks. The countries covered in the analysis are European Countries plus the United States (US). The shocks analysed are equity shocks which emanate from the US[5]. They find that asset prices are the main transmission channel in the short run with cost and quantity of credit being longer term determinants. These conclusions are reached using generalised forecast error variance decompositions (GFEVD). It is found that for US variables' real equity prices explain most of the forecast error variance in the short run with real credit growth and real GDP growth becoming more important over time. They also find significant co-movement of equity prices and country specific credit effects. There is, however, an ordering of regions and the strong co-movement result does not hold for emerging European regions. This is taken as an indication of their low degree of financial integration with the rest of the world [6].

Xu (2012) employs a GVAR containing financial and real variables to

[5] This analysis is done using monthly data over the years 1999-2008.

[6] Sgherri and Galesi (2009) use an alternative weighting scheme for the country-specific foreign variables. The weighting scheme they employ is constructed by bilateral bank lending exposures from consolidated foreign claims data as opposed to the trade based weights typically used in GVAR analysis.

investigate the international transmission of a negative shock to the level of US credit and the role of credit in explaining business cycle fluctuations. The paper analyses a general decline in credit and does not identify it as a supply or demand side effect. The paper adds a bank credit variable, in levels, to a standard GVAR model[7]. It is found that there are strong spillovers internationally of a shock to US credit, with a particularly strong impact on the UK. The model predicts a fall in the short term interest rate in response to a credit shock. As in Sgherri and Galesi (2009) it is found that there are strong international impacts from a shock to US real equity prices. The inclusion of the credit variable is found to provide a significant improvement in the sample fit of the country-specific models, particularly for advanced economies [8]. The paper also highlights the importance of bank credit as an explanatory variable for growth, inflation and long term interest rate changes. Following the GVAR framework Eickmeier and Ng (2011) analyse the transmission of credit supply shocks in the US, the Euro area and Japan to other economies[9]. It is found that a negative credit supply shock to the private sector has a strong adverse effect on the domestic economy of the US and that this shock also propagates internationally. As in Xu (2012) there is a strong impact on the UK. Credit supply shocks in the model are identified by sign restriction [10].

Chudik and Fratzscher (2011) analyse two hypotheses for the global spread of the 2008 financial crisis, the liquidity hypothesis and pricing of risk hy-

[7] The analysis covers of 26 countries and is conducted quarterly over the years 1979 to 2006, just prior the global financial crisis.

[8] The importance of the credit variable is found to be related to the depth of the banking sector in each country, where credit to the private sector is taken as an indicator of banking development.

[9] The sample is expanded from that in Xu (2012) as it covers 33 countries and extends from 1983 to 2009, covering the beginning of the financial crisis.

[10] Financial weights are used in the model and it is found that these weights allow a better fit of the model to the data than the trade weights typically used.

pothesis. To test the significance of these two transmission channels a GVAR model is used with shocks to liquidity conditions and the risk appetite. In their analysis shocks originate from the US and those to liquidity are measured via the TED spread with risk appetite shocks measured from the US VIX index. The authors draw on the literature on the time-varying risk of economic disaster and its impact on the business cycle and asset prices to identify the shocks. It is found that liquidity shocks were more important in advanced economies while the decline in the risk appetite was more important for emerging economies and had a stronger impact on EU economies than other advanced countries. It was also found that the importance of US specific shocks on foreign equity markets roughly doubled in importance during the crisis.

On the inclusion of financial stress measures, Dovern and van Roye (2013) combine a GVAR model and a financial stress index[11]. Their financial stress measures are constructed using the assumption that the financial stress of a market is related to the volatility in that particular market (Dovern and van Roye, 2013). The measures are calculated for the banking sector the bond market and the foreign exchange market (Dovern and van Roye, 2013). They find that financial stress indicators display strong co-movement, especially in financially open compared to financially closed countries and that there is an increasing trend in the cross country correlation of their financial stress measures, indicating increased international financial integration. As in other studies it is found that US financial stress transmitted internationally and with a persistent negative effect on output.

[11] This is calculated from a dynamic factor model for 20 countries, at monthly frequency, from 1970 to 2012.

Still looking at the question of cross-country financial linkages in the context of financial stress and financial frictions measures but not using the GVAR framework Metiu et al. (2015) analyse the role of financial frictions in facilitating the international propagation of US financial shocks[12]. The risk premium on US corporate bonds is used to proxy the financial friction and the data used is from the IMF stress index data set. The empirical results show that a positive shock to US financial frictions leads to a tightening of global financial conditions (Metiu et al., 2015). This is seen as a strong increase in uncertainty, proxied by an increase in global stock market volatility. The rise in the friction also leads to a global output contraction (Metiu et al., 2015). The results also maintain that the global corporate bond market is an additional transmission mechanism through which US financial shocks propagate as global corporate bond spreads rise significantly following the rise in US financial frictions.

In relation to studies focusing specifically on financial frictions measures, which are an important variable in the theoretical literature, there have generally been based on analysing a single country. In a study of the US which focuses on financial shocks, Sanjani (2014) hypotheizes that risk premiums are the central link between credit markets and the real side of the economy. Sanjani (2014) postulated that this is observable through the external finance premium. The paper uses Bayesian estimation with a vector autoregression and New Keynesian models to analyse the interaction between the real business cycle and the credit market. Sanjani (2014) decomposes the credit spread into a default risk spread and a liquidity risk component. The results show

[12]This is preformed using a two-region threshold vector autoregression on monthly data covering the years 1984 to 2012.

that both the liquidity and default components of the credit spread are countercyclical. It is also shown that while default spread risk shocks have a large impact, a shock to liquidity risk has a more severe economic impact.

Specifically analysing the interaction between corporate bond credit spreads and economic activity in the US Gilchrist and Zakrajsek (2012) construct a credit spread index and find it to be a powerful predictor of economic activity. Then the index is constructed from firm level data and decomposes the spread into two components. These two components are the expected defaults which move in a countercyclical way and the excess bond premium, which represents cyclical deviations in changes in the relationship between default risk of the issuer and the pricing of their corporate bonds (Gilchrist and Zakrajsek, 2012). This decomposition shows that the changes in the excess bond premium are driven by shocks to the profitability of leveraged financial intermediaries. This can be thought of as a measure of credit supply conditions[13]. The results show that a reduction in credit supply, from a change to the excess bond premium, has significant adverse macroeconomic consequences including a fall in asset prices. The result supports the theoretical predictions of a financial accelerator mechanism, from the financial frictions literature (Gilchrist and Zakrajsek, 2012) [14]. In keeping with this result on the importance of uncertainty for macroeconomic activity Ludvigson et al. (2015) find that, by using two constructed instrumental variables to first "disentangle" uncertainty shocks from shocks to real activity and secondly

[13]The predictive power of the indicator is reliant on the this component of the index (Gilchrist and Zakrajsek, 2012).

[14]There is also an observed comovement between the excess bond premium and the profitability of the US corporate sector and also the CDS spread (Gilchrist and Zakrajsek, 2012).

to disentangle macroeconomic uncertainty shocks from financial uncertainty shocks, there are strong effects from this financial uncertainty variable.

In terms of the financial stress indexes in Lall et al. (2009) these measures are used to identify periods of financial stress, to assess the impact of financial stress on the macroeconomy and to try to determine why some periods of financial stress lead to a major downturn and some do not. The analysis does not attempt to determine causality from financial variables to economic contractions but rather to provide a broad coverage of the potential channels and mechanisms through which financial stress affects the economy. On the accuracy of the financial stress measures, it is found using an event analysis based off the historical record of financial stress episodes that the measures are quite robust in capturing the main financial stress events (Lall et al., 2009). Lall et al. (2009) notes that although the index identified episodes of financial stress, only half the stress episodes identified are followed by contractions.

Applying the IMF financial stress index measures of Lall et al. (2009), Mittnik and Semmler (2014) analysis the interaction between industrial production and financial stress[15]. It is found that financial sector stress has a strong influence on economic activity, particularly stresses as measured by the TED spread, corporate bond spreads and a measure of stress in the banking sector, the "banks beta" (Mittnik and Semmler, 2014). This finding on the importance of the TED spread measure is also found in an analysis of the relevance of 30 systemic risk measures for forecasting adverse macroeconomic outcomes in Giglio et al. (2015)[16].

[15]This analysis uses a non-linear, multi regime vector autoregression approach (MRVAR) with Granger-causality and non-linear impulse response

[16]Using principal components quantile regression analysis is conducted in Giglio et al. (2015). They find that many of the measures do not match the broader historical context

4.2 Empirical Motivation and Strategy

In this chapter we will proceed by analysing the global significance of a wide range of financial shock measures as motivated by the existing literature. This will be done using a Global VAR and Generalised Connectedness Measures approach, as described in Section 3, as this approach has a number of advantages in dealing with the empirical complications which are discussed in the previous literature. Before proceeding with the empirical analysis these issues are outlined below.

A large number of the studies cited rely on identifying restrictions, Metiu et al. (2015). Bijsterbosch and Falagiarda (2014) note that there has been a fast growing literature attempting to identify credit shocks through vector autoregression models. To identify spread shocks, Sanjani (2014), relies on a block ordering with variables categorised into a block of macroeconomic variables, a financial block and a spread block. Gilchrist and Zakrajsek (2012) use an identified VAR framework to analyse their decomposed bond spread. Although Xu (2012) uses generalised impulse response functions the empirical methodology still employs four exact identifying restrictions in the error correction structure of the model. Eickmeier and Ng (2011) use theoretically motivated sign restrictions on short run impulse responses [17]. Specifically this involves imposing sign restrictions on corporate bond spreads jointly with restrictions on the response of other domestic variables. These sign restrictions

and record spikes a periods where there was no macroeconomic turmoil. It is also found that the individual measures, aside from the TED spread and equity volatility, have low predictive power for downturns in employment and industrial production but an aggregate measure preforms well. Giglio et al. (2015) observe that many of the variables used in the literature are better suited to recording occurrences of systemic risk rather than forecasting incidences of distress.

[17] These are taken from DSGE models containing a banking sector.

can be problematic, particularly when dealing with the comparatively new research field of the impact of financial shocks on macroeconomic variables as there is no settled theoretical modelling structure. As noted in, Jarociński and Maćkowiak (2013), aside from ordering, it is not even certain which variables should be included in a standard macro-financial model. As is noted in Borio and Drehmann (2011) "there are no satisfactory models of the economy as a whole linking balance sheets in the financial sector to macroeconomic variables". Indeed a number of papers in the literature note this difficulty, N'Diaye et al. (2010) notes the "enormous amount of identification" restriction needed to estimate their GVAR model with financial variables. Caldara et al. (2016) discusses how in using a structural vector autoregressive (SVAR) model the "fast-moving" nature of many of the indicators of financial distress, such as credit spreads, make it difficult to impose zero contemporaneous restrictions to identify disturbances.

In the identification of shocks in the analysis of the interaction between house prices, credit and standard macroeconomic variables in Goodhart and Hofmann (2008), the authors note that the ordering of the credit and asset price variables is "somewhat arbitrary". In disentangling the effects stemming from changes in liquidity and the risk appetite in a GVAR model Chudik and Fratzscher (2011) state that "it is inherently difficult to identify meaningful measures of shocks to liquidity and to risk appetite". In the dynamic factor model employed in Stock and Watson (2012) it is noted that given the high correlation of shocks particularly related to financial variables, separate interpretation can be difficult and they employ 18 instruments to identify structural shocks. In terms of credit supply dynamics, Bijsterbosch and Falagiarda (2014) note that the correct identification of credit supply dynamics is crucial for policy makers. In their paper on macro-financial linkages Guarda and Jeanfils (2012) note that for the financial variables used in their model that the exact ordering for the Choleski decomposition is not clear cut and that the theoretical literature does not have a clear guide for it. This uncertainty is further increased with the wide range of new variables that have been constructed to proxy for financial stress as among this broad array there is still a lack of agreement on precisely which measures should be used (Kliesen et al. (2012)).

In light of these issues using a more general framework has a number of advantages in terms of the analysis in this chapter. For this more general framework we combine the GVAR model with the connectedness measures approach of Greenwood-Nimmo et al. (2015). As discussed above there exists uncertainty in terms of the choice and also the identification ordering of variables in studies on macro-financial linkages. The Generalized Connectedness Measures proposed in Greenwood-Nimmo et al. (2015), which builds on the work of Diebold and Yilmaz (2009, 2014), are derived from generalised forecast error variance decompositions. The advantage of this approach is that the results generated are independent of the ordering of variables. Lanne and Nyberg (2014) state that generalised forecast variance decompositions are particularly useful when it is difficult to propose credible identifying restrictions. Furthermore, the GVAR approach combined with the connectedness measures allows a degree of quantification of the concept of "systemic risk" such as the importance of different countries and regions and the relative importance of different variables (Bisias et al. (2012)) [18]. Another advantage of employing the GVAR and GCM approaches is that in a cross country study of macro-financial linkages there is, as has been mentioned and as will be discussed in the subsequent section, a vast array of potential variables to consider. Even in benchmark GVAR macroeconomic models there is a considerable volume of statistical output produced and the addition of the variables from the array of macro-financial variables available will only add to this and make the traditional impulse response approach to detailing the models insights infeasible (Greenwood-Nimmo et al., 2015). This situation highlights another advantage, and in fact the original motivation for the GCM approach of Greenwood-Nimmo et al. (2015), that this empirical approach deals directly with the curse of "output dimensionality" and selectivity in the presentation of results. The GCM will provide a reductive method to summarising the output, this will permit a comprehensive reporting of the models results (Greenwood-Nimmo et al., 2015). This is particularly important in the context of the question in this chapter due to the considerable complexity and uncertainty in the transmission channels in a dynamic global macro-financial model.

Utilising the connectedness measures approach yields the above mentioned advantages, but using the Greenwood-Nimmo et al. (2015) innovation on the Diebold and Yilmaz (2009, 2014) approach has a particular advantage for the questions of interest in this chapter as it introduces a new stratum between

[18]The importance of this is further discussed in Borio and Drehmann (2011) in their assessment of indicators of banking stress they note that many country level indicators of financial imbalance miss imbalances caused problems originating in foreign exposures. They note that particularly in a globalised world with an intensification of global linkages that indicators based on the assumption that financial institutions in a country are only exposed to cycles in that country are limited (Borio and Drehmann, 2011).

individual variables and system-wide aggregates. This new stratum allows the connectedness measures to be employed at different aggregation levels and so look at the connection between countries, regions and in particular in our case between groups of variables within the model (Greenwood-Nimmo et al., 2015). This will allow measures of the cross-country dependence and influence of different measures of financial stress to be quantified.

This flexibility of approach is particularly applicable to the case of emerging market economies which will be included as part of the analysis. This applicability comes from the complexity of modelling the interaction between advanced and the more volatile emerging market economies in terms of specifying co-integrating relationships and an identification structure for shocks. Also for the dimensionality consideration the GVAR approach provides a framework that usefully summarises the complex interactions of particular economies with the outside world.

4.3 Empirical Methodology

4.3.1 The GVAR Approach

As discussed previously the theoretical and empirical literature suggest the importance of macro-financial linkages as well as the increase in linkages across countries. A departure from the standard GVAR approach is taken in this chapter in that although the GVAR approach is employed, as in Lui and Mitchell (2013), the stationary versions of the variables are used. As the analysis will be based on a covariance stationary representation of a VAR model, it will not be necessary to specify error-correcting relationships among the variables, as is required in much of the literature using GVAR models. This is advantageous as with the uncertainty in the theoretical links between the macroeconomic and financial variables noted in the literature, it is not clear what the nature of the long run relationships are among many of these variables[19].

Following the standard literature[20], it is supposed that there are $N+1$ countries or regions in the global economy, indexed by $i = 0, 1, ..., N$. Country 0 serves as the numeraire country and in keeping with the GVAR literature this is taken as the United States. The aim of the GVAR approach is to model a number of country specific macroeconomic variables over time, $t = 1, 2, ..., T$, and across the $N+1$ countries. While treating all country specific and global variables endogenously would be desirable given the interdependencies that may exist in the global economy, this would make estimation infeasible due to the "curse of dimensionality". To circumvent this issue, the GVAR approach imposes weak exogeneity of the foreign country-specific and global variables. This imposition implicitly assumes that the individual countries, aside from the US, are small with respect to the rest of the world. In this chapter the data is used in stationary form and therefore as in Lui and Mitchell (2013), weak exogeniety will be assumed.

The empirical model of each individual country includes a set of domestic, foreign specific and global variables, the number of which can vary across countries. Considering the structure of an individual country VARX*(1,1)

[19]Wickens (1996) outlines the importance specifying and incorporating a priori knowledge of the economic relationship among variables to counter the fundamental identification problem in cointegration analysis.

[20]See PSW (2004), DdPS (2007) and di Mauro and Pesaran (2013)

model, a VAR model with exogenous variables, for country i this is given by:

$$\boldsymbol{x}_{it} = \boldsymbol{a}_{i0} + \boldsymbol{a}_{i1}t + \boldsymbol{\Phi}_{i1}\boldsymbol{x}_{i,t-1} + \boldsymbol{\Lambda}_{i0}\boldsymbol{x}^*_{it} + \boldsymbol{\Lambda}_{i1}\boldsymbol{x}^*_{i,t-1} + \boldsymbol{u}_{it} \tag{4.1}$$

In this structure $\boldsymbol{x}_{it}$ is a $k_i \times 1$ vector of domestic variables, $\boldsymbol{x}^*_{it}$ is a $k^*_i \times 1$ vector of foreign variables, $\boldsymbol{a}_{i0}$ and $\boldsymbol{a}_{i1}t$ are the coefficients of the deterministics, in this case intercepts and linear trends, and $\boldsymbol{u}_{it}$ is a serially uncorrelated and cross-sectionally weakly dependent process. In terms of global variables, such as oil prices, every global variable enters as endogenous (domestic) in one country only and exogenous (foreign-specific) in the rest. This variable will thus enter into either the vector $\boldsymbol{x}_{it}$ or the vector $\boldsymbol{x}^*_{it}$ in each country. The country-specific foreign variables $\boldsymbol{x}^*_{it}$ are constructed as weighted averages of the corresponding domestic variables of all other countries. These weights are also country specific where, $\boldsymbol{x}^*_{it} = \sum_{j=0}^{N} w_{ij}\boldsymbol{x}_{jt}$, where $w_{ij}, j = 0, 1...., N$, are a set of weights such that $w_{ii} = 0$ and $\sum_{j=0}^{N} w_{ij} = 1$. The trade weights capture the importance of country j for country $i's$ economy. The benchmark analysis in this chapter will be preformed using weights estimated by bilateral trade data from the IMF Direction of Trade Statistics.

The GVAR model is solved by estimating the VARX* models on a country by country basis. Although this initial step is done country by country, the GVAR model is then solved for all countries in totality and takes account of the fact that all variables are endogenous to the system as a whole. Taking the estimated coefficients and deterministic from the VARX* models the GVAR model is constructed by first defining the $(k_i + k^*_i) \times 1$ vector:

$$\boldsymbol{z}_{it} = (\boldsymbol{x}'_{it}, \boldsymbol{x}^{*'}_{it})' \tag{4.2}$$

Equation 4.2 for each country model can then be rewritten as:

$$\boldsymbol{A}_{i0}\boldsymbol{z}_{it} = \boldsymbol{a}_{i0} + \boldsymbol{a}_{i1}t + \boldsymbol{A}_{i1}\boldsymbol{z}_{i,t-1} + \boldsymbol{u}_{it} \tag{4.3}$$

where

$$\boldsymbol{A}_{i0} = (\boldsymbol{I}_{ki}, -\boldsymbol{\Lambda}_{i0}),\ \boldsymbol{A}_{i1} = (\boldsymbol{\Psi}_{i1}, \boldsymbol{\Lambda}_{i1}) \tag{4.4}$$

The model collects all country-specific variables together into the $k \times 1$ global vector $\boldsymbol{x}_t = (\boldsymbol{x}'_{0t}, \boldsymbol{x}'_{1t}, ..., \boldsymbol{x}'_{Nt})'$ where $k = \sum_{i=0}^{N} k_i$ is the total number of endogenous variables in the global model for $i = 1, 2, ..., N$. All country specific variables can be written in terms of this global vector of endogenous variables. This is done by using link matrices $\boldsymbol{W}_i$, which is a $(k_i + k_i^*) \times k$ matrix of fixed known constants which are defined by the country specific trade weights. This allows the country specific models to be written in terms of the global vector of endogenous variables:

$$\boldsymbol{z}_{it} = \boldsymbol{W}_i\boldsymbol{x}_t,\ i = 0, 1, 2..., N, \tag{4.5}$$

The individual VARX* models can then be written in terms of the global vector:

$$\boldsymbol{A}_{i0}\boldsymbol{W}_t\boldsymbol{x}_t = \boldsymbol{a}_{i0} + \boldsymbol{a}_{i1}t + \boldsymbol{A}_{i1}\boldsymbol{W}_i\boldsymbol{x}_{t-1} + \boldsymbol{u}_{it} \tag{4.6}$$

Structuring the individual country models in this way allows for the final stage in the construction of the GVAR model, the stacking of the individual country models to yield a model for the global vector of endogenous variables.

This global model is now given by:

$$\boldsymbol{G}_0\boldsymbol{x}_t = \boldsymbol{a}_0 + \boldsymbol{a}_1 t + \boldsymbol{G}_1\boldsymbol{x}_{t-1} + \boldsymbol{u}_t \tag{4.7}$$

where

$$\boldsymbol{G_0} = \begin{bmatrix} \boldsymbol{A}_{00}\boldsymbol{W}_0 \\ \boldsymbol{A}_{10}\boldsymbol{W}_1 \\ . \\ . \\ \boldsymbol{A}_{N0}\boldsymbol{W}_N \end{bmatrix}, \boldsymbol{G}_1 = \begin{bmatrix} \boldsymbol{A}_{01}\boldsymbol{W}_0 \\ \boldsymbol{A}_{11}\boldsymbol{W}_1 \\ . \\ . \\ \boldsymbol{A}_{N1}\boldsymbol{W}_N \end{bmatrix}, \boldsymbol{a_0} = \begin{bmatrix} \boldsymbol{a}_{00} \\ \boldsymbol{a}_{10} \\ . \\ . \\ \boldsymbol{a}_{N0} \end{bmatrix}, \boldsymbol{a_1} = \begin{bmatrix} \boldsymbol{a}_{01} \\ \boldsymbol{a}_{11} \\ . \\ . \\ \boldsymbol{a}_{N1} \end{bmatrix}, \boldsymbol{u_t} = \begin{bmatrix} \boldsymbol{u}_{0t} \\ \boldsymbol{u}_{1t} \\ . \\ . \\ \boldsymbol{u}_{Nt} \end{bmatrix} \tag{4.8}$$

Since $\boldsymbol{G}_0$ is a known non-singular matrix made up of the trade weights and parameter estimates of the individual country level models the reduced-form global model is obtained as:

$$\boldsymbol{x}_t = \boldsymbol{G}_0^{-1}\boldsymbol{a}_0 + \boldsymbol{G}_0^{-1}\boldsymbol{a}_1 t + \boldsymbol{G}_0^{-1}\boldsymbol{G}_1\boldsymbol{x}_{t-1} + \boldsymbol{G}_0^{-1}\boldsymbol{u}_t \tag{4.9}$$

This equation can be solved recursively and allows the interactions among different economies and variables to be modelled through an number of channels.

4.3.2 Dynamic Analysis and Connectedness

The GVAR model described in the previous section can be used to perform generalized impulse response function (GIRF) analysis and generalised forecast error variance decompositions (GFEVD) as described in Pesaran and

Shin (1998). This is done to study the dynamic properties of the model and the time profile of variable specific shocks across economies (PSW 2004). An advantage of using GIRF as opposed to the orthogonalised impulse responses (OIR) of Sims (1980), is that the results will be invariant to the order in which the endogenous variables are stacked in $\boldsymbol{x}_{it}$ and also invariant to the ordering of the countries when constructing the global vector of endogenous variables, $\boldsymbol{x}_t$ (PSW 2004). As noted in PSW (2004) this non-invariance property of the OIR's is due to the standard non-uniqueness of the Choleski factor used in deriving the OIR's. PSW (2004) further note that in some cases OIR functions can be significantly impacted by the ordering of the variables in the GVAR model[21] [22]. In the context of this chapter this observation of PSW (2004) is of particular relevance, this is because, as discussed in previous sections, in addition to there being no framework for an ordering of countries in a GVAR model, there is no-clear theoretical benchmark for ordering variables in a macroeconomic model when combining and array of macroeconomic and financial data.

The GIRF approach considers shocks to individual errors in $\boldsymbol{u}_t$, with the ν^{th} shock, for $\nu = 1, ..., k$, in $\boldsymbol{u}_t$ corresponding to the ζ^{th} variable, and thus the ζ^{th} equation, in the i^{th} country and integrates out the effects of the other shocks using the historically observed distribution of shocks (PSW 2004,

[21] Pesaran and Shin (1998) note that GIRF and OIR will coincide in the case of the error variance matrix being diagonal.

[22] PSW (2004) highlight an alternative methodology in the macroeconometric literature for dealing with identification, that of "structural VAR" models. This approach is however very cumbersome when employing the GVAR approach as in a GVAR model with $N+1$ countries and k_i endogenous variables per country exact identification via a structural approach would require $k(k-1)/2$ theory-based restrictions (PSW 2004).

di Mauro and Pesaran (2013)). The GIRF of $\boldsymbol{x}_t$ is given as:

$$GIRF(\boldsymbol{x}_t; u_{i\zeta t}, n) = E(\boldsymbol{x}_{t+n}|u_{i\zeta t} = \sqrt{\sigma_{ii,\zeta\zeta},}\Gamma_{t-1}) - E(\boldsymbol{x}_{t+n}|\Gamma_{t-1}) \tag{4.10}$$

where Γ_{t-1} is the information set at time $t-1$, n is the horizon and $\sigma_{ii,\zeta\zeta}$ is the diagonal element of the variance-covariance matrix $\sum_u$, corresponding to the ζ^{th} equation in the i^{th} country PSW (2004). The GIRF can be interpreted as the time profile of the effect of a one standard error shock hitting at time t (Lanne and Nyberg, 2014). This is obtained as the difference between expectations of the global vector of endogenous variables conditional on the shock and the information set Γ_{t-1}, and the expectations conditional only on the information set Γ_{t-1}, absent a shock (Lanne and Nyberg, 2014). The information set consists of a matrix of initial values required to compute the conditional expectations (forecasts), usually by simulation (Lanne and Nyberg, 2014)[23].

As discussed in Pesaran and Shin (1998) and Lanne and Nyberg (2014) the generalised impulses can be used to construct the GFEVD. However, as also discussed in Pesaran and Shin (1998) and Lanne and Nyberg (2014), the interpretation of the GFEVD of a shock is complicated by the fact that the contribution of the shocks to the forecast error variance of a given variable at horizon n do not sum to unity if the covariance matrix of the error $\boldsymbol{u}_t$ is not a diagonal matrix. A normalisation is typically employed to solve this issue. In this chapter the same approach is taken, the formula for the GFEVD as proposed by Lanne and Nyberg (2014) is used as this formula is normalised

[23]One drawback of the GIRF as opposed to the OIR approach is that with GIRF there is no information on the reasons and or sources behind the shocks, they are simply shocks to a given equation in the model (Lanne and Nyberg, 2014).

by its construction as the denominator is the cumulative effect of all shocks. This normalisation restores the percentage interpretation of GFEVDs (Lanne and Nyberg, 2014). Following Lanne and Nyberg (2014) the GFEVD, is given as:

$$GFEVD(\boldsymbol{x}_{\zeta t}; u_{\nu t}; n) = \varphi^{(n)}_{\zeta \leftarrow \nu} = \frac{\sum_{s=0}^{n} (GIRF(\boldsymbol{x}_t; u_{i\nu t}, n))^2_{\zeta}}{\sum_{i=1}^{k} \sum_{s=0}^{n} (GIRF(\boldsymbol{x}_t; u_{i\nu t}, n))^2_{\zeta}} \tag{4.11}$$

In this formulation of the GFEVD the denominator measures the cumulative effect of all shocks while the numerator measures the cumulative effect of the ζ^{th} shock. In the context of the GVAR model, the formula thus measures the relative contribution of a shock to the ν^{th} equation in the i^{th} country to the total impact of all k shocks to the n periods ahead forecast error variance of the ζ^{th} element of $\boldsymbol{x}_t$ (Greenwood-Nimmo et al., 2015).

The GFEVD's are used to construct the connectedness measures in this chapter with the approach following the generalised connectedness measures as proposed in Greenwood-Nimmo et al. (2015). As discussed in Greenwood-Nimmo et al. (2015) the Diebold and Yilmaz (2014) framework is subject to a "processing constraints" and is suited to analysis with a single country with multiple variables or multiple countries with a single variable and not multi-country and global models which are the subject of this chapter. To overcome this processing constant Greenwood-Nimmo et al. (2015) propose a re-normalisation and a block aggregation structure for the GFEVD's. As in Greenwood-Nimmo et al. (2015) when considering a model with $i = 0, 1, ..., N$ countries each of which are described by k_i variables, where $k = \sum_{i=1}^{N} k_i$, the use of the block aggregation exploits the fact that the GEFEVD's are invariant to the ordering of the variables in $\boldsymbol{x}_t$. Therefore the variables in $\boldsymbol{x}_t$ may be reordered to align with a country ordering, such as $\boldsymbol{x}_t = (\boldsymbol{x}'_{2,t}, \boldsymbol{x}'_{2,t}, ..., \boldsymbol{x}'_{N,t})'$. With the adjustments and the ordering by country the structure is written as:

$$
\underset{(k\times k)}{\mathbb{C}_R^{(n)}} = k^{-1}\begin{bmatrix}
\phi^{(n)}_{1\leftarrow 1} & \cdots & \phi^{(n)}_{1\leftarrow k_1} & \phi^{(n)}_{1\leftarrow k_1+1} & \cdots & \phi^{(n)}_{1\leftarrow k_1+k_2} & \cdots & \phi^{(n)}_{1\leftarrow k} \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots & & \vdots \\
\phi^{(n)}_{k_1\leftarrow 1} & \cdots & \phi^{(n)}_{k_1\leftarrow k_1} & \phi^{(n)}_{k_1\leftarrow k_1+1} & \cdots & \phi^{(n)}_{k_1\leftarrow k_1+k_2} & & \phi^{(n)}_{k_1\leftarrow 1} \\
\phi^{(n)}_{k_1+1\leftarrow 1} & \cdots & \phi^{(n)}_{k_1+1\leftarrow k_1} & \phi^{(n)}_{k_1+1\leftarrow k_1+1} & \cdots & \phi^{(n)}_{k_1+1\leftarrow k_1+k_2} & & \phi^{(n)}_{k_1+1\leftarrow k} \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots & & \vdots \\
\phi^{(n)}_{k_1+k_2\leftarrow 1} & \cdots & \phi^{(n)}_{k_1+k_2\leftarrow k_1} & \varphi^{(n)}_{k_1+k_2\leftarrow k_1+1} & \cdots & \phi^{(n)}_{k_1+k_2\leftarrow k_1+k_2} & & \phi^{(n)}_{k_1+k_2\leftarrow k} \\
\vdots & & & & & & \ddots & \vdots \\
\phi^{(n)}_{k\leftarrow 1} & \cdots & \phi^{(n)}_{k\leftarrow k_1} & \phi^{(n)}_{k\leftarrow k_1+1} & \cdots & \phi^{(n)}_{k\leftarrow k_1+k_2} & \cdots & \phi^{(n)}_{k\leftarrow k}
\end{bmatrix}
$$

Re-normalisation by dividing each element of the matrix by the number of variables means the interpretation of the (ζ^{th}, ν^{th}) element of the matrix $\mathbb{C}_R^{(n)}$ represents the proportion of the total n-step ahead forecast error variance of the system accounted for by the effect from variable ν to variable ζ (Greenwood-Nimmo et al., 2015). The resulting structure allows the matrix of GFEVD's to be easily partitioned when constructing connectedness measures between different groups of countries and or variables. When arranged into b groups this will define the b^2 blocks of the matrix. Furthermore the re-normalisation maintains the percentage interpretation even when partitioning among different blocks of the matrix.

As described in Greenwood-Nimmo et al. (2015) the matrix can be reordered to support any block aggregation structure. These can be country level, regional or variable ordered blocks. This introduces a new stratum between which connectedness can be measured between countries and variables. These new measures made possible by the ordering include the Total To, Total From and net connectedness measure as well as the dependence and influence index measures proposed in Greenwood-Nimmo et al. (2015). The Total From, Total To and net connectedness measures of the k-th group are defined as:

$$\mathcal{F}^{(h)}_{k\leftarrow\bullet} = \sum_{\ell=1,\ell\neq k}^{b} \boldsymbol{e'}_{mk}\boldsymbol{B}^{(h)}_{k\leftarrow\ell}\boldsymbol{e}_{m\ell}, \quad \mathcal{T}^{(h)}_{\bullet\leftarrow\ell} = \sum_{\ell=1,\ell\neq k}^{b} \boldsymbol{e'}_{m\ell}\boldsymbol{B}^{(h)}_{\ell\leftarrow k}\boldsymbol{e}_{mk}, \quad \mathcal{N}^{(h)}_{\bullet\leftarrow k} = \mathcal{T}^{(h)}_{\bullet\leftarrow k} - \mathcal{F}^{(h)}_{k\leftarrow\bullet} \tag{4.12}$$

Where $\boldsymbol{e'}_{mk}$ is an $mk \times 1$ column vector of ones, mk is the number of variables in a given country k and $\boldsymbol{B}$ represents a block in the structure. As each normalised forecast error variance decomposition represents the proportion of the total n-step ahead forecast error variance of the system accounted for by the effect from variable ν to variable ζ, $\mathcal{F}^{(h)}_{k\leftarrow\bullet}$ thus measures the total spillover from all other groups to group k by summing the normalised forecast error variance decompositions. Similarly $\mathcal{T}^{(h)}_{\bullet\leftarrow\ell}$ measures the total spillover to all other groups from group k (Greenwood-Nimmo et al., 2015). The two further measures proposed by Greenwood-Nimmo et al. (2015), the dependence index and influence index. At horizon h these measures are given respectively as:

$$\mathcal{O}^{(h)}_{k} = \frac{\mathcal{F}^{(h)}_{k\leftarrow\bullet}}{\mathcal{W}^{(h)}_{k\leftarrow k} + \mathcal{F}^{(h)}_{k\leftarrow\bullet}}, \quad \mathcal{I}^{(h)}_{k} = \frac{\mathcal{N}^{(h)}_{\bullet\leftarrow k}}{\mathcal{T}^{(h)}_{\bullet\leftarrow k} + \mathcal{F}^{(h)}_{k\leftarrow\bullet}}, \tag{4.13}$$

Where $\mathcal{W}^{(h)}_{k\leftarrow k}$ is the within-group forecast error variance contribution for the k-th group.

The dependence index where, $0 \leqslant \mathcal{O}_k^{(h)} \leqslant 1$, measures the relative importance of external shocks to all shocks for the k-th group, the more important external shocks are the higher this index number will be. The influence index, $-1 \leqslant \mathcal{I}_k^{(h)} \leqslant 1$, has a threshold at zero whereby if $\mathcal{I}_k^{(h)} < 0$ the k-th group is a net shock recipient and if $\mathcal{I}_k^{(h)} > 0$ the group will be a net shock transmitter. A higher value of the influence index thus indicates a more dominant group.

4.4 Data, Variables and Model Specification

In this chapter an attempt is made to use the longest time series possible so that the relationships among the variables can be tested over several business cycles (Kliesen et al., 2012). Although Sgherri and Galesi (2009) and N'Diaye et al. (2010) use monthly data in a macro-financial GVAR, and the FSI data are available monthly, the analysis in this chapter will be conducted at a quarterly frequency. Although using quarterly data as opposed to monthly implies less observations the longer time span the quarterly series covers has two advantages in relation to the analysis in this chapter. Firstly, as already stated in Bisias et al. (2012), financial shocks occur relatively infrequently in the data so a longer series is desirable in attempting to quantify macro-financial relationships, for many series monthy data only began to be collected in more recent years and so will not cover as many shock episodes. In addition to allowing for a longer time series than monthly data, there is the benefit that, as noted in Canova (2007), with quarterly data the time aggregation should allow the issue of non-linearities to be abstracted from. This is important given that these non-linearities can be an important factor in monthly financial data (Canova, 2007).

The database constructed for this chapter draws heavily on the GVAR database [24]. The GVAR models in the chapter will be estimated over the period 1981(1)-2013(1) and so will capture the period of the financial crisis and its aftermath. The data series finishes at the given date as this is the latest vintage available for the GVAR database. This database provides a consistent cross country macroeconomic database free from possible distortions from revisions to national accounts. As in Eickmeier and Ng (2011) the analysis will use an updated version of the data set used in DdPS (2007)[25]. Along with the variables from the GVAR database a number of financial variables are added to the dataset to capture some of the variables which are indicated to be important in the theoretical and empirical literature on macro-financial linkages. The analysis will not however involve all countries available in this data set as once financial variables are added to the data set the number of usable countries reduces due to missing values in the financial data series. The analysis will begin with this initial reduced set of countries for which there is coverage of all the financial variables of interest [26].

One of the main sources for the financial data is the IMF financial stress index of Lall et al. (2009) are also used[27]. This is a uniform set of country

[24] For details of the GVAR database see di Mauro and Pesaran (2013) and DdPS (2007)

[25] This is taken from the GVAR Toolbox.

[26] The final set of countries used are; Australia, Austria, Belgium, Canada, Finland, France, Germany, Italy, Ireland, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom and the United States.

[27] The substantial number of papers in the literature that attempt to identify causality in the impact of financial stress on the macroeconomy by constructing financial variables that can be thought of collectively as a financial conditions index (FCI) (Kliesen et al., 2012). This approach is found in Alessi and Detken (2009) where indicators of asset price booms are tested off periods they identify as boom periods from the historical record. Departing from this Lall et al. (2009) constructs a financial stress index (FSI) for advanced economies composed of six financial stress indexes. For a discussion on the similarities and differenced between FSI and FCI measures, see, Kliesen et al. (2012). It should be noted

specific time series measures which highlights periods of banking and financial distress across a broad range of advanced national economies. The index includes six measures; the inverted term spread, a measure of banking sector risk, a measure of counter-party risk (the TED spread), the corporate bond spread, stock market returns, stock return volatility and exchange rate volatility. The construction and sources of these measures are outlined in detail in Lall et al. (2009). In this chapter these measures will be used as a proxy for different types of financial stress episodes.

The TED spread is defined as the 3-month Libor rate minus the government short term rate and is used as a measure of stress in financial markets (Hull, 2012). This is because the Libor, the London interbank offer rate, is the rate at which banks are willing to lend to other banks and so an increase in the spread indicates an increased perception of the risks of bank insolvency (Thornton, 2009). As discussed in Hull (2012), over the course of the financial crisis this measure increased sharply and spiked at an all-time high in October 2008. It then returned to normal levels, only to again increase during the Greek crisis. This pattern is seen in our data for most of the countries in the sample. The banking-sector beta is a measure of risk in the banking sector and is in line with the standard capital asset pricing model. The concept by which it measures banking sector risk is that if banking stocks move more than proportionately with the overall stock market then the banking sector

that this analysis is extended to emerging economies in Danninger et al. (2009). Many of the FSI and FCI measures are based on spreads. Throughout the 2008 financial crisis and its aftermath credit spreads came to prominence both as a measure of the stress in the financial system and for their predictive power for economic activity, particularly investors' expectations of future economic outcomes (Gilchrist and Zakrajsek, 2012). This focus is motivated by theories that depart from the Modigliani Miller world of frictionless financial markets (Gilchrist and Zakrajsek, 2012). Another potentially important feature of the spread movements is that they may also represent shifts in the supply of credit (Gilchrist and Zakrajsek, 2012).

is relatively risky (Danninger et al., 2009) [28]. In the financial stress indexes proposed by Lall et al. (2009) it is found that financial stress originating from banking stress is more likely to lead to strong and persistent downturns. In relation to the GVAR literature N'Diaye et al. (2010) find that a measure of bank distress has significant international spillovers and that the impact is larger in advanced economies.

The corporate bond spread variable is a proxy for risk in the corporate debt market (Lall et al., 2009). In the newest version of the IMF financial stress index, as used in this chapter, the volatility measures have a changed definition from those found in Danninger et al. (2009) and Lall et al. (2009). The previously used GARCH(1,1) measure is replaced with volatility measured as the 6-month (backward looking) moving average of the squared month on month returns (Semmler and Chen, 2014). The inverted term spread which is the short minus the long term government rate is not included in the analysis as a spread variable, as used in Guarda and Jeanfils (2012), will be included in the model [29].

Moving on to measures not contained in the IMF database, a variable that is highlighted as important in strands of the theoretical literature, but that is unobservable, is the level of financial frictions. Hall (2012) notes that the crisis raised financial frictions by depleting the equity capital of financial institutions and that this resulted in a sharp fall in investment. The empirical literature related to the impact of a change in the overall level of financial

[28] Frictions from the banking sector are an important element in the financial frictions literature as they can also contribute to the propagation of shocks from the supply side (Xu, 2012). As discussed in Bisias et al. (2012) there has been a secular growth in the share of the US and global economy accounted for by the financial and insurance industries. These industries have grown monotonically since the 1980's and so it is likely that shocks to the financial system will have a larger impact now than in the past (Bisias et al., 2012).

[29] There is a high correlation between this spread variable and the inverted term spread.

frictions is more limited than that related to the other variables motivated by the financial friction literature. In a contribution to the empirical assessment of financial frictions that tries to develop a measure which is close to the concept of a financial friction proposed in the theoretical literature, Chari et al. (2007) find that financial frictions as modelled by a costly state verification approach as in Bernanke et al. (1999) or a credit market frictions model such as Carlstrom and Fuerst (1997) are equivalent to a growth model with an investment wedge. Utilising the conceptual basis of the investment wedge financial friction in Chari et al. (2007), Hall (2012) and Hall (2013). Hall (2013) proposes a number of measures of financial frictions and finds that these frictions account for the long period of high unemployment, depressed output and stifled investment in the period after the global financial crisis.

The long and short safe rate are used to calculate the various spreads as this follows the concept of the financial friction of Hall (2011) where the friction places a wedge between the return earned by savers and the borrowing rate. The three measures of frictions used in this chapter coincide conceptually to those of Hall (2011) who presents a loan friction, a business investment friction and a mortgage friction. In the sample used in this paper these spreads increased during the financial crisis and remained high across a number of countries. The spreads calculated to capture the Hall (2011) measures differ in construction to what is common in the literature on cross country analysis. In Guarda and Jeanfils (2012) the spread between the short and long rate is used and is calculated on a country by country basis. This is not the approach taken in this chapter for the Hall (2011) financial friction measures. For these measures, for example, in calculating the mortgage spread by country the safe rate is taken as the 10 year bond rate on German government bonds for a number of countries. This is done as in a number of countries sovereign sustainability issues meant that the country's own 10 year bond rate was volatile over the period and could not be considered as a measure of the safe return as utilised by Hall (2011) [30] [31].

In considering which variables are important in analysing macro-financial linkages the aforementioned theoretical literature and also the global financial crisis have highlighted an important development in the financial system, that the role of credit has grown in many countries in the last number of decades (Xu, 2012). This growth is seen in that aggregate non-financial sector debt as percentage of GDP in advanced economies has increased from 167 percent in 1980 to 314 percent in 2009 (Cecchetti et al., 2011). The corporate sector accounted for 42 percentage points of this increase with households and governments accounting for 56 and 49 percentage points respectively (Cecchetti et al., 2011). This growth in credit, coupled with the global financial crisis, has led to an expansion of research on the impact of credit shocks and a renewed interest in the credit and business cycles literature [32]. A number of studies have also highlighted the importance of credit in the international transmission of shocks [33]. It is seen that credit markets can not only be a

[30] For a description of the sources and construction of the data see appendix A.

[31] For example in the case of Spain and Italy the spread between mortgage interest rates and long term bonds turns sharply negative after the financial crisis due to changes on their respective 10 year government bond yields, However, when measured using the German rate the spread rises.

[32] See for example Xu (2012).

[33] Using a time varying parameter vector autoregression model, and identifying the shocks with the DSGE model of Gerali et al. (2010)), Bijsterbosch and Falagiarda (2014)) find that credit supply shocks have been an important driver of business cycle fluctuations. They also point to the long lasting negative effects of credit supply constraints on the economy with heterogeneity between stressed and non-stressed economics in this result. Ciccarelli et al. (2012) use a time varying panel Bayesian VAR approach with real and financial variables and counterfactual shocks to analyse macro-financial linkages across countries and over

source of disturbances but also an important propagator of disturbances (Bijsterbosch and Falagiarda, 2014). Balke (2000) notes a similar finding from the theoretical literature whereby in theoretical models of financial frictions, credit conditions need not be an important source of shocks to have relevance in the model as they are an important propagator of shocks.

From the empirical literature on the importance of credit, Lall et al. (2009) finds that initial conditions matter in determining whether a period of financial stress is followed by a downturn, in particular important preconditions are the borrowing ratios of non-financial corporates, the credit to GDP ratio of the household sector and the dynamics of credit and asset prices in the pre-crisis period. This result is in line with results from the Bank For International Settlements, as outlined in Leeper and Nason (2014), that deviation in credit to GDP ratios and house prices from trend are real time indicators of the risk of a financial crisis. In support of this view Leeper and Nason (2014) further point to Bank of England estimates that a 1 per cent rise in the growth rate of the credit to GDP ratio raises the probability of a banking crisis in two years by 0.18 percentage points. Although the analysis in Lall et al. (2009) does not attempt identification the authors note that the results they find are consistent with the importance given to credit supply shocks as a key factor in the financial crisis.

There are two measures of credit considered in this chapter. The first credit measure considered is the credit to GDP ratio. This is used as The Basel Committee on Banking Supervision (Bank For International Settlements, 2010) noted that extraordinary private credit growth often results in

time. It is found that a tightening of the credit supply occurred in the 2008 financial crisis and that there were significant spillovers across countries.

widespread default and financial instability and so the credit to GDP ratio is a useful system-wide benchmark (Bisias et al., 2012). The credit gap is the seacond credit measure used. This measure is the cyclical component of the credit to gdp ratio. It is also noted in Bisias et al. (2012) that Alessi and Detken (2009) find that indicators based on the private credit gap are the best early warning indicators of costly cycles [34]. Asset prices are included for a similar reason, Borio and Drehmann (2011) note that the coexistence of unusually rapid credit expansions and asset price increases are good indicators of a build-up of financial stress [35].

To look in more detail at the evolution of the credit series over the sample period used in this chapter, Figure 4.1 presents the average annualised growth rate of the ratio of credit to private non-financial corporates to GDP for a sub-sample of six countries. This sub-sample is indicative of the border trends in the full sample. The growth in this credit to GDP ratio series displays cyclical behaviour over the sample for most countries. The exception to this is Japan where the series displays a steady decline until up to the period just before the global financial crisis. The global financial crisis is the most striking feature of the series over the sample used as many countries display a persistent rise in the growth rate prior to the crisis and a spike in the early period of the crisis. This was followed by a sharp contraction in the mid to latter stages of the crisis. The full cross-country variation in the general pattern of the evolution of the growth in the credit ratio as highlighted in

[34] The credit gap used in this chapter is that proposed in Alessi and Detken (2009) and is estimated by using the HP filter on the ratio of credit to GDP with a very slow adjusting lambda, set to 100,000. Credit is this case is credit to private non-financial corporates from all sectors

[35] For the sources of the credit and asset price series see Appendix A.

Figure 4.1 is also seen in Figure 4.2. This figure shows the average growth rate of credit to GDP for a 4 year period before the crisis and for a 3 year period after financial crisis. It can be seen from this figure that of the sample of countries Ireland and Spain recorded the highest average credit growth pre crisis with the lowest being Germany and Japan. It is noteworthy that by this measure the largest average reductions in credit to the private sector were recorded in the United States the United Kingdom, Germany, Norway and Japan. This group contains 4 out of the 5 largest economies in the world.

Asset prices are another variable highlighted as important in the theoretical literature. These are important as a collapse can be transmitted internationally through a deterioration in the balance sheets of connected institutions (Mittnik and Semmler, 2014) [36]. On the empirical side Guarda and Jeanfils (2012) in their analysis of macro-financial linkages find that financial shocks have a large contribution to real fluctuations and that shocks to asset prices are the most important source of these shocks. Looking specifically at the house price aspect of asset prices changes, Goodhart and Hofmann (2008) notes that in the pre-crisis period that along with the observed growth in credit there was also a strong increase in house prices across a substantial number of countries. This link between credit and house prices may arise from collateral effects on credit demand as higher prices enhance borrowing capacities (Goodhart and Hofmann, 2008). Goodhart and Hofmann (2008) also highlights that this house price effect should be positive for credit growth due to the aggregate asymmetry between beneficiaries and those who lose out from a general house price increase. Hall (2011) outlines another aspect of

[36]This will occur as in the model of Kiyotaki and Moore (1997), when leverage constraints are binding a fall in asset values forces an immediate balance sheet contraction process.

house prices whereby years of stable and rising house prices made leveraged real estate assets seem a safe asset and many risk analysts assigned zero probability to a significant decline in house prices and so the unexpected decline impacted the economy as a substantial financial shock.

4.4.1 Variables

As in DdPS (2007) the macroeconomic variables are converted to real terms and the log-transformation is applied, the spread variables are not log transformed [37]. Following Canova (2007) we proceed by checking the degree of integration of each series by performing unit root tests on the levels and differences of the series and then first difference the unit root variables until covariance stationary is achieved. This is important in this chapter as a stationary version of the GVAR model will be used. As discussed in Canova (2007), the conventional view is that many macroeconomic time series are characterised by near unit root behaviour. Given this feature statistical tests for distinguishing between stationary and unit root processes have low power (Canova, 2007) [38]. Because of this Kwiatkowski et al. (1992) propose an alternative test based on the null of stationarity to be used in compliment to standard tests so as to assist in distinguishing stationary and unit root series.

[37] As stated in Mayr and Ulbricht (2007) the log-transformation is typically applied to macroeconomic data due to the use of the normality assumption. The transformation should limit the effects of heteroscedasticity and skewness in level data resulting in a more homogeneous series with a more stable variance (Mayr and Ulbricht (2007), Lütkepohl and Xu (2012) and Xu (2012)). In Shin and Kang (2001), taking a transformation compared to using levels is found to have very little effect on the in-sample time series estimation, the transformation does however improve the out of sample forecasting performance of some variables (Lütkepohl and Xu (2012) and Xu (2012)).

[38] This point on the power of the tests is also discussed in Kwiatkowski et al. (1992) who note that many statistical tests propose as the null hypothesise that the series is a unit root process and so due to the tests low power result in a failure to reject the null. This may lead to series being designated unit root in error.

We utilise both types of tests to characterise the series used in this chapter. For the unit root null test, the augmented Dickey-Fuller test is used and for the stationary null test the test proposed in Kwiatkowski et al. (1992) is used. As discussed in Zivot and Wang (2006) it is imperative to specifying unit root tests to characterise the trend properties of the data under consideration and the presence or absence of a constant [39]. The results of the unit root tests indicate, in line with the existing GVAR literature, that the variables; real output, inflation, the long and short run interest rate, the real exchange rate, real equity prices, the credit to GDP ratio, the house price index, real investment and real private consumption are all integrated of order one, ($I(1)$). The unit root tests indicate that these variables are stationary in their growth rates and so these are used in the estimation. The growth rate used is the year-on-year quarterly growth rate. The unit root tests indicate that some of the variables used in the model are stationary in their levels. Variables with this property include all the credit spread variables, the mortgage interest spread, the consumer spread, the corporate spread and the long minus short spread, all the IMF index measures and credit gap are shown to be ($I(0)$).

The selection of country specific variables to be used as variables or to be used in the construction of variables for the stationary country specific VAR models are the growth rate of real GDP of country i at time t, (y^g_{it}), the growth rate of the real exchange rate (e^g_{it}), the growth rate of the rate of inflation (π^g_{it}), the growth rate of real equity prices (q^g_{it}), the quarterly short term interest rate (ρ^S_{it}), the quarterly long term interest rate (ρ^L_{it}), the spread (sp_{it}), the growth

[39]In relation to unit root tests and transformations Lütkepohl and Xu (2012) and Xu (2012) not that in general in practice if a variable is classified as I(1) its transformation will also be I(1).

in the house price index (hp^g_{it}), the mortgage interest rate spread (ms_{it}), the corporate borrowing spread (cps_{it}), the consumer borrowing spread (cs_{it}), the growth rate of credit to private non-financial corporates from all sectors ($cnfc^g_{it}$), the credit gap ($cgap_{it}$), the TED spread (ted_{it}), the "banking-sector-beta" ($beta_{it}$), corporate debt spread ($cbds_{it}$), stock market volatility (sv_{it}) and exchange market volatility (ev_{it}). More specifically, the variables are:

$$
\begin{aligned}
y^g_{it} &= ln(GDP_{it}/CPI_{it}) - ln(GDP_{i,t-4}/CPI_{i,t-4}),\\
e^g_{it} &= ln(FXDOL_{it}/CPI_{it}) - ln(FXDOL_{it-4}/CPI_{it-4}),\\
\pi^g_{it} &= \pi_{it} - \pi_{i,t-4},\\
\pi_{it} &= (p_{it} - p_{it-4}),\\
p_{it} &= ln(CPI_{it}),\\
q^g_{it} &= ln(EQ_{it}/CPI_{it}) - ln(EQ_{i,t-4}/CPI_{i,t-4}),\\
\rho^S_{it} &= 0.25 \times ln(1 + R^S_{it}/100),\\
\rho^L_{it} &= 0.25 \times ln(1 + R^L_{it}/100),\\
hp^g_{it} &= ln(HPXI_{it}) - ln(HPXI_{i,t-4}),\\
ms_{it} &= bsmrg_{it} - safe^L_{it},\ cs_{it} = ircl_{it} - safe^S_{it},\\
cps_{it} &= corpb_{it} - safe^S_{it},\\
sp_{it} &= \rho^L_{it} - \rho^S_{it},\\
cnfc^g_{it} &= ln(CPNFCA_{it}/GDP_{it}) - ln(CPNFCA_{i,t-4}/GDP_{i,t-4})
\end{aligned}
$$

where GDP_{it} is nominal Gross domestic Product, CPI_{it} is the consumer price index, $FXDOL_{it}$ is the exchange rate in terms of US dollars, EQ_{it} is the nominal equity price index, R^S is the short term interest rate, R^L is the long term interest rate, $HPXI_{it}$ is the house price index, $bsmrg_{it}$ is the quarterly interest rate on building society mortgages, $ircl_{it}$ is the average quarterly interest rate on consumer loans, $corpb_{it}$ is the average quarterly corporate borrowing rate, $safe^L_{it}$ is a measure of the safe long term interest rate for country i at time t, $safe^S_{it}$ is the safe short term interest rate for country i at time t and $CNFCA_{it}$ is nominal credit to non-financial corporates from all sectors. The TED spread, the "banking-sector-beta", corporate debt spread, stock market volatility and exchange rate volatility measures are all taken directly from Lall et al. (2009) [40]. It should be noted that as the spread variable, sp_{it}, is highly correlated with the inverted term spread, which is a measure of the slope of the yield curve, the inverted term spread variable from the IMF FSI measures is not used in the analysis. This variable is also a measure of banking sector risk (Lall et al., 2009)[41].

Along with the country specific variables the analysis will also include global variables. These are spread between the Aaa and Baa corporate bond yield ($Aaa - Baa_t$), the Gilchrist and Zakrajsek (2012) default risk (GZd_t) and excess bond premium ($GZebp_t$) and the growth rate of the log of the oil price index (oil^g_t) [42].

$$oil^g_{it} = ln(OIL_{it}) - ln(OIL_{i,t-4})$$

[40] For a discussion on the construction of these variables see (Danninger et al., 2009)

[41] This is because banks generate income through intermediation between short-term and long-term assets and so a change in this spread can impact banks profitability (Lall et al., 2009).

[42] On the properties of these series, the oil price is non-stationary while the three spread variables are all stationary.

4.4.2 Model Specification

In constructing the country specific models, the analysis follows the standard approach in the GVAR literature as seen in DdPS (2007) and Xu (2012) whereby the US is considered the dominant economy in the model. In line with this approach and dealing firstly with all countries aside from the US, each country specific model will include a set of domestic variables, where available, and their foreign specific counterparts, termed country-specific foreign variables. For all countries, aside from the US, the country-specific foreign variables will include any global variables and will exclude the exchange rate as it will already be contained in the set of domestic variables. Given it is the dominant economy, the specification of the US model differs accordingly. The global variables are included as endogenous variables in the US model. This allows macro variables to be influenced by the evolution of global variables such as the oil price (DdPS 2007). In relation to the financial variables the standard approach in the GVAR literature is again followed. Given the importance of the US financial variables in the global economy, the US country-specific foreign financial variables are not included in the US model as they are not considered long run forcing (weakly exogenous) with respect to the US domestic financial variables [43] (DdPS 2007). Following DdPS (2007) the country-specific foreign variables for the US for output and inflation are included in the US model. This is to capture possible second round effects of external shocks to the US [44] (DdPS 2007), (Xu, 2012). The analysis will begin by first constructing a benchmark model of the type used in DdPS (2007)

[43] Supporting evidence for this assumption is provided in Xu (2012).

[44] Evidence supporting the weak exogeneity assumption required can be found in Xu (2012).

and Guarda and Jeanfils (2012). The domestic and foreign variables for this model are shown in Table 1.

Once the variables to be included in the model are finalised, the appropriate lag order for the country-specific VARX for both the domestic and foreign variables, p_i and q_i respectively, are chosen (di Mauro and Pesaran, 2013). As in DdPS (2007), these are selected according to the Akaike information criterion [45]. As in Xu (2012) due to the limitations imposed by the sample size, p_{max} and q_{max} are not permitted to be no greater than two. As in (di Mauro and Pesaran, 2013) for the majority of countries, a VARX*(2,1) specification is deemed to be satisfactory. Also following Xu (2012) the models are estimated with unrestricted intercepts and restricted trend coefficients. In proceeding with the model specification the issue of structural breaks is abstracted from [46].

For the weights used in the GVAR model in this chapter trade weights are selected for the reasons discussed in Xu (2012) which uses these instead of other possible measures such as financial linkages. Citing a variety of research papers Xu (2012) states that trade is the most important determinant of cross country linkages and international business cycle linkages (Xu, 2012).

[45] This is a penalized likelihood approach which adds a term to the likelihood function of the model so that when estimating the parameters it is a complexity penalized likelihood function that is optimised (Sin and White, 1996).

[46] An important issue to consider when particularly with time series data with long sample sizes is the possibility of the presence of structural breaks (di Mauro and Pesaran, 2013). The importance of this issue in relation to macroeconomic time series is highlighted in Stock and Watson (1996). They do however also note that the conclusion on the presence or not of a structural break is dependent on the test employed (Stock and Watson, 1996). This point on the inconclusive nature of the best test of structural breaks is also noted in the GVAR literature. Following this literature a range of structural break tests are presented to assess the stability of the estimated coefficients and error variances of the country specific models. It should be noted that in the GVAR model, given that the country-specific models are specified conditional on foreign variables, this should, to an extent, alleviate problems of structural breaks (DdPS 2007). This is because with the presence of these variables the GVAR model can accommodate co-breaking and so the GVAR model may be more robust to structural breaks than compared to reduced-form single equation models (DdPS 2007).

Xu (2012) notes that given that there is a high degree of cross county correlation for financial and real variables mis-specification of weights will not have strong implications. Also in a GVAR model which contains financial variables; financial linkages will already be captured through the presence country specific foreign financial variables (Xu, 2012). In N'Diaye et al. (2010) alternative weighting schemes in the GVAR are again discussed, it is noted that in most of the GVAR literature trade weights are used or narrow financial weights which only cover one type of relationship. N'Diaye et al. (2010) construct weights based on the currency exposure measures of Lane and Shambaugh (2010)) which summarises five financial instruments. However, in robustness analysis using a variety of trade and financial weighting schemes N'Diaye et al. (2010) finds that the results show little change between specifications. It is also the case that time series data on bilateral trade is much more readily available for a longer time period and a larger array of countries than bilateral financial data (Xu, 2012).

In utilising the connectedness measures framework to analyse the impact of different measures of financial stress a benchmark GVAR model will first be presented. This benchmark model will be used to compare connectedness results with this sample of countries to the analysis in Greenwood-Nimmo et al. (2015). This comparison is of interest as in contrast to this chapter Greenwood-Nimmo et al. (2015) utilises the full set of available countries in the GVAR database and preforms the analysis with non-stationary data. To this benchmark model a measure of credit will then be added. This is because, as has previously been discussed, there is a growing empirical literature highlighting the importance of the information content of credit for business cycle fluctuations and financial crises (Borio et al., 2013). With the benchmark model now inclusive of a measure of credit the analysis will proceed by employing the connectedness measures framework to analyse the impact of the different measures of financial shocks that will be added to this model. The set of variables to be used in the benchmark model and those that will be added as measures of financial shocks are outlined in Table 2. As outlined in the previous section, this set of variables encompasses a broad range of liquidity, banking stress, volatility and asset price measures.

Once the financial variables that are the most influential have been identified, by utilising the connectedness analysis, for all these variables the analysis can then be expanded to a broader range of countries where data is available. This is because, initially, many countries were excluded from the analysis as no data was available for a large number of the financial stress and financial friction measures. It will be seen that the connectedness analysis will exclude many of the financial shock measures as having little global influence, a reduced set of financial shock variables will then be under consideration. Countries where this restricted set of variables is available will be added to the sample. The additions to the sample will be predominantly made up of emerging market economies. This will allow a limited comparison on the financial shock impact between developed and emerging market economies to be conducted.

4.5 Results

In conducting the analysis in this section a benchmark model is first established to assess the comparability of the results with the original GVAR and

GCM approach given the use of stationary data and a different sample of countries. This comparison is contained in Appendix B. The consistency of results that is found supports the use and comparability of this benchmark model when proceeding with the inclusion of financial variables. To this benchmark model a credit variable is added. The choice of credit measure and its and effect are outlined in Appendix C.

Turing to the analysis of the relative global importance of the array of financial shock variables, this will involve the GVAR model being estimated in accordance with the equation structure outlined in Table 2 [47]. This will allow the dependence and influence index measures from the connectedness measures framework to be calculated for each of the shock variables in turn, in a benchmark GVAR model with credit. The connectedness measure framework is then applied to summarise these results. To look at the impact of variables the bloc aggregation structure of the matrix of forecast error variance decompositions is changed from a country based structure to a variable based grouping structure. The results of this analysis for the dependence and influence index measures are shown in Figure 4.3. It should be noted that the dependence and influence measures are not the converse of each other, the dependence measure is bounded between zero and one while influence is bounded between one and minus one.

These measures show the dependence and influence of each variable when included separately in the benchmark model with credit. From the figure it

[47]The forecast horizon h used for all of the connectedness measures presented in this chapter will be set at $h = 4$. This follows the discussion of alternative choices of horizon, when using quarterly data, in Greenwood-Nimmo et al. (2015). In Greenwood-Nimmo et al. (2015) it is found that in the large majority of cases the choice of forecast horizon is unlikely to exert a decisive influence on the results of the connectedness measures and also that in most cases the connectedness measures converge to their long run value after 3-5 quarters.

can be seen that the most influential variables are the bond spread measures, the two measures proposed by Gilchrist and Zakrajsek (2012), (henceforth the GZ measures), and the Aaa-Baa corporate bond spread. The other influential variables, albeit at a relatively much reduced magnitude, are the exchange rate volatility measure, the spread measure and the corporate bond spread measure from the IMF's financial stress index measures. All other measures of financial stress/financial frictions are net shock recipients. It is noteworthy that two of the least influencing measures are house prices and the mortgage spread, this could be because as noted in Dees (2015) that housing markets are influenced predominantly by country specific factors, and so in a connectedness analysis it would be expected that their global influence measure will be low. This result for the GZ measures and the Aaa-Baa spread is congruent to the result found in papers not using the GVAR framework, such as Giglio et al. (2015) where the GZ measures and the default spread (what they term the Aaa-Baa spread) frequently Granger cause other variables and not the reverse. In their analysis on the predictive power of an array of systemic risk measures for the lower tail of macroeconomic shock the GZ measures were also found to have significant predictive power. The results of Sanjani (2014) are also in line with those in this chapter as in decomposing the credit spread liquidity risk shocks are found to have a severe economic impact.

The results of the connectedness measures analysis as presented thus far suggest that credit can be thought of as an endogenous variable in the model as it records a very low influence score and a high dependence. This result holds both at the at the global economy level, and at the individual country level where the shock to US credit is shown to have a very weak influence. As per the interpretation of Gilchrist and Zakrajsek (2012) of the link between their measure and the financial frictions literature of Bernanke et al. (1999), Kiyotaki and Moore (1997), Gertler and Kiyotaki (2010) and Hall (2011), our results also suggest that it is shocks to a measure of the financial friction and not shocks to the level of credit that are of importance. This result would be in keeping with the theoretical literature on macroeconomic variables, credit and financial frictions and is contrary to the approach employed by many papers in the empirical financial shocks literature which proceed by shocking a measure of credit [48]. From the perspective of the collateral constraints seam of the financial frictions literature as outlined in Kiyotaki and Moore (1997), Iacoviello (2005) and empirically in Hall (2011), it is the size of the financial friction that is of most importance not the amount of credit. In this theoretical literature the presence of a stock of borrowing in steady state depends on the existence of a financial friction not vise versa.

Figures 4.4-4.6 show how the influence of these financial shocks varies by country. It is notable that the cross-country variation in the pattern of which measures are influential and which are not is quite homogenious across most of the countries. The general pattern of a high recorded measure for the GZ variables and the Aaa-Baa spread measures and lower values for the other variables holds across countries. It is seen that Canada is much more influenced for almost all variables compared to other countries due to its close linkages with the US. Switzerland and Ireland as small open-economies with a relatively large financial sector, record a much higher influence from a shock to US stock market volatility than other countries. In relation to the

[48] See Xu (2012) and Eickmeier and Ng (2011).

other financial shock measures, aside from the GZ variables and the Aaa-Baa spread, Germany, Japan, Ireland and Switzerland record more sensitivity to the US TED spread and the US Banking Beta banking sector stress measures than other countries in the sample.

The results of the analysis for the set of advanced economies show that a benchmark model with credit is most impacted by shocks to the GZ spread measures and the Aaa-Baa spread. This benchmark model with credit is expanded to take in an extra nine countries many of which are emerging market economies [49]. Although these economies are selected given the availability of comparable macroeconomic and credit series over the relevant time horizon, there are still some missing values for these countries and the results must be taken in this context [50].

The influence index results for the combined sample of advanced and emerging market economies for the three influential financial shock measures are shown in Figure 4.7. The shocks are ordered by the influence of the excess bond premium measure. While three emerging market economies, South Africa, Thailand and India score in a low position in terms of the influence of US based financial shocks on their economy there is no clear pattern among the group of emerging market economies. As can be seen from the graph Turkey and Indonesia record an above average level of influence. This is in keeping with the results in Greenwood-Nimmo et al. (2015) where there is a diverse range of dependence and influence measures among emerging

[49] The additional countries are: Malaysia, Korea, Thailand, Singapore, Mexico, South Africa, India, Indonesia and Turkey.

[50] From the GVAR database the equity price index variable is missing for, Thailand, Mexico and India. Due to the unavailability of the long term interest rate in the GVAR database for many of the emerging market economies, out of the new countries added the spread variable is only available for Korea and South Africa.

market economies. This diverse reaction can depend on a broad array of factors such as differences in measures of macroeconomic fundamentals and financial integration (Adler and Mora, 2012). In this context the result for Turkey is interesting to note as it is a highly open economy which registered one of the highest output contractions in the aftermath of the global financial crisis and openness is highlighted as one of the key factors that determines the size of impact of a global financial shock on an emerging market economy (Ozkan and Unsal, 2012).

As previously noted, the connectedness measures indicate that the most influential variables in the benchmark model are the equity price and the oil price. Figure 4.8 shows the magnitude of the influence index measure of the two GZ measures and the Aaa-Baa spread relative to the other benchmark variables in the model. The negative figure for output should not be taken as a lack of importance; it is because it is heavily influenced by other variables and so this will reduce its influence index number.

In relation to the sign and magnitude of the impact of the financial shocks the strongest impact is from a rise in the default component of the corporate bond spread on the equity price index. This result of the strong response of the equity price index may be due to the forward looking nature of stock prices, that they anticipate the changes in output, indeed in empirical forecasting exercises GDP growth is found to be highly correlated with the lagged stock price changes (Nalewaik, 2010). For each of the variables the effect on the credit to GDP variable is positive. It is probable that this occurs because in the data, as can be seen from Figure 4.1, this ratio spikes during the early crisis periods and only begins to contract in the years after the onset of the crisis.

4.6 Conclusions

This chapter analysed cross-country macro-financial interactions through looking at a variety of measures of financial stress and financial frictions. The framework employed allowed this complex set of interactions to be analysed in a single model and for the results to be condensed down to a more limited range of summary measures that can be presented in a more stylised and less selective way. This framework had significant advantages in relation to analysing these types of interaction due to the large amount of uncertainty regarding their measurement, transmission mechanisms and possible identification structures. The contribution of the chapter was that this was the first analysis which utilises the GVAR and connectedness measures frameworks to gain an insight into the global transmission and influence of different types of financial shock and it does this in a way which minimised the amount of assumptions and restrictions required.

In testing an array of financial stress and financial friction measures in a large global VAR model combined with connectedness measures it was found that many proposed measures were net receivers of shocks and not net transmitters. In particular the connectedness measures suggested, in line with the theoretical literature, that the measure of credit was not a highly influential measure. The measures found to be most influential on other macroeconomic variables were liquidity measures as constructed from the corporate bond market. The component of this bond spread which was found to be most influential was that which was most closely aligned to the concept of a financial friction from the theoretical financial frictions literature. This finding on the importance of this financial friction measure is supported in other studies. There was also a considerable degree of consistency in the cross-country reaction to US originating financial shocks. In relation to an expanded sample of economies including more emerging market economies there was considerable variation in the reaction to financial shocks eliminating from the United States.

These results contributed to the literature on the measurement and influence of financial shocks, the cross-country variation in the impact of the shocks among emerging market economies warrants further investigation as there are a number hypothesis on the factors that determine this reaction.

4.7 Chapter 4 Appendix

4.7.1 Appendix A. Data Sources

The variables GDP, the price level, equity price index, exchange rate, short and long term interest rates as well as the oil price index are all drawn from the latest version of GVAR database as outlined in DdPS (2007). For Finland the series for the interest rate on long term government bonds is not contained in the original GVAR database. This is because in the case of Finland the series used for the other countries 'Interest Rates, Government Securities, Government Bonds' from the IMF International Financial Statistics only begins in Q1 1988. This series is included in the analysis in this chapter and is back dated using data from the OECD Economic outlook and the OECD Main Economic Indicators. The series used are 'Finland, Long-Term Interest Rate On Government Bonds, AR, SA' and 'Finland, Long-Term Government Bond Yields, 10-Year, Main (Including Benchmark), Yield 10-Year Government Benchmark Bonds'. Both series are sourced from Datastream. The correlation between the IMF bond series for Finland and the two OECD bond series is above 0.99.

The data source for the house price index for all countries is the Oxford Economics 'House Price Index' and is sourced from Datastream. An alternative house price measure also from Datastream is the 'Residential Property Prices' series from the Bank for International Settlements. The Oxford Economics series was selected as it covered more countries relevant to the sample in this chapter and the correlation between these two house price indexed was above 0.99 for most countries.

For the majority of countries the data on mortgage, consumer, and corporate interest rates used to compute the financial friction indicators are all sourced from Oxford Economics through Datastream. For the corporate interest rate the 'Corporate Borrowing Rate, Period Average' series is used. For the consumer rate the series used is 'Interest Rate, Average On Consumer Loans' and for the mortgage rate it is the series 'Interest Rate On Building Society Mortgages'. For the series 'Interest Rate On Building Society Mortgages' the data for Germany is only available from Q1 1990. This series is interpolated backwards using the yield on the mortgage Pfandbreief. The series used is 'BUBA Yield - Mortg Pfandbreief - middle rate' and is from Datastream. As discussed in Fischer and Winkler (2009) there is a link between the Pfandbruef yield and mortgage interest. For the period over which both series are available the correlation between the Oxford Economics mortgage interest series and the Pfandbruef yield is above 0.98. For Switzerland and Norway there is no mortgage interest data available from Oxford Economics. As an alternative the series used for Switzerland is 'Mortgage Lending Rates, New Business, Mortgages, Variable Interest Rates' from the Swiss National Bank. This series is sourced from Datastream. For Norway the series used is 'Mortgage Lending Rates, Mortgage Companies, Total, Average'. This series begins in Q4 1988 and is interpolated back using the series 'Personal Lending Rates, Total'. Both series for Norway are from Statistics Norway and are accessed through Datastream.

The data for the credit series all come from the Bank For International Settlements. The series used for credit to private non-financial corporates from all sectors is, 'Credit to Nonfinl Corps from all Sectors'. The credit series are adjusted for breaks and are sourced from Datastream. For Turkey the credit series from the Bank For International Settlements is only available from Q1 1986. This series in interpolated backwards using the discontinued series 'Other Banking/Nonbank Financial Institutions, Domestic Credit, Claims On Private Sector' from the IMF International Financial Statistics as this is found to have a correlation of 0.99 with the Bank For International Settlements credit series. The IMF series used for interpolation is sourced from Datastream. The credit series for Mexico commences in Q4 1980. This series is interpolate back to commence in Q1 1980 by using the series 'EXTERNAL DEBT - PRIVATE' from Oxford Economics as sourced from Datastream. The credit series are adjusted for seasonality using the X-12 quarterly seasonal adjustment method in EViews.

Data for the global corporate bond yield variable is taken from Datastream with the variables being 'United States Corp Bonds Moodys Seasoned BAA' and 'United States Corp Bonds Moodys Seasoned AAA'. The (Gilchrist and Zakrajsek, 2012) variables are taken from the Boston University web-page of Simon Gilchrist.

Ireland is not included in the original GVAR database and so data for the Irish variables, GDP, the price level, equity price index, exchange rate, short and long term interest rate had to be sourced. For the price level the data is from the same source as other countries and is the series 'Consumer Prices, All Items' from the IMF International Financial Statistics. For the short term interest rate the series 'Interest Rates, Money Market Rate' from the IMF International Financial Statistics is used, this is the same data source as is used for the short term interest rate for most of the other European countries in the GVAR database. As is used in the majority of countries in the GVAR database the series 'Interest Rates, Government Securities, Government Bonds' from the IMF International Financial Statistics is used for the long term interest rate. For the exchange rate the series 'IR US $ to 1 Euro (Irish Punt Derived History Prior 1999)' data from the Bank of England is used and is sourced from Datastream. For the equity price index the series 'Ireland-Datastream Market' is used and is sourced from Datastream. For other countries in the dataset the 'MSCI country Index' is used for equity prices. The Datastream series is used for Ireland as in comparing the 'MSCI country Index' series to the 'Datastream Market' for a sample of countries it is found there is a correlation of above 0.99. For the variables price level, equity price index, exchange rate and short and long term interest rate for Ireland all data are sourced from Datastream. For GDP at current prices the series for Ireland is more problematic as there is no GDP series available at a quarterly frequency before Q1 1997. A series at a longer frequency is constructed by interpolation using the annual GDP series along with earnings and retail sales data. The latter two series are available at quarterly frequency for the relevant time period. The series used for earnings and retail sales are 'Hourly Earnings: Manufacturing for Ireland' and 'Value of Total Retail Trade sales for Ireland' respectively, both series are sourced from the Federal Reserves FRED database. This series is found to be a close match to the a commonly used interpolated series for quarterly GDP for Ireland as constructed by the Central Bank of Ireland, see Bermingham et al. (2012). The correlation between both the nominal and real interpolated series and the Central Bank interpolated series is above 0.99. The series for GDP is finally adjusted for seasonality using the X-12 quarterly seasonal adjustment method in EViews, under the additive option.

For the majority of countries, for the investment variable, the series used is "Gross Fixed Capital Formation, Total, Current Prices, AR, SA" from the OECD Economic Outlook and is sourced from Datastream. However, for Ireland this series only begins in Q1 1990. For Ireland this series is interpolated back using unpublished historical series from the Central Bank of Ireland as it is found that the correlation between unpublished investment series and the OECD series is above 0.99.

For the expanded analysis which includes a number of emerging market economics the series for nominal GDP is sourced from Oxford Economics through Datastream. It should be noted that for a number of emerging market economies parts of the time series are quarterly averages of annual data as no quarterly data is available.

4.7.2 Appendix B. Model Comparison

To illustrate the connectedness estimation results and to provide a comparison with the analysis of Greenwood-Nimmo et al. (2015) in advance of proceeding with the analysis of the financial shock variables, the results of the connectedness measures analysis of the benchmark model with no financial factors is shown in Table 4.3. This table shows the To, From and Net connectedness measures at the four-quarters-ahead horizon measured as a percentage of the systemwide forecast error varaince. It can be seen from the To measures this table that the United States accounts for 8.5 per cent of all the fore-quarters-ahead forecast error varaince in the system. This number illistrates the dominant position of the United States in the global economy and is in line with the results of Greenwood-Nimmo et al. (2015). the To and From measures for oil also have similar magnitudes to Greenwood-Nimmo et al. (2015). These numbers are more fully discussed in Greenwood-Nimmo et al. (2015) and they conclude that the analytical framwork they propose match esteblished belifs about the openess and influence of economies. In this table presented here we show our results, with the methodological changes outlined, also mathced these patterns. The variables used in the benchmark model are outlined in Table 4.1. Large values of the Total To connectedness measure indicates that a shock to a country's variables has a strong impact on the other countries variables. From this measure the United States is the dominant economy in the model with spillovers from the US to the other economies accounting for 8.5% of all the four-quarters-ahead forecast error variance of the system. This result adds to the empirical justification of focusing on US based shocks as is done in much of the GVAR literature and in the broader literature on financial shocks. In the sample used in this chapter the economies with a weak impact on other economies are Canada and Switzerland. These results are a close match to Greenwood-Nimmo et al. (2015) who notes that the impact measure tends to be weaker in small open economies which belong to significant free trade areas. Higher values of the Total From connectedness measure indicated an economy is more strongly affected by other economies. This measure also reveals the dominant role of the US as it has the lowest value of all countries in the sample, indicating it is the least influenced by external factors. The dependence and influence index confirm this pattern with the US and Japan the least impacted by external shocks, The United

States and the oil price are the strongest transmitters of global shocks in the sample. For the US it should be noted that the connectedness measures suggest that by far the most important variable for shock transmission is the US equity price index. This result was found in Greenwood-Nimmo et al. (2015) which revealed the substantial spillover from financial markets to real activity throughout the sample period. The US equity price result has also been seen in the GVAR literature, in Sgherri and Galesi (2009) and Xu (2012).

The consistency of this benchmark model with that of Greenwood-Nimmo et al. (2015) is interesting to note as not only is the model in this chapter estimated on a reduced sample of countries, this model also employs stationary as opposed to non-stationary data, as is used in Greenwood-Nimmo et al. (2015).

4.7.3 Appendix C. The Credit Variable

With the introduction of the credit variable to the benchmark model in our analysis it is found that, whether it be the growth of the credit to GDP ratio or the HP filtered credit gap, its inclusion improves the fit of almost all country specific models [51]. More specifically, the average of the adjusted R-squared measures across the country-specific models increased from 0.83 without credit to 0.86 and 0.88, respectively, with the credit gap and credit to GDP measure included. Figure 4.9 shows the difference in the adjusted R-squared measure between the benchmark model and the models including the two alternative measures of credit. It can be seen that the credit to GDP ratio improves the fit of all country-specific models by more than the credit gap

[51] This improvement of fit from the introduction of credit is also found in Xu (2012).

measure. Taking the adjusted R-squared as a measure of the fit of the model, it can also be seen that in the case of Austria and the Netherlands the inclusion of the credit gap measure reduces the fit compared to the basic model. Based on these estimates, the credit to GDP ratio is taken as the credit measure to be used in all models when proceeding to the financial shocks analysis. From the connectedness measures framework, Figure 4.10 shows the changes in the dependence and influence index measures for each country resulting from the inclusion of the credit variable. The influence of the UK and the US as a transmitter of shocks increases while their dependence decreases [52]. The influence of Germany and Japan reduces with the introduction of the credit variable.

[52] This also occurs for Italy but this is because the Influence index measure was increasing from a low initial value.

4.7.4 Appendix D. Figures and Tables

Table 4.1: Benchmark Model and Financial Variables

Country	Domestic Variables	Foreign Variables
US	$y^g_{US,t}, \pi^g_{US,t}, q^g_{US,t}, sp_{US,t}, oil^g_t$	$y^{*g}_{US,t}, \pi^{*g}_{US,t}, e^{*g}_{US,t}$
Rest of the World	$y^g_{it}, \pi^g_{it}, q^g_{it}, e^g_{it}, sp_{it}$	$y^{*g}_{it}, \pi^{*g}_{it}, q^{*g}_{it}, sp{*}_{it}, oil^g_{it}$

Table 4.2: Benchmark Model and Financial Variables

Benchmark Model						Credit	Shock Variable
y^g_{it}	π^g_{it}	e^g_{it}	q^g_{it}	sp_{it}	oil^g		
y^g_{it}	π^g_{it}	e^g_{it}	q^g_{it}	sp_{it}	oil^g	$cnfc^g_{it}$	
y^g_{it}	π^g_{it}	e^g_{it}	q^g_{it}	sp_{it}	oil^g	$cnfc^g_{it}$	cps_{it}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	ted_{it}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$beta_{it}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	cs_{it}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	hp^g_{it}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	ms_{it}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$cbds_{it}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	sv_{it}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	ev_{it}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$GZebp_t$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	GZd_t
y^g_{it}	π^g_{it}	e^g_{it}	q^g_{it}	sp_{it}	oil^g	$cnfc^g_{it}$	$Aaa - Baa_t$

Table 4.3: Connectedness measures Among Countries, Four-Quarters Ahead

	To	From	Dep	Inf
Australia	2.90	3.68	0.63	-0.12
Austria	3.18	4.83	0.82	-0.21
Belgium	6.16	4.86	0.83	0.12
Canada	2.77	4.45	0.76	-0.23
Finland	4.33	4.32	0.73	0.00
France	4.86	4.88	0.83	0.00
Germany	6.10	4.81	0.82	0.12
Italy	3.98	4.59	0.78	-0.07
Japan	3.19	3.53	0.60	-0.05
Netherlands	3.51	4.95	0.84	-0.17
Norway	3.70	4.78	0.81	-0.13
Spain	4.47	4.39	0.75	0.01
Sweden	3.01	4.86	0.83	-0.24
Switzerland	2.91	4.82	0.82	-0.25
United Kingdom	5.30	4.41	0.75	0.09
United States	8.50	2.83	0.60	0.50
Oil	3.26	0.41	0.35	0.78
Ireland	3.57	4.35	0.74	-0.10
Average	4.21	4.21	0.74	0.00
Average (excl. oil)	4.26	4.43	0.76	-0.04

Figure 4.1: The One Year Average Growth in Credit

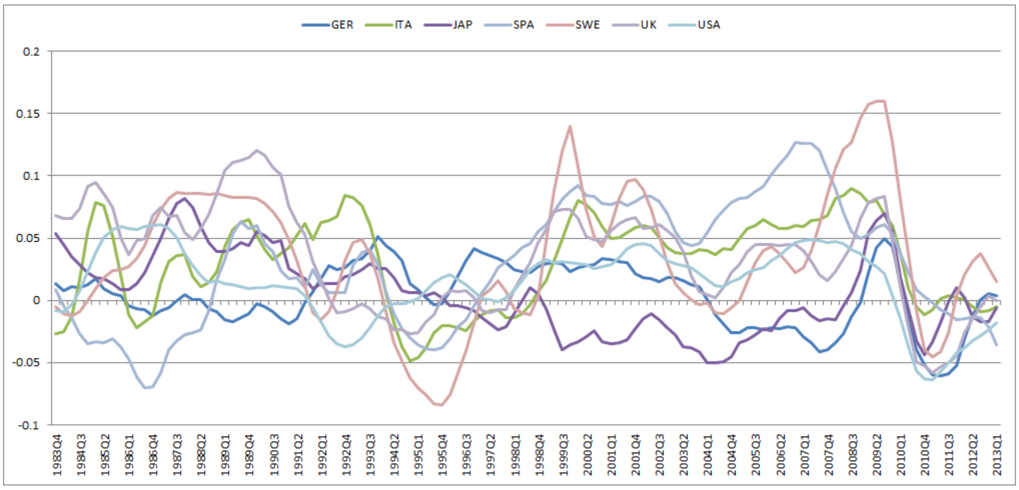


Figure 4.2: Growth in Credit Pre and Post Financial Crisis

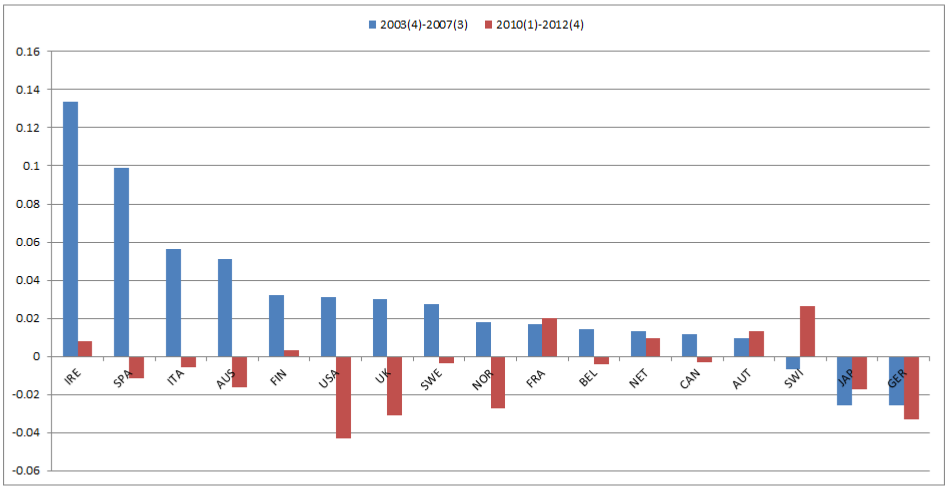
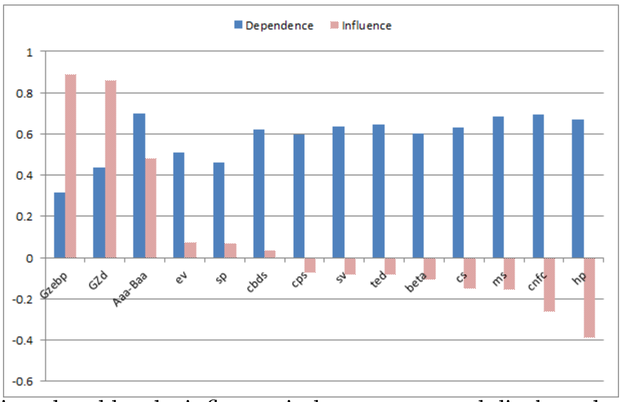
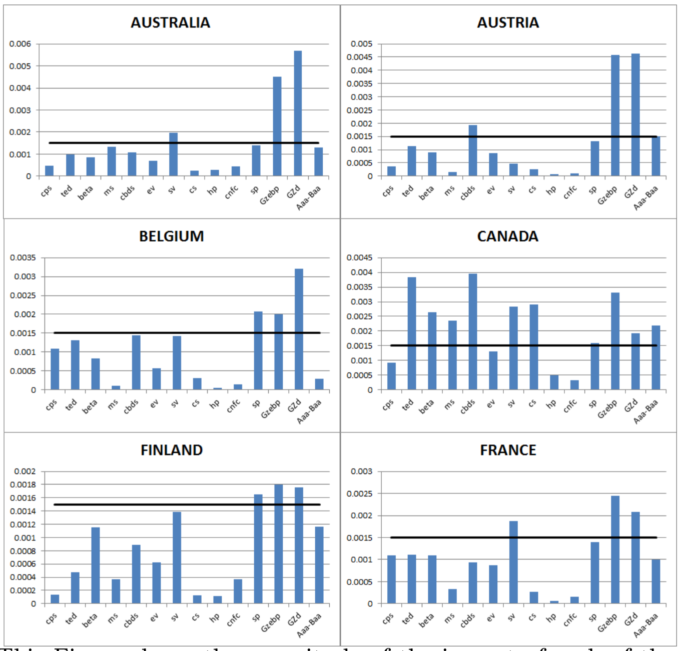


Figure 4.3: Influence of Financial Variables



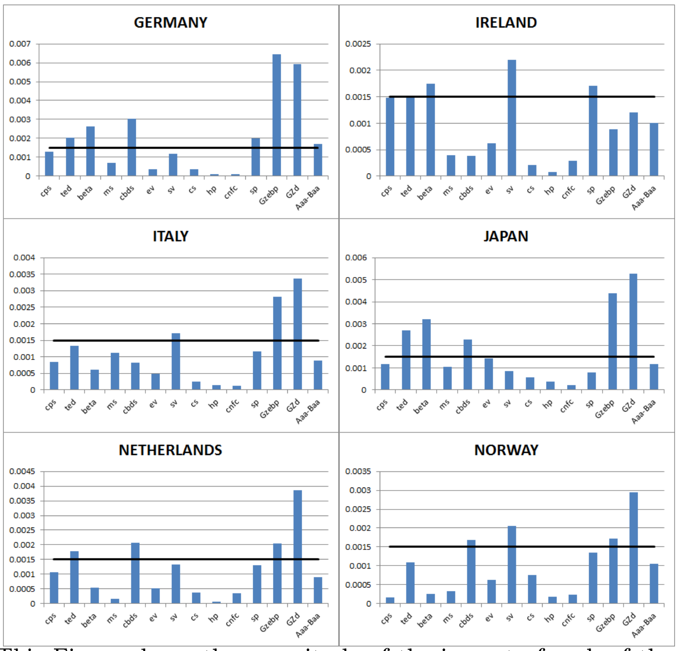
This Figure is ordered by the influence index measure and displays the cross country influence and dependence index measures from an array of financial shocks. The results are obtained by running the baseline model and adding a different financial shock variable each time, with replacement.

Figure 4.4: Magnitude of Influence Across Countries (1)



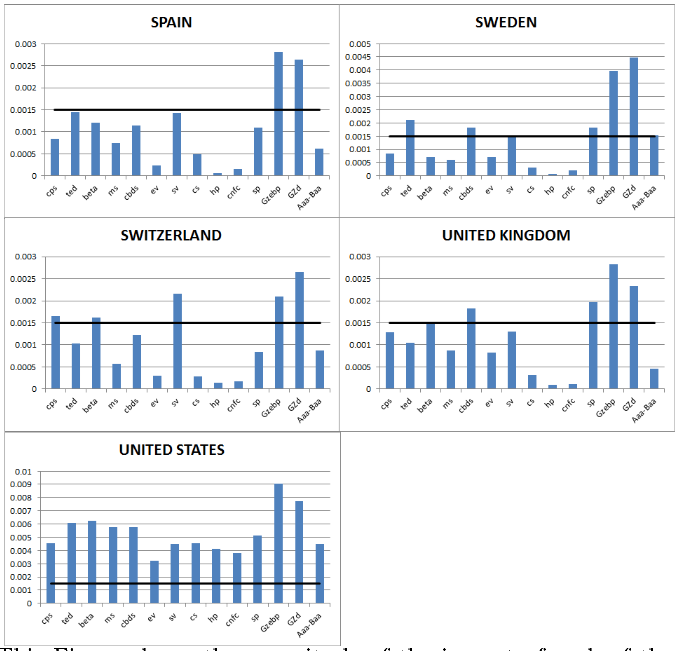
This Figure shows the magnitude of the impact of each of the financial shock measures in turn, this magnitude is given in terms of the TO connectedness index measure. This measures the aggregate impact on a countries macroeconomic and financial variables.

Figure 4.5: Magnitude of Influence Across Countries (2)



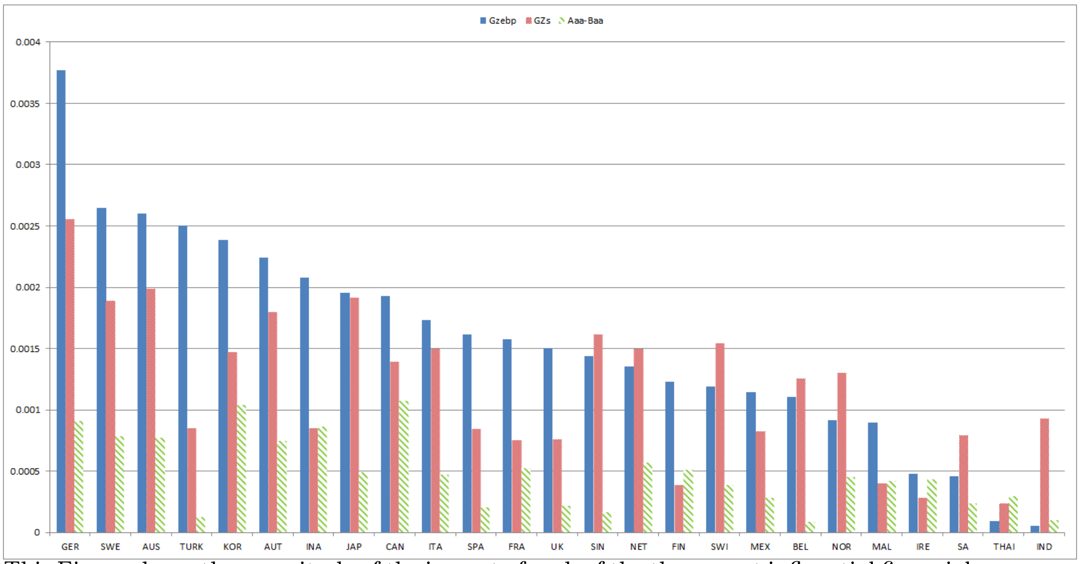
This Figure shows the magnitude of the impact of each of the financial shock measures in turn, this magnitude is given in terms of the TO connectedness index measure. This measures the aggregate impact on a countries macroeconomic and financial variables.

Figure 4.6: Magnitude of Influence Across Countries (3)



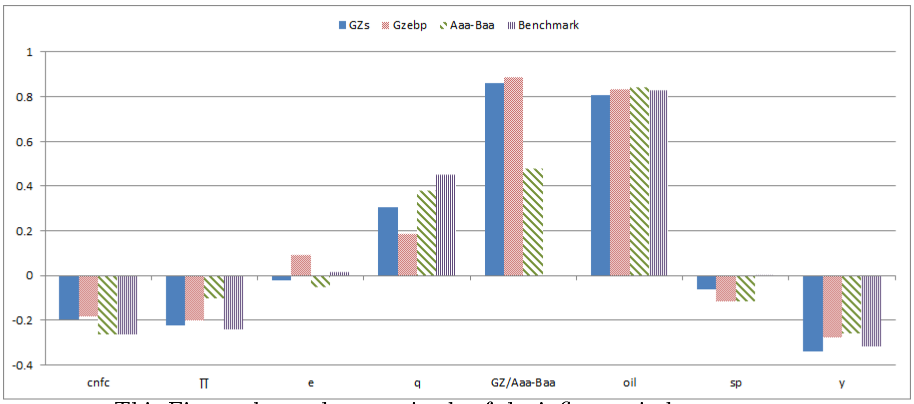
This Figure shows the magnitude of the impact of each of the financial shock measures in turn, this magnitude is given in terms of the TO connectedness index measure. This measures the aggregate impact on a countries macroeconomic and financial variables.

Figure 4.7: Influence of Shocks to Selected United States Financial Variables on Advanced and Emerging Market Economies



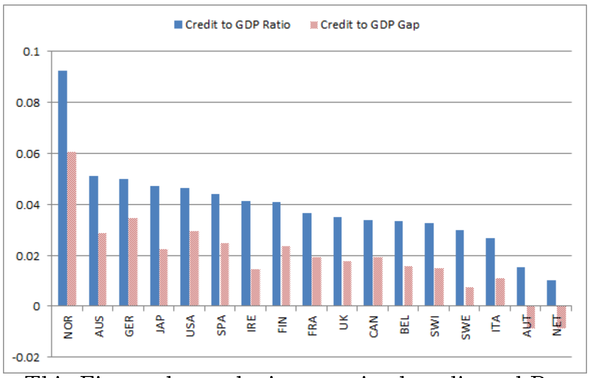
This Figure shows the magnitude of the impact of each of the three most influential financial shock measures, the GZ probability of default, the GZ excess bond premium and the Aaa-Baa corporate bond spread. This magnitude is given in terms of the TO connectedness index measure. This measures the aggregate impact on a countries macroeconomic and financial variables.

Figure 4.8: Magnitude of Influence Across Variables



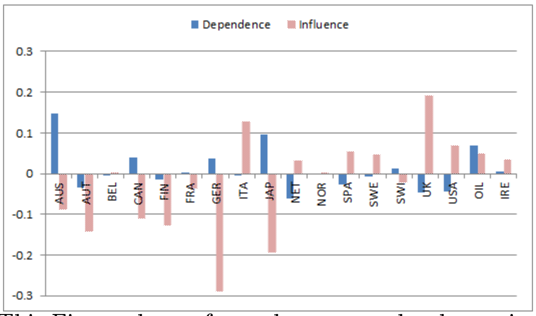
This Figure shows the magnitude of the influence index measure of the two GZ measures and the Aaa-Baa spread relative to the other benchmark variables in the model. The y-axis is measured ad the index measure of influence.

Figure 4.9: Credit and Models Fit



This Figure shows the increase in the adjusted R-Squared statistic from the country level VAR models that comes from the addition of the different credit variables.

Figure 4.10: Change in Dependence, Influence from Credit



This Figure shows, for each country, the change in the dependence and influence connectedness index measured that results from the inclusion of credit as an explanatory variable in the benchmark country level VAR model model.

Chapter 5

Conclusions

The main purpose of this thesis was to examine the interaction between financial frictions and macroeconomic variables in a range of macroeconomic models. The thesis contains both theoretical and empirical chapters and there is a strong degree of commonality in the modelling framework employed across the chapters. The first chapter of the thesis described a benchmark theoretical framework for financial frictions. The chapter then described how this benchmark framework was embedded into a benchmark macroeconomic model, a DSGE model, and adds a number of extensions. The second chapter builds on the detailed description of the financial frictions modelling framework of the first chapter in order to embed this model into a different type of macroeconomic model. In contrast to the first chapter, the analysis of the second proceeds by embedding the financial frictions framework into a benchmark overlapping generations model as opposed to a DSGE model. In the third chapter the approach changes to an empirical analysis, but the theme remains the same as in the first two chapters, that of the interaction of financial frictions and macroeconomic variables. The third chapter drew on the theoretical insights gained in the first two chapters in order to construct and select variables for analysis, to motivate the selection of the empirical framework and also to interpret the results of the analysis.

In Chapter 2, the aim was to present a detailed description of a financial frictions mechanism and to analyse how the inclusion of this feature into a benchmark macroeconomic model impacts the model's response to both conventional macroeconomic and financial shocks. The financial frictions framework used was the collateral constraint approach of Kiyotaki and Moore (1997). This approach to financial frictions focuses more explicitly on the supply side of the credit market and therefore more easily facilitates the analysis of changes in the quantity of credit in the economy. This occurs as agents borrowing is constrained by their holding of a durable good that is added to the model and used as collateral. This model uses a heterogeneous agent structure, with agents divided according to their degree of patience, via their rate of time preference. Having described the key assumptions, the embedding of this model into a DSGE model, as in Iacoviello (2005), was then outlined. This DSGE model also contains a heterogeneous agent structure with consuming agents divided into Patient Households and Entrepreneurs. The model contains the standard features of sticky prices and a Central Bank. This basic model was then extended by adding further stochastic processes. Having established and extended the model, four shocks were considered to illustrate its properties; a monetary shock, a technology shock, a borrowing shock and a real estate demand shock. This was a broader range of shocks than considered in the benchmark versions of this model in the previous literature. The analysis was conducted by calibrating and simulating the model, and was described by way of the impulse response functions. These shocks were used to provide a comparison of the model's responses between different levels of financial development. Different stages of financial development could be modelled in this framework as there is an exact expression for the quantity of credit. Through adjusting the parameters of the model to relax the financial frictions the model attains a higher steady state level of debt. It was found that at higher levels of debt, financial shocks have a greater impact on variables than at lower levels of debt. This situation was not true of conventional shocks, where there was little difference found between the responses to these shocks between the different debt levels. This result was in line with a previous literature from the Great Moderation, where aggregate volatility from technology shocks was seen to decline with increases in an indicator of financial development. This finding provides a rationale that the lack of appreciation of the risks leading up to the recent financial crisis as even in models with a financial friction present the conventional macroeconomic shocks usually considered in macroeconomic projections and policy experiments do not show a substantial quantitative difference between initial condition of high as opposed to low debt.

The focus in Chapter 3 shifted to the steady state interest rate. This was motivated by the fact that across the broad range of literature on financial friction in macroeconomic models this variable was typically treated as a fixed exogenous parameter. This occurs as in these models the steady state interest rate depends on the rate of time preference of the patient agent only. In the financial frictions models the steady state value of other variables of interest can vary, aside from the interest rate. A model which allows this variable to vary, and which establishes the nature of the relationship between financial frictions and this steady state rate, is of interest due to the persistently low interest rates observed across a large number of the most important monetary policy jurisdiction's in the aftermath of the financial crisis. The chapter proceeded by constructing a model that included financial frictions and also allowed for a variable steady state interest rate. In order to allow an endogenous steady state interest rate an overlapping generations model was used, specifically a perpetual youth structure. This was selected as the financial friction framework that was used to extend the model was originally embedded in a DSGE model, and the perpetual youth structure is the OLG model that is most closely aligned to the DSGE structure. This allowed the steady state rate of interest to be a function of more variables than just the rate of time preference. For the financial frictions element of the model the collateral constraints approach described in the first chapter was used. As noted, this framework explicitly models the supply side of the credit market, this entered into the steady state expression of the interest rate and thus allowed this rate to vary with credit market conditions. This feature was the source of the main difference between the nature of supply and demand in the credit market between a benchmark DSGE model in comparison to an overlapping generations model, when both models contain a financial friction. In a DSGE model the credit market is characterised by a perfectly elastic supply curve, whereas in an overlapping generation setting the supply of credit is responsive to the price.

In terms of results it was found that a tightening of the financial friction leads to a fall in the steady state rate of interest. This result was in line with the empirical literature in which drops in the interest rate are observed in the aftermath of financial crisis. This result was suggestive of the zero lower bound issue arising after a financial crisis being related to a dislocation in the credit market. The relationship was also found to be non-linear. The fall in the interest rate in response to the same change in the credit constraint is larger under certain circumstances. In the model these circumstances were seen to be a combination of population ageing and financial liberalisation. These factors together meant that an economy was much more susceptible to entering into a period of persistently low interest rates when a financial shock occurred. This was suggestive of a Secular Stagnation type argument and also added a rationale that contradicted the pre-financial crisis narrative that issues of persistently low interest rates would occur infrequently. The model showed that if certain parameters change, non-linear relationships mean that an economy would have a higher probability of experiencing this phenomenon. A possible scenario in the model was that if there was a relaxation of the financial friction and a process of population ageing, this would lead to a situation of an economy with the same observed steady state interest rate as prior to the occurrence of theses dynamics. The economy in this new state could however be more vulnerable to entering a period of a persistently low interest rate following a tightening of the financial friction from, for example, a financial crisis.

Chapter 4 continued with the analysis of financial frictions and macroeconomic aggregates, except this time in an empirical setting. The chapter sought to uncover which measures of financial frictions and financial stress are the most influential in the global economy as well as in national economies.

There were a number of complicating factors in addressing these questions, dealing with these complicating factors guided the modelling choices made in the chapter. There were three main areas of uncertainty to be considered; the first was the intensification of cross-country financial linkages. This feature made it difficult to justify modelling countries individually when looking at financial shocks. The second area was the multitude of models proposed which were dealing with the interaction of financial frictions and macroeconomic aggregates. This array of models was reflective of the fact that there is no set theory to describe the nature of this interaction and so variable selection and the identification of shocks was a difficulty. Finally financial stress and frictions are latent conditions and therefore there is a vast array of proposed measured to attempt to capture these concepts. When confronted with a question that is cross-country in nature, and given the uncertainty as to the nature of the linkages between the variables and a vast array of potential measures of financial shocks the chapter proceeded in the analysis by adopting a Global VAR and Generalised Connectedness Measures approach. The advantage of these approaches were that the GVAR approach allowed a multi-country model to be easily constructed while at the same time it avoided dimensionality issues. The important cross-country linkages are facilitated in this framework.

The Generalised Connectedness Measures approach utilised the generalised impulse response functions from the GVAR model for distilling the results of a large scale model. By using the generalised impulse response functions the approach avoided many of the difficult identification issues of the existing literature. Through distilling the results of a large scale model this approach also avoided selectivity in presenting results. By distilling results into a few index measures the approach allowed concepts like influence and dependence to be quantified and could rank countries and variables according to these measures. This allowed the variables to be ranked in a way that did not draw heavily on identification structures or a set theoretical framework. Given its flexibility this framework allowed a wide array of measures to be considered in a comparable framework.

From this analysis it was found that the most influential financial variables were those that were derived from corporate bond spreads. This result was of interest as this measure of financial frictions was the closest match to the concept of financial frictions as proposed in the theoretical literature. This result held at the global level in the model and, taking advantage of the disaggregation possible with the GVAR model, this result also held at the country level. Interestingly, given credit has been a common choice as a shock variable in the empirical literature on macro-financial linkages, the results suggest that credit may be an endogenous variable. This was an important result as it has implication for the identification of a model containing credit as a variable. This result was also in line with the supply orientated theoretical models where credit is a function of the financial friction and thus in modelling a financial shock it would make little sense to model this through a shock to a measure of aggregate credit. In line with previous studies, that did not focus on financial variables, the United States was found to be the most influential economy in the system in terms of both macroeconomic and financial shocks. It was also noteworthy that there was considerable consistency found in the cross-country response to all financial shocks originating from the United

States. The exceptions to this were Canada, which is much more connected to the US economy and was influenced by a broader array of shocks. Volatility indicators measured highly in terms of influence in Ireland and Switzerland, which are small economies with large financial sectors. This chapter also contained results on an expanded set of countries, this expanded set included a number of emerging market economies. The results for this expanded set show that there was substantial diversity of the impact across these countries with some showing a high degree of sensitivity and others much lower.

One of the contributions of this thesis was that it added a broader array of shocks to the standard collateral constraints model. From doing this it found that there was a heterogeneous reaction to these shocks between low and high debt levels. From this result it found that this financial frictions model supported a Great Moderation narrative, in that the financial liberalisation reduced the economy's reaction to certain shocks. The results of this chapter contributed an explanation to the lack of appreciation of the risks in the lead up to the financial crisis, as standard shocks showed no major difference in the magnitude of their impact between a situation of high as opposed to low debt. The thesis also established, in a benchmark macroeconomic model, an analytical link between the financial frictions literature and a feature of the zero lower bound literature; that of prolonged low interest rates after a crisis. This model outlined the presence of non-linearities in the relationship between financial development and the reaction to shocks to the financial friction. The model used for this analysis also highlighted the potential role of phenomena like population ageing and financial liberalisation to influence the relationship between financial frictions and persistently low interest rates. This model lends support to a narrative from the Secular Stagnation hypothesis of persistently low interest rates. In progressing towards this result, a technical contribution was made in terms of ensuring that in the steady state for a perpetual youth model that there was a binding financial friction when using the collateral constraints approach. On the empirical contribution the thesis applied the connectedness measures approach of Greenwood-Nimmo et al. (2015) to rank the global influence of an array of measures of financial frictions and financial stress. The analysis took a different approach to much of the previous literature on GVAR modelling in that it proceeded in a way that further reduced the number of assumptions used in the estimation. Specifically the model was based on stationary time series and generalised impulse response functions. This analysis was done in a flexible way that reduced the need for structural assumptions. This was particularly relevant to the analysis of macro-financial interactions given the uncertainty around the nature of these linkages. This analysis also extended over a limited set of emerging market economies. This was a further contribution as these countries are not typically included in these types of analysis. The model presented a novel outline of these results at the country level and also added a number of emerging markets to this analysis.

There are several points on which the analysis in this thesis could be developed further. A finding in the third chapter raises the prospect of financial frictions and credit market dynamics impacting on the interest rate. This suggests there may be a value is testing this in the context of the emerging literature on estimating the underlying interest rate as is done in Laubach and Williams (2003) and Cùrdia et al. (2015). Given that this chapter also shows that demographic and financial liberalisation factors impact on the natural rate and that these factors vary across countries, it raises issues in terms of the conduct of monetary policy across currency unions. In the fourth chapter the analysis has the potential to be extended to a broader group of emerging market economies as there is relatively sparse empirical work on the transmission of a broad array of financial shocks from advanced to emerging market economies in the setting of a global model. By adding a rolling sample structure to the estimation it would also be possible to estimate if the influence and dependence measures of different financial stress variables increased or decreased over the financial cycle.

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