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Essays in Macroeconomics and the Financial Cycle

Ph.D. Thesis

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Summary

This thesis is divided into three essays macroeconomics and credit markets. It puts a special emphasis on (i) the recurring nature of macroeconomic events, in particular cycles in financial markets and their effects on the real economy, (ii) cross-country interactions through credit markets, and (iii) the role that policy interventions can play at mitigating damage to the economy from crises in credit markets.

In my first chapter, I offer a new empirical synthesis of the Great Moderation and the Great Recession, that acts through the relationship between the real business cycle and the financial cycle. I first show that the defining features of the Great Moderation were a shift from output volatility to medium-term fluctuations and a shift in the origin of those fluctuations from the real to the financial sector. I establish a link between these shifts to financial market activity by showing a Granger-causal relationship by which financial cycles *attenuate short-term* business cycle fluctuations while they *amplify longer-term* fluctuations. As a result, financial shocks systematically drive medium-term output fluctuations, whereas shocks to the non-financial sector drive short-term output fluctuations. I use these results to argue that the Great Moderation and Great Recession are two sides of the same coin, as both result from the same economic forces. I further show that standard DSGE models with financial sectors do not replicate the aforementioned properties of the business cycle-financial cycle relationship, as they miss that financial shocks systematically drive medium-term fluctuations. I then propose *long-run risk* à la Bansal and Yaron (2004) as a fix that enables DSGE models with financial sectors to replicate these shifts. Finally, I use this DSGE model to refine the *good luck* and *good policy* hypotheses of the Great Moderation. Both hypotheses are true in the short-run but do not account for long-run risk and detrimental medium-run effects of the monetary policy.

In the second chapter, I study how capital flows between countries affect the synchronization of those countries' financial cycles. To this end, I introduce the *Finance Co-movement Slope*. This slope measures the effect of capital flows on financial cycle synchronization over windows of different horizons. I find that this slope is positive and increasing in the time horizon over which it is calculated, but financial synchronization is reduced the more asymmetric the capital flows are. In other words, higher capital flows increase medium-term synchronization of financial cycles by more than they increase short-term synchronization. I then show a DSGE model of cross-border capital flows that can replicate the main empirical findings. I use this model to decompose the Finance Co-movement Slope. The model suggests that in the short-run, capital flows in the market for corporate loans drive the shape of the Finance Co-movement Slope, whereas medium-run effects are driven by interbank credit flows. Finally, I show that macro-prudential policy can dampen the effects of capital flows on financial synchronization, but only in the short run.

The third chapter of this thesis focuses on sovereign debt. Specifically, I study the incidence of bailouts with the possibility that bailouts may be required repeatedly before the crisis is resolved. I build a model in which a country in crisis and a rescuing country engage in a strategic interaction. In this setting, repeated bailouts are required until the country in crisis regains the trust of international creditors, which roll over its debt. Credit market re-access can be facilitated if either the country in crisis implements austerity measures, or if the rescuing country grants the country in crisis a one-off transfer of resources. The strategic interaction ends when the country in crisis has either re-accessed the international credit markets or defaulted. Evaluating the properties of the Markov-equilibrium of the model, I show how the rescuing country trades off the costs of bailout with the spillover costs from default. I find that the fundamental conflict of interest over austerity arises over the speed of repayment of the crisis country's debt. To the rescuer, austerity measures and a transfer of resources to the country in crisis are strategic complements: this is because only the implementation of austerity measures by the country in crisis ensures that the resources of the transfer do not go towards consumption, but into debt reduction. The findings of this paper suggest a new definition for austerity that distinguishes between a solvency and a liquidity dimension of a sovereign debt crisis.

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Chapter 1

The Great Moderation and the Financial Cycle

Friedrich Lucke[1,2]

Abstract

We show that the defining features of the Great Moderation were a shift from output volatility to medium-term fluctuations and a shift in the origin of those fluctuations from the real to the financial sector. We discover a Granger-causal relationship by which financial cycles attenuate short-term business cycle fluctuations while they amplify longer-term fluctuations at the same time. As a result, financial shocks systematically drive medium-term output fluctuations whereas real shocks drive short-term output fluctuations. We use these results to argue that the Great Moderation and Great Recession both result from the same economic forces. On the theoretical front, we show that long-run risk is a critical ingredient of DSGE models with financial sectors that seek to replicate these shifts. Finally, we used this DSGE model to refine "good luck" and "good policy" hypothesis of the Great Moderation.

JEL Classifications: E00, E32, E44, E50

Great Moderation, *Business Cycle*, *Financial Cycle*, *Frequency-Domain*

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1.1 Introduction

After 25 years of relatively mild business cycle fluctuations in the U.S., the so-called "Great Moderation", the Great Financial Crisis (GFC) caused tremendous turmoil and drew the U.S. economy into the Great Recession of 2009. In the business cycle literature, the Great Moderation (see among others Stock and Watson (2002), Gali and Monacelli (2005) and Giannone et al. (2008)) was one of the most studied phenomena until the Great Recession diverted researchers' attention (see among many others Christiano et al. (2014), Mian and Sufi (2010), Aiyar (2012)). However, the relationship between the two has been largely neglected. This paper argues that the Great Moderation and Great Recession are essentially one phenomenon – two sides of the same coin – and that the financial cycle is the force that forged it.

This approach is motivated by the observation in Figure 1.1. This figure shows that the financial cycle – represented by credit-volume-to-GDP (the so-called "credit gap") and house prices - witnessed large gains in its amplitude precisely at the same time at which the business cycle began its *moderation*. An *increase* of financial market volatility thus occurred long before the housing market bubble that eventually led to the GFC even began to build up. We find a single Granger-causal empirical relationship between the credit gap and output that rationalizes this observation. This relationship is such that credit can attenuate short-term output fluctuations *and* amplify medium-term output fluctuations. This led to two "shifts" that give the Great Moderation a new narrative: a shift of output volatility toward longer-term fluctuations and a shift in the source of medium-term volatility from the real (non-financial) to the financial sector. These shifts are both independent of the Great Recession.

This paper makes two contributions: The first contribution is the empirical characterization of the relationship between the business cycle and the financial cycle over the last five decades. Herefore, we use spectral analysis to decompose business cycle fluctuations into volatilities of different periodicities. Then, we estimate vector-autoregressive models (VARs) that describe the relationship between output and financial variables. In this context, we show how to use frequency-domain techniques to evaluate the properties of the VAR models and obtain novel results. Specifically, we characterize Granger-causal relationships between the financial cycle variables credit gap and house prices, and output (GDP). Finally, we identify structural shocks from the estimated VAR models to assess which shocks drive fluctuations of different periodicities. With this approach, we find that the volatility of the post-1984 economy moved mainly outside the classic business cycle range of cycles of 5-32 quarters (Burns and Mitchell (1946)) onto medium-term fluctuations between 32 and 120 quarters. While this led to a reduction in short-term volatility, medium-term volatility increased. This shift came with a shift in the origin of output volatility from the real (non-financial) sector to the financial sector: we show that shocks to financial variables increase greatly in importance but systematically drive mainly medium-term output volatility in the Great

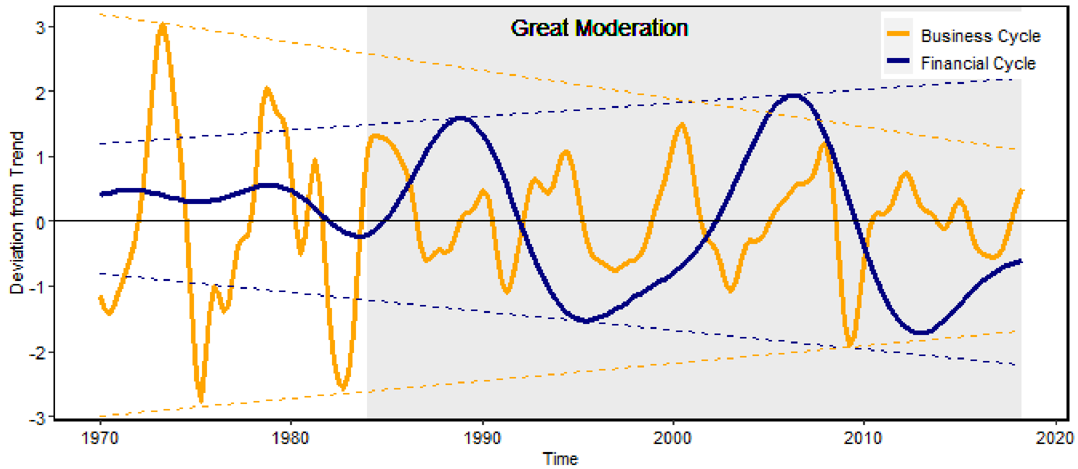


Figure 1.1. Business Cycle (GDP) and Financial Cycle (Indicator) in the United States

This figure shows the evolution of the U.S. business cycle and financial cycle between 1970 and 2018. The business cycle is calculated as the fluctuations between 5 and 32 quarter of GDP around its trend. The financial cycle is an indicator routinely calculated by the Bank for International Settlements as the average of the cyclical components of total credit volume, credit gap and house prices. The cyclical components are extracted with a bandpass filter with bounds of 32 and 120 quarters.

Moderation economy. Meanwhile real shocks (such as TFP shocks) continue to drive the majority of short-term output volatility.

Jointly, these shifts imply that the defining feature of the Great Moderation was a finance-driven shift in the origin of output volatility and in the distribution of output volatility across fluctuations of different lengths. These changes of the Great Moderation are linked by a Granger-causal relationship between between credit gap and output, which is not uniform across fluctuations of different lengths. Short-period reductions in output lead to short-period expansions of the credit gap. At the same time, medium-period expansions (contractions) in credit gap lead to medium-period expansions (contractions) of output. In other words, short-period credit gap movements attenuate short-period output movements, while medium-term credit gap movements amplify medium-term output movements. The short-term fluctuations for which we find the attenuation forces of credit are precisely the same on which we find that a moderation of output volatility occurred. At the same time, the fluctuations in which financial shocks manifest themselves as volatility are those on which the amplification forces and the resulting increases in output volatility are found.

We show that the attenuation-amplification property of the relationship between credit gap and output is not an artefact of the Great Moderation or the Great Recession period, but can be found in multiple periods of the U.S. economy after World War II. We argue that by this relationship, the Great Moderation and the Great Recession are the consequences of the attenuation and amplification forces, respectively. Therefore, they are inextricably linked.

The second contribution is the construction of a model that can replicate the most important frequency-domain features of the data. We show that a combination of modelling elements is required for this: a collateral constraint on an entrepreneur as in Iacoviello (2005) that gives rise to a financial accelerator, a leverage constraint on the financial intermediary as in Gertler and Karadi (2011) and the presence of long-run risk borrowed from Bansal and Yaron (2004) on the cost of entrepreneurial investments and on the lending ability of the financial intermediary. The collateral and leverage constraints generate the necessary interaction between the financial sector and the real sector. The long-run risk generates the necessary persistence to explain the medium-term fluctuation and ensures that shocks to the investment cost systematically feed into medium-term output volatility. In the absence of any of those three elements, the model's moments do not come close to those of the data. This extends to many standard off-the-shelf models from the literature, which consistently fail to reproduce the non-uniformity of the effects of financial and non-financial shocks on fluctuations of different lengths. In a similar spirit as emphasized by Gourio (2013), the right set of financial frictions is required to amplify the effects of the risk-structure of shocks to replicate the properties of the data.

The long-run risk is the theoretical counterpart in the argument that the Great Moderation and the Great Recession are two sides of the same coin. The presence of this risk has effects on prices in phases of moderate volatility but its main effect is only observed in relatively rare, but consequential events. We then use the parameter estimates of the model to refine the "good luck" hypothesis of the Great Moderation by showing that only the standard deviation of non-persistent (short-run) shocks occurred, while very persistent (long-run) shocks witnessed increases in their standard deviations. Additionally, we isolate the changes of monetary policy that occurred during the Great Moderation. We show that while monetary policy in the Great Moderation reduced short-term output volatility, it contributed to the systematic way that financial shocks cause medium-run output volatility - therefore came at the expense of more medium-run volatility. In other words, we can use the model to refine the "good policy" hypothesis of the Great Moderation as well.

In the course of this paper, there are several instances where the frequency-domain approach is required in order to discover new insights on the economics of business cycle and financial cycle. It reveals the non-uniformity of the empirical relationship between credit gap and output. Additionally, it leads to the finding that financial shocks systematically drive medium-term volatility. This adds a new property that economic models should be able to replicate.

The remainder of this paper is structured as follows: In section 1.2 we discuss the relation of my paper to the existing literature. Section 1.3 presents the empirical case. Section 1.4 introduces the model section 1.5 discusses its estimation. Section 1.6 analyses the performance of the model on the frequency-domain properties of the time series. Section 1.7 concludes.

1.2 Related Literature

The paper is related to the literature in three ways: First, it is connected to the literature that characterizes the empirical properties of (domestic) financial cycles and their relationship with business cycles (see for instance Borio and White (2004), Borio et al. (2018), Claessens et al. (2011), Strohsal et al. (2015), Schularick and Taylor (2012), Jordà et al. (2011), Jordà et al. (2016), Jordà et al. (2017), Drehmann et al. (2012) or Adarov (2018)). Especially noteworthy is the work by Jordà et al. (2011) who provide very long-run data on financial cycles. The main results of this literature that 1) the financial cycle is significantly longer than the business cycle, 2) business cycle recessions that coincide with financial cycle downturns are larger and longer than those who do not and 3) the financial cycle is aligned with medium-term business cycle fluctuations are reflected in the findings of this paper. The prevalent approach of the literature has usually been to isolate fluctuations of a certain periodicity-range with a band-pass filter and calculate the average effect over the periodicity window (see for instance Drehmann et al. (2012) and Pancrazi (2015)). The former use this technique to find strongly positive correlation of medium-term output fluctuations and the (BIS) financial cycle indicator[3]. We advance this result by showing that the relationships between credit gap, house prices and output are non-uniform across different periodicities. In fact, the frequency-domain approach of this paper allows us to calculate a profile of correlations associated with different periodicities and give a Granger-causal interpretation to them. The combination of the two yields in a more detailed characterization of the empirical forces compared to the literature. In the case of credit gap and output, this yields a negative dynamic correlation on short periodicities in which output is Granger-causal and a positive dynamic correlation in which credit gap is Granger-causal on medium periodicities.

It has been recognized that credit booms sow the seeds of credit crunches (Minsky (1986), Kindleberger and Aliber (2011), Schularick and Taylor (2012), Aikman et al. (2014)). Therefore, the relationship between financial variables and output has been used to explain the Great Recession (Gorton and Ordoñez (2016), Bean (2010), Jordà et al. (2013)) or the failure to predict it (Gadea Rivas et al. (2014)) and it has been shown that the pair of credit and asset prices is one of the most powerful early warning indicator of a recession (Aldasoro et al. (2018)). However, this analysis is usually focused on the build-up of credit that occurred during the 2000s - not on the entire Great Moderation. This paper shows that the relationship between credit and output that underlies drives credit booms and busts, phases of moderation and phases of high volatility, already existed long before the Great Recession and even before the Great Moderation. Instead, the relationship has intensified: Granger-causality from financial to non-financial sector has become more significant and financial shocks cause more output volatility.

[3] This indicator is computed as the cyclical components between 32 and 120 quarters of total credit volume, credit gap and house prices; which are then averaged.

Second, these findings allows us to contribute to the literature on the Great Moderation with a novel view that complements the existing ones. Ever since Stock and Watson (2002) coined the term "Great Moderation", the academic debate largely evolved around the question of whether "good luck" or "good policy" were responsible for the Great Moderation. The good luck hypothesis, put forward among others by Stock and Watson (2003) and Ahmed et al. (2004) suggest that merely the size of shocks had decreased during the Great Moderation. The good policy hypothesis (see Bernanke (2004)[4]), Boivin and Giannoni (2006), and Benati and Surico (2009) accredits the perceived reduction in output volatility to the more aggressive reaction to inflation of monetary policy and better forward guidance under Volcker and Greenspan, compared to the pre-Volcker era. Without formalizing their ideas in a model, Drehmann et al. (2012) warn that monetary policy that does not take into account credit growth could dampen short-term volatility at the expense of more medium-term volatility which implicitly questions how "good" the revised monetary policy actually was. Bilbiie and Straub (2013) and Carvalho and Gabaix (2013) have pointed to increased asset market participation and the overall expansion of the U.S. financial sector as causes for the Great Moderation. The results of this paper do not stand in contrast to these positions, but we argue that none of these explanations is at the core of the changes that occurred during the Great Moderation. "Good luck", "good policy" or structural changes are competing narratives on the initial cause of the upswing in the credit gap at the beginning of the Great Moderation. We remain largely agnostic regarding what caused the upswing in credit gap. Instead we emphasize that the increased amplitude over the duration of the cycle lead to the Great Moderation. In this regard, we sharpen the finding of an increased contribution of the financial sector to output volatility in the Great Moderation (Carvalho and Gabaix (2013), Khieu (2018)), by showing that financial shocks systematically feed into medium-term volatility. Consequently, we concur with Pancrazi (2015) and Crowley and Hallett (2015)[5] that the Great Moderation was a very heterogeneous phenomenon. The term "Great Moderation" is therefore misleading.

Thirdly, this paper is related to the theoretical literature that studies financial frictions and amplification mechanisms in relation to recessions. In the business cycle literature, the contributions of Bernanke et al. (1999), Kiyotaki and Moore (1997), Iacoviello (2005) and Gertler and Karadi (2011) stand out and are the basis for the theoretical model presented in section 1.4 of this paper.

Borio (2014) summarizes the theoretical insights into the relation between the financial cycle and business cycle and emphasizes the importance of studying the micro-level linkages between real and financial sector.

Herein, Rajan (2006) was among the first to suggest that increased access to finance may make the world riskier. He argues that while the expansion of the financial sector has made the world

[4]https://www.federalreserve.gov/boarddocs/speeches/2004/20040220/ (accessed 19/09/2021)

[5]They show that the rolling-window variances only of certain short-frequency wavelets experience decreases in their rolling window variance, whereas fluctuations between 64-128 quarters have seen an increase in the variance. This is the closest that the literature has come in documenting the "shift" fo volatility to longer fluctuations.

better off overall, financial intermediaries may "accentuate real fluctuations, they can also leave themselves exposed to certain small probability risks that their own collective behaviour makes more likely". In other words, when financial intermediaries grant credit, they can alleviate the real sector of some of its idosyncratic risk. Increased access to credit enables firms to smooth out some short-term financing constraints, which leads to a reduction in short-term volatility. However, these risks are pooled on banks' balance sheets where they pile up until either the loan is paid back or the risks materialize. The pooling of idiosyncratic risks creates systemic risk in the banking sector. When too many risks materialize at the same time (which is more likely, the higher the credit volume is), banks tighten credit constraints for firms; which has adverse effects on real economic activity. When enough risks materialize to push the banks to their own financing constraint, this can result in market freezes (such as in 2008) and banks become the super-spreaders in an financial crisis contagion - which leads to higher overall (medium-term) volatility. These ideas are taken up and formalized by Brunnermeier and Sannikov (2014)'s paradox of volatility and paradox of prudence. The former shows that in a model with lower exogenous volatility, intermediaries may be induced to increase leverage, which results in higher endogenous volatility. The latter describes how the individually rational deleveraging of financial intermediaries when financial turmoil is on the horizon can collectively drive the entire financial sector into a crisis. Gourio (2013) argues along similiar lines that lower perceived disaster risk can make the economy more fragile as agents lever up.

1.3 Empirical Case

This section first introduces the data and explains the methodological approach. Then, we show the shift of output volatility towards longer-term fluctuations that defines the Great Moderation. Further, we document the intensifying relationship of attenuation and amplification between credit gap and output, by characterizing co-movement and Granger-causality between these variables in the course of the Great Moderation. Finally, we move to a structural interpretation that shows how shocks on financial markets systematically cause medium-term output volatility in the Great Moderation economy.

1.3.1 Data

To study the interactions of real and financial markets we focus on GDP as the most common measure of aggregate activity, while credit volume and asset prices measure financial activity[6]. To gauge credit supply to demand, we use the "credit gap", defined by the BIS as total credit to the

[6] The BIS computes an financial cycle indicator which is made up of the cyclical components between 32 and 120 quarters of total credit volume, credit gap and house prices. We use the same information in our three main variables. However, we study fluctuations of all frequencies (above seasonal ones).

private non-financial sector, divided by GDP. The role of asset prices in the description of financial market activity is that of a determinant of collateral value. As described by Borio (2014), the pair of credit gap and asset prices is the smallest set of variables that can describe the medium-term cycles that arise from the "self-enforcing interactions of perception of value and financing constraints" that constitute the financial cycle. Hence, we obtain indicators of stock prices and house prices. We do not have data on the composition of collateral by asset type and its evolution throughout time, but there is anecdotal evidence that the share of mortgage-backed lending has increased over time. As described by Drehmann et al. (2012) the lower short-term volatility of house prices relative to stock prices also makes houses a more suitable asset to pose as collateral. Additionally, Aldasoro et al. (2018) show that house prices are a better predictor of future recessions than stock prices. Hence, we use house prices as the main asset price and use stock prices only for a robustness check[7]. To these three variables, we add the Fed Funds rate - as it stands right at the intersection of the real and the financial economy. In another robustness check, we also extend the analysis to include the inflation rate which underwent a moderation of its own in the so-called "Volcker-disinflation" in the 1980s. The data are obtained from the Federal Reserve Economic Database (FRED) and the database of the Bank for International Settlements (BIS).

The data are available at quarterly frequency for the period 1970Q1-2018Q2, where the house price index constrains the sample to start in 1970. All time series with the exception of the policy rate and inflation rate are in real terms and are transformed into log-levels. We filter out the long-term trends using a one-sided band-pass filter to stationarize the time series (which is required for frequency-domain analysis). Importantly, the filter only removes the long-term trend but neither alters the frequency components of the data, nor uses future observations to extract the trend. This filter has a flat transfer function except at frequency zero. Hence it does not artificially accentuate some frequencies at the expense of others. To ensure that the results are not driven by the choice of filter, we run a robustness check in which the data is detrended with a one-sided HP-filter[8]. All variables are standardized.

To test the robustness further, we build the analogue data set for the UK with data from the FRED, BIS and the Office for National Statistics (ONS). In addition, we use the data set of Jordà et al. (2011) to cover the longest possible period. This data set covers the relevant variables for the U.S. from 1891 to 2016 but it is only available at yearly frequency (and therefore has even fewer data points than the main data set).

In addition to the full time series, we study multiple different sub-periods in the course of the analysis. In accordance with the literature (Stock and Watson (2003), Galí and Gambetti (2009)),

[7] As a further robustness check we compute the first principal component of detrended house prices and stock prices as an indicator of asset prices.

[8] The HP-filter does not have a flat transfer function as the band-pass filter. Hence, it accentuates the fluctuations of some frequencies at the expense of others in the detrending process. Therefore, the results obtained with the band-pass filter are of superior quality.

we choose the first quarter of 1984 as the beginning of the Great Moderation. The period 1970Q1-1983Q4 is hence called pre-Great Moderation (and sometimes abbreviated pre-GM). The choice of end date is trickier: The standard narrative is that the Great Moderation was ended by the Great Recession[9]. This is not a consensus though: Gadea Rivas et al. (2014) and Clark et al. (2009) argue that the low volatility persists. In the context of a Markov-switching model, Grazzini and Massaro (2021) claim that the Great Moderation was only interrupted by the Great Recession and that the past decade could be characterized as a “Great Moderation (again)”. Here, we will label the entire period between 1984Q1 and 2018Q2 as the “Great Moderation economy” (abbreviated GM) and call the period between 1984Q1 and 2007Q1 "narrow Great Moderation" (narrow GM). In contrast to Grazzini and Massaro (2021), the Great Recession is interpreted as a materialization of medium-term volatility rather than as two regime-switches. This choice is justified by the finding that short-term volatility has given way to more medium-term volatility. Additionally, in the study of financial markets, a cutoff in 2008 seems flawed as it would separate the Great Financial Crisis from the build-up of credit gap and house prices which led to it[10] (Gorton and Ordoñez (2016)).

1.3.2 Methodology

In this section we introduce the empirical methodology, which is based on vector autoregressive (VAR) models. In contrast to the majority of the literature, we will find it is useful to analyze the time series and the estimated VAR-processes in the frequency-domain. Herefore, we make use of the duality between time- and frequency-domain. It is important to stress that this does not change the properties of the time series or VAR-models - it is merely a different lens through which the properties are viewed.

Rather than evaluating the effects of shocks at a certain horizon, the frequency-domain approach decomposes the time series into cycles of frequency $\omega \in (0, \pi)$ and studies the effects at each frequency. For illustrative purposes, we use the inverse of frequencies - “periodicities.”. Denote periodicities $\tilde{\omega} = 1/\omega$. Fluctuations of frequency π correspond to a cycle that lasts only two periods (periodicity=2) while fluctuations of frequency 0 correspond to infinitely long-lasting cycles. For purposes of this paper, we are only interested in fluctuations between 5 and 120 quarters per cycle, which we categorize as follows: we refer to fluctuations between 5 and 16 quarters per cycle as “shorter business cycle periodicities”, fluctuations between 16 and 32 quarters as “longer

[9] Bean (2009) argues this because of the increased volatility that came with the Great Recession. Taylor (2011)’s argument that the Great Moderation has ended is that policy rules deviated from the supposedly "good" policy rules of the Great Moderation era. Ng et al. (2012) find that the Great Moderation period is not enough to forecast the Great Recession. Therefore, they argue that there has been a structural break.

[10] Additionally, there are two technical issues with defining 2008 as the end of the Great Moderation: 1) the Great Recession was such and extreme event that the choice of putting it into either a "Great Moderation Sample" (1984-2008) or a "post-Great Moderation Sample" (2009-2018) may sway results by construction. 2) Splitting the data at or near the peak of one time series may lead to instationarity of the resulting sub-series.

business cycle periodicities". This classification is borrowed from Pancrazi (2015)[11]. Following Drehmann et al. (2012), we refer to fluctuations between 32 and 120 quarters as "financial cycle periodicities". Seasonal fluctuations (below five quarters) are not of interest for purposes of this paper and neither are cycles longer than 120 quarters.

There are two reasons why the frequency-domain approach is advantageous in the study of the interactions between business cycle and financial cycle. The first reason is conceptual: The economic nature of the objects of study is inherently cyclical. The interaction of (collateral) asset prices and financing constraints gives rise to amplification effects in both directions that drive large booms an ensuing busts. Similarly, the business cycle is by definition the fluctuation of output around its trend or balance growth path[12]. By decomposing time series into cycles of different periodicities, the frequency-domain approach acknowledges the cyclical nature of the objects of study.

The second reason is more technical: The frequency-domain approach is especially suitable when a time series is an aggregate of multiple sub-series and we can give an interpretation to disaggregated frequency components. This is the case for output, which we know is the sum over all sectors of the economy[13]. It cannot be taken as given that the financial cycle interacts with all sectoral components of aggregate output in the same way, hence it should also not be assumed that it interacts equally with all periodicity components.

Misconceptions may arise when the periodicity-structure of time series is not properly taken into account: when two time series consist of multiple sub-series each, it is possible that the aggregate series have a zero correlation, even when the sub-series they are made up of are highly correlated. Recognizing the relation between two such series may require an intuition on how series can be correlated at a sub-aggregate level in order to specify relevant econometric models. After the estimation, frequency-domain tools can show how the time series interact at different frequencies.

Further, it is possible that a time series and its structural shocks only (Granger-) cause a certain periodicity-component of the fluctuations of another time series. In case of Granger-causality between time series, it is important to recognize which components of the time series we can forecast[14]. If such a component is related to a periodicity-range, frequency-domain Granger-tests can

[11]Note: Pancrazi (2015) original definitions use the terms "higher business cycle frequencies" and "lower business cycle frequencies" instead of "shorter" and "longer" business cycle periodicites as he works with frequencies rather than periodicities.

[12]This argument is supported by the fact that Schmitt-Grohé and Uribe (2021) show that a simple financial accelerator can in theory give rise to deterministic limit cycles. Similarly, Beaudry et al. (2016) and Gomes and Sprott (2017) explore limit cycle approaches to the business cycle, driven by demand complementarities or sentiment cycles, respectively.

[13]For example, tourism, agriculture and construction industry display a lot of fluctuations on seasonal frequencies, whereas industrial processes tend to exhibit longer cycles. Although these sectors are not orthogonal, the disaggregation of the business cycle can provide new insights.

[14]Examples for such frequency-specific Granger-causal relationships are easy to find: The tourism sector is often affected by the weather (both in origin and destination of the tourist), which goes through seasons each year. Hence, temperature can be a powerful predictor of economic activity in the tourism sector but it only affects the seasonal frequencies. Temperature data does not help to predict economic activity on a multiyear horizon but it will help predict in which season tourists are coming.

detect it, whereas time-domain Granger-test only calculate an average statistic over all frequencies. In case of structural shocks, the frequency-domain approach shows which types of fluctuations are caused by each shock.

On top of that, when we compare the interactions between two cycles, the amplitudes, differences in cycle length and phase interactions are of key interest. It is possible that a time series is at a short-cycle trough at the same time at which it is at a medium-cycle peak. The cycle with the larger amplitude then disguises the effects that play out on the smaller cycle.

The approach of the literature in response to this has often been to use a band-pass filter to isolate fluctuations of a specific frequency range to then study each component. In theory, the frequency-domain measure can be pieced together if this approach is performed on many different frequency ranges (Croux et al. (2001)). In practice, the application of frequency-domain methods to a VAR without selective filtering is a more wholistic and analyzes the effects at a much more disaggregated level. It allows us to calculate effects for each frequency rather than averages over a certain frequency-band as is done when components of the cycle are isolated with a band-pass filter.

In practice, we proceed as follows: We estimate VAR models and identify the orthogonal innovations. Then, we calculate the *dynamic correlation* implied by the VAR-model. Introduced by Croux et al. (2001), dynamic correlation is a measure of how the phases of two cycles interact. A negative dynamic correlation implies that the upswing of periodicity-$\tilde{\omega}$ cycle of variable x is associated with the downturn in periodicity-$\tilde{\omega}$ cycle of variable y. Conversely, a positive dynamic correlation implies that periodicity-$\tilde{\omega}$ components of x and y move through booms and busts together. The coefficient describes the direction of movements of one variable relative to the other, but cannot be interpreted as a directed coefficient in itself. To interpret the dynamic correlations as economic forces, we need to pair it with the second tool: A periodicity-specific measure of (Granger)-causality, following Breitung and Candelon (2006). This tests for each periodicity whether the whole time series x contains information that can be used to forecast periodicity-$\tilde{\omega}$ component of time series y (but not necessarily y's fluctuations of different frequencies).

The combination of Granger-test and dynamic correlation provide a directed measure of the strength and sign of the relationship between x and y at each periodicity $\tilde{\omega}$, which we can use to describe the economic forces that drive the interactions between business cycle and financial cycle variables.

Finally, we can conduct a structural decomposition by error. Via the Choleski-decomposition[15] we can identify the orthogonal innovations of the VAR-models. We impose 6 identification assumption: 1-3) The orthogonal shocks to the Fed Funds rate do not affect any other variable contemporaneously. 4-5) The orthogonal shocks to house prices do not affect neither output, nor the Fed Funds rate contemporaneously. 6). The orthogonal shocks to credit gap do not affect output con-

[15] Under the notation of Lütkepohl (2013), this is the "B-model".

Table 1.1. Baseline VAR key statistics

Sample		full	pre-GM	narrow GM	GM
		1970Q1-2018Q2	1907Q1-1983Q4	1984Q1-2007Q1	1984Q1-2018Q2
number of lags		10	4	4	10
portmanteau p-values		0.07913	1	0.9936	0.0821
Granger-causality p-values	Credit Gap to House Prices	0.1497	0.0103	0.3764	0.1366
	House Prices to Credit Gap	0.0001	0.0576	0.1084	0.0016
	Credit Gap to Output	0.2061	0.9541	0.3911	0.1369
	Output to Credit Gap	6.37e-07	0.1479	0.0221	0.0056
	House Prices to Output	0.0021	0.7649	0.0141	0.0967
	Output to House Prices	0.4874	8.44e-08	0.8487	0.1451

This table summarizes the key statistics of the baseline VAR model estimated on four different subsamples. The table lists the number of lags, the p-values of the Portmanteau-tests on serial correlation, and Granger-causality tests of the variable pairs listed in the first column.

temporaneously[16][17]. Next, we can recalculate the spectra, dynamic correlations and Granger-tests to assess which shocks are responsible for the effects at each periodicity that the SVAR gives rise to when all shocks except for one are shut down. The resulting spectra show how the volatility that the structural shocks cause spreads out over fluctuations of different periodicities. Such an error decomposition is standard procedure in the calculation of the forecast error variance decompositions (FEVD), which we can also represent in the frequency domain. The interpretation of the latter is almost exactly the same of as for a time-domain FEVD, except that it shows the forecast error variance at each frequency rather than for different horizons. Both dynamic correlation and FEVD are particularly helpful to visualize medium-term effects that are often hard to see in IRFs (that quickly converge to zero) and time-domain FEVD (that are often constant beyond a certain horizon). A detailed mathematical description of the frequency-domain methods is relegated to Appendix 1.E.

We choose as the baseline model the four-variable model of credit gap, house prices, output and the FED funds rate. The number of lags is chosen according to Akaike's information criterion subject to the Portmanteau test not rejecting its null hypothesis at 95% confidence. Table 1.1 summarizes key statistics of the baseline VAR models of the analysis. We also run bivariate VARs between credit gap, house prices and output to confirm the findings in a simplistic setting that help us to understand the effects between variable pairs in isolation[18]. In addition, we estimate a five-variable VAR model that adds the inflation rate to the variables of the baseline model.

[16] The identification assumptions are the same as in the model in Section 1.4.

[17] Multiple identification yield the same qualitative results. One alternative is to assume that 1-3) credit shocks do not affect any other variable contemporaneously, 4-5) house prices shocks affect neither output nor the Fed Funds rate contemporaneously and 6) Output does not affect the FED funds rate contemporaneously.

[18] In the bi-variate case, one assumption is sufficient to identify the structural shocks. In this particular case, the results of all three bivariate VARs are qualitatively robust to the choice of identifying assumption. In other words, the reduced form VARs are almost identified. The unrestricted entries of the B-matrix are close to zero.

1.3.3 Results

This subsection describes the results from the exercises outlined in the previous subsection. To keep the exposition simple and concise, we show only the results of the baseline VAR model of credit gap, house prices, output and interest rate in the main body of the text. The full results of the bivariate analysis and the inclusion of inflation can be found in the Appendix 1.A.

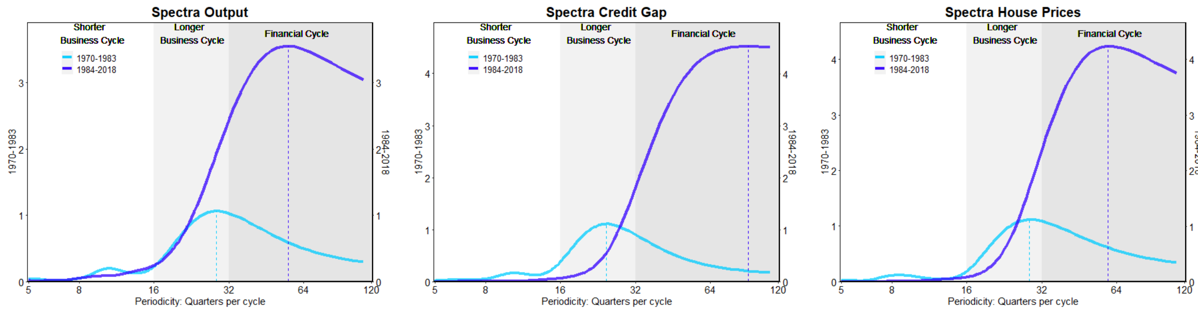
We first show that volatility has shifted to more medium-term fluctuations in the course of the Great Moderation. Then, we show existence of the Granger-causal relationship between the credit gap and output and discuss the differences between the estimates on the pre-GM and GM subperiods. The empirical characterization of the Great Moderation and its connection to the financial cycle is then pieced together from the results of the different exercises.

The first important observation stems from the analysis of the spectra prior to and during the Great Moderation. Figure 1.2 shows the spectra of output, credit gap and house prices that were estimated on the pre-Great Moderation (1970Q1-1983Q4) and Great Moderation sample (1984Q1-2018Q2). Output volatility has shifted dramatically towards longer periodicities. While the spectrum of the pre-Moderation sample features two peaks (near 10 and near 28 quarters per cycle) the Great Moderation spectrum has only one peak near 60 quarters. Volatility decreased on most shorter-business cycle periodicities during the Great Moderation but it increased on most longer-business cycle periodicities and on all financial cycle periodicities. In fact, the Great Moderation spectrum exceeds the pre-Moderation spectrum on all periodicities greater than 24 quarters per cycle. These effects are also found when the narrower definition of the Great Moderation (1984Q1-2007Q1) is applied as is shown in Figure 1.A.6. in the Appendix. The spectra of credit gap and house prices have also moved towards longer periodicities: their peaks moved from longer-business cycle to financial cycle periodicities and their volatility on shorter business cycle periodicities disappeared almost entirely. Compared to output, the changes in the spectra of credit gap and house prices are even larger. Volatility of output has increased 4-fold on whereas volatility of credit gap and house prices has increased 6-fold and 20-fold, respectively. The shifts towards longer periodicities are also larger in the financial cycle variables, especially for credit gap.

This means that both business cycle and financial cycle have increased substantially in length - short-term fluctuations of these variables have all given way to longer-term fluctuations. The increase in output volatility on financial cycle periodicities implies that the characterization of the business cycle post-1984 as a “moderation” is incomplete.

The first piece of evidence that substantiates the importance of the financial cycle to the changes of the Great Moderation comes from the dynamic correlations in combination with the Granger-causality statistics implied by the baseline VAR-models. Consequently, they are plotted together in Figure 1.3, in the left and right column, respectively. In the dynamic correlation plots, the dashed

Figure 1.2. Spectra pre-GM and GM: Output, Credit Gap and House Prices



This figure shows the spectra of output (left panel), credit gap (middle panel) and house prices (right panel) estimated on the time series of the pre-GM (light blue) and the GM (dark blue) sample. The left axis measures the variance of the pre-GM spectrum. The right axis measures the variance scales the variance of the GM spectrum. The x-axis is the periodicity, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. The spectra are normalized such that for each variable, the higher peak has a maximum of one.

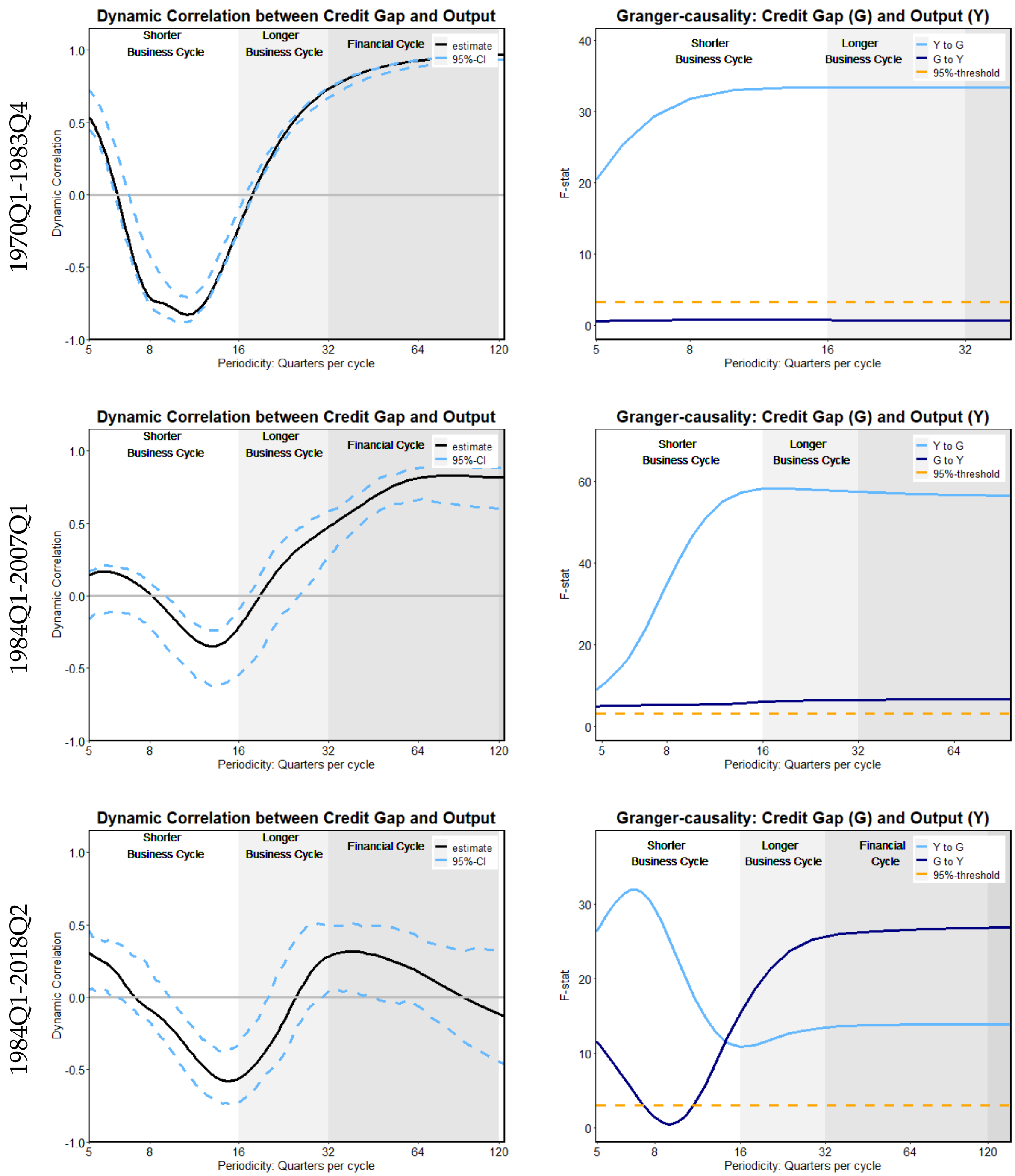
lines represent 95-% confidence bounds that are calculated from bootstrapping the coefficients of the VAR-model. The top row shows the estimates from the pre-GM sample, the middle row the estimates from the narrow-GM sample and the bottom row the estimates of the GM sample. By construction, dynamic correlation is between minus one and one.

We notice the following: The dynamic relationship between credit gap and output is negative on most shorter business cycle periodicities. It transitions into positive territory on longer business cycle periodicities and is positive on all financial cycle periodicities. While the magnitude of the dynamic correlation coefficients decreases in absolute terms from pre-GM to GM sample, the periodicity ranges on which it is positive and negative remain largely the same in all three samples. Importantly, the periodicity range on which the dynamic correlation coefficient is negative matches the range on which the output spectrum shows decreases in volatility closely. Conversely, the periodicity range on which output gained volatility during the Great Moderation corresponds to the positive dynamic correlation coefficient of credit gap and output.

We pair the dynamic correlations with the results of the Granger-causality tests in the right column. The solid lines show the F-statistics of the tests for Granger-causality at each periodicity. The dashed line is the 95% confidence threshold for these tests. The frequency at which the test-statistic reaches its maximum describes the fluctuations of y which are predicted most powerfully by x. If the Granger-test is not significant on a certain frequency range, this confirms that the economic forces are only relevant in a periodicity range around the peak of the test-statistic. This range must be interpreted with caution: the test-statistics are a continuous function $F(\tilde{\omega})$. Hence, even when there is only a causal effect on one specific periodicity, the test will still reject the null hypothesis of Granger-non-causality on the neighboring periodicities.

We see the following: prior to the Great Moderation output Granger-caused the credit gap and

Figure 1.3. Dynamic Correlation and Granger Causality between Credit Gap and Output



This Figure shows the dynamic correlations (left column) and the F-statistics of the Granger-causality test (right column). These measures are calculated on data from 1970Q1-1983Q4 (top row), 1984Q1-2007Q1 (middle row) and 1984Q1-2018Q2 (bottom row). The x-axis is the periodicity, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. Dynamic correlation is measured on a y-axis from -1 to 1. The y-axis of the Granger-causality test measures the F-statistic. The solid lines show the F-statistic at each periodicity, where the legend shows the cause variable of each test. The dashed line is the 95% threshold of the Granger-test.

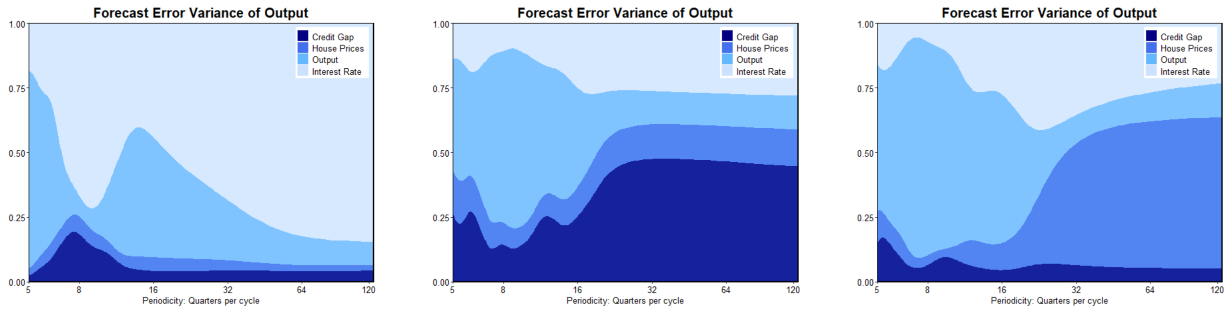
the significance of this relationship was monotonically increasing towards longer periodicities . At this time the reverse was not true. During the Great Moderation, both variables Granger-cause each other. In the narrow-GM sample, the significance of the Granger-causality of credit increase monotonically towards longer periodicities. On the other hand, the F-statistics when output is the cause variable reach their peak already on shorter business cycle periodicities and decline thereafter. In the GM sample, we see that credit gap and output Granger-cause each other at fundamentally different periodicities. The peak of Granger-causality of output on credit gap is located near 8 quarters and thereby within the shorter business cycle periodicities. For longer-period fluctuations of the credit gap, output exerts less Granger-causal influence, as the test statistic of the Breitung-Candelon tests decreases substantially, yet stays well above the significance threshold. In contrast, the credit gap's Granger-causality on output is insignificant for a range of shorter business cycle periodicities. It then increases for longer-period fluctuations and attains its maximum on financial cycle periodicities.

The combination of dynamic correlation and Granger-causality statistics point to the following relationship between credit gap and output: A short-period downturn in output (Granger-) predicts a short-period upswing of credit gap. In turn, the upswing in credit gap predicts an attenuation of the downturn in output. However, as we move through longer business cycle- and financial cycle periodicities, the effects change: A medium-period credit boom predicts an output boom but when credit gap falls into a medium-period trough, we expect that it draws output with it as well. In other words, credit movements amplify medium-term movements of output.

Figures 1.A.3 - 1.A.5 in the Appendix show the results for bivariate models between credit gap, house prices and output. Their results can be confirm our findings: The relationship between credit gap and output has the same properties as in the baseline VAR model: Output Granger-causes the credit gap on short fluctuations but on financial cycle periodicities the direction of Granger-causality is reversed. The dynamic correlation between house prices and output is low (near zero) on for fluctuations between 5 and 12 quarters. It then increases and is strongly positive for fluctuations between 16 and 120 quarters. The relationship is bidirectionally Granger-causal both prior to and during the Great Moderation. The Granger-causality of house prices on output is more significant in the GM sample than in the pre-GM sample, whereas the reverse is true for the Granger-causality of output on house prices. The dynamic correlation between credit gap and house prices is near zero on short periodicities and significantly positive on longer periodicities. The periodicities on which it is significantly positive have become substantially longer in the course of the Great Moderation.

The second piece of evidence shows the changes in the relationship between financial cycle and business cycle that caused the shifts in the spectrum that we observed earlier. This is derived from the results of the FEVD of the baseline VAR model, which shows two things: Firstly, prior to the Great Moderation, neither of the financial cycle variable played a major role. In fact, most

Figure 1.4. FEVD for the pre-GM, narrow GM and GM sample.



This figure shows the frequency-domain FEVD of output derived from the baseline VAR-model. The left panel was estimated on data from 1970Q1-1983Q4. The panel in the middle was estimated on data from 1984Q1-2007Q1. The right panel was estimated on data from 1984Q1-2018Q2. The x-axis is the periodicity, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. The y-axis shows the contribution of each shock to the overall forecast error variance.

of the forecast error in the pre-GM sample is driven by monetary shocks. However, in the Great Moderation sample, we see that structural shocks to the credit gap and house prices have gained significantly in importance relative to output shocks during the Great Moderation. Both financial shocks have in common that they exert most of their influence on medium-period output fluctuations, while short-period output fluctuations are largely driven by real shocks (structural innovations to output). Depending on whether the narrow or wide definition of the Great Moderation is applied, the forecast error share is attributed either to credit shocks or house price shocks. The periodicities on which the forecast error share of either financial shock increases the most - fluctuations between 16 and 20 quarters - is very close to the periodicity where the dynamic correlation between credit gap and output transitions from negative to positive. The same thing can be seen when we analyze the spectra that these VAR models imply when all shocks but one are shut down (Figure 1.A.7 in the Appendix). Financial shocks systematically lead to lower volatility on short periodicities but to more volatility on medium-term periodicities than output shocks. This property developed during the Great Moderation.

1.3.4 Robustness

We check the robustness of these results along four dimensions. First, we show that the main properties of dynamic correlation and FEVD also hold in the bivariate VAR-models as well as when inflation is added to the baseline specification. The qualitative properties of the dynamic correlation and FEVD described above also hold in the VAR-model that includes inflation. Dynamic Correlation is negative on shorter business cycle periodicities and positive on longer business cycle periodicities. The effects are Granger-causal and importantly, the Granger-causal effect from output to credit gap is more clearly significant on shorter periodicities. Dynamic correlation between house prices and output is close to zero on shorter business cycle periodicities but significantly positive on financial cycle periodicities. The significance of Granger-causality from house prices to output rises towards longer periodicities. If anything, the Granger-causality from output to house prices is more strongly significant on shorter business cycle periodicities.

The forecast error variance decompositions show roughly the same pattern. Orthogonal innovations of output are the dominant driver of only shorter business cycle periodicities but have little effect on longer periodicities in the samples that include the Great Moderation. In contrast, the innovations to the financial variables lead to forecast error mostly on long periodicities, especially the innovations to the credit gap. The variance attributed to monetary shocks comes in between and attain their maximum forecast error variance share at around 20 quarters per cycle. Inflation behaves similarly to the financial variables, driving very little forecast error at short periodicities and a lot on long periodicities.

Secondly, we show that the dynamic correlation pattern is not driven by any particular period in the data. Specifically, we assess the robustness in the following sub-samples: The post-war economy (1946-1983), the Bretton-Woods era (1944-1976), the narrowly defined Great Moderation (1983-2007)[19] and the longest possible pre-GM sample available in the JST data (1893-1983). The plots of dynamic correlation, Granger-causality and forecast error variance decomposition can be seen in the Appendix (Figures 1.A.6 and 1.B.1). The results hold without qualifications when the narrow definition of the Great Moderation is applied. They also hold in the Bretton-Woods and post-war sub-sample with some qualifications: The dynamic correlation between credit gap and output is negative for short-term fluctuations (<4 years) before becoming positive on medium term fluctuations - however, it turns negative again for periodicities beyond 7 years[20]. The effects between house prices are Granger-causally driven by output on short periodicities and driven by house prices on long-periodicities, each time with a positive coefficient. The FEVD of the Bretton-Woods era tells a different story than the GM one. The financial cycle has next to no relevance as a driver of volatility. Additionally, monetary shocks drive most short-term volatility and output is the main driver of medium-term fluctuations. The results cannot be found in the very long-run pre-GM sample.

Thirdly, I run the same analysis on UK data from the FRED, BIS and Office of National Statistics (ONS). The results of this robustness check can be seen in Appendix 1.C.1. Overall, they point in the same direction - although less significantly as in the U.S.: In the UK data, the financial cycle is characterized by a medium-term dynamic correlation between credit gap and house prices. Dynamic correlation between credit gap and output is negative on some shorter-business cycle

[19]The selection of a cutoff in 2008 is not possible - by then the boom in house prices was so large that it is impossible to estimate a stationary model on such a sub-sample.

[20]House prices were used as a collateral value to a much smaller extend prior to the 1980s. We can find results that show very similar patterns to those of the latter samples by using a weighted average of stock prices and house prices for this era.

periodicities and positive on longer periodicities. The FEVDs show that financial shocks systematically drive mainly medium-term fluctuations and the largest increase in the share attributed to financial shocks is also located near cycles of 16 quarters. The greatest disparity between the U.S. and the UK is the Granger-causal power of house prices on output, which is non-existent in the UK[21]. Finally, I confirm that the results are not driven by the choice of filter. I obtain similar results when using a one-sided HP-filter to remove the trend (see Appendix 1.D.1).

1.3.5 An accurate picture of the Great Moderation

The results shown above propose a novel interpretation of the Great Moderation and the forces that led to it. An accurate characterization must primarily point to a transfer of volatility from short-term fluctuations to medium-term fluctuations and a shift in the source of those fluctuations from real to financial sector. At medium periodicities, the U.S. economy witnessed increases in volatility which are especially pronounced for the credit gap and house prices (where volatility has increased 6-fold and 20-fold, respectively. This transfer of volatility to longer-term fluctuations parallels the findings of increased persistence of the literature (Giannone et al. (2008), Pancrazi (2015)). The structural error decomposition has shown that in this periodicity range, output fluctuations are primarily driven by financial shocks. Hence, we must infer that the origin of output volatility has gravitated to the financial sector.

These shifts are not driven by the Great Recession of 2008 (see Figure 1.A.2 in the Appendix). Hence, even when the narrow definition of the Great Moderation is applied, it was not as moderate as its name suggests. The volatility between 1984 and 2007 was merely a prelude to the dramatic downturn that came with the Great Recession. While there may be multiple reasons for the increases in persistence of output volatility, it fits into the picture of a finance-driven Great Moderation that the financial cycle itself, i.e. the dynamic interaction of credit gap and house prices has shifted to longer periodicities in the course of the Great Moderation. This is shown in Figure 1.A.3. We see that the range in which this dynamic correlation is strongly positive shifted significantly towards medium-term, "financial cycle" periodicities. This shift across periodicities in the dynamic correlation of credit gap and house prices is far greater than the shifts in the dynamic correlations between credit gap and output or house prices and output. Instead, the most significant changes to the latter relationships that came with the Great Moderation concern the development or strengthening of Granger-causality on output; and the diminution of the reverse effect. Rather, the fact that the qualitative properties of the dynamic correlations regarding attenuation and amplification were already present before the Great Moderation suggests the presence of a structural link between credit and output which is not a product of any mechanism that the literature has used explained the Great Moderation. The story of the Great Moderation must hence

[21] A likely source of the differences is the lower usage of mortgages as collateral in the UK.

be about the intensification of the previously existing links between real and financial sector of the economy and the stronger attenuation and amplification forces that resulted from it. This intensification of the existing volatility transmission mechanisms coupled with the increased persistence of the financial cycle then leads to the heterogeneous phenomenon that we witnessed over the past 35 years: Episodes of moderation with low short-term volatility and finance-driven phases in which medium-term output volatility surfaces in the form of great recessions.

These findings sideline the academic debate on whether "good luck" or "good policy" drove the Great Moderation. Our analysis nevertheless allows us to comment on the positions of this debate. The first main comment is that there was indeed "good luck". An analysis of the structural innovations (figure 1.D.5 in the Appendix) shows that a reduction in the error variance did occur in the 1980s and affected both real and financial variables. However, we also see that the error variance did not remain low until the Great Recession. Instead it rose sharply in the 1990s and early 2000s - which points again towards the result that the Great Recession was part of a medium-term fluctuation and not of a sudden increase in short-term volatility. With regard to "good policy", we notice that the contribution of monetary shocks to the forecast error of output has decreased substantially in the course of the Great Moderation. However, it is hard to call the effects of either shocks or policy "good" while we argue that overall volatility has increased on medium-term periodicities.

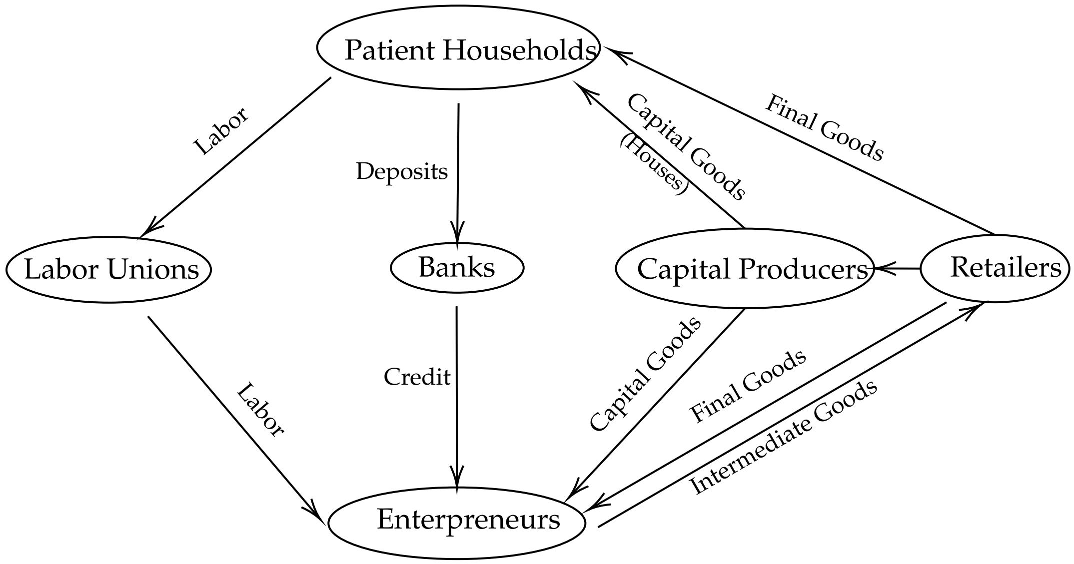
1.4 Model

This section shows that while off-the-shelf models with financial frictions largely fail to replicate the frequency-domain statistics, a model with long-run risk and the right set of financial frictions can go a long way towards doing so. Herefore, we examine 6 models from the literature[22] on the dynamic correlations and FEVD they imply. Additionally, we build and estimate a model that nests the financial sectors of Iacoviello (2005) (abbreviated "IAC" in the following) and Gertler and Karadi (2011) (abbreviated "GK") and the combination of the two in a New Keynesian economy. These financial sectors are characterized by a collateral constraint on entrepreneurial borrowing and a leverage constraint on financial intermediaries, respectively. Throughout the rest of this paper, we refer the model with both collateral and leverage constraint as the "IGK model".

As a first pass on the data, we show that Bayesian-estimated forms of the three submodels all fail to replicate the empirical frequency-domain statistics. The key shortcoming of all submodels is that in contrast to the data, financial shocks never feed systematically into medium-term fluctuations. To reconcile model and data, we show in a second step that the inclusion of long-run risk elements

[22] The six models are: Iacoviello (2005), Kannan et al. (2012), Gambacorta and Signoretti (2014), Stracca (2013) and Villa (2016) which contains two estimated models with the frictions of Bernanke et al. (1999) and Gertler and Karadi (2011).

Figure 1.5. Model Economy: Agents and Flows of Goods



This picture shows the model economy. The optimizing agents of the model are encircled. The arrows designate flows of goods and services between agents.

in spirit of Bansal and Yaron (2004) has the ability to mitigate this shortcoming. The resulting submodel with both frictions can be calibrated to fit the data well.

Notation and the majority of the model's setup follows Villa (2016)[23]. The basic framework is a New Keynesian economy which is enriched with elements found to be of quantitative importance by Smets and Wouters (2003). We further set up the model in spirit of Christiano et al. (2005) in order to maintain a close mapping between model and the identifying restrictions of the structural VARs. Figure 2.4.1 summarizes the general structure of the model economy:

There is a mass 1 of identical patient households indexed by i. Households maximize their utility through choice of consumption C_t, housing K_{t+1}, deposits D_t in a financial intermediary and labor supply L_t. Their utility from consumption depends on external habit and capital depreciates at rate δ. Each household owns a bank and receives its bank's profits. Their maximization problem is:

$$\begin{aligned} maxE_t \sum_{t=0}^{\infty} \beta^t \Big\{ & log(C_{it} - hC_{t-1}) - \frac{L_{it}^{1+\phi_l}}{1+\phi_l} + \nu log(K_{it+1}) \\ & - \mu_{it}[C_{it} + Q_t(K_{it+1} - (1-\delta)K_{it} + D_{it+1} - R_{t-1}D_{it} - W_t^H L_{it} - \Pi_t + T_t - TR_t] \Big\} \end{aligned}$$

Houses are bought and sold but cannot be rented. Households are subjected to government taxation T_t and transfers TR_t. Labor is supplied to labor unions, which differentiate it, aggregate it and sell the labor aggregate to entrepreneurs. There is a mass 1 of identical entrepreneurs indexed

[23] Villa (2016) builds a similar model in which the costly state-verification framework gives rise to the BGG financial accelerator.

by j in the economy. As in Iacoviello (2005), entrepreneurs only consume non-durable goods and use the capital goods to produce new intermediate goods. Entrepreneurs choose non-durable consumption C_t^F, labor demand L_t and capital utilization U_t. Increased capital utilization results in higher output and comes at higher costs of maintenance of the capital stock. To maintain its capital, the firm needs to purchase additional final goods. Entrepreneurs' production technology is:

$$Y_{t+1} = A_t(U_t K_{t+1}^F)^\alpha L_t^{1-\alpha} - \Theta$$

where Θ is a fixed cost and A_t is an AR(1) process for TFP. To finance themselves, entrepreneurs can borrow B_{t+1}^F from a financial intermediary through one-period loans at interest rate R_t^L. As in Iacoviello (2005), a framework of costly state-verification introduces a financial friction into the economy. Originally introduced by Townsend (1979), this friction micro-founds the requirement for entrepreneurs to pose collateral for the loans they obtain from the financial intermediary[24]. We assume that the cost of state verification amounts to a share ζ of the value of assets that the banks can recover. Hence, when banks can only keep $1-\zeta$ of the entrepreneurs assets in case the latter does not repay, they can ensure themselves of full repayment by only lending up to $(1-\zeta)$ of the entrepreneur's collateral. Credit given to the entrepreneur B^F times the lending rate R^L must be smaller than the loan-to-value ration $(1-\zeta)$ times the collateral value QK^F This leads to a financial accelerator: If collateral value increases (exogenously), more credit can be obtained, used for more purchases of houses which can again be used for collateral. On the flipside, the entrepreneurs may be forced into a liquidation spiral if house prices decrease.

Entrepreneurs discount the future at factor $\gamma\beta$, where $\gamma < 1$ shrinks their discount factor below the one of the patient households and ensures that entrepreneurs will always be borrowing constraint. Accordingly, the problem of the entrepreneur is:

$$\begin{aligned} maxE_t \sum_{t=0}^{\infty} (\gamma\beta)^t \Bigg\{ & \frac{(C_{jt}^F - h^F C_{t-1}^F)^{1-\phi_f}}{1-\phi_f} \\ & + \mu_{jt}^F[\Phi_t Y_{jt} + B_{jt+1}^F - C_{jt}^F - W_t L_t - \Psi(U_{jt})K_{jt}^F - Q_t(K_{jt+1}^F - (1-\delta)K_{jt}^F) - R_{t-1}^L B_{jt}^F] \\ & + \mu_t^C E_t[(1-\zeta_t)Q_{t+1}K_{jt+1}^F(1-\delta) - R_t^L B_{jt+1}^F] \Bigg\} \end{aligned}$$

The modeling of the financial intermediaries (banks) follows Gertler and Karadi (2011). In this framework, the managers of financial intermediaries (banks) can divert a fraction of the assets that they manage back to their household. They will do so whenever their continuation value of stealing (and then being prohibited from managing the bank in future periods) is greater than

[24] Alternatively, the costly state-verification can be used to justify an external finance premium as in Bernanke et al. (1999)

their continuation value from not stealing. The incentive constraint that resolves this moral hazard problem restricts the bank's ability to lever up - it must accumulate net worth to use alongside deposits in order to lend to entrepreneurs: As a consequence, the bank may not be able to raise enough to deposits to satisfy the entrepreneurs' demand for credit at a lending rate which equals the deposit rate. Hence, the lending rate in the GK-framework will exceed the deposit rate whenever the leverage constraint is binding. Banks die in each period with probability $1-\theta$. In this case, they return their entire net worth to their household, who consumes it and starts a new bank. This setup leads to the objective:

$$
\begin{aligned}
\Upsilon_t &= max E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \beta^{i+1} \Lambda_{t,t+i+1} N_{t+i+1} \\
\Upsilon_t &= max E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \beta^{i+1} \Lambda_{t,t+i+1} (R^L_{t+i} B^F_{t+1+i} - R_{t+i} D_{t+1+i} - R_{t+i} N_{t+i})
\end{aligned}
$$

Gertler and Karadi (2011) show that this implies the leverage constraint:

$$
B^F_{t+1} \leq \frac{H_t}{\lambda_t - V_t} = lev_t N_t
$$

where H_t and V_t stand for the banks value of increasing assets and increasing net worth, respectively. lev_t represents the leverage ratio (assets/net worth) and N_t is the bank's net worth. The inability of the bank to obtain sufficient funds to equalize the marginal return to capital of the entrepreneur with the households intertemporal margin drives a wedge between deposit and lending rate - such that the firm earns positive profits.

When both frictions are active at the same time, they interact as follows: At the steady-state, the values of ζ and λ determine which constraint is binding. For very low values of λ, the leverage constraint will be non-binding the equilibrium lending rate will be $R^L = R = \frac{1}{\beta}$. A λ increases, the leverage constraint tightens and eventually starts binding. The binding leverage constraint leads to a shortage in credit supply, which leads to an increase in the lending rate. This continues as long as $R^L \leq \frac{1}{\gamma\beta}$. If λ increases further the collateral constraint stops binding and only the leverage constraint binds. The leverage constraint has made credit so expensive that entrepreneurs will no longer borrow up to their collateral constraint. Accordingly, the equilibrium level of debt and the lending rate should satisfy:

$$
\begin{aligned}
B^F_{t+1} &= min \left\{ \frac{(1-\zeta_t)(1-\delta)Q_t K^F_{t+1}}{R^L_t}, \frac{(1-\zeta)Q_{t+1}K^F_{t+1}}{R_t EP^{-1}(EP_t)}, lev_t N_t \right\} \\
R^L_t &= max\{R_t, R_t EP_t\}
\end{aligned}
$$

The combinations that are possible are most conveniently written in two complementary slackness conditions, that capture the economics described above:

$$0 = \mu_t^C (B_{t+1}^F R_t^L - (1-\zeta_t)(1-\delta) Q_{t+1} K_{t+1}^F)$$
$$0 = (EP_t - 1)(B_{t+1}^F - lev_t N_t)$$

We can distinguish the following cases: When only the Iacoviello friction is active, $\mu_t^C > 0$ so we can divide by it and obtain the collateral constraint. Since the leverage constraint will not be binding, the second equation delivers $EP_t = 0$. When both Iacoviello and GK-friction are active, the first equation gives the collateral constraint and the second one the leverage constraint. In this case the parameters ζ and λ control the strengths of the frictions and we can analyze their interaction throughout their support. Suppose that in steady state for a particular parameterization only the collateral constraint binds. When the fraction λ that managers can divert is increased at one point the leverage constraint will bind as well. As λ is increased further both constraints continue to bind and the interest rate increases as a consequence of the GK-friction. But as soon as the interest rate increases enough to offset the impatience of entrepreneurs completely, the collateral constraint will cease to bind in steady state. For all higher values of λ, only the leverage constraint binds.

The financial frictions ζ and λ are also used to introduce financial supply shocks into the model. That is, ζ and λ follow AR(1) processes with persistences ρ_ζ, ρ_λ and standard errors $\epsilon_\zeta, \epsilon_\lambda$. This generates an "active" financial accelerator that is not solely a propagator, but also a source of shocks[25]. Retailers differentiate intermediate goods and aggregate them into a final good. Final goods are sold to the patient household for consumption, to entrepreneurs for consumption and maintenance of the capital stock; and to capital producers as a production input. Retailers adjust their prices according to a Calvo scheme with parameter σ_p the probability that they cannot adjust their price in a given period. In this case, the prices of firms that cannot re-optimize are indexed to inflation. Thus, the retailers maximize

$$maxE_t \sum_{s=0}^{\infty} \frac{\mu_{t+s}}{\mu_t} (\beta\sigma_p)^s Y_{t+s}(f) \left[\frac{P_t^r(f)}{P_{t+s}} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{\sigma_{pi}} - \frac{\Phi_{t+s}}{P_{t+s}} \right]$$

The optimal mark-up that retailers choose is subject to an AR(1) mark-up shock ϵ_t^p. Capital producers purchase some of the final goods and transform them into houses (capital goods) and sell them to households and entrepreneurs. The problem of capital producers is:

$$maxE_t \sum_{t=0}^{\infty} \beta^t \Pi_t + \mu_t^K \left[\Pi_t - (Q_t^n - P_t) I_t + x_t I_t \left(1 - F\left(\frac{I_t}{I_{t-1}} \right) \right) \right]$$

[25]This responds to the criticisms of Schularick and Taylor (2012), Borio (2008) and Hume and Sentance (2009)

where x_t is a stochastic process which includes an investment cost shock.
The central bank sets its policy rate according to the Taylor rule

$$ln\left(\frac{R_t^n}{R_t}\right) = \rho_i ln\left(\frac{R_{t-1}^n}{R^n}\right) + (1-\rho_i)\left[\rho_\pi ln\left(\frac{\Pi_t}{\Pi_{t-1}}\right) + \rho_y ln\left(\frac{Y_t}{Y_t^p}\right)\right] + \rho_{\Delta_y} ln\left(\frac{Y_t/Y_{t-1}}{Y_t^p/Y_{t-1}^p}\right) + \epsilon_t^r$$

at the end of each period. ϵ_t^r is a monetary shock.
Market clearing on final goods market and capital market is given by:

$$Y_t = C_t + C_t^F + I_t + \Psi(U_t)K_t^F + G_t$$
$$I_t = K_{t+1} - (1-\delta)K_t + K_{t+1}^F - (1-\delta)K_t^F$$

Final goods that are produced in this economy are split between private, entrepreneurial and government consumption of non-durables, investment into durables and maintenance of the current capital stock at the chosen utilization rate. On the market for durable capital, total investment is given by the changes in the durables stocks of patient household and entrepreneurs. Labor markets and credit markets clear.
In this form, we have a model that is very close to work-horse models of the literature. However, we show in Appendix 1.H.2 that Bayesian-estimated forms of this model are unable to replicate the main periodicity-domain statistics of the data. Specifically, we document this failure for the dynamic correlations for the pairs credit gap and output, house prices and output, and credit gap and house prices and for the FEVD of output. Two discrepancies between model and data arise consistently: firstly, no matter which financial friction is used, the model generates a dynamic correlation between credit gap and house prices that is positive on short periodicities and decreases towards longer periodicities. In other words, the models contain a financial cycle that is a short-term phenomenon. This stands in contrast to the data where this interaction, the financial cycle, was shown to be a medium-term phenomenon, described by a dynamic correlation that only only turned significantly positive on medium-term periodicities. Secondly, all submodels generate forecast error shares that are relatively flat across periodicities. Hence, the property of the data that TFP shocks drive short-term fluctuations while financial shocks drive medium-term fluctuations is not contained in the model.
The dynamic correlations between credit gap and output and between house prices and output also show large departures from their data counterparts, albeit in less consistent ways. The key ingredient that these models are missing is long-run risk. Long-run risk mechanically leads to a shift of spectral density towards longer periodicities. With the goal of ensuring that financial shocks drive medium-term volatility, we augment the stochastic process of λ_t and x_t by long-run

Figure 1.6. Within-period timing of the model

Timing within a period

- Enter with debt and capital stocks - Observe technology, capital quality and mark-up shocks.	- Firm chooses labor demand and utilization rate. - Final goods is produced and final goods market clears.	- Investment shocks and financial supply shocks are realized. - Capital is produced and capital and debt markets operate.	- Central Bank observes output gap and inflation and chooses its policy rate.

This figure shows the sequence of events that happen in every period in the model.

risk components in the spirit of Bansal and Yaron (2004):

$$
\begin{aligned}
x_t &= e_t^x + s_t^{LR} \\
s_t^{LR_x} &= \rho_x s_{t-1} + e_t^{LR_x} \\
\lambda_t &= e_t^\lambda + s_t^{LR_\lambda} \\
s_t^{LR_\lambda} &= \rho_\lambda s_{t-1} + e_t^{LR_\lambda}
\end{aligned}
$$

Hence, the composite process features both short-run and long-run risk. To maintain a close mapping between empirical and model-based analysis, we impose timing assumptions on the model in spirit of Christiano et al. (2005) as shown in the timeline below:

This allows for the derivation of six short-run restrictions that can be used to identify a four-variable SVAR of the credit gap, asset prices, output and the policy rate: The central bank moves last in each period. Hence, the monetary shock cannot affect any other variable contemporaneously. Credit and capital markets operate after goods markets have already closed. Output was produced with the capital installed yesterday and labor input and utilization rate were chosen to optimize the production plan. Hence, neither financial shocks cannot affect output contemporaneously[26]. In summary, this gives us the following restrictions:

1. The monetary shock ϵ_r cannot affect any other variable contemporaneously. This is achieved by making the central bank the last mover in each period. This provides three restrictions.

2. The investment price shock ϵ_x cannot affect output contemporaneously (because output is created with last period's installed capital). As the investment price shock does not have an immediate effect on output, it does not have any immediate effect on the policy rate either - as this is set according to a purely backward-looking Taylor rule that only follows output gap and inflation. This adds two restrictions.

[26] In the bivariate models of credit gap and output, and house prices and output, the results of the SVAR are robust to the choice of identification assumption. That is, the unrestricted element of the B-matrix is almost zero - so that the VAR is almost identified on its own. This finding supports the choice of the identification assumption that neither financial shock affects output contemporaneously.

3. The credit supply shock cannot affect output contemporaneously as it is realized after the production in period t has taken place. It also has no contemporaneous effect on the policy rate for the same reason mentioned for the capital quality shock.

1.5 Calibration

We fix the parameters of the households, entrepreneurs, unions, retailers and financial frictions that are related to steady state values. As can be seen in Table 1.2 we set these parameters equal to values estimated in Villa (2016) or used Bernanke et al. (1999), Iacoviello (2005) and Gertler and Karadi (2011). The capital share in the production function of 0.33, the discount factor of 0.99 when periods represent quarters and a depreciation rate of 0.025 are used throughout the literature and require no further discussion. Entrepreneurial impatience relative to households (=0.9898) and survival probability (=0.972) are taken from Iacoviello (2005) and Gertler and Karadi (2011), respectively. The inverse Frisch elasticity of 1.81 is near the higher end of the range that the literature has found. The weight of houses in the household's utility function and curvature of entrepreneurs utility are almost the same as those used in Iacoviello. While the habit parameter for households is standard, most models that follow Iacoviello abstract from entrepreneurial habit. As the agent in the economy that engages in risky ventures, entrepreneurial income is more likely to be volatile - hence we assume a low value of the habit parameter. The elasticities of substitution for both goods and labor varieties equal 6, which implies steady-state mark-ups of 20%. Steady-state utilization costs are set to 5% of output. We also fix the values of the Calvo parameters of goods prices and wages and indexation to past prices, which we simply set the values of Smets and Wouters (2003). In accordance with Iacoviello (2005), the cost of state-verification is set to 0.11 (Bernanke et al. (1999) use 0.12). The fraction of divertable funds is equal to 0.38 as in GK. Next, we modify the parameters which govern the financial frictions to obtain the three sub-models that the model nests: Under the benchmark parameterization from Table 1.2 only the collateral constraint is binding (Iacoviello model). However, when the fraction of divertable funds is increased to 0.52 (which is the posterior mode Villa (2016) obtains), both leverage and collateral constraint bind in steady state. The collateral constraint can be de-activated by setting $\zeta = \infty$.
The remaining parameters are calibrated to fit the model to the data. Herein, we use simulated method of moments to target the empirical dynamic correlations for the variable pairs credit gap and output, credit gap and house prices, and house prices and output. Additionally, we target the FEVD estimated by the four-variable VAR of credit gap, house prices output and the policy rate. Herefore, we pick the policy parameters of the Taylor rule, persistences and standard errors of the shocks to minimize the distance between model and data moments. Given that the empirical targets consist of one moment for each frequency, the model is overidentified. Since section 1.3 focused mainly on the dynamic correlation between credit gap and output, we penalize deviations

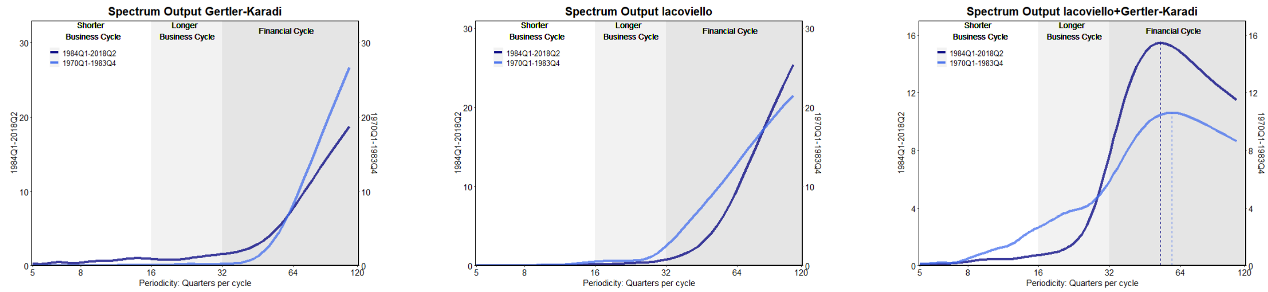
Table 1.2. Parametrization

Parameter	Description	Value	Source
α	capital production elasticity	0.33	Iacoviello (2005)
β	discount factor	0.99	Villa (2016)
γ	entrepreneurial impatience	0.9898	Iacoviello (2005)
θ	survival probability banks	0.972	GK (2011)
δ	depreciation rate	0.025	Bernanke-Gertler-Gilchrist (1999)
ϕ_l	inverse Frish elasticity	1.81	Villa (2016)
ν	weight of durables in utility	0.03	Iacoviello (2005)
ϕ_f	curvature utility entrepreneurs	0.99	∼Iacoviello (2005)
h	habit households	0.8	GK (2011)
h^F	habit entrepreneurs	0.1	-
ϵ_p	elasticity of substitution goods	6	Villa (2016)
ϵ_w	elasticity of substitution labor	6	Villa (2016)
σ_w	Calvo parameter labor unions	0.7370	Smets-Wouters (2003)
σ_{wi}	wage indexation	0.7630	Smets-Wouters (2003)
σ_p	Calvo parameter retailers	0.9080	Smets-Wouters (2003)
σ_{pi}	wage indexation	0.4690	Smets-Wouters (2003)
ψ_0	steady-state utilization expenditure	0.05	-
ψ_1	marginal utilization expenditure	0.0351	Villa (2016)
ψ_2	curvature utilization expenditure	0.850	Villa (2016)
ξ	adjustment costs	4.500	Villa (2016)
χ	scale of transfer to new banks	0.002	GK (2011)
$\bar{\zeta}$	cost of state-verification banks	0.11	Iacoviello (2005)
$\bar{\lambda}$	share of divertable funds banks	0.38	GK (2011)
G	government consumption	0.2	Bernanke-Gertler-Gilchrist (1999)

This benchmark calibration yields a binding collateral constraint and a non-binding leverage constraint when collateralization is required by the lender (Iacoviello model). When $\bar{\zeta} = 0.52$, both collateral and leverage constraint are binding (Iacoviello-Gertler-Karadi model. Without collateralization, the leverage constraint binds (Gertler-Karadi case).

Figure 1.7. Spectra of model-generated data

GK Model | IAC Model | IGK Model



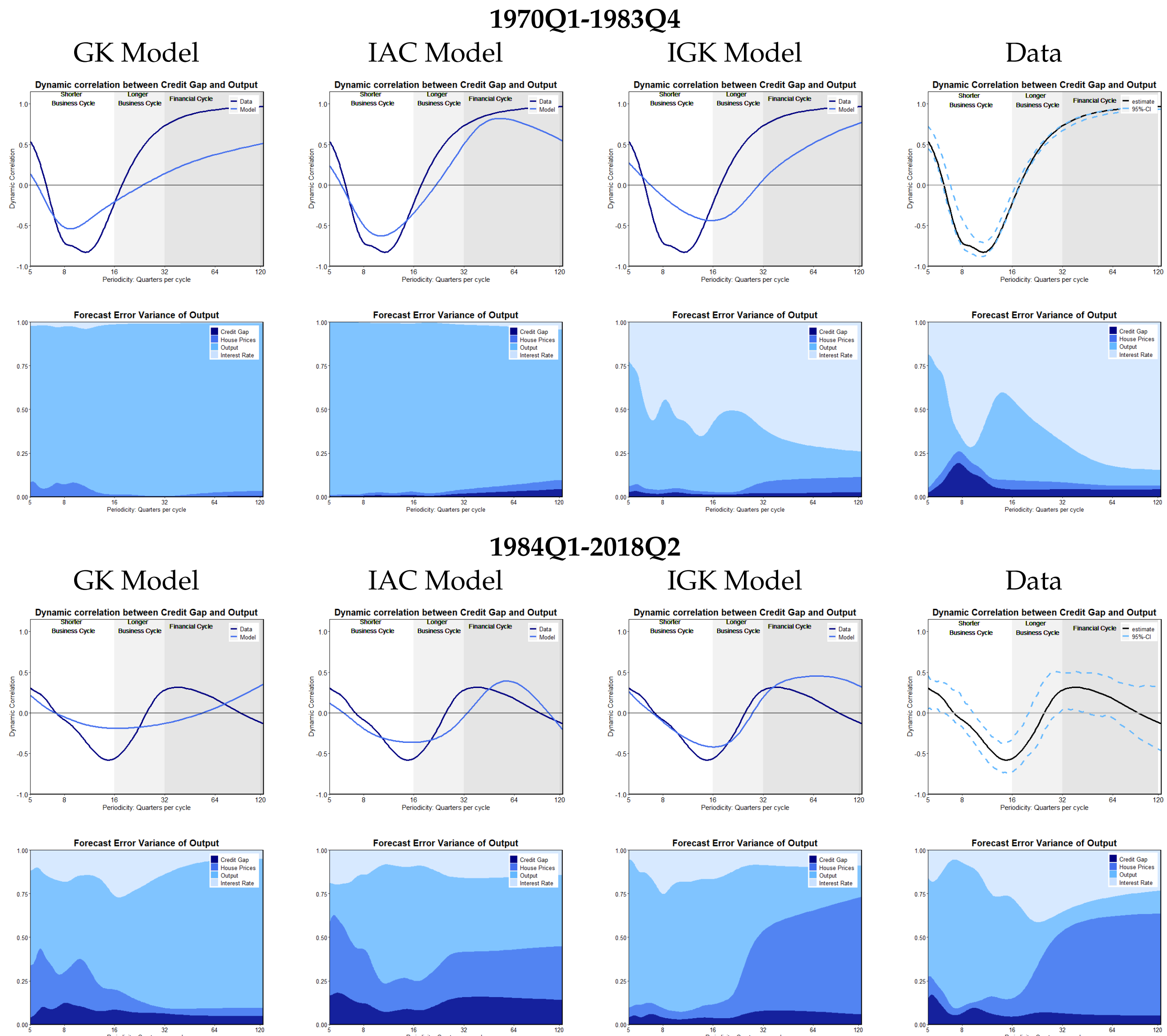
This figure shows the spectra of the calibrated models. he x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes show the variance and the respective periodicity.

from this dynamic correlation more heavily than deviations from the other dynamic correlations. Dynamic correlations and FEVD enter the loss function with equal weights. Deviations of model moments from data moments are penalized uniformly for all periodicities. For further details on the calibration exercise, we refer the reader to Appendix 1.H.1. We calibrate each sub-model separately for pre-GM and GM period. For expositional reasons, we only discuss the calibration of the best-performing submodel here: the framework that combines collateral and leverage constraint. The calibrated parameters of this submodel are shown in Table 1.H.1. We make three observations in Table 1.H.1: Firstly, central bank policy responds more to inflation and output gap in the Great Moderation period than prior to the Great Moderation, but the importance of interest rate smoothing has decreased. Secondly, the persistences of the financial shock, adjustment cost shock and monetary shock have remained on the same order of magnitude. However, the persistence of TFP shocks has increased from 0.364 to 0.9701. The persistence of mark-up shocks has decreased from 0.4478 to 0.1153. Thirdly, there are also important changes in the standard errors of the shocks. The standard error of the short-run investment cost shock has increased 5-fold and the standard error of the long-run risk shock has increased even 7-fold. Meanwhile, the standard errors of the financial shock, TFP, monetary and mark-up shock have fallen.

Figure 1.7 shows the spectra of the model-generated data. We can see that both GK and IAC model perform poorly. The models generate too much long-term volatility for both samples. While the IAC model at least produces more short-term volatility in the calibration to pre-GM data, the spectra implied by the GK-model do not have any of the qualitative properties of the empirical spectra. The IGK model replicates the feature that short-term volatility has decreased relative to medium-term volatility in the GM sample. However, it does not replicate the overall shift towards longer periodicities. The peak of the spectrum of the IGK model calibrated to fit the pre-GM moments is already on financial cycle periodicities.

Figure 1.8 shows how the model-implied dynamic correlations between credit gap and output and the FEVD of output compare to their data counterparts.

Figure 1.8. Dynamic correlation and FEVD: Model versus Data



This figure shows how the model-implied dynamic correlations and FEVD compare to their data counterparts of the baseline VAR-model. The top two rows show the results when the model is calibrated to fit the moments from the estimates on data between 1970Q1-1983Q4. The bottom two rows the results when the model is calibrated to fit the moments from the estimates on data between 1984Q1-2018Q2. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes measure the dynamic correlation on a scale from -1 to 1. The y-axes of the FEVD plots measure the contribution of the orthogonal shock to variable listed in the legend to the overall forecast error variance.

First and foremost, the model with both collateral constraint and leverage constraint (IGK model) is by far the best-fit to the data. It vastly outperforms the models with only one financial friction especially regarding the FEVD, but also on the dynamic correlation between credit gap and out-

put.
In both pre-GM and GM sample, the IGK model replicates the qualitative properties of the frequency-domain statistics of the data. The dynamic correlation between credit gap and output is negative on short-periodicities and positive on medium periodicities. In the GM sample the model-implied dynamic correlation closely tracks the empirical one. In the pre-GM sample, the model-implied dynamic correlation is flatter than the empirical estimate and only turns positive on financial cycle periodicities rather than on longer business cycle periodicities. The model-implied FEVD also replicates most qualitative and even quantitative properties of the empirical FEVD: In the pre-GM sample it replicates the large forecast error share of monetary shocks that still increases on longer periodicities. It largely replicates the forecast error share of TFP shocks that decrease in importance on longer periodicities. It also acknowledges the minor role that financial shocks played prior to the Great Moderation. In the GM sample, the model exhibits the feature that short-term fluctuations are mainly driven by TFP shocks, where as medium-term fluctuations are driven by financial, especially asset price shocks (investment cost shocks in the model). It matches the forecast error share and the periodicities that investment cost shocks feed into closely. The most obvious shortcoming of the model is that it somewhat underestimates the role that monetary shocks played in the GM, especially on longer-business cycle and financial cycle periodicities.
The GK and IAC model do not come close to the performance of the IGK model. The IAC model replicates the qualitative properties of the dynamic correlations between credit gap and output but falls short quantitatively. The qualitative features of the IAC-model-implied dynamic correlations depart from the empirical ones on every dimension. Importantly, the qualitative properties of the pre-GM and GM sample are largely the same. In the GK model, the dynamic correlation of the GM-sample is negative on almost all periodicities. Its FEVD does not have the targeted feature that financial shocks mainly feed into medium-term periodicities.
Despite all successes, the IGK submodel still falls short on other the targeted moments. The dynamic correlations that it produces between house prices and credit gap, and house prices and output, are positive on short periodicities and decrease (sometimes become negative) on longer periodicities (Figure 1.H.1). As discussed previously, in the data the opposite is the case - these dynamic correlations should increase towards longer periodicities. This disparity between model and data is shared by all submodels[27]. The difficulty of any model from the literature of producing a dynamic correlation between credit gap and house prices that increases towards longer periodicities indicates that this problem may be systematic. The construction of a model that contains a medium-term financial cycle is thus a task that still requires more attention in future research.

[27] This may not be surprising, since these dynamic correlations were weighted less heavily in the calibration.

1.6 Discussion

The estimated parameters shed light on the changes that define the Great Moderation. Firstly, the largest changes are the increases in the standard errors of the investment cost shocks. These changes directly affect house prices in the model, which are responsible for the largest part of medium-term volatility. The long-run risk shock has gained in variance even more than the short-run component. The financial supply shock has seen reductions in the standard errors of both its short-run and its long-run component; and the short-run component has decreased relative to the long-run component. Hence, the calibrated parameters suggest that a key feature of the Great Moderation was an increase in long-run risk relative to short-run risk. Hence, we can argue that that the "good luck hypothesis" can be refined with respect to the medium-run: There was indeed "good luck" but only concerning the short-run risk, but through the financial sector, there was no good luck in the medium-run. A short-run reduction of risk can also be detected in the standard deviation of the TFP shock size in the GM sample - points towards "good luck" as a relevant contributing factor to the Great Moderation. The small changes to persistence and standard error of the mark-up shocks indicate that the model assigns at most a minor role to inflation as a driver of the Great Moderation.

Secondly, the fact that only the combined Iacoviello+Gertler-Karadi financial sectors in combination are able to replicate the frequency-domain properties of the data emphasizes the importance of modeling both collateral and leverage constraint and offers further insights into the mechanics by which shocks feed into fluctuations of different periodicities. In the pure Iacoviello framework, the interest rate is purely determined by the difference between the discount factors of patient household and lender. Hence, if a shock hits the collateral constraint, it transmits immediately to the entrepreneurial capital holdings and thereby affects production. In combination with the Gertler-Karadi friction, the lending rate increases in response to a negative shock on the banks' maximum leverage and thereby can absorb the immediate effect of the shock. Paired with the long-run risk persistence of the shock to the credit supply technology of the banks, this can then feed into much longer-term fluctuations than shocks that hit the collateral constraint directly.

Despite the success of the long-run risk augmented model in replicating those key features of the data, long-run risk remains a mechanical way of increasing the persistence of volatility in the model. This relates to the well-known issue that RBC models only generate persistence when it is explicitly built into the model. A model that contains an accurate financial cycle in the form of a purely medium-term interaction between credit gap and house prices that can endogenously generate the frequency-domain statistics would enhance our understanding of the relationship between real and financial sector more than the notion of long-run risk.

We can use the model to run "counterfactuals" to isolate the effects that result from the changes in the Taylor Rule, the persistences of the shocks and the shock sizes. We calculate these by re-

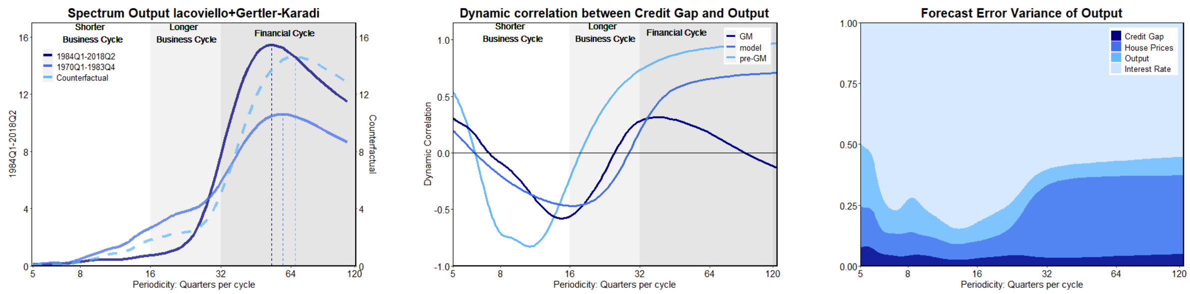


Figure 1.9. Monetary Policy Counterfactual
This Figure shows summary statistics of the monetary policy counterfactual. This is calculated by using the pre-GM estimates of the model and substituting out the Taylor Rule coefficients by the GM-estimated values. The left subfigure shows the resulting spectra of pre-GM model, GM model and counterfactual. Equivalently, the middle subfigure shows the corresponding dynamic correlations. The right subfigure shows the FEVD of the counterfactual.

running the model calibrated to pre-GM (GM) data while replacing the relevant values by those estimated from GM (pre-GM) data. The results are shown in Figures 1.H.4 and 1.H.5 and yield interesting insights: In the pre-GM model economy with the GM Taylor Rule there is lower short-term output volatility but more medium-term output volatility compared to the pure pre-GM scenario, as can bee seen in Figure 1.9. Additionally, the investment shock already drives systematically medium-term fluctuations. In contrast, the contribution of financial shocks to the output forecast error is small and relatively flat in a hypothetical GM-economy with the calibrated pre-GM Taylor Rule. This suggests that monetary policy may have contributed to the effects of financial markets on medium-term volatility[28]. Hence, we can argue that the "good policy" hypothesis of the Great Moderation can also be refined with respect to the medium-run implications of monetary policy.

At the same time, the change in Taylor Rule does not affect the dynamic correlations between credit gap, house prices and output much. The analogue experiments can be run to test the effects of changes to the shocks persistences and standard deviations. When we reset the persistences to the values of the other period, we also adjust the shock sizes to ensure that the overall variance of the stochastic process remains constant. The details of this exercise are in 1.H.3[29]. Their results imply that changes to the persistences greatly amplified the contribution of the financial shocks to the forecast error of output. On top of that, they show that the qualitative properties of financial shocks feeding systematically into medium-term volatility vanishes easily when any of the coefficients are replaced by their counterparts from the other subperiod. This re-emphasizes the fact that only a combination of multiple model ingredients has the ability to replicate the features of the Great Moderation and its relationship with the financial cycle.

[28] This confirms the suspicion of Drehmann et al. (2012) that monetary policy can reduce short-period volatility at the expense of more long-term volatility.

[29] 1.H.4 also contains a further sensitivity analysis of the model and its properties in the GM economy.

1.7 Conclusion

In this paper we have shown that the narrative of the Great Moderation as a pure reduction of volatility does not hold when financial cycle data is included in the analysis. Instead, we saw that the defining features of the Great Moderation were a shift of volatility to longer periodicities and a shift in the source of volatility to the financial sector. The latter shows up in the data as a systematic manifestation of financial shocks into medium-term output fluctuation. On top of that, we showed that a frequency-domain analysis reveals previously undiscovered properties of the interaction of the business cycle with financial cycle variables. In point of fact, we documented a Granger-causal mechanism between credit gap and output that features attenuation forces on short periodicities but amplification forces on medium periodicities. This mechanism is not linked to a specific period and also appears in UK data. Hence, we argued that it should be thought of as structural. We use this evidence to argue that Great Moderation and Great Recession are intrinsically tied together. The former was a consequence of the short-term attenuation forces whereas the latter was an inevitable result of the amplification forces.

These features are only improperly replicated by off-the-shelf quantitative DSGE models. The elements Smets and Wouters (2003) found to be important to throw sand in the wheels of the model and generate the persistent fluctuations we observe in the data, and the financial frictions of Iacoviello (2005) and Gertler and Karadi (2011) do not distinguish accurately between the different period fluctuations that shocks emerging in different sectors of the economy feed into. This led to a disparity between the dynamic correlations of key variable pairs between model and data. We showed that a long-run risk structure enhances the models flexibility in this respect. The interaction of long-run investment cost risk with collateral and leverage constraint gets very close to replicating a) the dynamic correlation between credit gap and output that is negative on short periodicities and positive on long periodicities and b) shocks on the relative price of capital goods that feed mainly into medium-term volatility while leaving short-term volatility relatively unaffected.

We used the estimated parameters of the model to show that the “good luck” hypothesis of the Great Moderation is only true with respect to short-run risk. Meanwhile, long-run risk has increased. We also used a monetary policy counterfactual of the model to argue that the “good policy” hypothesis of the Great Moderation can be refined with respect to the longer-run effects. While the changes in monetary policy during the Great Moderation led to lower short-term output fluctuations, this came at the expense of higher medium-term volatility.

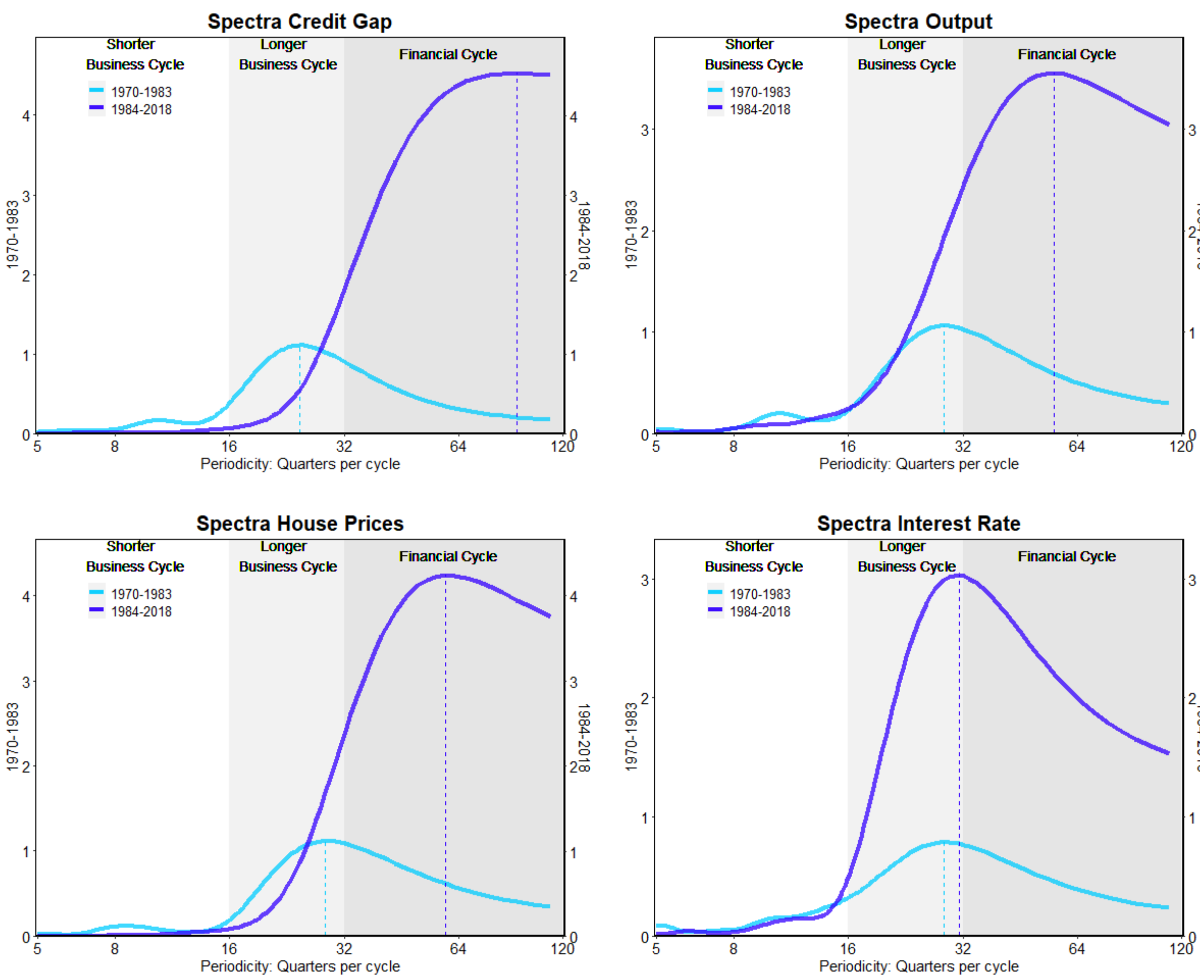
More research is needed to fully understand the mechanisms that led to the Great Moderation and Great Recession. On the empirical side this concerns the initial developments that triggered the intensification of the relationship between real and financial sector. Additionally, a causal identification of the resulting effects of financial intermediaries and the growth of the financial sector on short- and medium-term output volatility would greatly enhance our understanding of the linkages that ultimately led to the Great Financial Crisis and Great Recession. On the theoretical front the main shortcoming is that the model does not represent the financial cycle, the interaction between credit gap and house prices accurately. Additionally, at this point it is not clear whether other existing models are able to replicate the frequency-domain properties outlined above. Fruitful avenues for future research open up: A model that can capture both attenuation and amplification of finance to the real economy, containing a financial cycle that captures the medium-term self-enforcing interactions of credit and house prices and accurately replicate the periodicity-structure of output volatility would go a long way towards a deeper understanding of the relationship between finance and the real economy. An accurate understanding of whether an economic situation is truly a fundamental moderation or merely a low-volatility phase of a longer and larger cycle could help predict and prevent great finance-related recessions of the future.

Appendix

1.A Robustness Checks main data

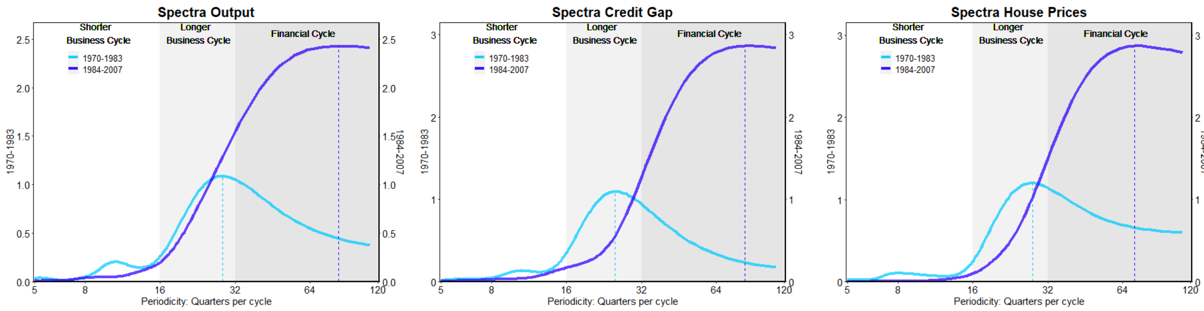
1.A.1 Spectra

Figure 1.A.1. Spectra Main Variables



This figure shows the spectra of house prices (left panel) and the FED funds rate (right panel) estimated on the time series from 1970Q1-1983Q4 (light blue) and the GM from 1984Q1-2018Q2 (dark blue) sample. The left axis measures the variance of the pre-GM spectrum. The right axis measures the variance scales the variance of the GM spectrum. The x-axis is the periodicity, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated.

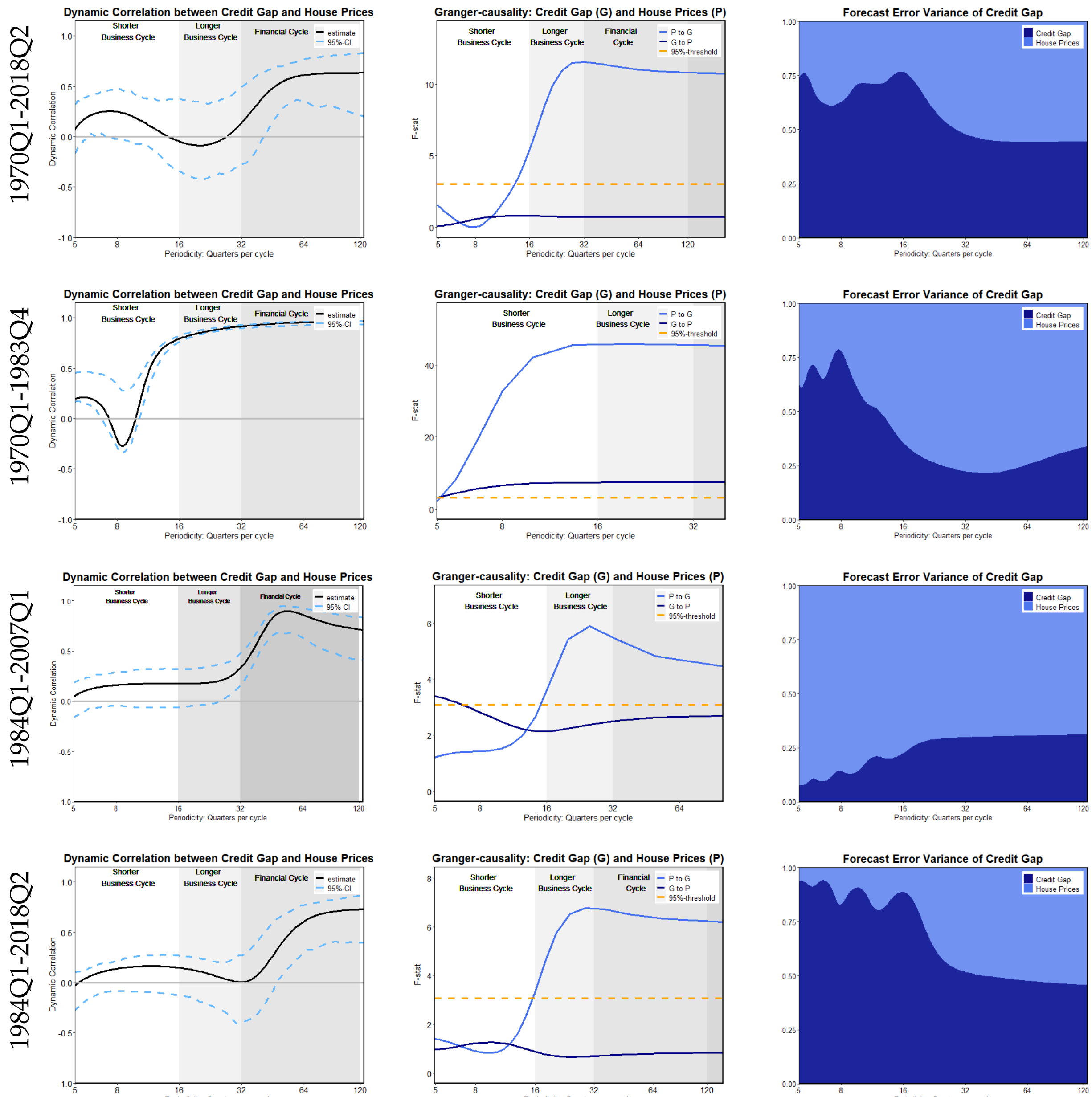
Figure 1.A.2. Spectra Credit Gap and Output and House Prices 1984-2007



This figure shows the spectra of output (left panel) and credit gap (right panel) estimated on the time series from 1970Q1-1983Q4 (light blue) and the narrowly-defined GM from 1984Q1-2007Q1 (dark blue) sample. The left axis measures the variance of the pre-GM spectrum. The right axis measures the variance of the GM spectrum. The x-axes are the periodicities i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated.

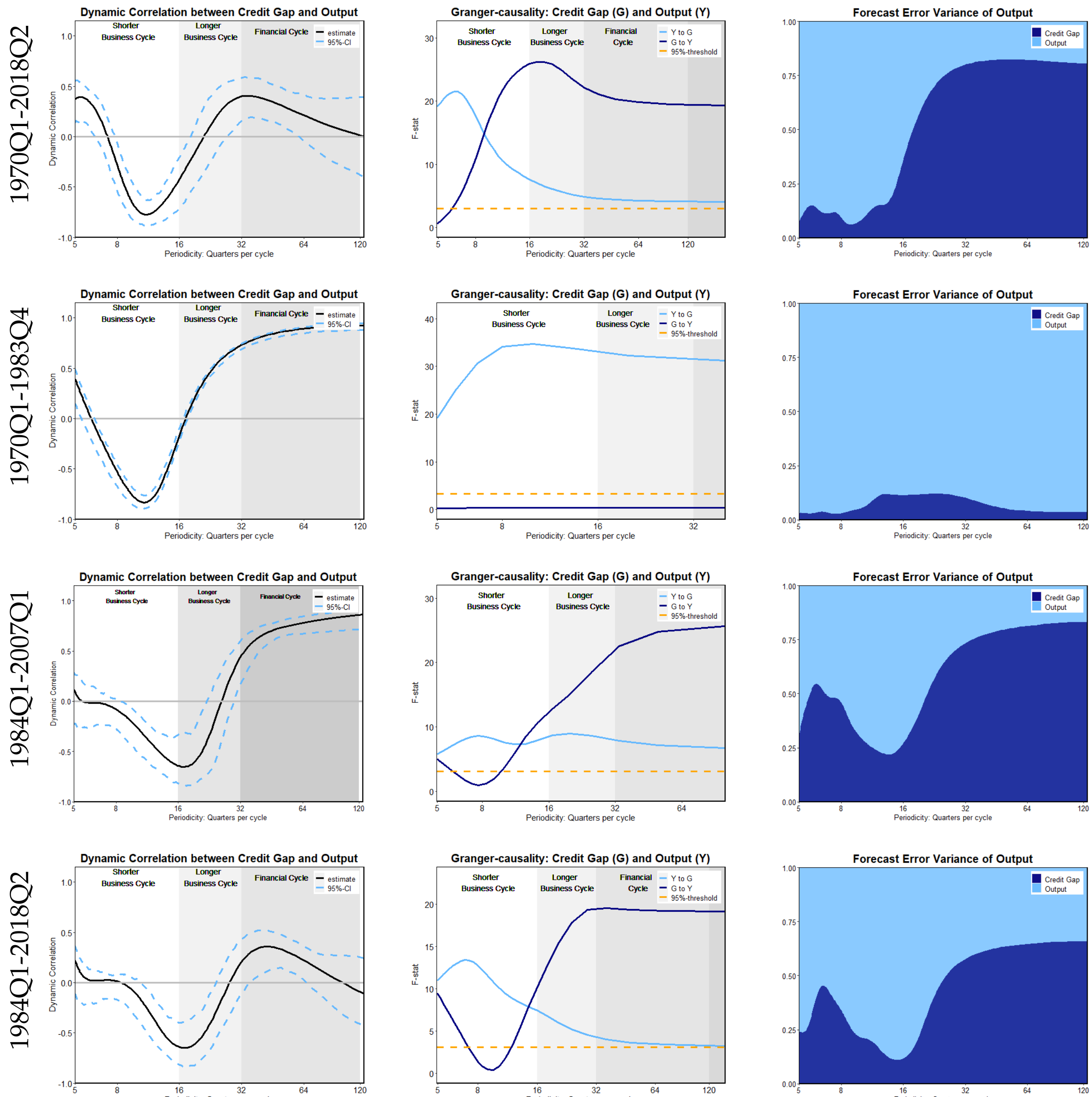
1.A.2 Result from bivariate VAR models (1), (2) and (3)

Figure 1.A.3. Dynamic Correlation, Granger-Causality and FEVD between Credit and House Prices



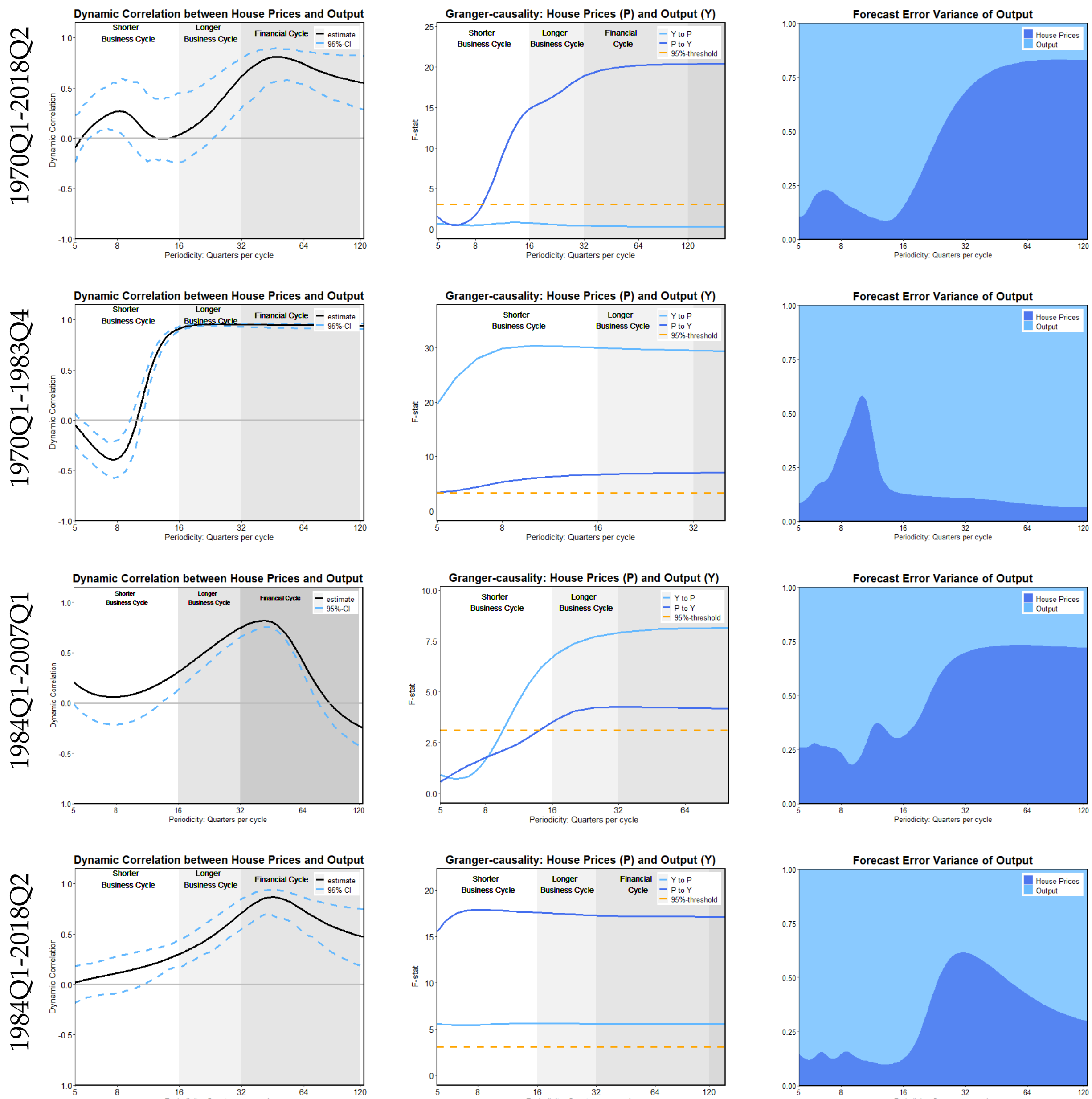
This Figure shows the dynamic correlations (left column), the F-statistics of the Granger-causality test (middle column) and FEVD (right column) of the bivariate VAR model of credit gap and house prices. These measures are calculated on data from 1970Q1-2018Q2 (first row), 1970Q1-1983Q4 (second row), 1984Q1-2007Q1 (third row) and 1984Q1-2018Q2 (fourth row). The x-axis is the periodicity, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. Dynamic correlation is measured on a y-axis from -1 to 1. The y-axis of the Granger-causality test measures the F-statistic. The solid lines show the F-statistic at each periodicity, where the legend shows the cause variable of each test. The dashed line is the 95% threshold of the Granger-test. The y-axes of the FEVD measure the contribution of orthogonal shocks to the variables listed in the legend to the overall forecast error.

Figure 1.A.4. Dynamic Correlation, Granger-Causality and FEVD between Credit Gap and Output



This Figure shows the dynamic correlations (left column), the F-statistics of the Granger-causality test (middle column) and FEVD (right column) of the bivariate VAR-model of credit gap and output. These measures are calculated on data from 1970Q1-2018Q2 (first row), 1970Q1-1983Q4 (second row), 1984Q1-2007Q1 (third row) and 1984Q1-2018Q2 (fourth row). The x-axis is the periodicity, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. Dynamic correlation is measured on a y-axis from -1 to 1. The y-axis of the Granger-causality test measures the F-statistic. The solid lines show the F-statistic at each periodicity, where the legend shows the cause variable of each test. The dashed line is the 95% threshold of the Granger-test. The y-axes of the FEVD measure the contribution of orthogonal shocks to the variables listed in the legend to the overall forecast error.

Figure 1.A.5. Dynamic Correlation, Granger-Causality and FEVD between House Prices and Output

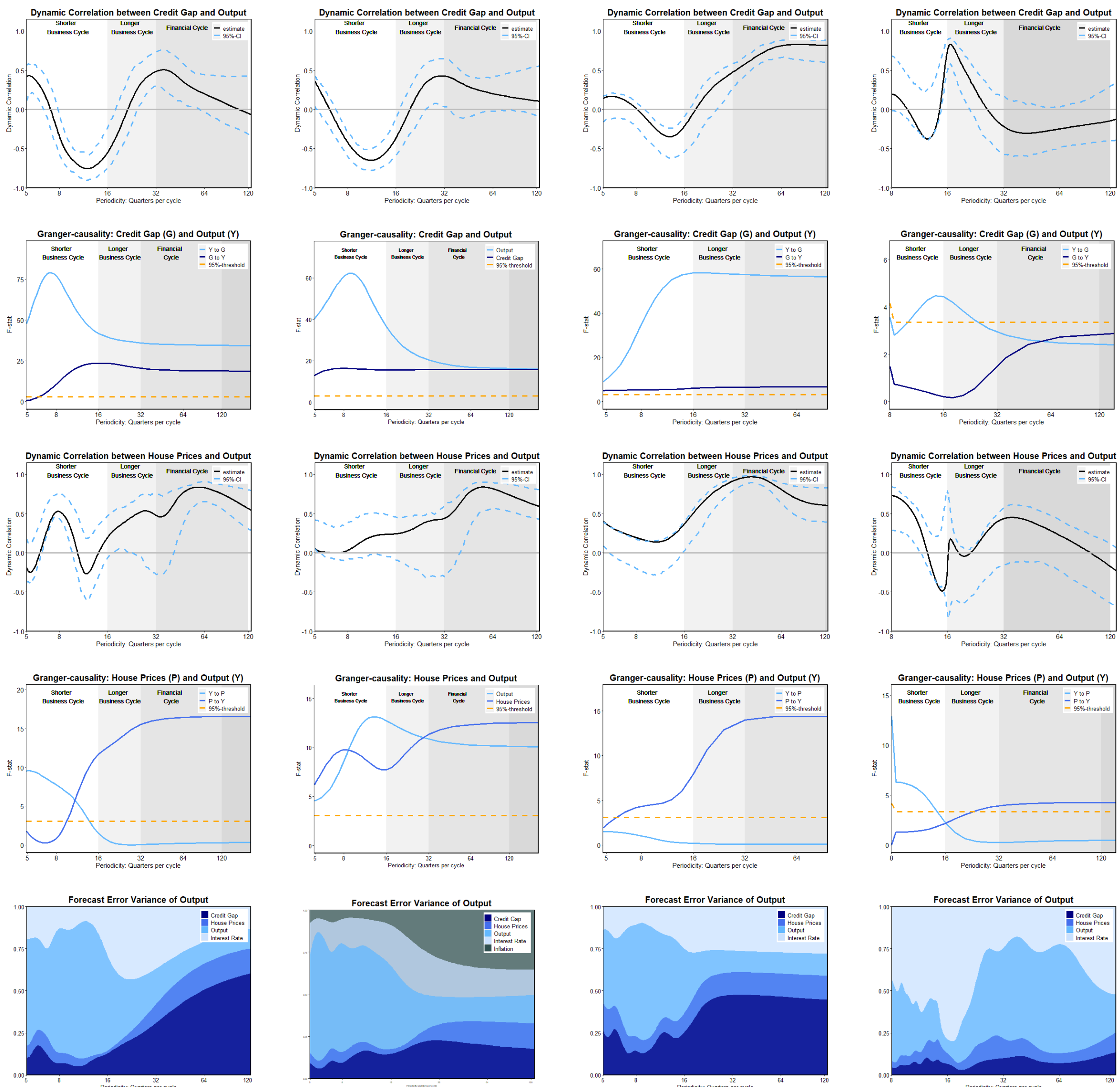


This Figure shows the dynamic correlations (left column), the F-statistics of the Granger-causality test (middle column) and FEVD (right column) of the VAR-model (3). These measures are calculated on data from 1970Q1-2018Q2 (first row), 1970Q1-1983Q4 (second row), 1984Q1-2007Q1 (third row) and 1984Q1-2018Q2 (fourth row). The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. Dynamic correlation is measured on a y-axis from -1 to 1. The y-axis of the Granger-causality test measures the F-statistic. The solid lines show the F-statistic at each periodicity, where the legend shows the cause variable of each test. The dashed line is the 95% threshold of the Granger-test. The y-axes of the FEVD measure the contribution of orthogonal shocks to the variables listed in the legend to the overall forecast error.

1.A.3 Robustness checks with VAR models (4) and (5)

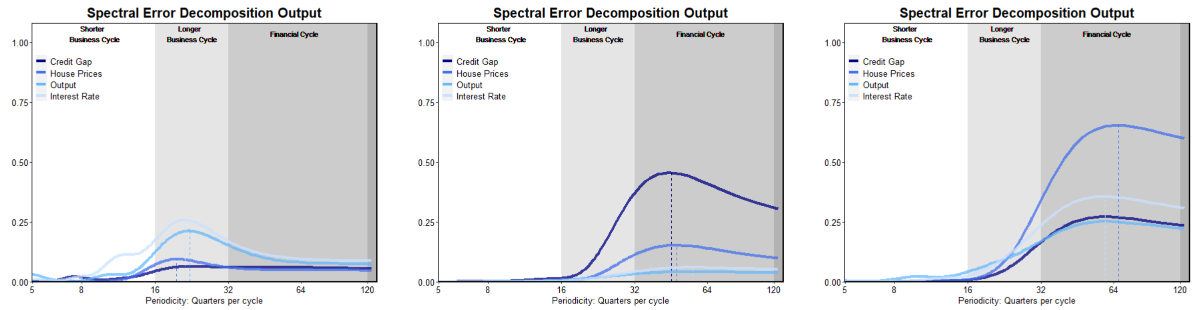
Figure 1.A.6. Robustness Checks Dynamic Correlation and FEVD

1970-2018 (Model 4) | 1970-2018 (Model 5) | 1983-2007 (Model 4) | 1944-1976 (Model 4)



This Figure shows the dynamic correlations (1st and 3rd row), the F-statistics of the Granger-causality test (2nd and 4th row) and FEVD (bottom row) of the VAR-models (4) and (5).

Figure 1.A.7. VAR-implied spectra for the pre-GM (left), narrow GM (middle) and GM (right) sample.

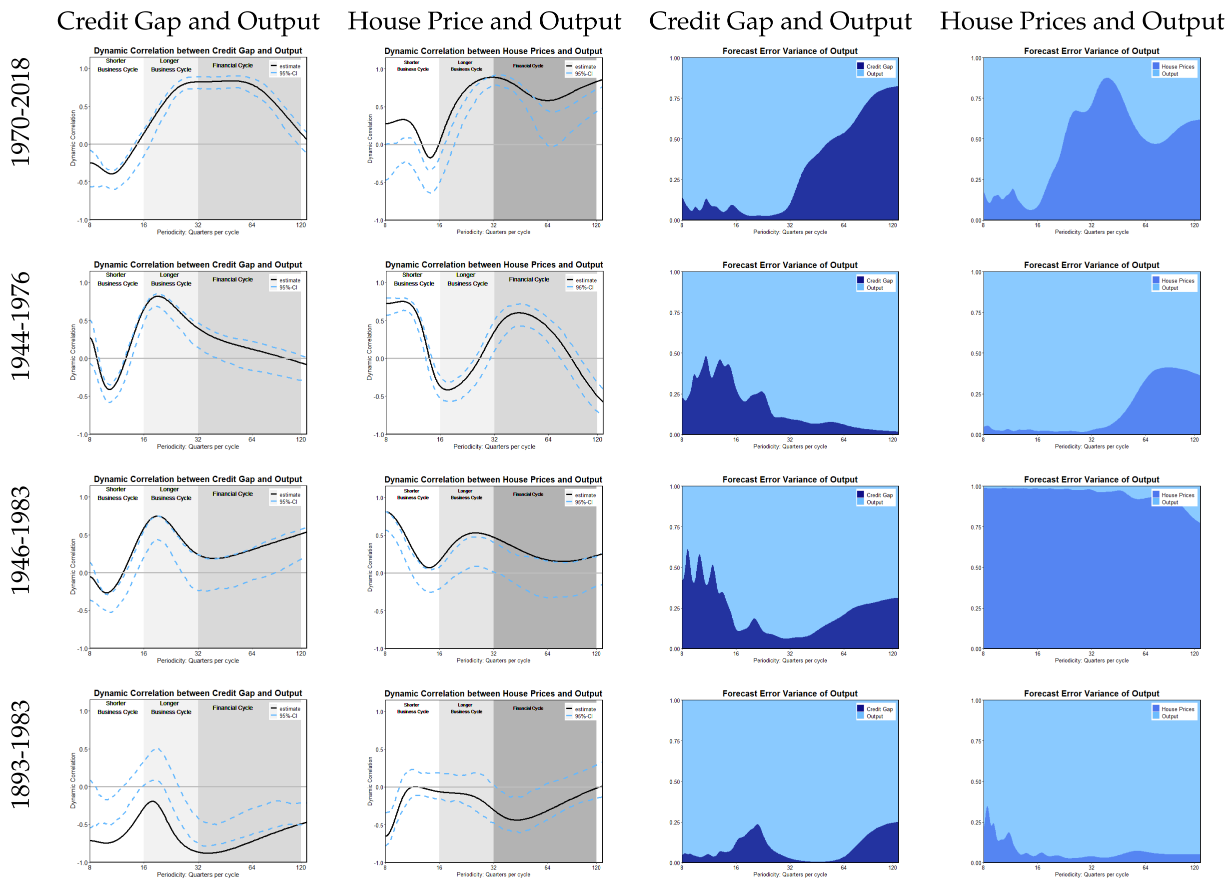


This figure shows the spectra of output derived from the baseline VAR-model. The left panel was estimated on data from 1970Q1-1983Q4. The panel in the middle was estimated on data from 1984Q1-2007Q1. The right panel was estimated on data from 1984Q1-2018Q2. The x-axis is the periodicity, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. The y-axis measures the volatility. Each line represents the resulting spectrum, when only one type of structural shock is active.

1.B Robustness checks Jordà et al. (2011) data

The fact that the statistics look very different for the very early sample is not surprising, and in line with Schularick and Taylor (2012) categorization of "two eras of finance capitalism". The first one up to 1939 and the second one post 1945 (or 1944, the start of Bretton-Woods). Noticeably, the dynamic correlation curves of credit gap and output are very similar to those estimated from the main data - with the exception of dataset that begins in 1893. The dynamic correlation curves between house prices and output do not show a qualitatively similar pattern in the pre-Great Moderation samples. While I do not investigate this more closely, I remark that the use of houses as collateral surged only later - so that houses assumed a fundamentally new role in the financial cycle.

Figure 1.B.1. Dynamic Correlation, Granger-Causality and FEVD, Bivariate VARs, JST data



This Figure shows the dynamic correlations (left columns), and FEVDs (right columns) of the VAR-model (1) and (3). These measures are calculated on data of the time period stated on the left. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. Dynamic correlation is measured on the y-axes from -1 to 1. The y-axes of the FEVD measure the contribution of orthogonal shocks to the variables listed in the legend to the overall forecast error.

1.C Robustness checks UK data

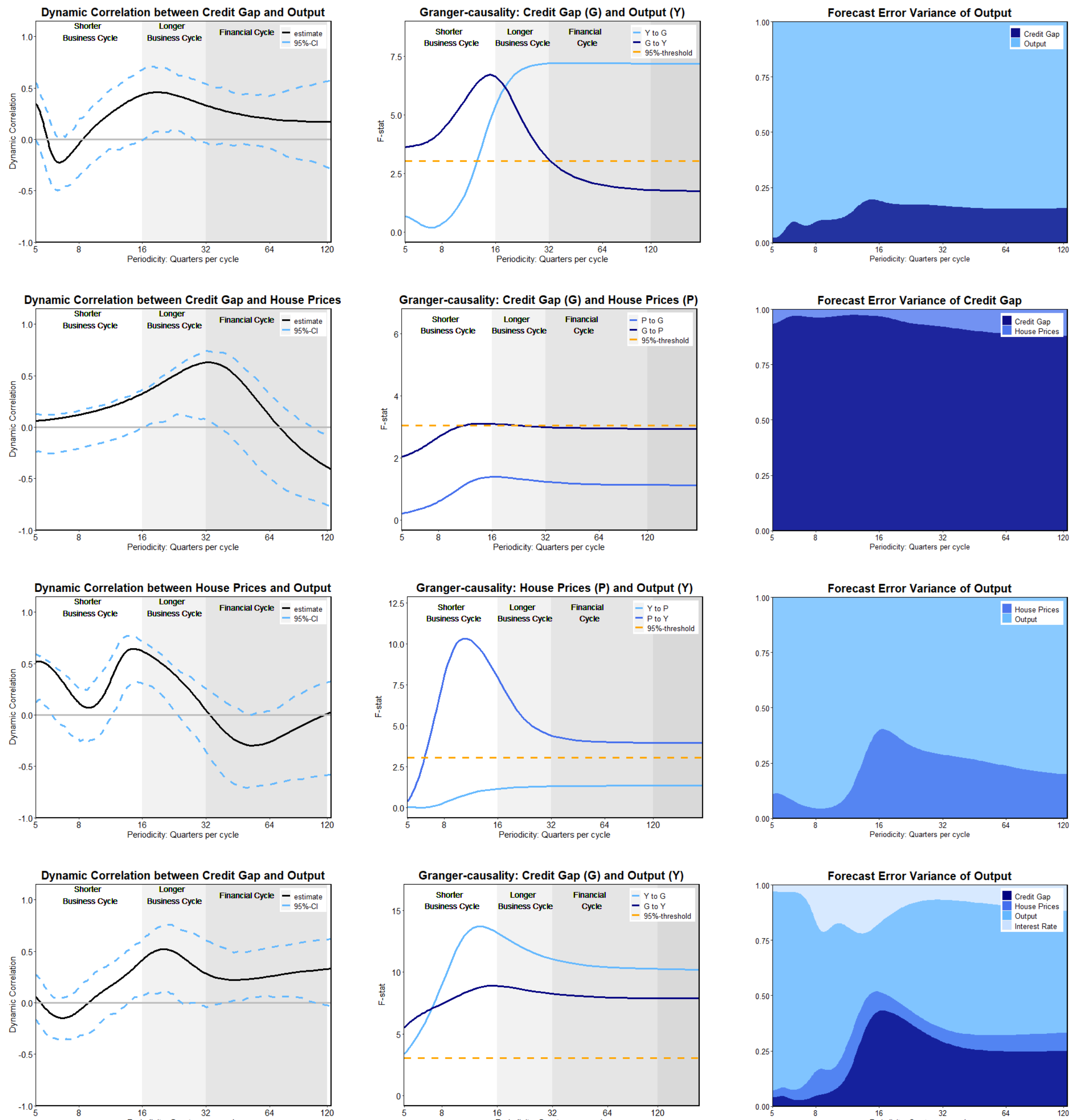
Figure 1.C.1. UK: Dynamic Correlation, Granger-Causality and FEVD

VAR-model (2)

VAR-model (2)

VAR-model (3)

VAR-model (4)

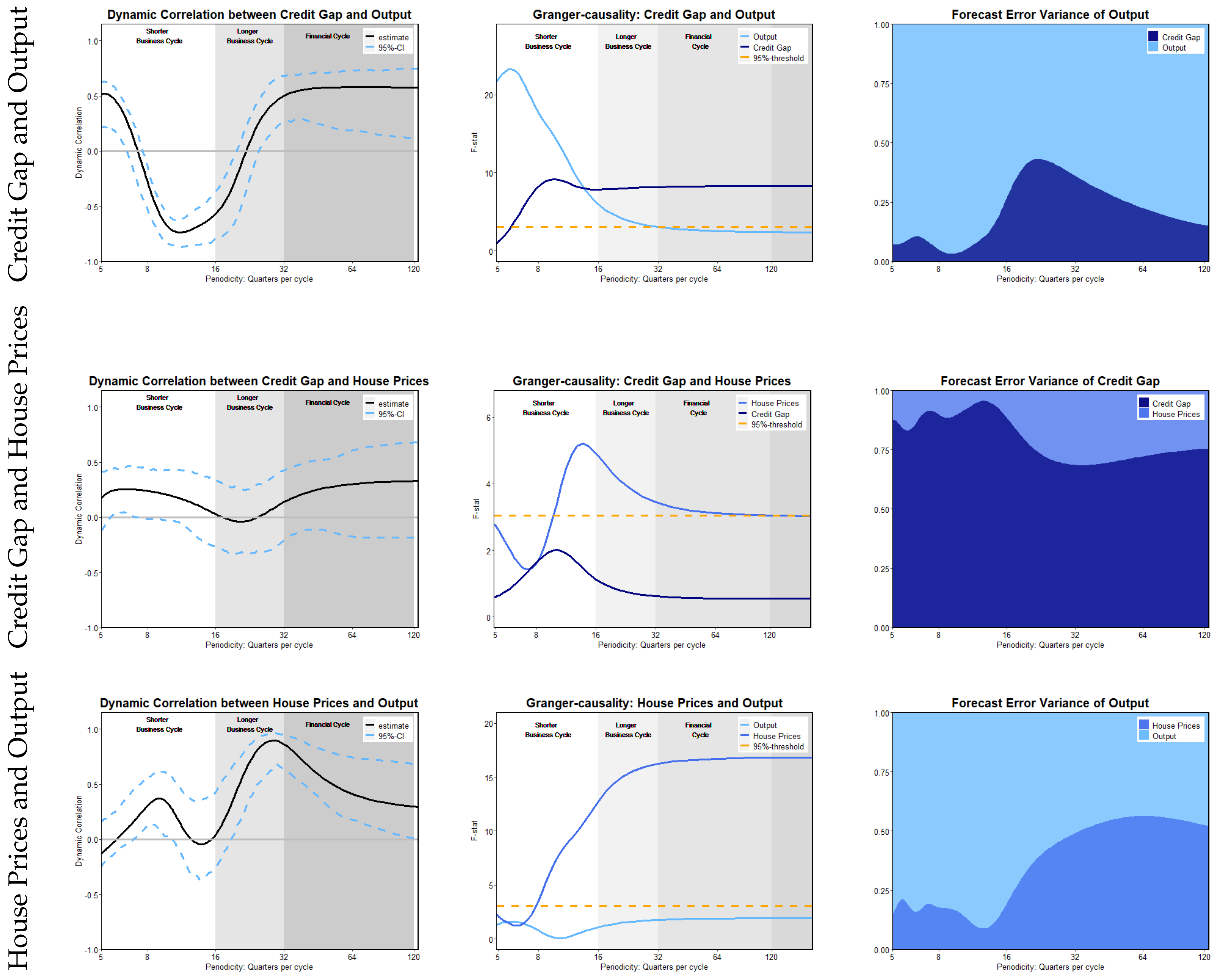


This Figure shows the dynamic correlations (left column), the F-statistics of the Granger-causality test (middle column) and FEVD (right column) of the VAR-model (1-4). These measures are calculated on UK data from 1970Q1-2018Q2 (top row), 1970Q1-1983Q4 (middle row) and 1984Q1-2018Q2 (bottom row). The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. Dynamic correlation is measured on a y-axis from -1 to 1. The y-axis of the Granger-causality test measures the F-statistic. The y-axes of the FEVD measure the contribution of orthogonal shocks to the variables listed in the legend to the overall forecast error.

1.D Other Robustness Checks

1.D.1 Robustness check HP-filter

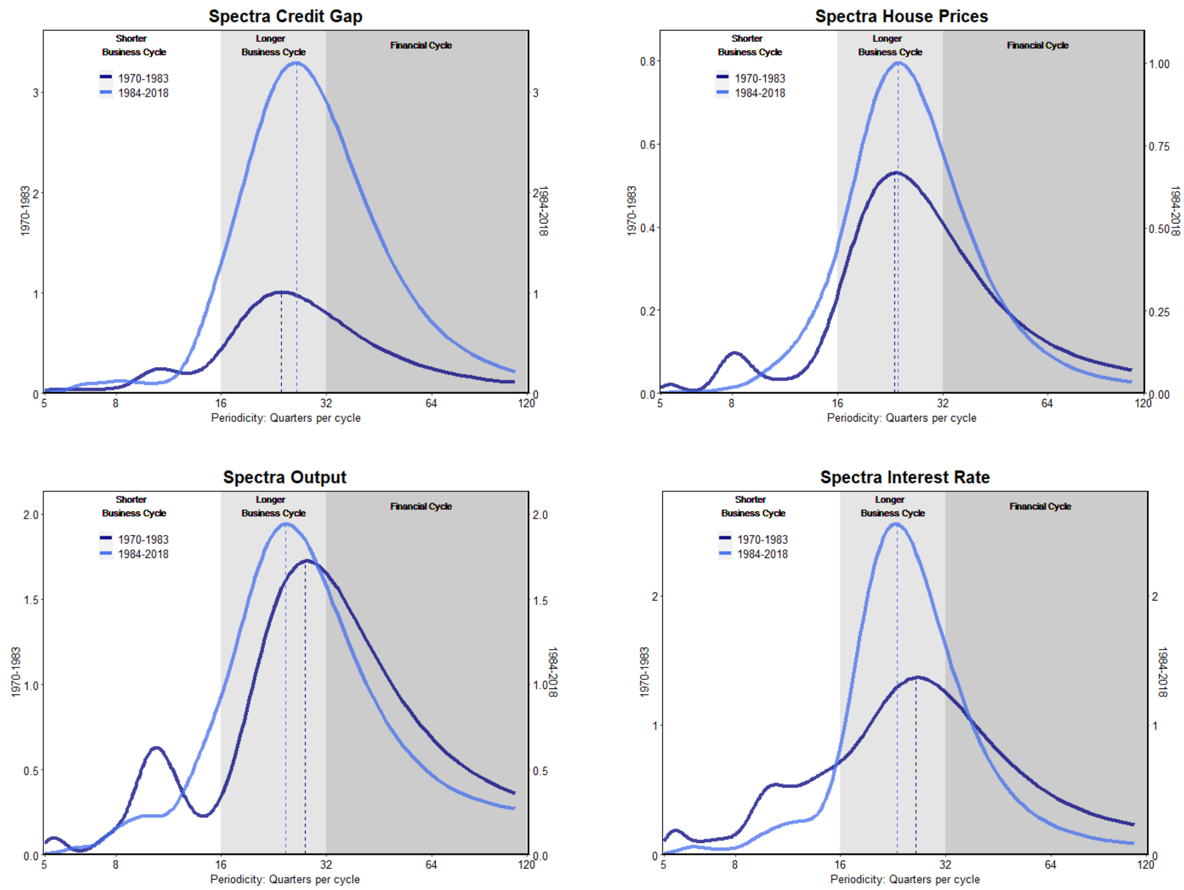
Figure 1.D.1. HP Filter: Dynamic Correlation, Granger-Causality and FEVD between House Prices and Output



This Figure shows the dynamic correlations (left column), the F-statistics of the Granger-causality test (middle column) and FEVD (right column) of the VAR-model (3). 1984Q1-2007Q1 (bottom row) for VAR-models (1-3). The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measure is calculated. Dynamic correlation is measured on a y-axis from -1 to 1. The y-axis of the Granger-causality test measures the F-statistic. The solid lines show the F-statistic at each periodicity, where the legend shows the cause variable of each test. The dashed line is the 95% threshold of the Granger-test. The y-axes of the FEVD measure the contribution of orthogonal shocks to the variables listed in the legend to the overall forecast error.

1.D.2 Deliberate false filtering

Figure 1.D.2. Selective Filtering: Spectra pre- and during Great Moderation

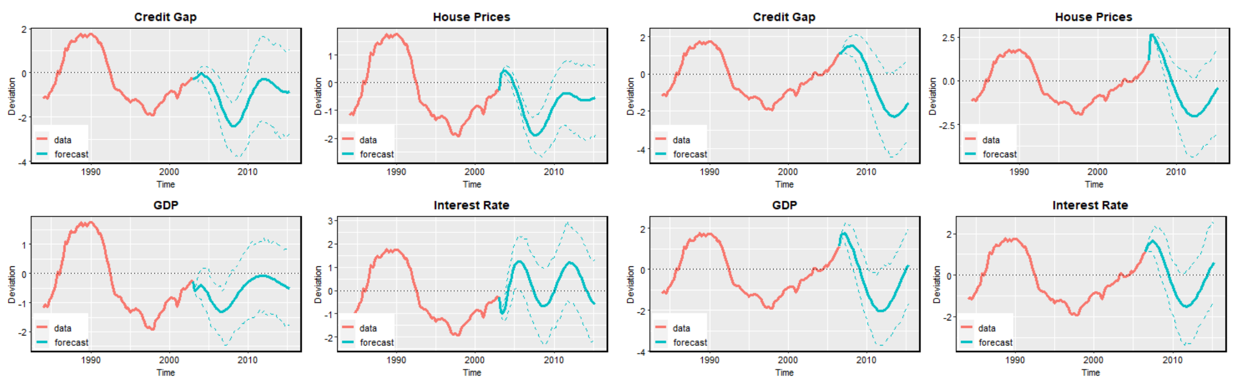


This figure shows the spectra of the main variables of this analysis filtered between 5 and 32 quarters. This illustrates that error that is generated when a frequency-specific filter is applied. All variables have the majority of their volatility below 32 quarters by construction in both subsamples. We can see the "heterogenous Great Moderation" in the reduction of output volatility on periodicities up to 16 quarters but not between 16 and 32 quarters as Pancrazi (2015) has shown. However, we are missing the shift to longer periodicities entirely. The better option is to analyse data in the frequency-domain when it is economically reasonable to focus the analysis on cycles. As stationarity is a prerequisite of the frequency-domain analysis, the trend should be removed either through a one-sided filter or by differencing (in the absence of cointegration).

1.D.3 Forecasting the Great Recession

Here, I document the following exercise: I estimate a four-variable VAR model (credit gap, house prices, output, interest rate) on data up to 2003Q1 (left) and 2007Q1 (right). I then forecast the evolution from there onwards until 2010. From the standpoint of 2003Q1 there is no evidence of a great recession on the horizon. The model predicts downturns in credit gap and house prices and output, but especially the forecast predicts at worst a mild recession. This changes drastically when looking at the forecast of 2007Q1: Here, the model predicts drastic declines in all variables, especially for house prices and output. This is exactly what happened with the Great Financial Crisis. Borio et al. (2018) find that the financial cycle indicator outperforms the term spread as a predictor of recessions. The predictability of the Great Recession in this model should hence not be surprising.

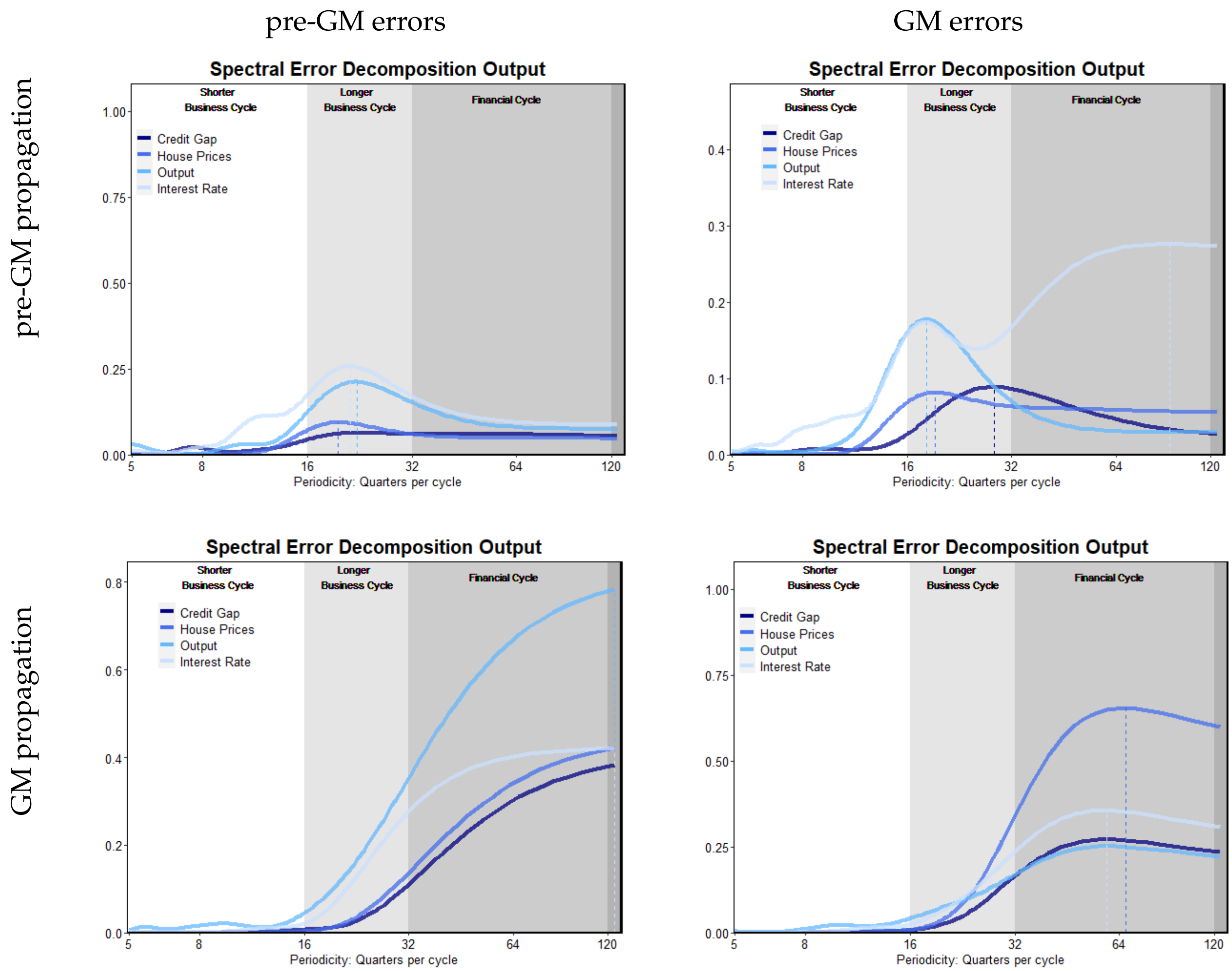
Figure 1.D.3. Great Recession Forecast



This figure shows the evolution of the four variables of VAR-model (4), credit gap, house prices, output and interest rate up to 2003 (left panel) and 2007 (right panel). The green lines are the forecasts implied by the VAR model (4) with the 95% confidence intervals (dashed lines).

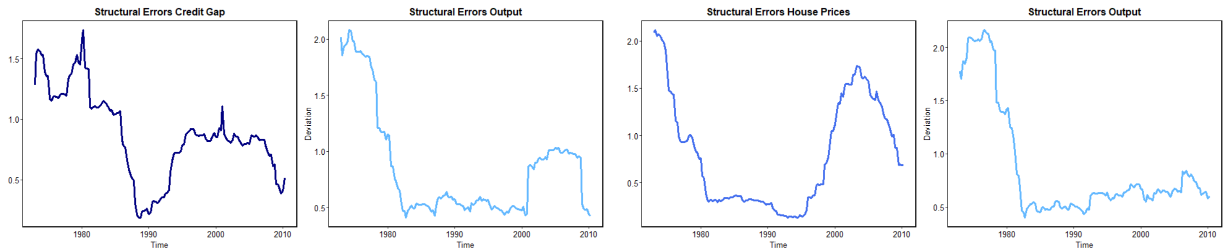
1.D.4 Good Luck and Good Policy

Figure 1.D.4. Counterfactuals holding the propagation or shock distribution constant



The empirical analysis of good policy is based on comparing the error decomposition of the spectrum of output (top-left, bottom-right) to counterfactual scenarios (bottom-left,top-right). The counterfactual scenarios are calculated by simulating the spectral error decomposition using the VAR-coefficients of the pre-GM scenario with the orthogonal innovations from the GM estimation (top-right); and using the VAR-coefficients of the GM scenario with the innovations of the pre-GM estimation. This reveals the following: Without any change in propagation, the monetary policy shocks during the Great Moderation would have still led to much more volatility than prior to the Great Moderation. This is especially true on financial cycle periodicities. Hence the monetary shocks did not do any good. However, central bank policy may have had beneficial effects that affected propagation. Here we essentially see the same thing. Given the change in propagation that occurred, monetary policy shocks still lead to much higher volatility on financial cycle periodicities than in the pre-GM benchmark. However, on shorter business cycle volatility did decrease. Hence: We do not know if monetary policy caused or contributed to causing the changes in propagation that occurred during the Great Moderation. But if it did, the positive effects of reduced volatility has to be weighted against the higher volatility on financial cycle periodicities in a normative analysis to assess whether policy was "good.

Figure 1.D.5. Rolling-Window Error Variance

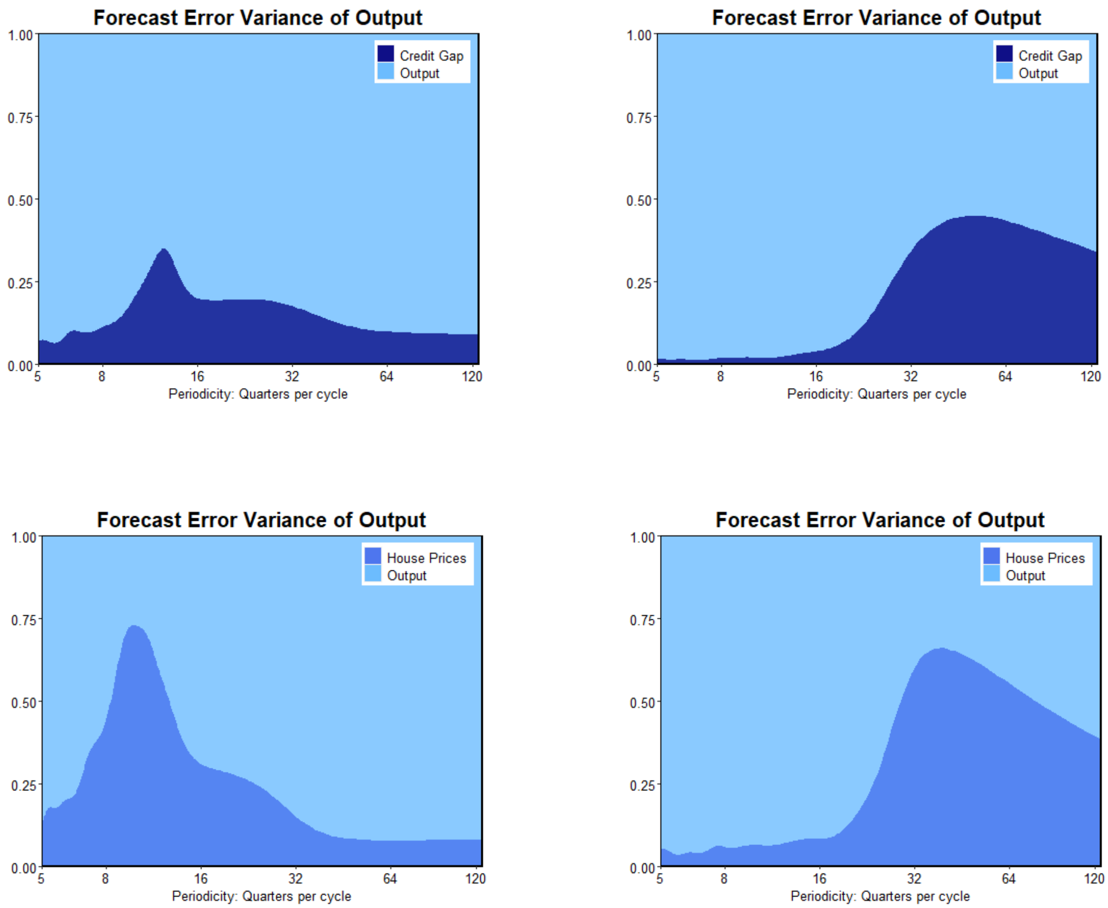


Model: Credit Gap and Output   Model: House Prices and Output

Each date labels the time-window that begins in this year, i.e. 1984 refers to the variance between 1984 and 1992. We can see that in the beginning of the 1980s, the error variance of all variables decrease significantly. However, after a short period of low volatility, the error variance of financial variables increase sharply long before the year 2007. While output volatility was still low, innovations to credit and house prices were already laying the groundwork for the Great Recession downturn (i.e. medium-term volatility of output). Additionally, we notice that in relative term,s the error variance of output has reduced with respect to the error variance of house prices. Hence, the Great Moderation spectra must be closer to the one driven only by house price errors than to the one created by only output errors.

1.D.5 Impulses versus propagation

Figure 1.D.6. Impulse versus propagation



The first row shows the bivariate analysis of credit gap and output, the second row the one of house prices and output. The first column shows the FEVD of the VARs estimated on the 1970-1983 sample, using the errors of the 1984-2018 sample. The second column shows the FEVD of the VARs estimated on the 1983-2018 sample, using the structural errors of the 1970-1983 sample. In both cases, the shift towards longer periodicities seems to be a result of changes in the propagation of the shocks. In case of credit gap and output, there may however be also a non-negligible effect of the shocks.

1.E Frequency-domain tools:

Frequency-domain methods build on the Fourier-transform, which disaggregates time series into cycles of different frequencies $\omega \in (0, \pi)$. The most commonly used frequency-domain tool in economics is the spectrum, denoted S_{xx}, which measures how much variance is attributed to the cycles of each frequency. It is calculated as the Fourier-transform of the autocovariance function

$\Gamma_{xx} = Cov(x_t, x_{t-j})\;\; j \in (\underline{t}, \bar{t})$ of time series x_t (with $\underline{t} \leq t \leq \bar{t}$):

$$S_{xx} = \frac{1}{2\pi} \sum_{j=\underline{t}}^{\bar{t}} \Gamma_{xx}^{(j)} e^{-i\omega j}$$

In multivariate time series, the (complex) cross-spectrum between two variables x and y is denoted $S_{xy}(\omega)$ and describes the co-variance on each frequency - calculated as the Fourier-transform of the cross-covariance function Γ_{xy}.
Assume that the evolution of our variables can be described by a vector-autoregressive process of K variable of p lags each. Without loss of generality, define $X = (x, y, z_1, ...z_{K-2})$ the variables of the VAR. Each regression equation of the underlying VAR is of the form

$$x_t = c_k + \sum_{i=1}^{p} \alpha_i x_{t-i} + \sum_{j=1}^{p} \beta_j y_{t-j} + \sum_{k=1}^{K-2} \sum_{l=1}^{p} \gamma_{k,l} z_{k,t-l} + e_t$$

where c_k is the equation-k intercept and α_i, β_j and γ_k, l are the regression estimates. Transforming the VAR(p) into its VAR(1) form, denote M the companion matrix of the VAR, then

$$\tilde{X}_t = M\tilde{X}_{t-1} + \epsilon_t$$

From this state-space form of the VAR, the dynamic correlation P_{xy} is calculated as[30]:

$$P_{xy}(\omega) = (I - Me^{-i\omega})^{-1} \Sigma (I - Me^{i\omega})^{-1}$$

where I is a $K \times K$ identity matrix and Σ is the estimated covariance matrix of the VAR. The test for frequency-domain Granger-causality tests the hypothesis

$$H_0 : \quad M_{y\to x}(\omega) = 0$$

that cause variable y does not Granger-cause effect variable x at frequency ω in a bivariate VAR model[31]. The corresponding test statistic from Geweke (1982) is

$$M_{y\to x}(\omega) = log\left[\frac{2\pi S_{xx}(\omega)}{|\Psi_{11}(e^{-i\omega})|^2}\right]$$

where $\Psi(L)\eta_t = \Phi(L)\epsilon_t$, $\Phi(L)$ is the lag polynomial and $\eta_t = G\epsilon_t$ where G is a lower-triangular matrix such that $E(\eta_t \eta_t) = I$ is an identity matrix. As shown by Breitung and Candelon (2006),

[30] On time-series data, the dynamic correlation can be computed as: $\rho_{xy}(\omega) = \frac{real(S_{xy}(\omega))}{\sqrt{S_{xx}(\omega)S_{yy}(\omega)}}$ as shown by Croux et al. (2001)

[31] For the multivariate models Breitung and Candelon (2006) show how to modify the test to condition on variables $z_1...z_{K-2}$, i.e. to test the hypothesis $M_{y\to x|(z_1,...,z_{K-2}}(\omega) = 0$.

this is equivalent to testing a pair of linear hypotheses $H_0 : R(\omega)\beta = 0$ where β is the vector of estimates and

$$R(\omega) = \begin{bmatrix} cos(\omega) & cos(2\omega) & ... & cos(p\omega) \\ sin(\omega) & sin(2\omega) & ... & sin(p\omega) \end{bmatrix}$$

The forecast error variance of the h-step forecast of variable j is:

$$MSE[y_{j,t}(h)] = \left(\sum_{i=0}^{h-1} \Phi_i \Sigma_u \Phi_i' \right)_{jj}$$

The frequency-domain counterpart is:

$$MSE[y_{j,t}(\omega)] = \left(\sum_{i=-\infty}^{\infty} \Theta_i \Theta_i' \right)_{jj} e^{-ik\omega} = \left(\sum_{i=-\infty}^{\infty} \Phi_i \Sigma_u \Phi_i' \right)_{jj} e^{-ik\omega}$$

Then the frequency-domain FEVD is:

$$FEVD_{jl,\omega} = \left[\left(\sum_{i=-\infty}^{\infty} \Phi_i \Sigma_u \Phi_i' \right)_{jj} e^{-ik\omega} \right] / \left[\sum_{j=1}^{K} \left(\sum_{i=-\infty}^{\infty} \Phi_i \Sigma_u \Phi_i' \right)_{jj} \right]$$

where $\Theta_i = \Phi_i P$ and P is a lower triangular matrix obtained from a Choleski decomposition of Σ_u.

1.F Detailed Description of the Model

The setup of the model closely builds on Villa (2016), modifying the framework only where necessary to incorporate all financial frictions. There is a mass one of identical patient households which consume two goods: A non-durable final good and a capital good - housing. Houses are bought and sold but cannot be rented. To pay for their expenses, households supply labor to labor unions, which differentiate it, aggregate it and sell the labor aggregate to entrepreneurs. Households deposit their savings with financial intermediaries (banks), which use these funds to give credit to entrepreneurs. Entrepreneurs combine labor and the capital good to produce intermediate goods which they sell to retailers. Retailers aggregate intermediate varieties into a final good. Final goods are sold to the patient household for consumption, to entrepreneurs for consumption and for maintenance of the capital stock; and to capital producers as a production input. Capital producers transform final goods into durable capital/houses and sell them to patient households and entrepreneurs. Additionally there is a central bank that chooses its policy rate according to a Taylor rule, and a government that levies taxes on the household and can purchase final goods.

1.F.1 Households' Problems

There is a mass 1 of identical patient households indexed by i. Households maximize their utility through choice of consumption C_t, housing K_{t+1}, deposits D_t in a financial intermediary and labor supply L_t. Their utility from consumption depends on external habit and capital depreciates at rate δ. Each household owns a bank and receives its bank's profits. Household are subjected to government taxation and transfers. Their maximization problem is:

$$
\begin{aligned}
maxE_t \sum_{t=0}^{\infty} \beta^t \Bigg\{ & log(C_{it} - hC_{t-1}) - \frac{L_{it}^{1+\phi_l}}{1+\phi_l} + \nu log(K_{it+1}) \\
& - \mu_{it}[C_{it} + Q_t(K_{it+1} - (1-\delta)K_{it}) + D_{it+1} - R_{t-1}D_{it} - W_t^H L_{it} - \Pi_t + T_t - TR_t] \Bigg\}
\end{aligned}
$$

where K_{it} are houses, D_{it} are deposits with the bank and L_{it} stands for labor supply. Q_t is the relative price of houses. Since all households are identical, the index i is suppressed in the following. The first order conditions of this problem are:

$$
\begin{aligned}
L_t^{\phi_l} &= \frac{W_t^H}{(C_t - hC_{t-1})} \\
(C_t - hC_{t-1})^{-1} &= \beta R_t E_t (C_{t+1} - hC_t)^{-1} \\
Q_t (C_t - hC_{t-1})^{-1} &= \beta \left(\nu K_t^{-1} + E_t \left[(C_{t+1} - hC_t)^{-1} (1-\delta) \right] \right)
\end{aligned}
$$

This yields standard Euler equation, consumption-labor margin, and investment equation.

1.F.2 Labor Unions' Problems

Households supply homogenous labor to monopolistic labor unions which differentiate it:

$$
L_t = \left[\int_0^1 L_t(l)^{\frac{\epsilon_w - 1}{\epsilon_w}} dl \right]^{\frac{\epsilon_w}{\epsilon_w - 1}}
$$

The unions' optimization problems are:

$$
\begin{aligned}
& min \int_0^1 W_t(l) L_t(l) dl \\
& st. \bar{L} \leq \left[\int_0^1 L_t(l)^{\frac{\epsilon_w - 1}{\epsilon_w}} dl \right]^{\frac{\epsilon_w}{\epsilon_w - 1}}
\end{aligned}
$$

The demand for labor of union l is given by:

$$
L_t(l) = \left(\frac{W_t(l)}{W_t} \right)^{-\epsilon_w} L_t
$$

This implies for wages:

$$W_t = \left[\int_0^1 W_t(l)^{1-\epsilon_w} dl \right]^{\frac{1}{1-\epsilon_w}}$$

Unions adjust wages according to a Calvo scheme with parameter σ_w. In a given period, the wages of firms that cannot re-optimize are indexed to inflation. The union maximizes

$$maxE_t \sum_{s=0}^{\infty} \frac{\mu_{t+s}}{\mu_t} (\beta\sigma_w)^s L_{t+s}(l) \left[\frac{W_t^r(l)}{P_{t+s}} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{\sigma_{wi}} - \frac{W_{t+s}^H}{P_{t+s}} \right]$$

The first-order condition is:

$$E_t \sum_{s=0}^{\infty} \frac{\mu_{t+s}}{\mu_t} (\beta\sigma_w)^s L_{t+s}(l) \left[\frac{W_t^r(l)}{P_{t+s}} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{\sigma_{wi}} - \frac{W_{t+s}^H}{P_{t+s}} \frac{\epsilon_w}{\epsilon_w - 1} u_t^w \right] = 0$$

where u_t^w is a mark-up shock that follows:

$$u_t^w = \rho_w u_{t-1}^w + \epsilon_t^w, \qquad \epsilon_t^w \sim N(0, \sigma_w^2)$$

1.F.3 Retailers' Problems

Monopolistic retailers purchase intermediate goods at marginal cost from entrepreneurs, differentiate the goods and sell a final good made from the different varieties: Retailers adjust according to a Calvo scheme with parameter σ_p. In a given period, the prices of firms that cannot re-optimize are indexed to inflation. The retailers maximize

$$maxE_t \sum_{s=0}^{\infty} \frac{\mu_{t+s}}{\mu_t} (\beta\sigma_p)^s Y_{t+s}(f) \left[\frac{P_t^r(f)}{P_{t+s}} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{\sigma_{pi}} - \frac{\Phi_{t+s}}{P_{t+s}} \right]$$

The first-order condition is:

$$maxE_t \sum_{s=0}^{\infty} \frac{\mu_{1t+s}}{\mu_{1t}} (\beta\sigma_p)^s Y_{t+s}(f) \left[\frac{P_t^r(f)}{P_{t+s}} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{\sigma_{pi}} - \frac{\Phi_{t+s}}{P_{t+s}} \frac{\epsilon}{\epsilon - 1} u_t^p \right] = 0$$

where u_t^w is a mark-up shock that follows:

$$u_t^p = \rho_p u_{t-1}^p + \epsilon_t^p, \qquad \epsilon_t^p \sim N(0, \sigma_p^2)$$

Final output is a composite of the differentiated intermediate goods $f \in (0, 1)$:

$$Y_t = \left[\int_0^1 Y_t(f)^{\frac{\epsilon-1}{\epsilon}} df \right]^{\frac{\epsilon}{\epsilon-1}}$$

Final goods firms are competitive and their optimization problems are:

$$min \int_0^1 P_t(f) Y_t(f) df$$
$$st.\bar{Y} \leq \left[\int_0^1 Y_t(f)^{\frac{\epsilon-1}{\epsilon}} df \right]^{\frac{\epsilon}{\epsilon-1}}$$

The demand for the good of retailer f is given by:

$$Y_t(f) = \left(\frac{P_t(f)}{P_t} \right)^{-\epsilon} Y_t$$

This implies for prices:

$$P_t = \left[\int_0^1 P_t(f)^{1-\epsilon} df \right]^{\frac{1}{1-\epsilon}}$$

The equation describing the dynamics of aggregate price level is given by:

$$P_{t+1} = \left[(1-\sigma_p)(P^r_{t+1}(f))^{1-\epsilon} + \sigma_p (P_t \left(\frac{P_t}{P_{t-1}} \right)^{\sigma_{pi}})^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}$$

1.F.4 Capital Producers

Capital producers purchase some of the final goods and transform them into (durable) capital goods. They sell them to the household which consume capital (interpreted as housing) and to entrepreneurs which use the capital to produce. The problem of capital producers is:

$$maxE_t \sum_{t=0}^{\infty} \beta^t \Pi_t + \mu_t^K \left[\Pi_t - (Q_t^n - P_t) I_t + x_t I_t \left(1 - F\left(\frac{I_t}{I_{t-1}} \right) \right) \right]$$

The first order condition is

$$(Q_t^n - P_t) \equiv Q_t = x_t \left[1 - F\left(\frac{I_t}{I_{t-1}} \right) - \frac{I_t}{I_{t-1}} F'\left(\frac{I_t}{I_{t-1}} \right) \right] + \beta E_t x_{t+1} \left(\frac{I_{t+1}}{I_t} \right)^2 F'\left(\frac{I_{t+1}}{I_t} \right)$$

1.F.5 Financial Intermediaries' Problems

Competitive financial intermediaries (banks) maximize the discounted sum of their future profits. Banks survive a period with probability θ. In case they die, they give their entire net worth back to their household, after which they are immediately reborn and given transfer N^n by their household.

Banks take deposits from patient households which are paid deposit rate R_t in exchange. Each bank uses those funds along with its own net worth to provide credit to entrepreneurs. Credit comes in the form of simple 1-period bonds and the lending rate is denoted R_t^L. Two frictions impact the choices of the banks: 1) Costly state-verification, 2) moral hazard of bankers, which may try to divert the banks' funds back to their household. The following shows how each financial friction constrains the financial intermediary's optimization.

Costly-state verification and repossession: The framework of costly state-verification goes back to Townsend (1979). It is assumed that if the debtor fails to repay the loan, the bank needs to pay a cost of ζ to find and repossess one unit of the borrower's assets. In this paper, I assume that this cost ζ is stochastic and evolves according to

$$\zeta_t = \zeta_{t-1}^{\rho_\zeta} \bar{\zeta}^{1-\rho_\zeta} e^{\epsilon_t^\zeta}$$

so that its average over time is $\bar{\zeta}$. This can be interpreted as a shock to the financial technology of the bank. Hence, the bank will ensure itself of repayment by forcing the entrepreneur to pose collateral for the debt, thereby imposing a quantity restriction on the debt incurrence of the entrepreneur. This is the approach of Iacoviello (2005) which gives rise to the financial accelerator as in Kiyotaki and Moore (1997). The collateral constraint is:

$$(1-\zeta_t)Q_{t+1}K_{jt+1}^F(1-\delta) \geq B_{jt+1}^F$$

When the entrepreneur does not repay, the bank can pay the repossession cost and will (in expectation) be able to cover its losses completely by selling the entrepreneur's leftover capital. Hence, the lending rate will equal the deposit rate in the Iacoviello economy.

Moral hazard: Finally, following Gertler and Karadi (2011), the manager of the bank has the option to divert a fraction λ of the bank's resources back to his household. As the cost of state verification, I assume that λ is stochastic. This gives rise to an incentive constraint in the form of a leverage constraint. This limits the ability of the bank to obtain deposits. This setup leads to the objective:

$$\Upsilon_t = max E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \beta^{i+1} \Lambda_{t,t+i+1} N_{t+i+1}$$

$$\Upsilon_t = max E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \beta^{i+1} \Lambda_{t,t+i+1} (R_{t+i}^L B_{t+1+i}^F - R_{t+i} D_{t+1+i} - R_{t+i} N_{t+i})$$

In this optimization, $\Lambda_{t,t+1} = \frac{\mu_{t+1}}{\mu_t}$. To ensure that the banker does not divert any funds, we require that the value of continuing to operate the bank is always greater than the value of stealing:

$$\Upsilon_t = \lambda_t D_{t+1}$$

As Gertler and Karadi (2011) show, this can be written as:

$$Y_t = V_t D_{t+1} + H_t N_t$$

with

$$V_t = E_t(1-\theta)\beta\Lambda_{t,t+1}(R_t^L - R_t) + \beta\theta\Lambda_{t,t+1}X_{t,t+1}V_{t+1}$$
$$H_t = E_t(1-\theta) + \beta\Lambda_{t,t+1}\theta Z_{t,t+1}H_{t+1}$$

where $X_{t,t+1} = B_{t+2}^F / B_{t+1}^F$ and $Z_{t,t+1} = N_{t+1}/N_t$. To ensure that the banker does not divert any resources, the bank then needs to fulfill the constraint

$$V_t B_{t+1}^F + H_t N_t \geq \lambda_t B_{t+1}^F$$
$$B_{t+1}^F \leq \frac{H_t}{(\lambda_t - V_t)} N_t = lev_t N_t$$

which places an upper bound on the leverage of the bank. This leverage constraint prevents banks from channeling enough funds from patient household to entrepreneurs to equilibrate households marginal value of saving and entrepreneurs' marginal value of credit. Hence, the bank can charge up to $R^L > R$ without fearing that its profits are competed away. The lending rate R^L is given by the entrepreneurs marginal value of credit.
The net worth of banks evolves a follows:

$$N_t^{total} \equiv N_t = N_t^e + N_t^n = \theta\Big((R_t^L - R_t)lev_t + R_t\Big)N_t + \chi Q_t K_{t+1}^F$$

where $N_t^n = \chi B_{t+1}^F$ is the transfer that newborn banks receive from their household in order to start operations.

1.F.6 Entrepreneurs' Problems

There is a mass 1 of entrepreneurs indexed j in the economy. As in Iacoviello (2005) they only consume non-durable goods and use the capital goods to produce new intermediate goods. In this model the entrepreneurial problem is set up in such a way that if utility is linear consumption C_t^F, entrepreneurs can be reinterpreted as the intermediate firms' which profit Π_t which are returned to the patient households[32].

[32] In this case, the optimization problem can simply be written as:

$$\begin{aligned} maxE_t \sum_{t=0}^{\infty} (\theta\beta)^t \{ \pi_{jt} \\ &+ \mu_{jt}^F[\Phi_t Y_{jt} + B_{jt+1}^F - W_t L_t - \Psi(U_{jt})K_{jt}^F - Q_t(K_{jt+1}^F - (1-\delta)K_{jt}^F) - R_{t-1}B_{jt}^F - \pi_{jt}^F] \\ &+ \mu_t^C[(1-\zeta_t)Q_{t+1}K_{jt+1}^F(1-\delta) - R_t B_{jt+1}^F]\} \end{aligned}$$

Households are perfectly diversified across firms.

As in Christiano et al. (2005), the entrepreneurs engage in a sequence of actions. Upon entering a period, entrepreneurs first observe their state variables K_t^F and B_t^F and technology, capital quality and mark-up shocks $\epsilon_a, \epsilon_k, \epsilon_w, \epsilon_p$. Given this information, they choose their labor demand and capital utilization. Increased capital utilization results in higher output and comes at higher costs of maintenance of the capital stock. To maintain its capital, the firm needs to purchase additional final goods[33]. The entrepreneurs' production, unions' and retailers' decisions as well as labor market and final goods market clearing occur simultaneously. Next, capital producers sell capital goods (housing) which they created from the final goods they bought. Entrepreneurs and households observe the financial and investment shocks $\epsilon_\zeta, \epsilon_\lambda$ and ϵ_x, respectively, and determine their capital demands and debt/savings decisions - markets for capital and credit clear. Finally, the central bank observes output gap and inflation and resets its policy rate.
Entrepreneurs' production technology is:

$$Y_{t+1} = A_t(U_t K_{t+1}^F)^\alpha L_t^{1-\alpha} - \Theta$$

Entrepreneurs also die in each period with probability γ. In this case entrepreneurs are immediately reborn. This effectively shrinks their discount factor and ensures that they will always be borrowing constraint. Accordingly, the problem of the entrepreneur is:

$$\begin{aligned} maxE_t \sum_{t=0}^{\infty} (\gamma\beta)^t \Bigg\{ & \frac{(C_{jt}^F - h^F C_{t-1}^F)^{1-\phi_f}}{1-\phi_f} \\ & + \mu_{jt}^F [\Phi_t Y_{jt} + B_{jt+1}^F - C_{jt}^F - W_t L_t - \Psi(U_{jt}) K_{jt}^F - Q_t(K_{jt+1}^F - (1-\delta)K_{jt}^F) - R_{t-1}^L B_{jt}^F] \\ & + \mu_t^C E_t[(1-\zeta_t) Q_{t+1} K_{jt+1}^F (1-\delta) - R_t^L B_{jt+1}^F] \Bigg\} \end{aligned}$$

Given that entrepreneurs die, they will effectively discount the future at lower values than the patient household. Thus, they will always borrow funds from the bank. The lending rate depends on the financial frictions that are present in this economy. In case of the Gertler-Karadi friction, the bank can charge the marginal value of debt to the entrepreneur as the lending rate. Since credit markets operate after consumption of period t has taken place, all funds obtained in the credit market goes towards capital purchases. Hence, the marginal value of debt to the entrepreneur is equal to its marginal return to capital divided by the price of capital. The return to capital purchases today is the sum of the instantaneous benefit of loosening the collateral constraint and tomorrow's return to capital. In the Iacoviello case, the borrowing rate and deposit rate will be

[33] As an example, think of a machine (durable good) that can be utilized more only if more electricity (final good) is used. Alternatively, think of a Diesel engine that need oil changes more frequently if it is utilized more. The costs of maintenance are usually related to non-durable goods.

equal. The fact that entrepreneurs die out makes them discount the future more heavily which implies that the collateral constraint will always be binding.
The entrepreneurs' first order conditions are (again surpressing index j):

$$\begin{aligned}
\mu_t^F &= (C_t^F - h^F C_{t-1}^F)^{-\phi_f} \\
(C_t^F - h^F C_{t-1}^F)^{-\phi_f} - \mu_t^C R_t^L &= \gamma\beta R_t^L E_t[(C_{t+1}^F - h^F C_t^F)^{-\phi_f}] \\
W_t &= \Phi_t(1-\alpha)A_t\left(\frac{U_t K_t^F}{L_t}\right)^{\alpha} \\
\Psi(U_t)K_t^F &= \alpha\Phi_t A_t (K_t^F)^{\alpha}\left(\frac{L_t}{U_t}\right)^{1-\alpha} \\
Q_t(C_t^F - h^F C_{t-1}^F)^{-\phi_f} - \mu_t^C(1-\zeta_t)(1-\delta)E_t Q_{t+1} &= \beta\gamma E_t\Bigg\{[(C_{t+1}^F - h^F C_t^F)^{-\phi_f}] \\
&\quad \left[\Phi_{t+1}\alpha A_{t+1}(U_{t+1})^{\alpha}\left(\frac{L_{t+1}}{K_{t+1}^F}\right)^{1-\alpha} + Q_{t+1}((1-\delta) - \Psi(U_{t+1}))\right]\Bigg\}
\end{aligned}$$

1.F.7 Central Bank

The central bank sets its policy rate according to the Taylor rule

$$ln\left(\frac{R_t^n}{R_t}\right) = \rho_i ln\left(\frac{R_{t-1}^n}{R^n}\right) + (1-\rho_i)\left[\rho_\pi ln\left(\frac{\Pi_t}{\Pi_{t-1}}\right) + \rho_y ln\left(\frac{Y_t}{Y_t^p}\right)\right] + \rho_{\Delta_y} ln\left(\frac{Y_t/Y_{t-1}}{Y_t^p/Y_{t-1}^p}\right) + \epsilon_t^r$$

and

$$R_{t+1} = E_t\left[\frac{R_t^n}{\Pi_{t+1}}\right]$$

I have to assume that the central bank chooses its policy after all other actions have taken place so that the there is no contemporaneous effect from the monetary policy innovation to asset prices.

1.F.8 Market Clearing Conditions

Market clearing on final goods market and capital market is given by:

$$\begin{aligned}
Y_t &= C_t + C_t^F + I_t + \Psi(U_t)K_t^F + G_t \\
I_t &= K_{t+1} - (1-\delta)K_t + K_{t+1}^F - (1-\delta)K_t^F
\end{aligned}$$

In words, the final goods that are produced in this economy are split between private, entrepreneurial and government consumption of non-durables, investment into durables and maintaining the current capital stock at the chosen utilization rate. On the market for durable capital, total investment is given by the changes in the durables stocks of patient household and entrepreneurs.

1.F.9 Government

The government's budget constraint is

$$T_t = G_t$$

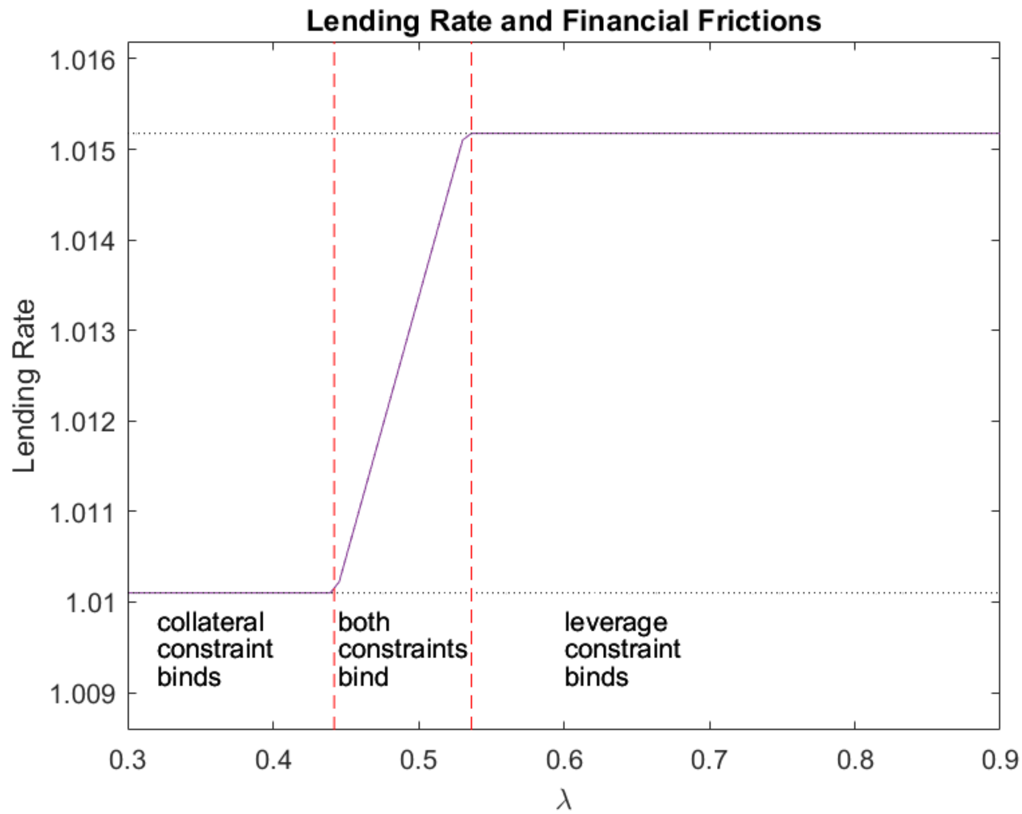
For maximum simplicity, I assume that government spending is an exogenous stochastic process (AR(1)) and taxes are lump-sum and levied on the patient household only. Government spending is either useless or simply rebated lump-sum to the patient household.

1.F.10 Steady State of the Model

There are 22 variables: $L, W, C, C^F, K, K^F, \Phi, Y, B^F, R, R^L, \mu^C, Q, V, H, Z, X, N, N^e, N^n, lev, EP$ and 22 equations.

$$
\begin{aligned}
L^{\phi_l} &= W^H((1-h)C)^{-1} \\
\frac{1}{\beta} &= R \\
Q((1-h)C)^{-1} &= \beta(\nu K^{-1} + (1-\delta)((1-h)C)^{-1}) \\
Q &= 1 \\
(1-\gamma\beta R^L)((1-h^F)C^F)^{-\phi_f} &= \mu^C R^L \\
Y &= A(UK^F)^\alpha L^{1-\alpha} \\
\frac{W}{\psi_1 K^F} &= \frac{1-\alpha}{\alpha}\frac{U}{L} \\
((1-h^F)C^F)^{-\phi_f}[1-\beta\gamma(\Phi\alpha\frac{Y}{K^F} + Q(1-\delta) - \psi_0)] &= \mu^C(1-\bar{\zeta})(1-\delta)Q \\
(1-\bar{\zeta})QK^F(1-\delta) &= R^L B^F \\
C^F + WL + \psi_0 K^F + Q\delta K^F + R^L B^F &= \Phi Y + B^F \\
Y &= C + C^F + \delta(K + K^F) + \psi_0 K^F + G \\
EP(.) &= \frac{R^L}{R} \\
\Phi &= \frac{\epsilon_p - 1}{\epsilon_p} \\
W^H &= \frac{\epsilon_w - 1}{\epsilon_w} W \\
V &= (1-\theta)\beta(R^L - R) + \beta\theta V \\
H &= (1-\theta) + \beta\theta H \\
Z &= 1 \\
X &= 1 \\
N^n &= \chi Q K^F \\
N^e &= \theta((R^L - R)lev + R)N \\
N &= N^e + N^n \\
lev &= \frac{H}{\bar{\lambda} - V} \\
0 &= \mu^C(R^L B^F - (1-\bar{\zeta})(1-\delta)QK^F) \\
0 &= (EP - 1)(B^F - levN)
\end{aligned}
$$

Figure 1.F.1. Financial Frictions and the Steady State



This figure shows the steady-state lending rate through the parameter space of λ. The x-axis measures λ, the y-axis measures the resulting lending rate. The figure divides the parameter space into three regions in which different financial constraints bind.

The steady-state has to be obtained as follows: For very low values of $\bar{\lambda}$, the leverage constraint will be non-binding and the steady-state is calculated with only the Iacoviello friction. This implies that $R^L = R = \frac{1}{\beta}$. As $\bar{\lambda}$ increases, the leverage constraint tightens and eventually starts binding. This leads to increases in the steady-state lending rate so that $R^L > \frac{1}{\beta}$. This continues up to $\bar{\lambda} = \frac{1}{\gamma\beta}$, at which point the collateral constraint stops binding and the steady state can be computed purely from the Gertler-Karadi equations. The profile of the lending rate R^L evaluated throughout the parameter space of λ is shown in the figure below: This figure was created using $\gamma = 0.995$ and $\theta = 0.94$. The dotted lines represent $R = \frac{1}{\beta}$ and $R^L_{GK} = \frac{1}{\gamma\beta}$. The further γ decreases below 1, the wider will the area in which both constraints bind be, as this increases the spread between the minimum and maximum lending rate.

1.F.11 Log-linearized model

Table 1.F.1. Log-linearized Model Equations

(1) Household Euler Equation	$\frac{1+h}{1-h}\hat{C}_t = \frac{1}{1-h}\hat{C}_{t+1} + \frac{h}{1-h}\hat{C}_{t-1} - \hat{R}_t$
(2) Household Investment	$\hat{Q}_t - \frac{1}{1-h}\hat{C}_t + \frac{h}{1-h}\hat{C}_{t-1} = \frac{-\nu K^{-1}}{Q(C(1-h))^{-1}}\hat{K}_{t+1} + \beta(1-\delta)Q(\hat{Q}_{t+1} - \hat{C}_{t+1} + h\hat{C}_t)$
(3) Phillips Curve Wages	$\hat{W}_t = \frac{(1-\beta\sigma_w)(1-\sigma_w)}{1+\beta\sigma_w^2}\left[\phi_l\hat{L}_t - \frac{h}{1-h}\hat{C}_{t-1} + \frac{1}{1-h}\hat{C}_t\right] + \frac{1}{1+\beta\sigma_w^2}\hat{W}_{t-1} + \frac{\sigma_{wi}}{1+\beta\sigma_w^2}\hat{\pi}_{t-1} - \frac{(1+\beta\sigma_{wi})}{1+\beta\sigma_w^2}\hat{\pi}_t + \frac{\beta}{1+\beta\sigma_w^2}E_t\hat{W}_{t+1} + \frac{\beta}{1+\beta\sigma_w^2}E_t\hat{\pi}_{t+1}$
(4) Capital Producers' FOC	$\hat{I}_t = \frac{1}{\xi(1+\beta)}(\hat{Q}_t + \hat{x}_t + \beta\hat{x}_{t+1}) + \frac{1}{1+\beta}\hat{I}_{t-1} + \frac{\beta}{1+\beta}E_t[\hat{I}_{t+1}]$
(5) Entrepreneur Euler Equation	$\frac{-\phi_f}{1-h^F}\hat{C}^F_t + \frac{\phi_f h^F}{1-h^F}\hat{C}^F_{t+1} = \beta\gamma R^L\hat{R}^L_t - \beta\gamma R^L\frac{\phi_f}{1-h^F}\hat{C}^F_{t+1} + \beta\gamma R^L\frac{\phi_f h^F}{1-h^F}\hat{C}^F_t + \frac{\mu^C R^L}{((1-h^F)C^F)^{-\phi_f}}(\hat{\mu}^C_t + R^L_t)$
(6) Production Function	$\hat{Y}_t = \hat{A}_t + \alpha(\hat{K}^F_t + \hat{U}_t) + (1-\alpha)\hat{L}_t$
(7) Entrepreneurs' FOCs	$\hat{W}_t = \hat{K}^F_t + \hat{U}_t + \frac{\psi_2}{\psi_1}U\hat{U}_t - \hat{L}_t$
(8) Entrepreneurs' Investment Equation (Consumption and Collateral constraint)	$\frac{-\phi_f}{1-h^F}\hat{C}^F_t + \frac{\phi_f h^F}{1-h^F}\hat{C}_{t-1} + \hat{Q}_t = \beta\gamma\left(\frac{-\phi_f}{1-h^F}\hat{C}^F_{t+1} + \frac{\phi_f h^F}{1-h^F}\hat{C}^F_t\right)\left((1-\delta)Q - \psi_0 + \alpha\Phi\frac{Y}{K^F}\right)$ $+\beta\gamma\left[(1-\delta)Q(+\hat{Q}_{t+1}) - \psi_1 U\hat{U}_{t+1} + \alpha\Phi\frac{Y}{K^F}(\hat{\Phi}_{t+1} + \hat{Y}_{t+1} - \hat{K}^F_{t+1})\right] + \frac{\mu^C(1-\delta)(1-\bar{\zeta})}{((1-h^F)C^F)^{-\phi_f}}[\hat{\mu}^C_t + \hat{Q}_{t+1}] - \frac{\mu^C(1-\delta)\bar{\zeta}}{((1-h^F)C^F)^{-\phi_f}Q}\hat{\zeta}_t$
(9) Entrepreneurs' Real Marginal Costs	$\hat{\Phi}_t = (1-\alpha)\hat{W}_t - \hat{A}_t - \alpha(\frac{\psi_2}{\psi_1}U\hat{U}_t)$
(10) Entrepreneurs' Budget Constraint	$C^F\hat{C}^F_t + \psi_1 K^F U\hat{U}_t + \psi_0 K^F\hat{K}^F_t) + WL(\hat{W}_t + \hat{L}_t) + QK^F(\delta\hat{Q}_t + \hat{K}^F_{t+1} - (1-\delta)(\hat{K}^F_t)) + R^L B^F(\hat{R}^L_{t-1} + \hat{B}^F_t) = \Phi Y(\hat{\Phi}_t + \hat{Y}_t) + B^F\hat{B}^F_{t+1}$
(11) Final Goods Market Clearing	$\hat{Y}_t = \frac{C}{Y}\hat{C}_t + \frac{C^F}{Y}\hat{C}^F_t + \frac{I}{Y}\hat{I}_t + \frac{G}{Y}\hat{u}^g_t + \psi_1\frac{K^F}{Y}\hat{U}_t$
(12) Capital Goods Market Clearing	$\hat{I}_t = \frac{K}{I}\hat{K}_{t+1} - \frac{(1-\delta)K}{I}\hat{K}_t + \frac{K^F}{I}\hat{K}^F_{t+1} - \frac{(1-\delta)K^F}{I}\hat{K}^F_t$
(13) Phillips Curve Prices	$\hat{\pi}_t = \frac{(1-\beta\sigma_p)(1-\sigma_p)}{\sigma_p(1+\beta\sigma_p\sigma_{pi})}\hat{\Phi}_t + \frac{\sigma_{pi}}{\sigma_p(1+\beta\sigma_p\sigma_{pi})}\hat{\pi}_{t-1} + \frac{\beta}{\sigma_p(1+\beta\sigma_p\sigma_{pi})}E_t\hat{\pi}_{t+1} + \epsilon^p_t$
(14) Central Bank's Taylor Rule	$\hat{R}^n_t = \rho_i\hat{R}^n_{t-1} + (1-\rho_i)[\rho_\pi\hat{\Pi}_t + \rho_y(\hat{Y}_t - \hat{Y}^p_t)] + \rho_{\Delta y}[\hat{Y}_t - \hat{Y}^p_t - (\hat{Y}_{t-1} - \hat{Y}^p_{t-1})] + \epsilon^r_t$
(15) Fisher Equation	$\hat{R}^n_t = \hat{R}_{t+1} + E_t\hat{\Pi}_{t+1}$
(16) Banks' Lending Rate	$\hat{R}^L_t = \hat{R}_t + \hat{EP}_t$
(17) Banks' gain from expanding assets	$V\hat{V}_t = ((1-\theta)\beta\Lambda)\left((R^L - R)E_t[\hat{\Lambda}_{t,t+1}] + R^L E_t[\hat{R}^L_t] - R\hat{R}_t]\right) + \theta\beta VX\Lambda E_t[\hat{X}_{t,t+1} + \hat{V}_{t+1} + \hat{\Lambda}_{t,t+1}]$
(18) Banks' value from expanding net worth	$H\hat{H}_t = \theta\beta ZHE_t[\hat{\Lambda}_{t,t+1} + \hat{Z}_{t,t+1} + \hat{H}_{t+1}]$
(19) Gross growth rate in net worth	$\hat{Z}_{t,t+1} = \frac{1}{Z}[levR^L E_t[\hat{R}^L_t] + R(1-lev)\hat{R}_t + (R^L - R)lev\hat{lev}_t]$
(20) Gross growth rate in in assets	$\hat{X}_{t,t+1} = E_t\hat{lev}_{t+1} + \hat{Z}_{t,t+1} - \hat{lev}_t$
(21) Leverage	$\hat{lev}_t = \hat{H}_t + \frac{\lambda}{\lambda-V}\hat{\lambda}_t - \frac{V}{\lambda-V}\hat{V}_t$
(22) Net worth of existing banks	$\hat{N}^e_t = \hat{N}_{t-1} + \frac{1}{Z}[levR^L E_t[\hat{R}^L_t] + R(1-lev)\hat{R}_t + (R^L - R)lev\hat{lev}_t]$
(23) Net worth of new banks	$\hat{N}^n_t = \hat{Q}_t + \hat{K}^F_{t+1}$
(24) Total net worth of banks	$\hat{N}_t = \frac{N^e}{N}\hat{N}^e_t + \frac{N^n}{N}\hat{N}^n_t$
(25) Complementary Slackness condition 1	$0 = (B^F R^L - (1-\bar{\zeta})(1-\delta)QK^F)\hat{\mu}^C_t + B^F R^L(\hat{B}^F_{t+1} + \hat{R}^L_t) - (1-\bar{\zeta})(1-\delta)QK^F(\hat{Q}_{t+1} + \hat{K}^F_{t+1}) + (1-\delta)QK^F\hat{\zeta}_t$
(26) Complementary Slackness condition 2	$0 = (B^F - levN)EP\hat{EP}_t + (EP-1)(B^F\hat{B}^F_{t+1} - levN(\hat{lev}_t + \hat{N}_t))$
(IAC) Collateral Constraint	$-\frac{\zeta}{1-\zeta}\hat{\zeta}_t + \hat{Q}_{t+1} + \hat{K}^F_{t+1} = \hat{R}^L_t + \hat{B}^F_{t+1}$
(GK) Banks' incentive constraints	$\hat{B}^F_{t+1} = \hat{lev}_t + \hat{N}_t$

The redundant equation (left out by Walras Law) is the budget constraint of the patient households. The 26 variables are: $C, C^F, Y, I, K, K^F, U, W, L, \pi, \Phi, R, R^n, R^L, Q, X, V, Z, H, lev, N, N^e, N^n, B^F, \mu^C, EP$.

1.G Implementation in Dynare

This section describes how the model, specifically the interaction of the financial sectors was implemented in dynare. The implementation is more or less standard, but there are a few noteworthy points:

- The steady states of the model are declared as parameters. Their values are calculated in a verbatim block, which automatically creates a matlab function, to which the calculation is outsourced. The code inside the verbatim block checks which framework is used, which constraints are binding and accordingly calculates the steady state values.
- At this point it is not possible to use a completely frictionless model. The steady state calculations are not set up for this. At least one of the frictions has to be active for the model to work. When deactivating the frictions, it is advisable to set them to a sufficiently small, but positive number. Economically, this is equivalent. A zero parameter may mess with the calculation of $\mathfrak{G}(\bar{e})$ even when this value is not needed.
- The model block contains the 26 equations of Table 1 that describe the sticky price economy, 24 equations of the flexible price economy (Fisher equation and Taylor rule do not have flexible-price-counterparts), two auxiliary equations for Λ_t and Λ_t^{flex}. The final equation defines the credit gap as $cred_t = \frac{B^F}{Y_t}$. This is in line with the empirical definition of "credit to the non-financial sector".
- Everything else is standard dynare procedure.

1.H Calibration and Estimation

1.H.1 Calibration

We use simulated method of moments to target the empirical dynamic correlations and forecast error variance decomposition. We pick parameters to minimize the loss function:

$$
\begin{aligned}
Loss = \quad & 0.1 \sum_{\tilde{\omega}=5}^{120} \left(\rho^{model}_{Credit\ Gap, House\ Prices}(\tilde{\omega}) - \rho^{data}_{Credit\ Gap, House\ Prices}(\tilde{\omega}) \right)^2 \\
& + 0.8 \sum_{\tilde{\omega}=5}^{120} \left(\rho^{model}_{Credit\ Gap, Output}(\tilde{\omega}) - \rho^{data}_{House\ Prices, Output}(\tilde{\omega}) \right)^2 \\
& + 0.1 \sum_{\tilde{\omega}=5}^{120} \left(\rho^{model}_{House\ Prices, Output}(\tilde{\omega}) - \rho^{data}_{House\ Prices, Output}(\tilde{\omega}) \right)^2 \\
& + \sum_{i=1}^{4} \sum_{\tilde{\omega}=5}^{120} \left(forecast\ error\ share\ shock\ i^{model}(\tilde{\omega}) - forecast\ error\ share\ shock\ i^{data}(\tilde{\omega}) \right)^2
\end{aligned}
$$

Table 1.H.1. Calibrated Parameters

Parameter	Period Description	GK pre-GM	GK GM	IAC pre-GM	IAC GM	IGK pre-GM	IGK GM
ρ_π	Taylor Rule Inflation	2.8757	2.4203	1.0100	4.8540	1.8991	2.3028
ρ_i	Taylor Rule Interest Rate	0.8431	0.8152	0.9350	0.0856	0.9657	0.7812
ρ_y	Taylor Rule Output Gap	0.0058	0.0061	0.6698	0.4363	0.0722	0.1438
ρ_{dy}	Taylor Rule Output Gap Change	0.0874	0.1458	0.3429	0.2382	0.1651	0.2729
ρ_λ	persistence λ	0.2610	0.2765	0.5506	0.9534	0.928	0.8905
ρ_x	persistence adj.costs	0.6521	0.4899	0.9510	0.0802	0.8499	0.9652
ρ_a	persistence TFP	0.9513	0.9565	0.5153	0.9098	0.364	0.9701
ρ_r	persistence interest rate shock	0.6277	0.3401	0.0388	0.5000	0.675	0.6473
ρ_p	persistence mark-up shock	0.0158	0.4834	0.0100	0.0888	0.4478	0.1153
σ_λ	std.error short-run risk λ	0.3839	6.9835	7.5804	8.3061	1.9096	1.0323
σ_x	std. error short-run risk adj.costs	13.2173	6.2877	6.8723	11.1321	0.2715	1.2887
σ_a	std. error TFP	3.9376	8.1011	6.6513	1.8104	0.7892	0.0801
σ_r	std. error monetary shock	5.3708	2.6680	0.0100	7.1535	0.4438	0.373
σ_p	std. error mark-up shock	0.3419	1.2679	0.2182	0.7267	0.1717	0.1595
σ_λ^{LR}	std. error long-run risk	4.8006	4.8469	4.1614	5.0799	0.5323	0.3724
σ_x^{LR}	std. error long-run risk	3.3049	1.3036	1.6257	6.1017	0.0794	0.5543

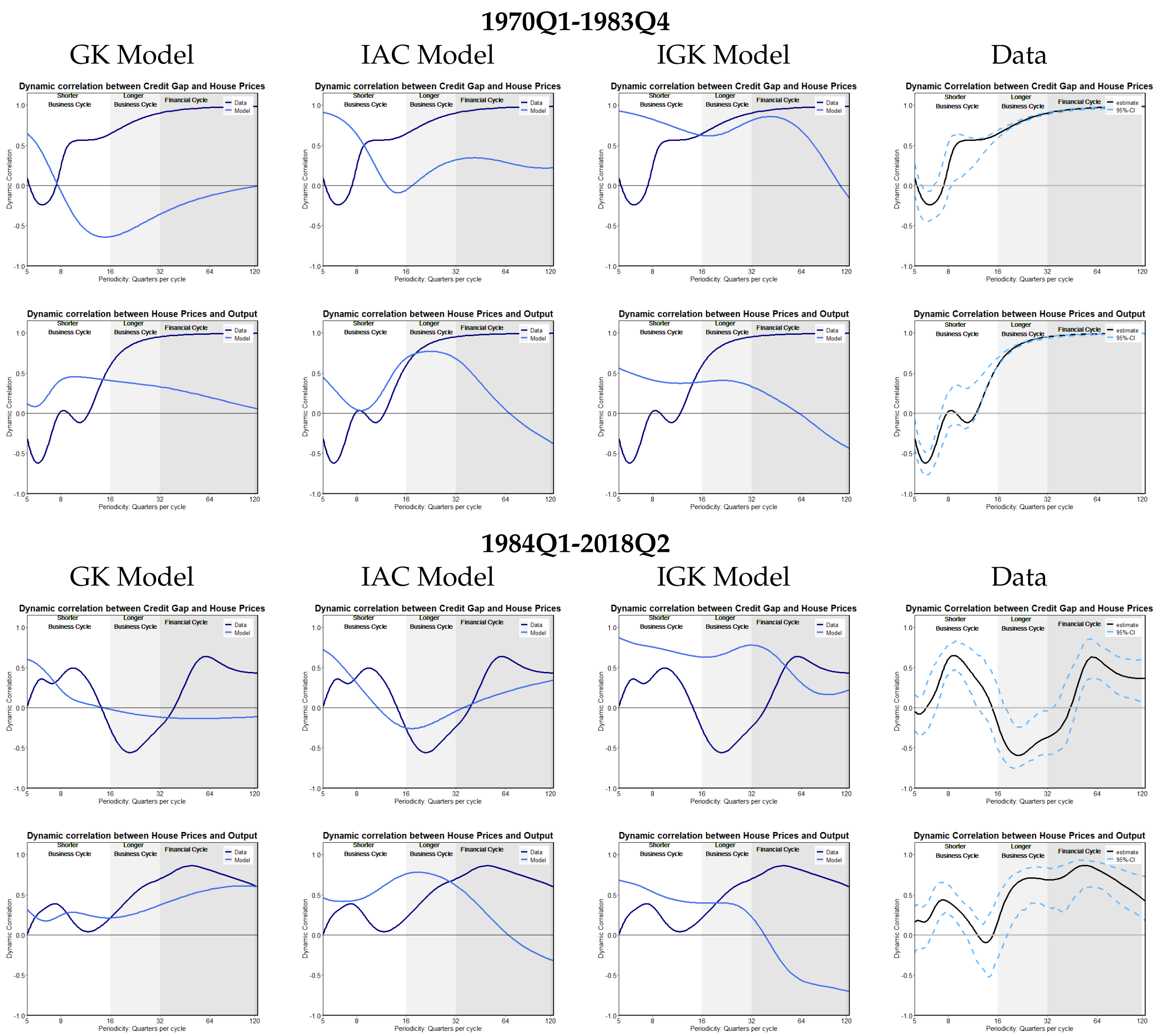
This table shows the calibrated values for the three sub-models. GK stands for the model with only the leverage constraints (as in Gertler and Karadi (2011)). IAC stands for the model with only the collateral constraint (as in Iacoviello (2005)). IGK stands for the model with both frictions (Iacoviello (2005)+Gertler and Karadi (2011)). The pre-GM columns corresponds to the parameters of the model calibrated to match the frequency-domain statistics of the baseline VAR-model on data from 1970Q1-1983Q4. The GM columns correspond to the parameters of the model calibrated to match the frequency-domain statistics of the baseline VAR-model on data from 1984Q1-2018Q2.

where $\tilde{\omega}$ is the periodicity, i.e. the inverse of frequency, measured in quarters per cycle: Mathmatically, $\tilde{\omega} = \frac{2\pi}{\omega}, \quad \omega \in (0, \pi)$. The minimization is implemented in Matlab with the function cmaes.m (Evolution Strategy with Covariance Matrix Adaptation (CMA-ES) for nonlinear function minimization). Table 1.H.1 shows the calibration results for all three submodels for the pre-GM and GM period.

1.H.2 Estimation

Each model contains five orthogonal structural shocks: a technology shock ϵ_a, a financial supply shock $\epsilon_f, f \in \{\zeta, \lambda\}$, an investment shock ϵ_x, a mark-up shock ϵ_p and monetary policy shock ϵ_r. The financial supply shock is modeled as a shock on the cost of state-verification whenever this friction is relevant. In the pure Gertler-Karadi model, in which the cost of state-verification is not relevant, the financial supply shock is modeled as a shock on the stealing technology of bank managers. All shocks follow AR(1) processes except for the monetary policy shock, which is identically independently distributed. To achieve full identification, I use the same five observables as in the empirical section: The credit gap, house prices, output, policy rate and inflation

Figure 1.H.1. Dynamic correlation: Model versus Data



rate. The data stem from the FRED and BIS databases and cover the period from 1970Q1-2018Q2. However, I depart from the empirical exercises in two important ways: Firstly, in order to avoid issues related to the zero-lower bound after 2009, the Fed Funds rate is replaced by the shadow interest rate from Wu and Zhang (2019)[34]. Secondly, to stick as closely as possible to the prevalent estimation strategy of the literature, I estimate the model on the first differences of the credit gap,

[34]https://sites.google.com/view/jingcynthiawu/shadow-rates (04/06/2021)

Table 1.H.2. Estimation Results

Parameter	Description	Prior distribution			Posterior mode		
		1st moment	2nd moment	shape	GK	IAC	IAC+GK
ψ_2	utilization elasticity	0.85	0.1	normal	1.1656	0.1142	0.1748
ξ	adjustment costs	4.5	2.5	normal	0.1933	4.2520	4.3961
ρ_π	Taylor rule inflation	1.75	0.25	normal	1.5800	3.4799	3.2161
ρ_y	Taylor rule output gap	0.125	0.05	beta	0.0163	0.1545	0.0164
ρ_{dy}	Taylor rule change in output gap	0.0625	0.05	beta	0.1947	0.0123	0.0179
ρ_i	Taylor rule interest rate smoothing	0.80	0.1	beta	0.8526	0.6723	0.8387
ρ_z	persistence ζ	0.85	0.1	beta	-	0.8177	0.7881
ρ_l	persistence λ	0.85	0.1	beta	0.4297	-	-
ρ_x	persistence investment shock	0.85	0.1	beta	0.7926	0.1825	0.4379
ρ_a	persistence TFP	0.85	0.1	beta	0.8792	0.6796	0.7727
ρ_p	persistence mark-up shock	0.85	0.1	beta	0.7416	0.9398	0.5979
σ_ζ	standard error ζ	0.5	2	inv. gamma	-	32.6560	113.6227
σ_λ	standard error λ	0.5	2	inv. gamma	13.6287	-	-
σ_x	standard error investment shock	0.5	2	inv. gamma	2.2366	54.8954	41.8979
σ_a	standard error TFP	0.5	2	inv. gamma	0.9781	0.8681	2.8899
σ_r	standard error policy shock	0.5	2	inv. gamma	0.3328	1.2501	1.2440
σ_p	standard error mark-up shock	0.5	2	inv. gamma	0.0114	0.0180	0.1232
	log data density				-1687.3560	-1818.3554	-2090.3163

house prices and output rather than on filtered levels. I hence have 5 observational equations:

$$\begin{aligned}
\Delta cred_t^{obs} &= \hat{cred}_t - \hat{cred}_{t-1} \\
\Delta Q_t^{obs} &= \hat{q}_t - \hat{q}_{t-1} \\
\Delta Y_t^{obs} &= \hat{y}_t - \hat{y}_{t-1} \\
r_t^{obs} &= \hat{R}_t^n - 1 \\
\pi_t^{obs} &= \hat{\pi}_t
\end{aligned}$$

The estimation is executed in dynare and follows standard dynare procedure. The results of the estimation can be found in Tables 1.H.2 and 1.H.3. There are substantial differences in the posterior estimates of the different sub-models, especially between the submodels with collateralization versus those without collateralization. Firstly, the model with the GK financial sector attains the highest log-density, followed by the IAC-type model and the combined model. The models also differ substantially in how the estimation decides to match the persistence of the data. While GK model yields high persistences of the shock processes ρ and low values of ξ, the IAC and IAC+GK model yield the opposite. The models with collateral constraint also produce vastly greater standard errors of the shocks. Then, I use the estimated models to generate 200 artificial time series of 1000 periods each, from which I calculate the same frequency-domain statistics as on the actual data. To achieve maximum comparability between the four submodels, I use the same sequence of errors drawn from a standard normal distribution for each submodel - scaled by the estimated standard deviations of the shocks.

A subsequent analysis of the model generated data shows that no financial sector that the model nests replicates the quantitative and qualitative properties of the frequency-domain statis-

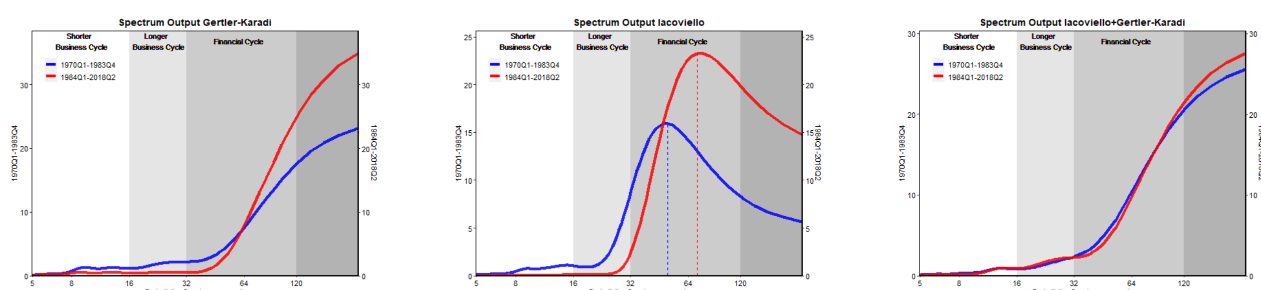
Table 1.H.3. Subsample Estimation Posteriors

Parameter	Description	1970Q1-1983Q4			1984Q1-2018Q2		
		GK	IAC	IGK	GK	IAC	IAC+GK
ψ_2	utilization elasticity	0.8526	0.1049	0.7892	1.0930	0.2266	0.1002
ξ	adjustment costs	0.1556	1.3132	2.2580	0.0699	9.8202	11.3330
ρ_π	Taylor rule inflation	2.2614	1.8688	2.7971	3.1149	3.2520	3.1160
ρ_y	Taylor rule output gap	0.0036	0.5302	0.0100	0.0163	0.0920	0.0015
ρ_{dy}	Taylor rule change in output gap	0.2760	0.0097	0.0188	0.1947	0.0149	0.0586
ρ_i	Taylor rule interest rate smoothing	0.5561	0.6028	0.7806	0.6223	0.7663	0.8560
ρ_z	persistence ζ	-	0.5878	0.7114	-	0.8776	0.2726
ρ_l	persistence λ	0.8085	-	-	0.7657	-	-
ρ_x	persistence investment shock	0.3946	0.1735	0.2634	0.9778	0.4385	0.5158
ρ_a	persistence TFP	0.6395	0.8135	0.7200	0.5106	0.9913	0.9582
ρ_p	persistence mark-up shock	0.2019	0.9685	0.5492	0.6119	0.8815	0.6809
σ_ζ	standard error ζ	-	34.3424	117.6259	-	29.4022	114.8479
σ_λ	standard error λ	8.3510	-	-	8.3619	-	-
σ_x	standard error investment shock	2.9313	53.1559	42.7528	1.0613	56.3684	44.8990
σ_a	standard error TFP	1.3877	0.9194	3.3110	1.1097	0.5436	1.5822
σ_r	standard error policy shock	1.1694	2.1870	2.0619	0.7920	0.5581	0.8068
σ_p	standard error mark-up shock	0.0097	0.0277	0.1959	0.0093	0.0239	0.2044
	log data density	-453.1186	-567.2295	-685.0693	-909.8452	-1067.1725	-1350.9275

The estimation follows a two-step process, in which first only the standard errors are estimated with the priors specified in the table above. The second step estimates all variables listed above and uses the posterior modes of the first step as priors.

Figure 1.H.2. Spectra of model-generated data

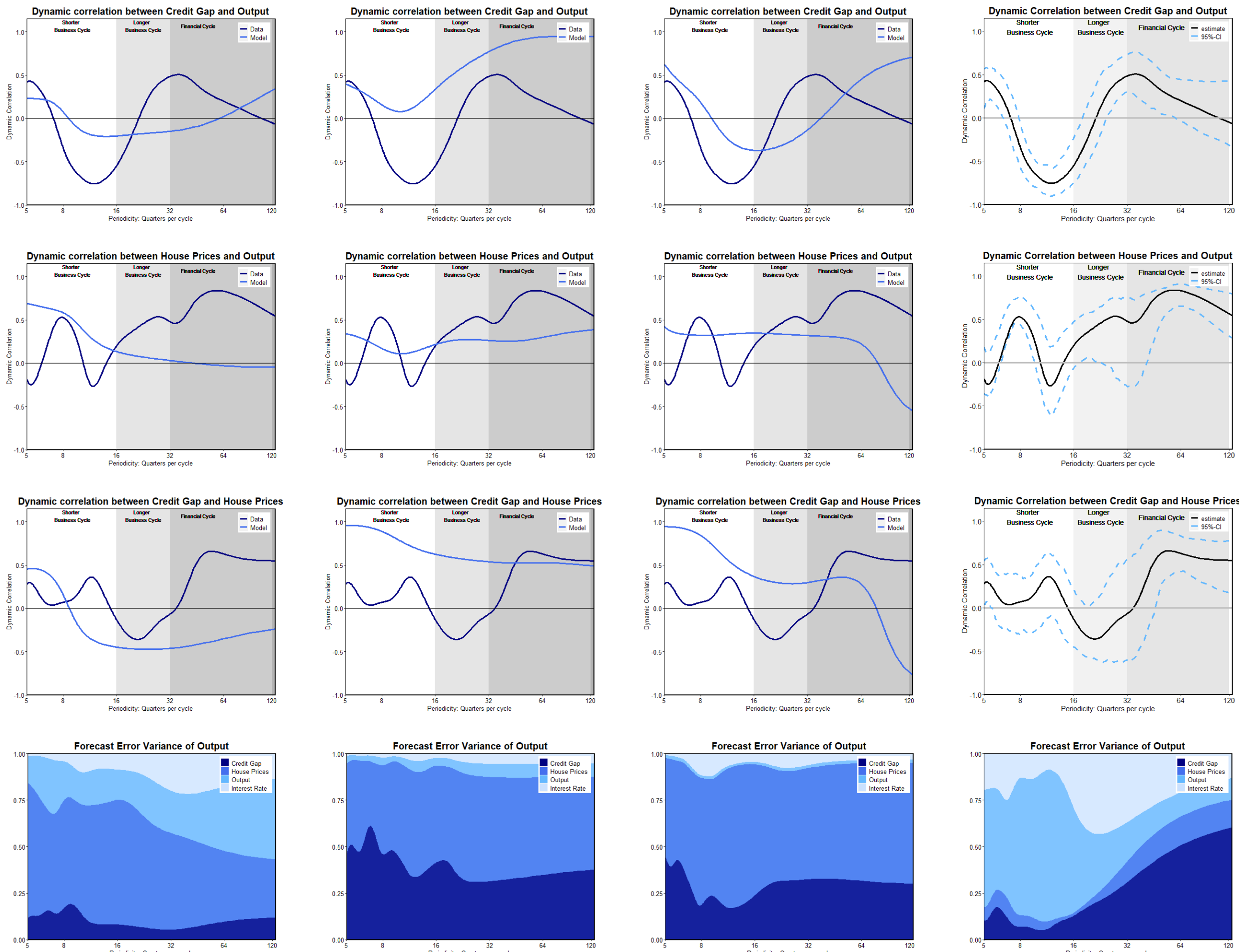
GK | Iacoviello | Iacoviello+GK



This figure shows the spectra implied by the models, estimated on data from 1970Q1-1983Q4 and 1984Q1-2018Q2. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes measure the variance at each periodicity.

Figure 1.H.3. Dynamic Correlation and FEVD: Benchmark Model

GK model IAC model IGK model Data



This figure shows how the moments of the estimated models compare to their data counterparts. The models were estimated on data from 1970Q1-2018Q2. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes measure the dynamic correlation on a scale from -1 to 1. The y-axes of the FEVD plots measure the contribution of the orthogonal shock to variable listed in the legend to the overall forecast error variance.

tics even to a moderate extent. While the model-generated spectrum of the GM-sample shifts towards longer periodicities compared to the pre-GM spectrum, the periodicities at which this occurs are not the same as we observe in the data. All financial sectors also fail to replicate the dynamic correlation patterns of the data. In the model with a collateral constraint (Iacoviello framework) the dynamic correlation between credit gap and output is positive on all periodicities. When a leverage constraint is included (GK and IGK framework) the dynamic correlation is negative on a intermediate range of periodicities, but it is not the same as in the data. The dynamic correlation between credit gap and output is negative well into financial cycle periodicities. The dynamic correlation between house prices and output, and credit gap and house prices are also replicated inaccurately: In the data they are near to zero and highly positive on financial cycle periodicities, all models generate dynamic correlations that are decrease towards longer periodicities. This is especially clear for the relationship between credit gap and house price, i.e. the financial cycle. Their dynamic interaction is medium-term in the data but is consistently produced as short-term in the model. In fact, we run robustness checks with 6 other off-the-shelf models with financial sectors from the literature which all err in the same way with regard to the financial cycle.

1.H.3 Counterfactuals

In this subsection, we use the model to run six "counterfactual" exercises. For this, we take the IGK-model calibrated to the pre-GM period. We build three counterfactuals by changing 1) only the Taylor Rule coefficients, 2) only the persistences of the shocks and 3) only the standard errors of the shocks to the values of the model calibrated to the GM period. Equivalently, we build the analogue counterfactual with the GM-calibrated model as a benchmark and changing Taylor Rule, persistences and standard errors to their pre-GM values. It is important to note that when changing the persistences, we ensure that the overall volatility of the stochastic processes stays constant. For example, when variance the TFP AR(1) process in the pre-GM sample is:

$$var(a_t)^{pre-GM} = \frac{\sigma_a^{pre-GM}{}^2}{1 - \rho_a^{pre-GM}{}^2}$$

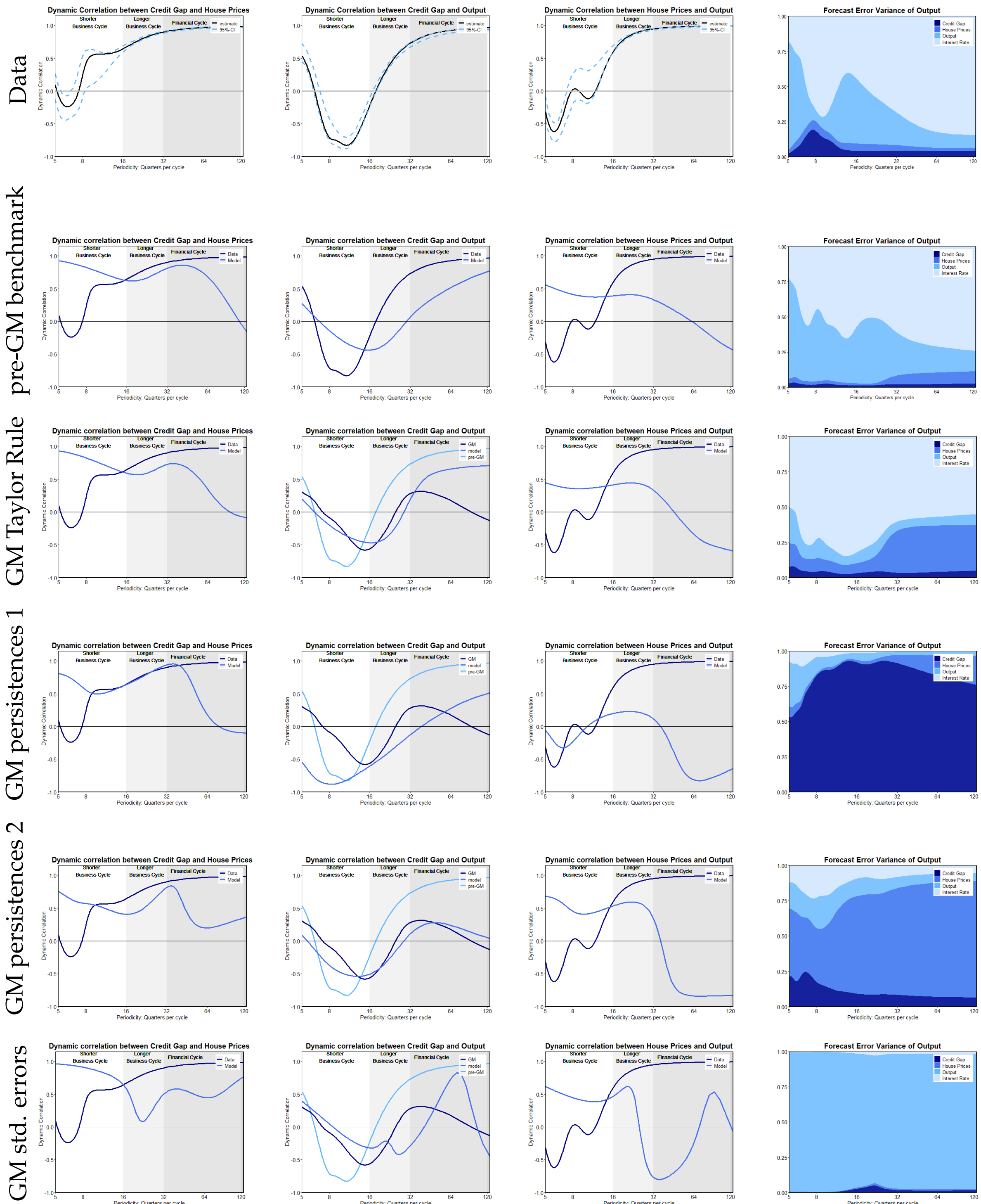
Then, when replacing ρ_a^{pre-GM} by ρ_a^{GM}, we also adjust σ_a^{pre-GM} to

$$\sigma_a^{pre\tilde{-}GM} = \sqrt{var(a)^{pre-GM}(1 - \rho_a^{GM2})}$$

The same holds for the monetary and mark-up shocks. The long-run risk processes of x and λ have two shocks each, hence, we need to run two counterfactuals each. Counterfactual 1 holds the standard error of the long-run shock constant and adjusts the short-run standard error to maintain the volatility. Counterfactual 2 holds the standard error of the short-run shock constant and adjusts the long-run standard error to maintain the level of volatility. Figures 1.H.4 and 1.H.5 show the results of this exercise.

Figure 1.H.4. Dynamic correlation and FEVD: Counterfactuals

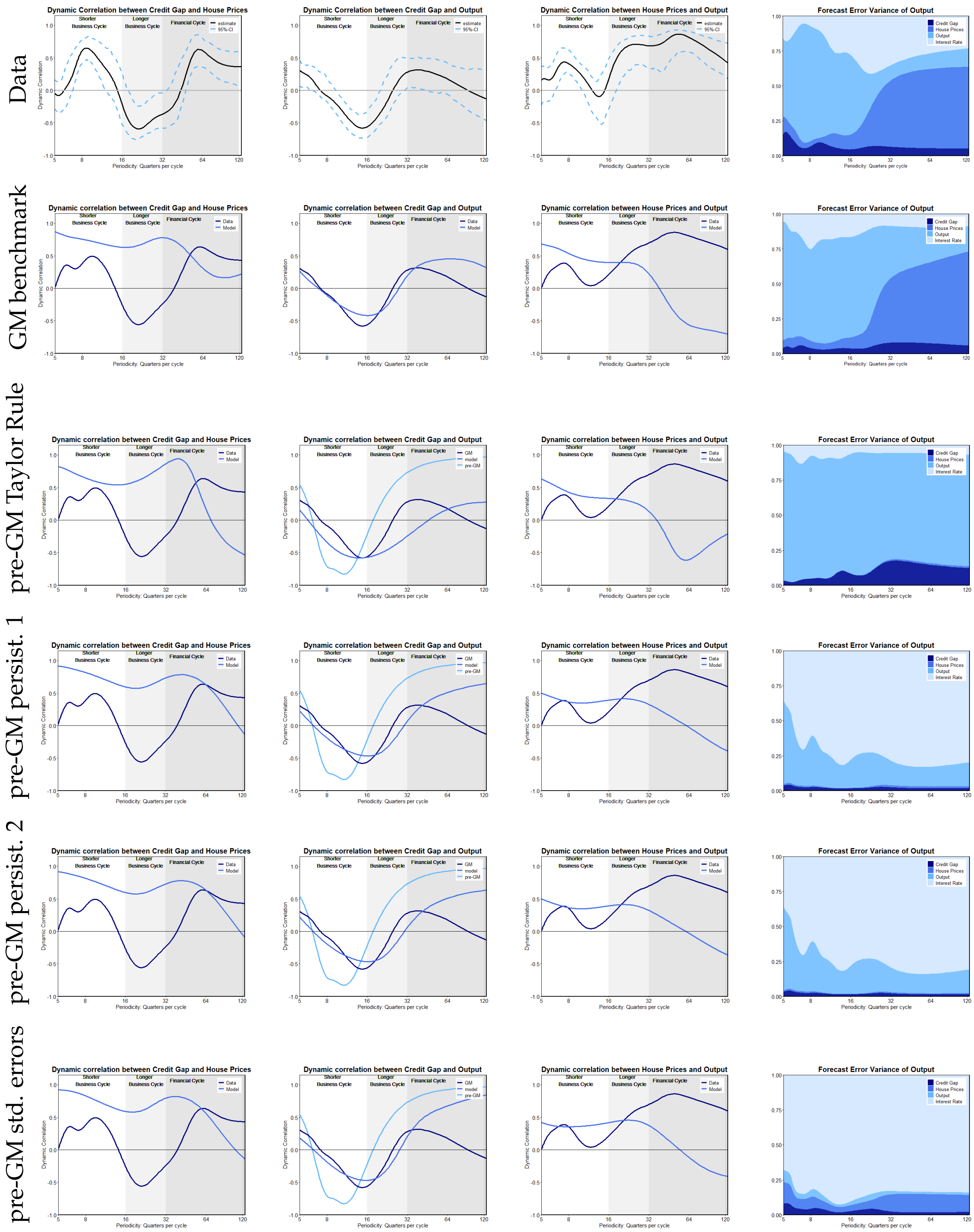
Benchmark: pre-GM calibration



This figure shows how the model-implied dynamic correlations and FEVD compare to their data counterparts of the baseline VAR-model. The first row shows the data moments. The second row shows the moments of the model calibrated to fit the pre-GM data. The third row shows the model moments when only the Taylor Rule coefficients are replaced by those calibrated to GM data. The fourth row shows the model moments when the persistences of the GM calibration are used. The fifth row shows the model moments when the standard errors of the GM calibration are used. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes measure the dynamic correlation on a scale from -1 to 1. The y-axes of the FEVD plots measure the contribution of the orthogonal shock to variable listed in the legend to the overall forecast error variance.

Figure 1.H.5. Dynamic correlation and FEVD: Counterfactuals

Benchmark: GM calibration

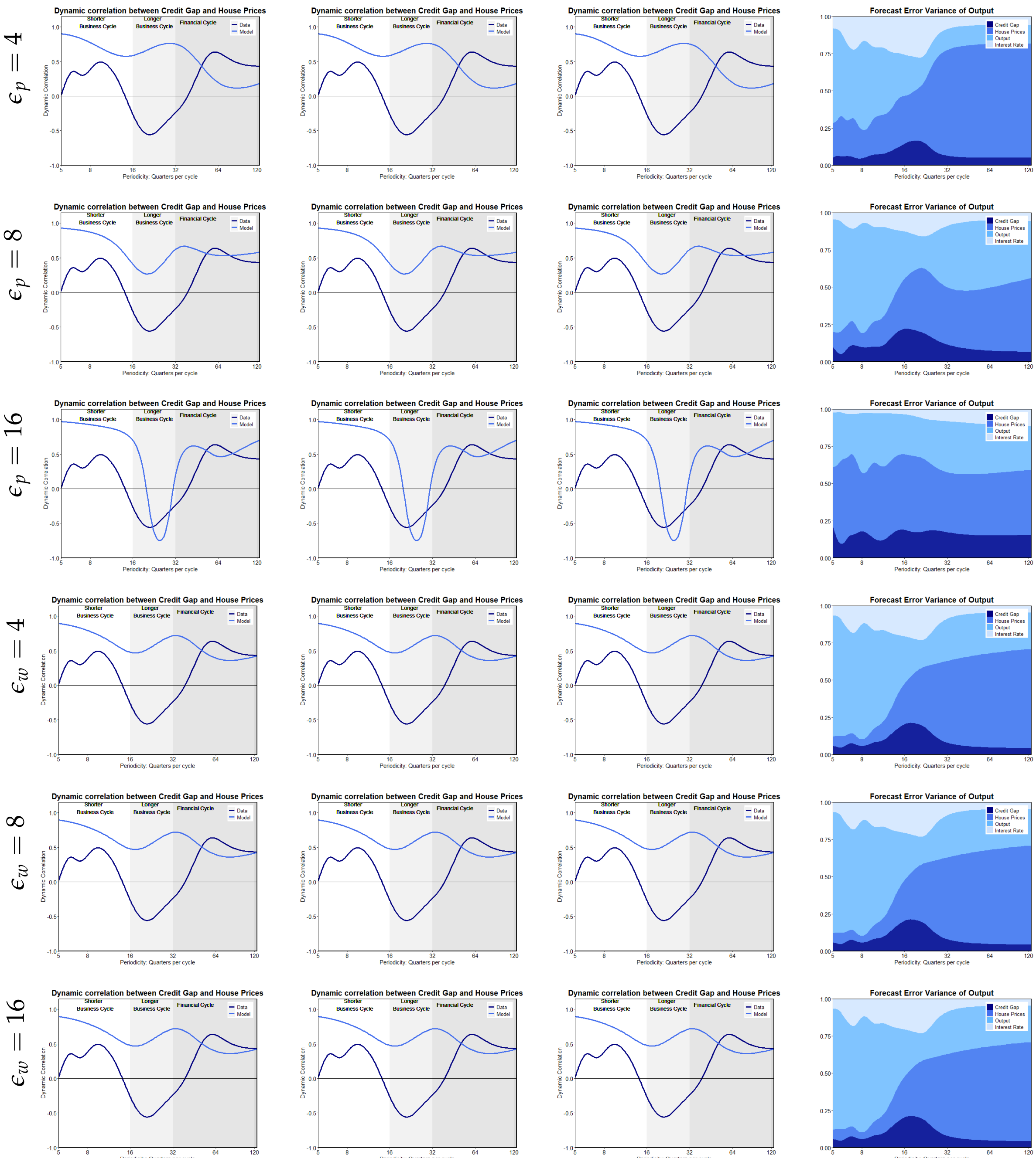


This figure shows how the model-implied dynamic correlations and FEVD compare to their data counterparts of the baseline VAR-model. The first row shows the data moments. The second row shows the moments of the model calibrated to fit the GM data. The third row shows the model moments when only the Taylor Rule coefficients are replaced by those calibrated to pre-GM data. The fourth row shows the model moments when the persistences of the pre-GM calibration are used. The fifth row shows the model moments when the standard errors of the pre-GM calibration are used. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes measure the dynamic correlation on a scale from -1 to 1. The y-axes of the FEVD plots measure the contribution of the orthogonal shock to variable listed in the legend to the overall forecast error variance.

1.H.4 Sensitivity Analysis

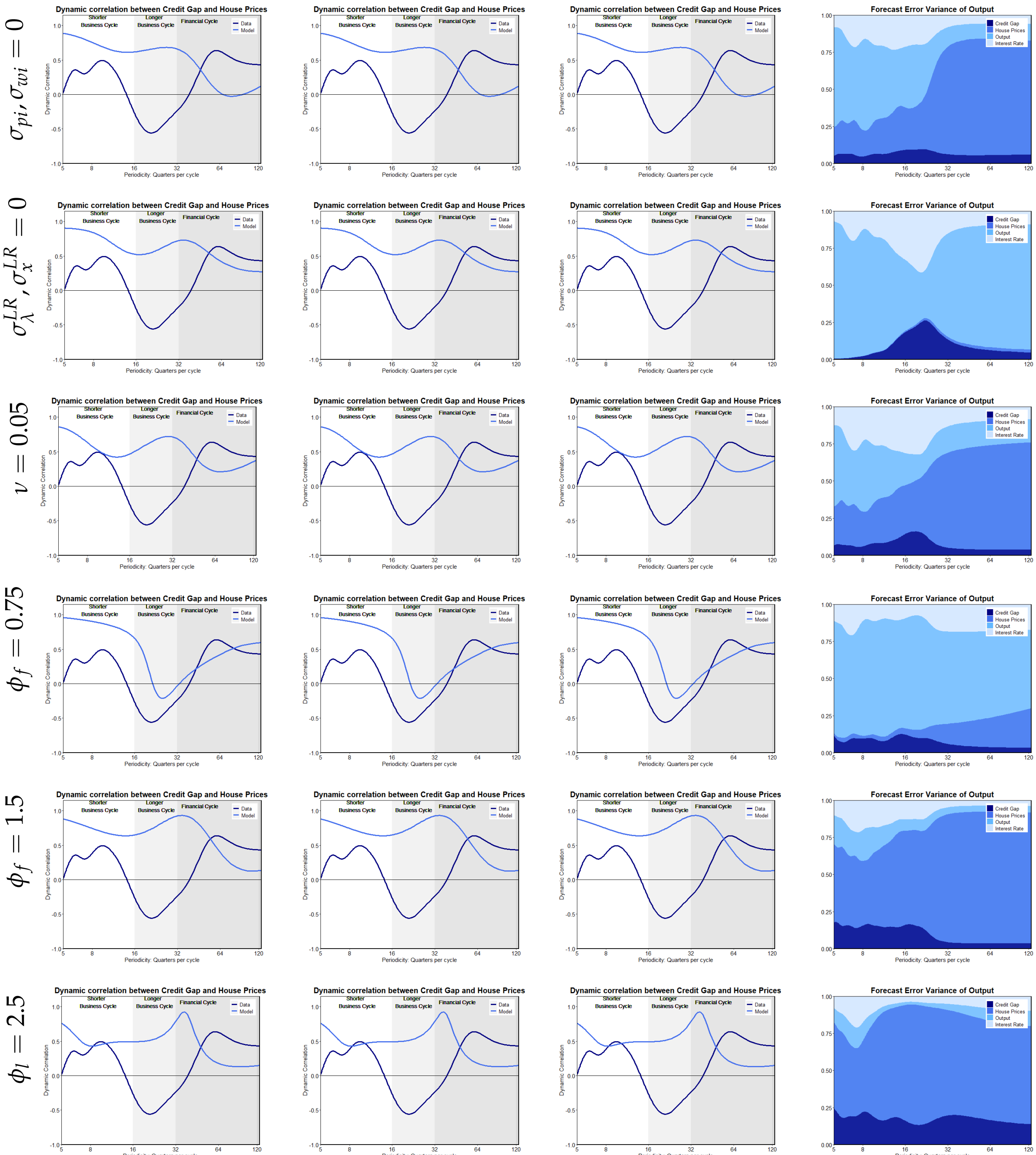
This section shows the results of a further sensitivity analysis on the parameters of the model. This includes both parameters that were fixed, as well as calibrated parameters.

Figure 1.H.6. Dynamic correlation and FEVD: Model Sensitivity



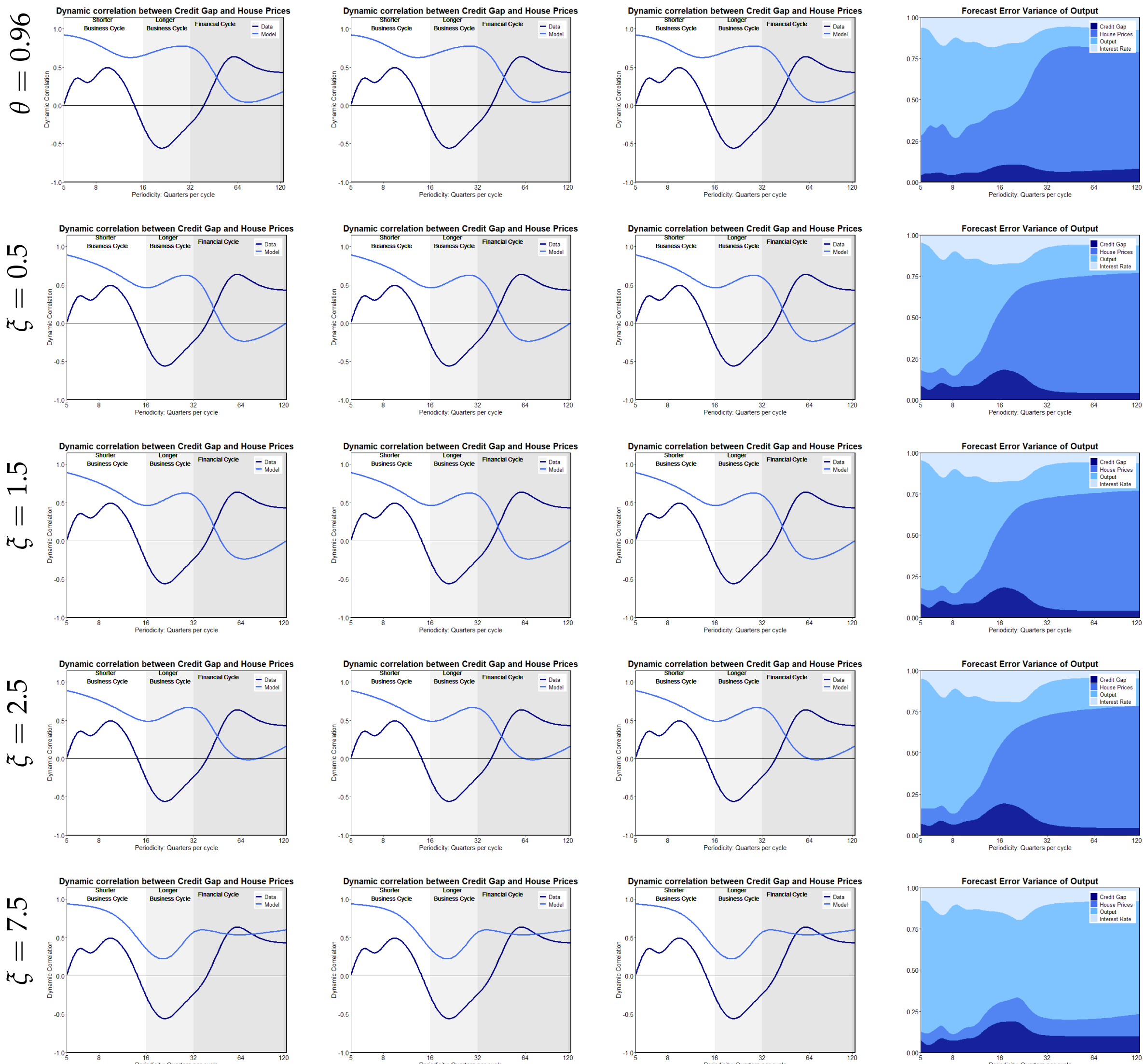
This figure shows the results of a sensitivity on the model parameters. The left column indicates the parameter change. The subfigures show the model moments. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes measure the dynamic correlation on a scale from -1 to 1. The y-axes of the FEVD plots measure the contribution of the orthogonal shock to variable listed in the legend to the overall forecast error variance.

Figure 1.H.7. Dynamic correlation and FEVD: Model Sensitivity



This figure shows the results of a sensitivity on the model parameters. The left column indicates the parameter change. The subfigures show the model moments. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes measure the dynamic correlation on a scale from -1 to 1. The y-axes of the FEVD plots measure the contribution of the orthogonal shock to variable listed in the legend to the overall forecast error variance.

Figure 1.H.8. Dynamic correlation and FEVD: Model Sensitivity



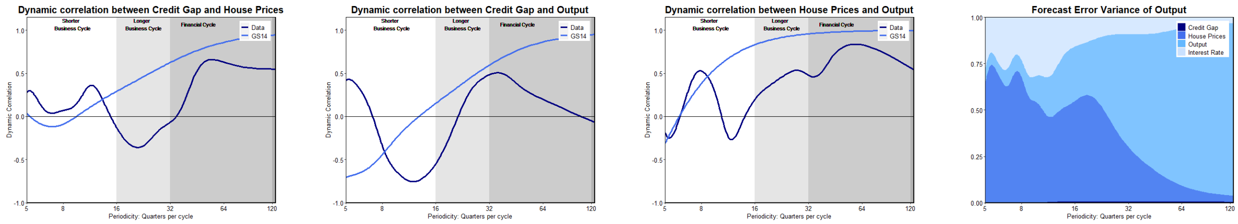
This figure shows the results of a sensitivity on the model parameters. The left column indicates the parameter change. The subfigures show the model moments. The x-axes are the periodicities, i.e. the number of quarters per cycle of the fluctuations for which the measures calculated. The y-axes measure the dynamic correlation on a scale from -1 to 1. The y-axes of the FEVD plots measure the contribution of the orthogonal shock to variable listed in the legend to the overall forecast error variance.

1.I Models from the literature

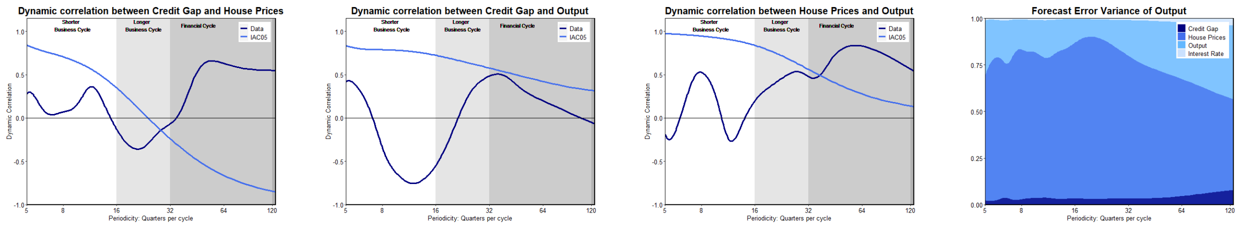
Additionally, I check for the robustness of the findings by generating time series from models of 6 models from the literature (in their original form).This is made possible by the Macro Modelbase from Wieland et al. (2012). The 6 models are: Iacoviello (2005),Villa (2016) (estimated BGG and GK models), Christiano et al. (2010) (financial factors), Gambacorta and Signoretti (2014) (leaning against the wind), Kannan et al. (2012) (house price booms) and Stracca (2013) (inside money). None of the models is able to accurately replicate the frequency-domain features of the data. All of the models have in common that they produce time series in which the credit gap and house prices have more short-term volatility than the output - which is clearly at odds with the data. Additionally, none of the models is really able to replicate the FEVD of the data. This strengthens the position that current models that are used to analyze the economy and on which policy decisions are made miss the the effects that the financial cycle has on the economy. As a result, endeavours should be undertaken to come up with models that can replicate the frequency-domain properties of the data.

Figure 1.I.1. Statistics of Models from the literature

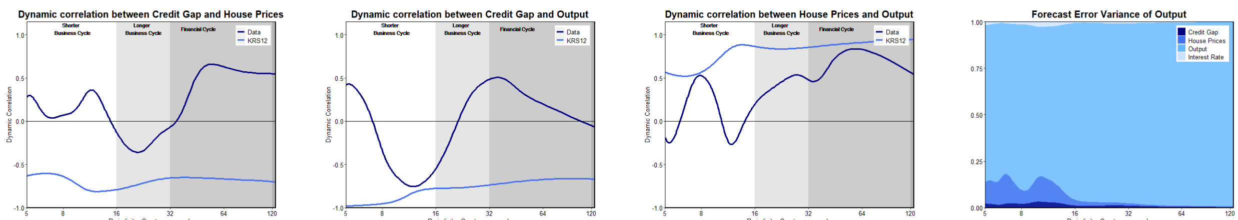
Gambacorta and Signoretti (2014)



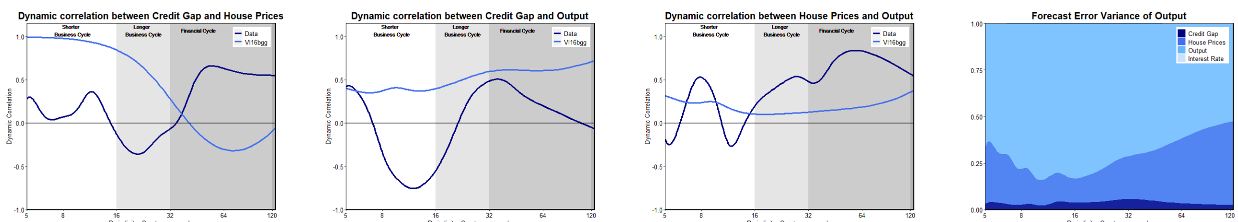
Iacoviello (2005)



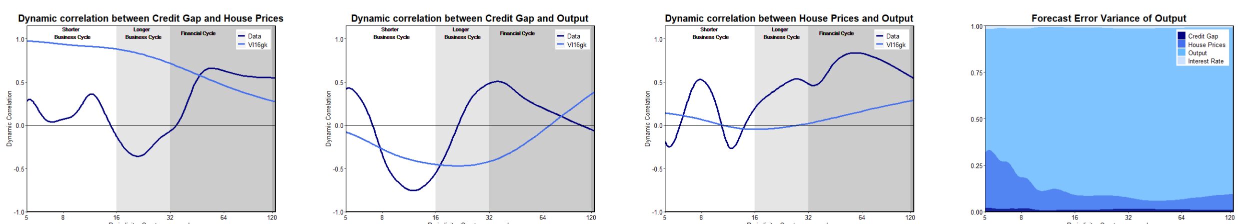
Kannan et al. (2012)



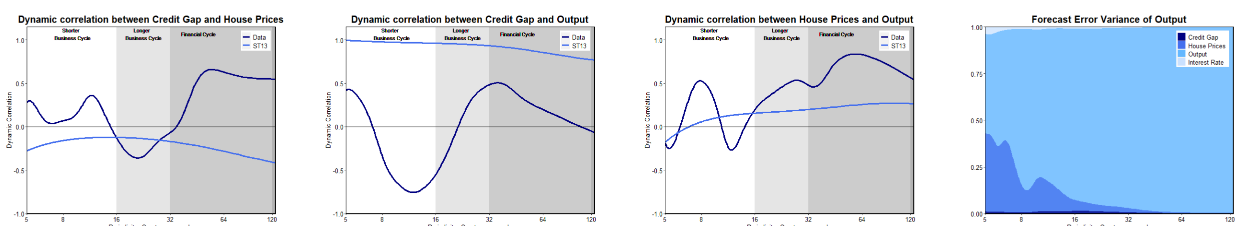
Villa (2016) (BGG-model)



Villa (2016) (GK-model)



Stracca (2013)



Chapter 2

Financial Crisis Contagion: Introducing the Finance Co-movement Slope

Friedrich Lucke[1,2]

Abstract

How do capital flows affect the synchornization of two countries' financial cycles? We obtain data on bilateral capital flows and domestic financial cycles to introduce a "Finance Co-movement Slope" that describes this relationship. We find that this slope is positive and increasing in the time horizon over which it is calculated, but financial synchronization is reduced the more asymmetric the capital flows are. We show that an existing DSGE model of cross-border capital flows can replicate the main empirical findings. We then use the model to gain further insights on the channels that drive the shape of the Finance Co-movement Slope and conduct policy experiments designed to dampen financial synchronization.

JEL Classifications: E00

Global Capital Flows, Financial Cycle

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2.1 Introduction

How do capital flows affect the synchronization of two countries' financial market activity? The answer to this question has important implications for policymakers who want to assess the international dimension of their own or other countries' monetary, macro-prudential, or even fiscal policies. Three examples illustrate the importance of this relationship: (1) It can help small economies to assess the effect of foreign macro-prudential and monetary policies (such as *leaning against the wind*) through international capital flows on their own credit markets. To the extent that capital flows measure the financial interconnectedness of a country with its counterparts, this relationship measures the risk of crisis contagion through financial markets. (2) Countries that peg their exchange rate to either attract capital inflows or boost exports need to monitor and control the adverse effects on financial crisis contagion of their exchange rate policies. (3) Within a fiscal union, official (public) capital flows into a certain region affect financial outcomes - which should be accounted for when devising optimal redistributive policies between different regions[3].

This paper contributes to the existing literature by quantifying this relationship and giving policymakers the appropriate tool to address the aforementioned questions. To that end, we introduce the empirical "Finance Co-movement Slope", which describes the relationship between two countries' bilateral capital flows and the correlation of their domestic financial cycles. Herein, the financial cycle is a combination of credit volume and asset prices that captures the state of an economy's financial market activity and its often cyclical evolution. To do that, we make use of recent improvements in data quality on bilateral capital flows in the database published by the European Commission[4], which we combine with data on domestic financial cycles to build a panel database of 354 country-pairs. We then exploit within-country-pair variation to calculate the empirical relationship between capital flows and financial cycle synchronization. Conceptually, these exercises are inspired by the literature on the "trade co-movement puzzle" (Frankel and Rose (1998), Kose and Yi (2006), Duval et al. (2016), De Soyres and Gaillard (2019) among many others) which quantifies the relationship between trade flows and business cycle synchronization.

The results that we find are threefold: Firstly, we find that higher gross capital flows between a country-pair lead to a higher synchronization of the two countries' financial cycles. A 1% increase in the level of gross capital flows between two countries (relative to GDP) leads to a 2.3 point higher correlation of those countries' financial cycles over a two-year time horizon. Secondly, the more asymmetric this relationship is, the less will the countries' financial cycles be synchronized. In other words, if much more capital is flowing in one direction than into the other, i.e. if net capital flows between the country pair are higher, this will significantly lower the synchronization

[3] Alfaro et al. (2014) provide the empirical background that justifies this example

[4] The Joint Research Center Finflows Project: https://data.jrc.ec.europa.eu/collection/id-00149 (26.4.2022) which is now regularly updated

of their financial cycles. Thirdly, we find that the finance co-movement slope varies with the horizon over which it is calculated. The absolute magnitude both of the effects of gross capital flows and net capital flows generally increases with its time horizon. Higher gross capital flows lead to even closer synchronization in the medium-term than in the short term. Specifically, the impact of capital flows on 9-year (medium-term) synchronization of financial cycles is roughly seven times larger than the effect on short-term (2-year) synchronization. This plays into the notion that financial cycles are mainly medium-term phenomena that build up over extended periods of time.

These findings suggest the following interpretation: Gross capital flows are a proxy for the interconnectedness of two countries' financial sectors. They facilitate the functioning of financial markets and help ensure the supply of credit to the two countries. Higher interconnectedness, therefore, implies a stronger exposure to the shocks of the other country, so that their financial market activity becomes highly synchronized. From that angle, bilateral capital flows can also be seen as a measure of vulnerability to another country's financial market risks. However, the finding that asymmetric capital flow relationships between two countries reduce their synchronization also points to a different role of capital flows - to insure the partner country. Given that a large asymmetry in the direction of capital flows between two countries implies that their financial cycles move in opposite directions, we can infer that cross-border capital flows effectively play an important role in equalizing imbalances in financial market conditions. When, for example, much more capital is flowing from the home country to a foreign country, this increases foreign credit supply and decreases domestic credit supply, thereby driving the two countries' financial cycles in different directions[5].

To complement the empirical analysis, we conduct a theoretical exercise. We build on the DSGE model of Poutineau and Vermandel (2017) of global banking and capital flows. This allows us to 1) verify whether an existing DSGE model can replicate the empirical properties; 2) extrapolate the effects for longer horizons than the current data availability allows; 3) investigate which shocks and which cross-border markets drive the shape of the slope and 4) run experiments on macro-prudential policy.

Overall, we find that the model gets very close to the slope found in the data. The extrapolation to longer horizons confirms the direction that the empirical analysis predicts for shorter horizons. Concerning the mechanisms at play, the model suggests that lending activities in the markets for corporate loans and in the interbank market are the most important drivers of the shape of the finance co-movement slope. In particular, the short-term shape seems to be mainly driven by capital flows through the market for corporate loans. At the same time, the model suggests that the medium- and long-term shape is driven by the market for interbank loans. The policy experiments we run show that a counter-cyclical capital buffer designed to minimize the variance of credit-to-GDP and output gap is an effective tool for policymakers to soften the relationship

[5]While this may be in part mechanical it still signals the presence of cross-country risk-sharing arrangements.

between capital flows and financial cycle synchronization in the short term.

To the best of our knowledge, a finance co-movement slope has never been calculated before. This may be because the measure of the "financial cycle" is not yet on par with the measure of the business cycle[6]. As researchers have recognized the importance of financial market activity for real outcomes, their interest in financial cycles has grown in the aftermath of the Great Financial Crisis of 2008, but it is still only one of many measures used to describe financial market activity. In particular, it focuses mainly on medium-term developments in the financial market whereas financial contagion is usually studied at very short horizons.

The remainder of this paper is structured as follows: The next section discusses the relation of this paper to the existing literature. Section 2.3 describes the data and the empirical exercises. Sections 2.4 and 2.5 describe the theoretical exercises. Finally, section 2.6 concludes.

2.2 Related Literature

The paper relates to the literature in three important ways: Firstly, it connects and adds to the literature that studies the properties of financial cycles. Here it is important to distinguish between two concepts of financial cycles in the literature: The “global” financial cycle (see among others Miranda-Agrippino and Rey (2021)) and the “domestic” financial cycle (see among others Borio (2014), Borio et al. (2018), Drehmann et al. (2012), Jordà et al. (2011)). While the former studies explicitly the dynamics of cross-border capital flows, the analytical focus of the latter was purely domestic - to study the effects of lean-versus-clean policies (Borio and White (2004)) and their ability to preclude banking crises. In that role, it is constructed as a combination of the cyclical components of credit volume-to-GDP and house prices to capture the “mutually reinforcing interactions of perceptions of value and financing constraints” (Borio (2014)). One of the results of this literature is that domestic financial cycles are only partially correlated but the implications of the partial correlations have not been explored. We add to this literature by showing that there are systematic economic relations that partially explain the correlation patterns of domestic financial cycle pairs. In point of fact, we show that domestic financial cycles are more positively correlated for country-pairs with a high level of capital flows between them. At the same time, we show that a more asymmetric relationship of capital flows diminishes the synchronization.

Secondly, this paper is related to the literature on financial integration and crisis contagion through finance. To this point, Devereux and Yu (2020) show in a theoretical model how internationally more integrated financial markets help diversify risks but also facilitate crisis contagion as a result of increasing global leverage and widespread exposure to financial risk. Similarly, Goldstein and Pauzner (2004) show how financial holdings of internationally diversified investors may foster crisis contagion. Acemoglu et al. (2021) show how shocks can spread through financial networks.

[6] The existing measures are mainly descriptive.

We contribute to this literature with a convenient quantification of the effects on the aggregate financial conditions in the partner country relative to the origin country. As its variables credit-volume-to-GDP and house prices have been shown to be powerful early warning indicators of crises (Aldasoro et al. (2018), Jordà et al. (2013)), the financial cycle is a particularly important measure to also prevent crisis contagion. Depending on the structure of capital flows, a country can then assess its exposure when a partner country's financial cycle enters a downward movement. In this context, we also show that bilateral capital flows are a proxy for the interconnectedness of two countries' financial sectors; and how the likelihood of financial crisis contagion within a country-pair can be assessed through the study of capital flows. Additionally, we contribute to the study of international financial contagion by breaking down within the framework of a DSGE model of cross-border capital flows, through which markets the contagious forces operate.

Thirdly, we connect to the literature on the international transmission of macro-prudential and monetary policy (see for instance Buch et al. (2019) and Coenen et al. (2010) by showing how the finance co-movement slope reacts to different macro-prudential and monetary policy experiments.

Finally, a more global view on crisis contagion is found in the literature on business cycle synchronization (Frankel and Rose (1998), Kose and Yi (2006) and many others). Poutineau and Vermandel (2015), Poutineau and Vermandel (2017) and Devereux and Yu (2020) study the effects of cross-border lending on the transmission of financial crisis between two countries. Another important contribution is the paper by Morgan et al. (2004) who build a model à la Holmstrom and Tirole (1997). The mechanics that they find are such that a shock to firms' net worth decreases synchronization while shocks to the financial sector increase synchronization. We use their exercise as a blueprint, to assess the effects of shocks on financial cycle synchronization. On the empirical front, Kalemli-Ozcan et al. (2013) finds ambiguous effects of increased capital flows (driven by bank integration in their analysis) on business cycle synchronization. Cesa-Bianchi et al. (2019) find that in a workhorse model of international real business cycles increased financial interconnectedness exacerbates the cycle asymmetry created by country-specific shocks. We contribute to this literature by extending the analysis from business cycle to financial cycle synchronization and studying the implications of capital flows thereto.

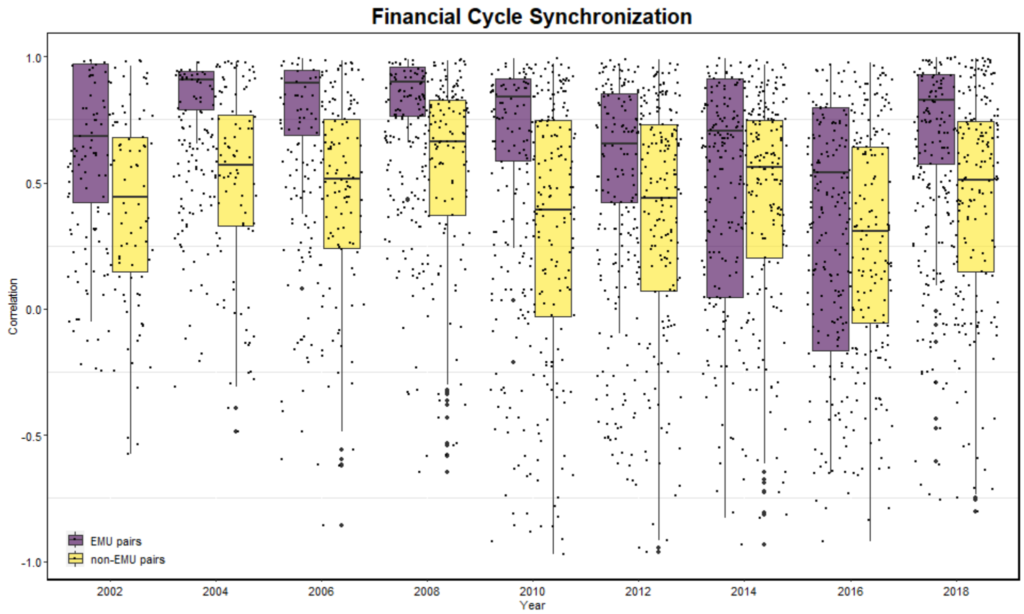
2.3 Empirical Exercise

2.3.1 Data

In this section, we describe the data used for the analysis, the problems that arose in the process, and how those problems were addressed.

The data stems from three sources: Firstly, the standard data to calculate financial cycles stems from the Bank for International Settlements (BIS). Drehmann et al. (2012) calculate the financial

Figure 2.3.1. Distribution of Financial Cycle Correlation through time



This box plot visualizes the synchronization of the financial cycles of country-pairs. The x-axis denotes time windows, where the correlation was computed over the 2 years (8 quarters) preceding the listed year. The y-axis measures the correlation computed over the time window. The box plot shows the distribution of correlations of country-pairs, split into those pairs where both countries are within the European Monetary Union (EMU) and those where at least one country is outside the EMU.

cycle at a quarterly frequency for 47 countries by averaging the cyclical components - between 32 and 120 periods per cycle - of total credit volume, credit-to-GDP gaps, and house prices. We depart from their methodology in one important way: we only extract a one-sided trend but do not selectively filter for a certain frequency band[7]. As we use the financial cycle to study financial contagion, we do not want to remove short-term volatility artificially. Rather, maintaining both short and medium-term volatility allows us to study both immediate and highly persistent effects of financial contagion. As a measure of synchronization, I use the correlation between two countries' financial cycles. We split the data into (non-overlapping) time windows of horizons from 8 to 36 quarters and calculate in each window. As the number of data points decreases with longer horizons, the estimates for the longer horizons will necessarily be less precise. Figure 2.3.1 visualizes key features of the synchronization of domestic financial cycles:

1. Most country-pairs have positively correlated financial cycles. In every time period, the average correlation is around 0.5.

2. Country-pairs of which both countries are inside the EMU exhibit on average more synchronized financial cycles than country-pairs where at least one country is outside the EMU.

[7]I nevertheless check for robustness with the standard methodology.

3. Financial cycles became significantly more aligned in the lead-up to the Great Financial crisis (GFC)[8]. After the GFC, financial cycle correlation became on average lower and more dispersed. Again, these effects are especially pronounced for country-pairs within the EMU.

The best available data on bilateral capital flows stems from the Finflows Project of the European Commission[9]. This data set covers the country-pair capital stocks and capital flows on a yearly basis between 2001 and 2018 for 87 countries. The data set is constructed by combining information on the balance of payment statistic to calculate the capital stocks that one country holds in another (i.e. calculate gross foreign asset holdings country-by-country). The financial flows are then calculated as the changes to gross financial stocks. This comes with an obvious problem: From the changes in financial stocks, we can only infer a lower bound for bilateral capital flows. When capital is flowing in both directions, these flows offset each other and are not reflected in the final tally. Additionally, estimating flows from stock disregards depreciation that may have decreased a country's foreign asset holdings without causing a flow. With these potential shortcomings in mind, we will take the data quality as given.

This implicitly assumes that this lower bound is a good proxy for actual bilateral capital flows[10]. Finally, we add information on real GDP of each country to scale the capital flows by the "potential" of the economy. The data on GDP stems from the OECD's main economic indicators. We combine the data to construct a panel that contains 354 country-pairs. For each country-pair, we construct the following measures:

- Intensity of gross capital flows:

$$F_1 = log\left(\frac{abs(Flows_{i\rightarrow j}) + abs(Flows_{j\rightarrow i})}{GDP_i + GDP_j}\right)$$

- Intensity of net capital flows

$$F_2 = log\left(\frac{abs(Flows_{i\rightarrow j} - Flows_{j\rightarrow i})}{GDP_i + GDP_j}\right)$$

- External Imbalance

$$F_3 = log\left(\frac{abs(Stocks_{i\ in\ j} - Stocks_{i\ in\ j})}{GDP_i + GDP_j}\right)$$

The first measure is an undirected measure of gross capital flows. It proxies the overall move-

[8]This points to the existence of and interaction with the "Global Financial Cycle" as in Miranda-Agrippino and Rey (2021)

[9]The authors describe the issues with collecting such data in detail on their website. https://data.jrc.ec.europa.eu/collection/id-00149 (21.3.2022)

[10]As we are obtaining the estimates from across-time variation within each country-pair, the underlying assumption is that the data underestimates capital flows to similar extents in each year. Given the relatively short period that the data spans, this is not unreasonable - at least measurement should not be a concern.

ments of capital between the two countries. Effectively, it this therefore a measure of financial interconnectedness of the country-pair. Its construction as an undirected measure implies the loss of information in which direction capital is flowing. This serves the purpose of making the measure invariant to which country is put first in each pair. The second measure is the intensity of net capital flows between the two countries. This reveals how much more capital is flowing from country i to j than in the reverse direction. In other words, this is the change in the bilateral imbalance of foreign asset holdings. As we use the absolute value of the difference, this measure is also undirected. As a result, this measure describes the asymmetry of the relationship between a country-pair. Finally, the third measure is the external imbalance, which is the difference between one country's holdings in another, minus the reverse. We will use these measures to calculate their effects on financial synchronization - the finance co-movement slope. Hence, we create different panels that contain information on financial cycle synchronization over a fixed time window and gross capital flows, net capital flows, and bilateral imbalance during the same time window. As the time windows usually exceed one year, the measures of capital flows are averaged within each time window[11]. The panels consist of 354 country-pairs. For time windows of 8 quarters, this yields 2582 observations, whereas we are left with 526 observations when time windows are 36 quarters. In addition to the measures of capital flows, we include a linear time trend, country-pair fixed effects, and a dummy when both countries are EMU members into the regression.

2.3.2 Calculating the Finance Co-movement Slope

As outlined in the introduction we define the "Finance Co-Movement Slope" as the effect of capital flows between a country-pair on the correlation of the country-pair's financial cycles. In practice, we compute this slope with the baseline regression equation 2.1:

$$Corr(FC_{ijt}) = \beta_1 \times ln\left(\frac{\Sigma\, Gross\ Capital\ Flows_{ijt}}{GDP_{it} + GDP_{jt}}\right) + \beta_2 \times ln\left(\frac{\Sigma\, Net\ Capital\ Flows_{ijt}}{GDP_{it} + GDP_{jt}}\right) + CP_{ij} + \epsilon_{ijt} \tag{2.1}$$

where

$$\Sigma Gross\ Capital\ Flows_{ijt} = Gross\ Capital\ Flows_{i \to j,t} + Gross\ Capital\ Flows_{j \to i,t}$$
$$\Sigma Net\ Capital\ Flows_{ijt} = |Gross\ Capital\ Flows_{i \to j,t} - Gross\ Capital\ Flows_{j \to i,t}|$$

[11] Of course the averaging out of capital flows within each time window comes with the risk of missing interesting dynamics within capital flows. Therefore, we run robustness checks that include the variance of capital flows within the time window and the difference in imbalance over the time window of the bilateral capital flows. However, these turned out to be insignificant in every regression. This indicates that the risk of losing critical information through this averaging is low.

The correlation of financial cycles of countries i and j in time window t depends on gross and net capital flows, country-pair fixed effects, and an unobserved term. Note that regressing on both gross and net flows incorporates the same information as if we were using capital flows from i to j and from j to i as separate regressors. We only removed the direction of capital flows to eliminate the arbitrariness of the country orderings within each pair. We run equation 2.1 for time windows that vary in size from 8 to 36 quarters to assess differences in the effects on short- and medium-term financial co-movement. Given the setup of the baseline regression, the estimates are driven by the within-country-pair variation across time. The regression results point to a result that is

Table 2.3.1. Benchmark Regression

	Dependent variable: Financial Cycle Correlation							
window	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross capital flows	0.023^{**}	0.050^{***}	0.070^{***}	0.107^{***}	0.035	0.114^{**}	0.150^{**}	0.163^{***}
	(0.011)	(0.017)	(0.023)	(0.031)	(0.035)	(0.053)	(0.058)	(0.060)
net capital flows	-0.021^{*}	-0.023	-0.068^{***}	-0.094^{***}	-0.047	-0.069	-0.133^{**}	-0.145^{**}
	(0.011)	(0.016)	(0.022)	(0.030)	(0.033)	(0.056)	(0.060)	(0.058)
Observations	2,559	1,688	1,166	852	791	566	547	522
R^2	0.671	0.763	0.781	0.832	0.856	0.891	0.893	0.908
p-value Hausman test	8.85e-10	1.849e-11	0.001714	0.03442	0.005134	0.09206	0.3377	0.3796

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

This table shows the regression results from the baseline exercise to compute the Finance Co-Movement slope. The regression equation is equation 2.1, where β_1 and β_2 are the estimated effects of gross capital flows and net capital flows, respectively. For expositional reasons, the other estimates were omitted from the table. The line "window" refers to the length of the time windows over which the financial cycle correlation was calculated. For the majority of the time windows, Hausman tests show that a fixed effects model is superior to a random effects model.

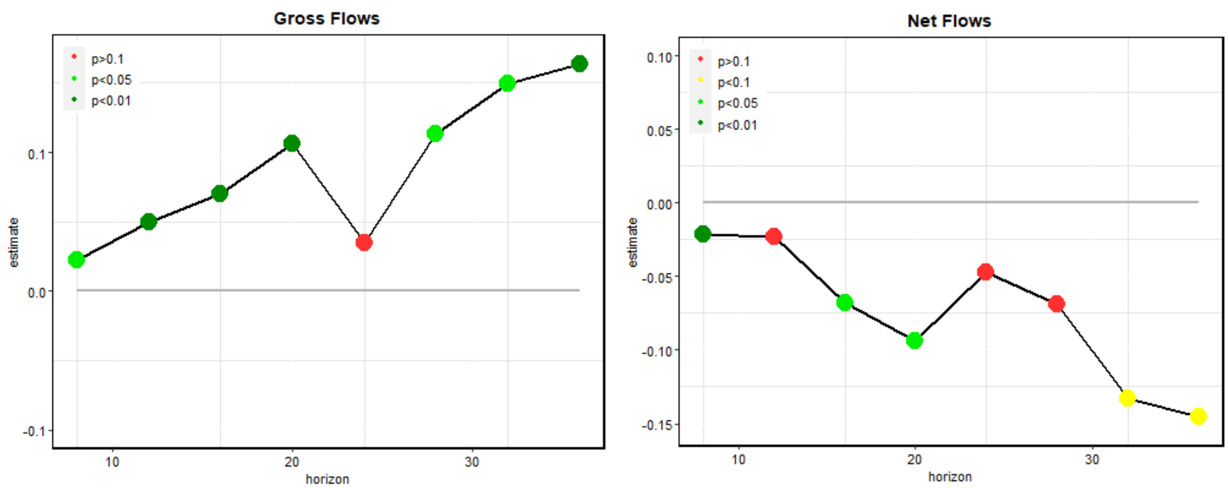
threefold:

1. A higher gross capital flow intensity leads to higher synchronization of financial cycles. A 1% higher ratio of joint gross capital flows over the sum of GDPs implies at least a 2.3% point higher correlation of financial cycles.

2. The more asymmetric this relationship is, i.e. the higher net capital flows are, the less will the financial cycles be synchronized. However, these effects are not always significant.

3. Both effects get stronger when we consider longer-term synchronization. Over a 9-year horizon, the effect of gross capital flows is roughly seven times larger than over the 2-year horizon. One exception is the effect over 6 years. It is not clear why this is the case. The effect of net capital flows on financial synchronization is roughly 7 times stronger (more negative) when we consider 9-year instead of 2-year synchronization.

Figure 2.3.2. Benchmark Finance Co-movement Slope



This figure shows the finance co-movement slope for gross flows and net flows. The x-axis shows the horizon over which the size was computed. The y-axis shows the estimate of the Finance Co-movement Slope.

The positive effect of gross capital flows can be interpreted as follows: The variable proxies the interconnectedness of two countries' financial sectors. Therefore, the more countries are interconnected - or exposed to developments in the partner countries' financial markets - the more will their financial cycles be correlated. In the short term, this effect is relatively small. A possible reason for this is that a part of financial investments are longer-term and are unaffected in the short term. The much stronger medium-term effects play into the narrative of the financial cycle as a medium-term phenomenon (Drehmann et al. (2012)). In fact, the stronger effects of capital flows in the medium-term suggest that the medium-term nature of financial cycles may partially result from the international transmission of shocks to partner countries' financial system through capital flows. At the same time, the negative effect of net capital flows suggests a different underlying story: A highly asymmetric relationship between two countries could be an indication of the existence of a risk-sharing scheme. Following a negative shock to credit volume in country i, credit would flow from country j into country i to smooth out the shock. This increases total credit to the non-financial sector in i while reducing it in j - thereby driving the financial cycles in different directions[12]. Continuing net flows in one direction then also explain why the effect is even more negative at long horizons through the same mechanics. Instead of supplying credit and purchasing assets in the home country, capital is flowing abroad and drives credit supply and asset prices there.

The existence of a risk-sharing scheme between two countries could also serve as an explanation for the lower effect of gross capital flows at short horizons. This argument is based on the hy-

[12]Herein, we are interpreting only the difference in capital flows as the flows that insure the partner country. It is irrelevant on top of which level of gross capital flows this difference exists.

pothesis that there are counteracting forces contained in the estimated coefficient: At all horizons, capital flows signal financial vulnerabilities. However, if in the short-term countries engage in risk-sharing schemes which lead to a negative relationship between gross capital flows and financial cycle correlation - reducing the overall coefficient.

At this point, it is important to note that the pair of gross and net capital flow intensity seems to capture the underlying economic relations well. We do not find any other regressor to be consistently of significance in determining the correlation of financial cycle pairs. Specifically, empirical results that are relegated to the appendix show that the level of outstanding capital stocks (both gross and net) do not have a consistent significant impact in combination with capital flows[13]. Additionally, we test if we lose information from averaging out the capital flow intensity within each window. To address this concern, we include regressors that capture the dynamics of capital flows within each time window better than the simple average. In particular, we use the standard deviation of capital flows within the time window and the difference in the bilateral imbalance in the first and last year (as a directional measure). The estimated coefficients of these additional measures are usually not significant. Hence, we conclude that the information loss from disregarding the dynamics within each time window is small. The results of this exercise can also be found in Table 2.A.10-2.A.12 in the appendix.

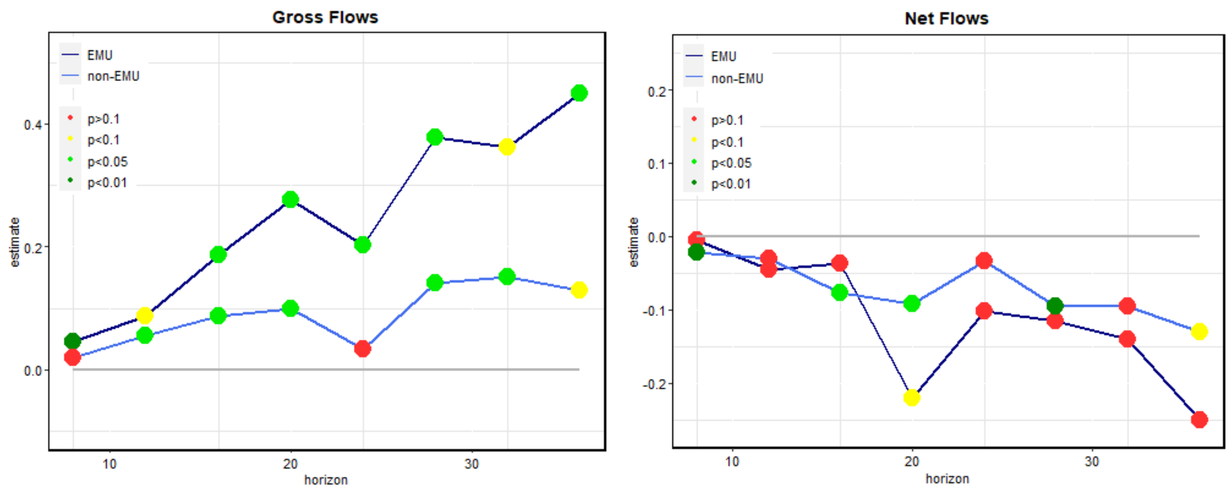
We conclude that the aforementioned threefold property describes the general economic relations that are contained in the finance co-movement slope well. However, beyond the positive impact of gross capital flows on financial cycle synchronization and the negative effect of asymmetry in the capital flow relationship, the full effect includes a country-pair specific effect that varies substantially between country-pairs with a mean of 0.43 and a standard deviation of 0.26. This country-pair-specific effect captures a multitude of factors that relate to country-specific characteristics of financial markets and integration thereof into world markets. One important component that can be named is membership in the European Monetary Union. When both countries are EMU members, both the average correlation of financial cycles as well as the effects of capital flows are larger. This can be seen clearly in Figure 2.3.3 Additionally, we notice that while gross capital flows are significant regressors in both subsamples at almost every horizon, an asymmetric relationship does not seem to have significant consequences for financial cycle synchronization in the EMU.

2.3.3 Robustness

We test the robustness of the empirical results along three different dimensions: Firstly, we want to address concerns with the measurement of the key variables: Therefore, we vary the method of calculating capital flows and the financial cycle. A common alternative in the literature on the

[13] Since capital flows are estimated from capital stocks, the latter are significant when capital flows are dropped from the regression. This is not surprising, since the information in the capital flows is the same as in the capital stocks data.

Figure 2.3.3. Finance Co-Movement Slope for EMU and non-EMU country-pairs



This figure shows the finance co-movement slope for gross flows and net flows for two subsamples: only EMU countries and non-EMU countries. The x-axis shows the horizon over which the size was computed. The y-axis shows the estimate of the Finance Co-movement Slope.

trade co-movement puzzle is to use the maximum flow between two countries as the trade intensity. This does not mitigate the problem that we may be misestimating capital flows from capital stocks in a systematic way, instead, it sidesteps the problem. By looking only at the maximum of the two flows, in a way we are acknowledging the lack of informativeness of one of the flows and the fact that actual capital flows are systematically underestimated. The regression results of this exercise can be found in table 2.A.2. Further, we also use alternative methods to calculate the synchronization of financial activity: Specifically, we can calculate the correlation of the first principal component (rather than the average) of credit-volume-to-GDP and house prices and look at the synchronization of each variable of the financial cycle separately. The results of this are found in table 2.A.6.

Secondly, it is well known that capital is often repatriated during financial crises (Giannetti and Laeven (2012)). Hence, we investigate if there is a reversal of the economic forces described above during the Great Financial Crisis of 2008-2009. In practice, we include a crisis dummy into our regression and study its interaction with the gross and net capital flow intensity in determining financial cycle synchronization. Table 2.A.7 shows that while the great financial crisis has significant effects on financial synchronization, these effects do not interact significantly with gross and net capital flows. Instead, the crisis dummy leaves the estimated values of the Finance Co-movement slope largely unaffected[14].

Thirdly, we verify the robustness of the results to different econometric specifications. We try to isolate the effect of EMU membership by including further dummies on common border, common

[14]The effects of the dummy for the financial crisis vary strongly with the horizon over which the relationship is calculated.

language, and a variable on geographical distance in the regression. The results of this analysis are in Table 2.A.8 in the appendix. We find that additional dummies do not consistently have significant effects on financial cycle synchronization, while the effects of gross and net capital flows only change marginally and retain their qualitative properties. This exercise also shows that even when controlling for geographical and cultural proximity, EMU membership still increases financial cycle synchronization, especially significantly at short horizons.

2.4 Model

In this section, we complement the empirical findings with a model exercise. We show that a medium-scale DSGE model of cross-border capital flows can replicate the main qualitative properties of financial co-movement and capital flows that we found in the data. The model can then be used to refine the interpretation of the findings and extrapolate results for longer horizons which data limitations do not allow us to calculate empirically. Finally, the model can be used to analyze counterfactual scenarios that can help policymakers understand the implications of their policy on financial co-movement.

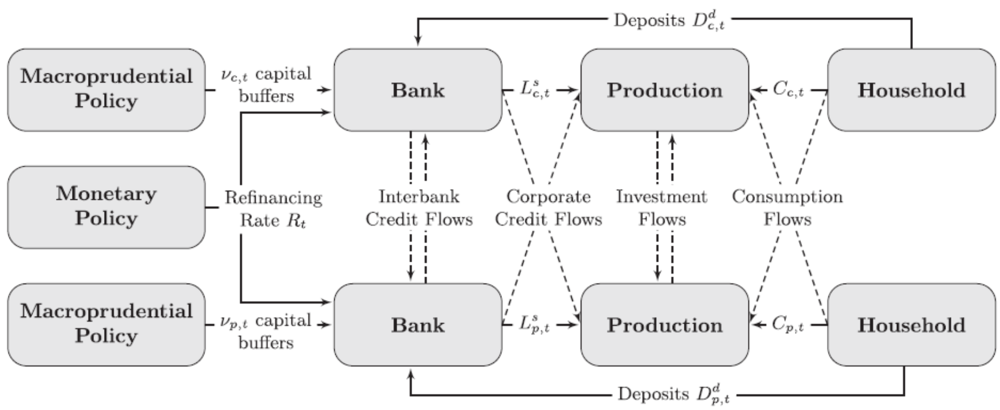
2.4.1 Setup

To perform the theoretical analysis, we use the DSGE model of cross-border capital flows of Poutineau and Vermandel (2017). This model is designed to study how macro-prudential and monetary policies feed through four cross-border markets and spill over to the other country. Therefore, it is very suitable for our purposes.

As we outline only the most important aspects here, we refer the reader to the appendix and to the original paper for a full description of the model. Time is discrete. There are two countries, home and foreign, denoted h and f. At the heart of the model stand the financial sectors of these two countries. The financial sectors are represented by a continuum of monopolistic banks that collect deposits from households and use these to finance risky investment projects into the economies' capital stocks, that are carried out by entrepreneurs. Financing comes in the form of corporate loans. Because a fraction $1-\eta_{i,t}$ of entrepreneurial projects default, the macro-prudential authority forces banks to hold a capital buffers of $\nu_{i,t}$. In addition to deposits, banks can obtain funds from the central bank. However, the model assumes that only a share λ of banks (called "liquid banks") has access to central bank funds, whereas a share $1-\lambda$ of banks is "illiquid". Illiquid banks then borrow on an interbank market when they need to raise more funds. Thus, the profits of a bank are:

$$\begin{aligned}\Pi_{i,t} = &[1-\mu^B(1-E_t\eta_{i,t+1})](1+R^L_{i,t})L^s_{i,t} - (1+R^D_{i,t})D_{i,t} \\ &- (1+P^{IB}_{i,t})IB^s_{i,t} - (1+R_t)liab_{i,t} - (1+R_t)L^{CB}_{i,t} - F(rwa^{liq}_{i,t} - \nu_{i,t})BK_{i,t}\end{aligned}$$

Figure 2.4.1. Model Economy in Poutineau and Vermandel (2017)



where $R^L_{i,t}$, $R^D_{i,t}$, $P^{IB}_{i,t}$ and R_t are the interest rates on corporate credit, deposits, interbank credit and central bank credit, respectively. $liab_{i,t}$ are other liabilities that follow an exogenous stochastic process and $BK_{i,t}$ is the bank's capital.

To introduce cross-border lending, the model assumes that foreign and domestic credit are only imperfectly substitutable. Banks' and entrepreneurs' basket of interbank and corporate loans (i.e. demand for loans), respectively takes the form:

$$IB^d_{i,t} = \left((1-\alpha^{IB}_i)^{1/\mu} IB^{(\mu-1)/\mu}_{hi,t} + (\alpha^{IB}_i)^{1/\mu} IB^{(\mu-1)/\mu}_{fi,t} \right)^{\mu/(\mu-1)}$$
$$L^d_{i,t} = \left((1-\alpha^{L}_i)^{1/\mu} L^{(\mu-1)/\mu}_{hi,t} + (\alpha^{L}_i)^{1/\mu} L^{(\mu-1)/\mu}_{fi,t} \right)^{\mu/(\mu-1)}$$

Hence, at the steady state, a share $1-\alpha^i_L$ of corporate loans and a share $1-\alpha^i_{IB}$ of interbank loans will come from the domestic bank. Banks set both deposit and credit interest rates by solving a Calvo problem. The rest of the model is the following: in each country, there is a representative household that consumes final goods and supplies labor to labor unions which in turn sell a labor aggregate to the country's firm. A representative firm combines labor with investment goods which it rents from entrepreneurs to produce intermediate goods. These are aggregated by retailers and sold back to the households. Similar to the credit market, consumption goods are imperfect substitutes and the household in country $i \in \{h, f\}$ consumes a goods basket that contains a share of $1-\alpha^i_C$ of the goods produced by his country's firm and α^i_C imported goods. Each unit of investment goods that the firm in country i uses consists of $1-\alpha^i_I$ goods produced in country i and α^i_I imported goods, is aggregated by an analog CES function. The problems of households, firms, and entrepreneurs are shown in Appendix 2.B.1. Given this setup, the model allows cross-border capital flows through four different markets, as summarized in Figure 2.4.1: Capital can flow from one country to the other 1) as payment for final goods C^i_t, 2) as payment for investment goods $q_t i^i_t$, 3) as corporate credit L^i_t and 4) as interbank credit IB^i_t where i is the country

Table 2.4.1. Interconnectedness in model

market	consumption goods	investment goods	corporate loans	interbank loans
coefficient	α_C	α_I	α_L	α_{IB}
home	0.091	0.045	0.378	0.041
foreign	0.108	0.066	0.322	0.115

of origin of the capital flow. In the model, gross capital flows are defined as:

$$
\begin{aligned}
interbank\ inflows\ h &= \alpha_{IB}^h IB_t^h + (1 + r_{IB}^h)\alpha_{IB}^f IB_t^f \\
interbank\ inflows\ f &= \alpha_{IB}^f IB_t^f + (1 + r_{IB}^f)\alpha_{IB}^h IB_t^h \\
corporate\ credit\ inflows\ h &= \alpha_L^h L_t^h + (1 + r_L^h)\alpha_L^f L_t^f \\
corporate\ credit\ inflows\ f &= \alpha_L^f L_t^f + (1 + r_L^f)\alpha_L^h L_t^h \\
investment\ goods\ payments\ h &= q_h \alpha_I^f i_t^h \\
investment\ good\ payments\ f &= q_f \alpha_I^h i_t^f \\
consumption\ goods\ payments\ h &= \alpha_C^f C_t^h \\
consumption\ good\ payments\ f &= \alpha_C^h C_t^f
\end{aligned}
$$

The interconnectedness of the two economies is governed by the parameters that control the substitutability of foreign goods and loans for domestic goods and loans in each country. This conveniently allows us to shut down markets (by setting the substitutability to zero) to test which market is driving the shape of the finance co-movement slope and how the finance co-movement changes with market integration. In the calibration of Poutineau and Vermandel (2017) the values of interconnectedness are those shown in the table 2.4.1.

The financial cycles of each country are defined as the combination of total credit volume to GDP and investment goods prices as the relevant asset price. In this model, credit volume to GDP is defined as:

$$
\begin{aligned}
cred_h &= (L_s^h + (1 - \lambda) IB^h)/y_h \\
cred_f &= (L_s^f + (1 - \lambda) IB^f)/y_f
\end{aligned}
$$

where L_s are loans to firms and IB denote interbank loans to illiquid banks. This means that the definition of credit volume does not include loans from the central bank to the commercial banks. Naturally, total credit volume is scaled by the respective country's GDP. Ten shocks enter the model: Households witness preference shocks, the firms face shocks to their net worth, TFP, and investment costs and markup. Labor unions' mark-up is also stochastic. In the financial sector, there are shocks to bank liabilities and credit mark-ups. Finally, there are monetary and government spending shocks.

The original model is written and estimated to describe cross-border capital flows between core

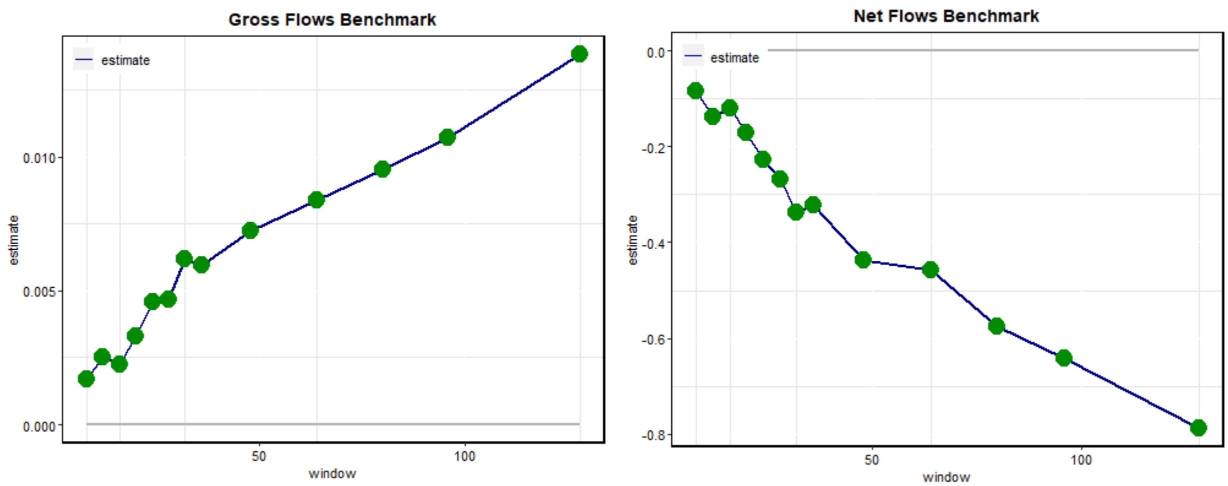


Figure 2.4.2. Model-implied Finance Co-Movement Slopes for Gross and Net Flows

This figure plots the model-implied finance co-movement slopes. The x-axis denotes the window length over which the correlation of the financial cycle was calculated. The y-axis measures the estimated impact of a 1-unit increase in capital flows on the financial cycle correlation. The coefficients are colour-coded as follows: Darkgreen= significant at 99%, light green = significant at 95%, yellow % significant at 10% and red=not significant at all.

and periphery countries of the European Monetary Union. While the monetary policy is decided by a single central bank of the monetary union, each country can decide on its own macro-prudential policy. This macro-prudential policy takes the form of minimum capital buffers that the fiscal authority prescribes to its banks.

The model is estimated with Bayesian techniques for the period 2002-2014[15]. For details of the estimation, we refer the reader to Poutineau and Vermandel (2017). The estimated model describes the dynamics of capital flows between a single country pair. To stick as close as possible to the empirical analysis and to ensure the robustness of the results to the specific parameterization of the model, we draw randomly out of the posterior distributions to receive 200 model country pairs. We simulate these model economies over 5120 periods and combine them to obtain a panel data set equivalent to the real data. Hence, we still have 40 independent observations to calculate the long-run finance co-movement slope (when the window size is 128). We use the model-generated data to estimate the equivalent regression as in equation 2.1. Figure 2.4.2 plots the estimated Finance Co-movement slope that the model of Poutineau and Vermandel (2017) gives rise to:

2.4.2 Benchmark Results

The model replicates the threefold property of the data very well. The model-implied finance co-movement slope in gross capital flows is positive for all horizons and it increases with longer

[15]The model does not address the question whether the presence of the zero lower bound interacts in any way with the drivers of the Finance Co-movement slope.

time windows. At the same time, the model-implied finance co-movement slope in net capital flows is negative at all horizons and is steeper (more negative) for longer time windows. The magnitude of the model-implied estimates for the finance co-movement slope for net flows is in the same range as the empirical ones. However, the estimates for the effect of gross flows are an order of magnitude smaller. Nevertheless, given that the qualitative properties are accurate, we conclude that this off-the-shelf model is at the aggregate level a good approximation of reality on this dimension. Consequently, we can use it to predict further properties of the empirical finance co-movement slope that the current data limitations do not allow us to reach directly.

2.4.3 Model Predictions

The first insight that the model provides on top of replicating the empirical results comes from an extrapolation of the finance co-movement slopes in gross and net flows to horizons longer than those that we can obtain from the data. As financial cycles are in the literature usually defined as fluctuations that may take up to 30 years (120 quarters), we calculate the values of the model-implied finance co-movement slopes for time windows up to 128 quarters[16]. The result is a straight extension of the shorter horizon slope: Higher gross capital flows have an even stronger impact on financial cycle correlation at 64 and 128 quarters and net capital flows reduce long-term synchronization even more than medium-term synchronization.

Furthermore, we can use the rich structure of the model to obtain insights into the formation of the finance co-movement slope and the channels that drive its shape. To do this, we calculate the finance co-movement slope when all markets except for one are completely shut down. In practice, that means that when for example the interbank market is the only cross-border market, we set $\alpha_f^C, \alpha_h^C, \alpha_f^L, \alpha_h^L, \alpha_f^I$ and α_h^I all equal to zero. Then, we re-simulate the model and run the same regression as before. The resulting Finance Co-movement Slopes are plotted in Figure 2.B.1. While this figure is relegated to the appendix for expositional purposes, we summarize the main results here. When the market for consumption goods is the only cross-border market, there is hardly any significant effect of cross-border financial flows on financial cycle synchronization. This is not surprising, as the payments of financial goods are made by households directly to firms, without any involvement of the financial sector and therefore no effect on credit volume. For horizons beyond 32 quarters, the finance co-movement slope of net flows does become significantly negative though. This suggests that if in the longer run, one country exports significantly more than the other, there will be general equilibrium effects onto the financial sector, to the effect that financial cycle synchronization decreases.

When only investment goods can be traded internationally, we have similar results. There is no significant effect of gross financial flows on financial cycle synchronization. However, the more

[16] We use 128 rather than 120 because this is a power of 2.

asymmetric the trade relationship is between the two countries, the less will their financial cycles be synchronized, and this effect gets stronger with longer horizons. This can be explained by the fact that in the model, investment goods are much more important to the financial sector than consumption goods, as investment goods are used in production and serve as collateral to the commercial banks who finance production.

When only the market for corporate loans is open, we observe that an increase in gross loans between the countries leads to a significantly increased synchronization of financial cycles. In the short run, loan supply equilibrates the demand for corporate loans across countries. At the same time, the more asymmetric this relationship is, the more will the financial cycles correlate. At longer horizons there is no significant effect of gross flows. However, at very long horizons the effect of asymmetry in the corporate credit flows is reversed and becomes negative.

Finally, the isolated effect of capital flows through the interbank market resembles the pattern that we see in the aggregated effect. It is positive and increasing in its horizon for gross flows and negative and decreasing further with its horizon for net flows. Interestingly, the estimate is only significant for horizons beyond 32 quarters and is insignificant on short horizons. Mechanically, interbank flows increase total credit volume where it is required, equilibrating supply and demand imbalances. On top of this, with increasing foreign asset positions, banks become more vulnerable to shocks in the other country. This is also the reason why higher asymmetry, reflected by higher net interbank flows implies a weaker correlation of financial cycles. Consequently, the higher the gross flows of loans are between the countries, the more will their financial cycles be synchronized.

Overall, the results from the market analysis suggest that the combination of corporate loans and interbank credit flows are the main drivers of the shape of the finance co-movement slope. Herein, the analysis suggests that corporate credit flows are driving the shape at short horizons, whereas the long-horizon effect is primarily driven by the interbank credit flows. The effect of capital flows in exchange for investment goods is of minor importance only and the conventional trade of non-durable goods has virtually no effect on financial cycle synchronization.

2.5 Policy Experiments

In this section, we investigate if macro-prudential and monetary policy can alter the relationship between financial synchronization and capital flows. In line with the reasoning laid out so far, the motivation may come from the desire to disentangle two economies' financial sectors and thereby improve risk-sharing between two countries.

To that end, we conduct five experiments with the policy tools that the model contains that are analogue to those in Poutineau and Vermandel (2017). The macro-prudential authorities target credit supply or credit demand, either in cooperation (at the federal level) or non-cooperatively, each country setting its own target for credit supply or credit demand. The fifth option is to target cross-border capital flows directly. In effect, this counter-cyclical capital requirement is an alternative to monetary "leaning against the wind" policies[17]. The macro-prudential policy instrument is a capital requirement $\nu_{i,t}$ that raises the marginal costs of banks. The macro-prudential authority sets this capital buffer according to the following policy rule:

$$\nu_{i,t} = (1 - \rho_i^{\nu})\bar{\nu} + \rho_i^{\nu}\nu_{i,t-1} + \phi(T_{i,t} - \bar{T}_{i,t})$$

where $\bar{T}_{i,t}$ is the macro-prudential target. This macro-prudential target can take the form of credit supply $L_{i,t}^{s}$, credit demand $L_{i,t}^{d}$ or cross-border capital flows.

To achieve comparability, we set the sensitivity to deviations from the target to $\rho_i^{\nu} = 0.05$ for both countries, in all of our experiments. We then evaluate the impact these policies have on the relationship between capital flows and financial synchronization. Figures 2.5.1 and 2.5.2 show the results of these experiments. We take away the following insights: Targeting of either credit supply or demand at the federal level does not have a strong effect on the finance co-movement slope for gross capital flows. It does, however, affect the finance co-movement slope for net capital flows. In the presence of this macro-prudential policy, the relationship between net capital flows and financial cycle synchronization becomes insignificant at short horizons up to 24 quarters. In the long run, however, it stays significantly negative. In contrast to this, national level targeting of credit supply and demand flattens the finance co-movement slope for gross capital flows at short horizons. As we can see in Figure 2.5.1, the estimate fluctuates around zero at short horizons. While some of the estimated coefficients are statistically significant, the fluctuating point estimate calls into question whether there is a robust economic relationship between gross capital flows and financial cycle synchronization in this scenario. In case of national macro-prudential policy targeting credit supply and demand the finance co-movement slope for net capital flows is positive and mostly statistically significant up to horizons of 80 quarters. The policy experiments with capital flow targeting are very inconclusive, as the estimates of the finance co-movement slope fluctuate wildly with the horizon over which they are calculated.

We interpret these findings as follows: Counter-cyclical capital buffers mechanically dampen the fluctuations of the financial cycle by reacting with higher buffers when credit volatility increases. This also counteracts any contagion effect, as the macro-prudential authority will effectively also react to higher capital inflows with an adjustment of the capital requirement. This works better in the short-term than in the medium- or long term, as the long-term effect is a cumulative one. Whether at the national or at the federal level, the macro-prudential policies also have the

[17] In addition to the macro-prudential policy experiment, we evaluate the sensitivity of the finance co-movement slope to the Taylor rule coefficients of the central bank.

effect of improving banks' abilities to absorb shocks when they hit. Thereby, contagion through capital flows is reduced, leading to an insignificant relationship at short horizons. With regard to monetary policy, we find this to be much less impactful than macro-prudential policy. This is not necessarily surprising, since the monetary authority only affects the lending activity indirectly through the setting of the policy rate, at which only the liquid banks can borrow. Setting capital requirements is therefore preferable when trying to affect the relationship between cross-border capital flows and financial synchronization.

In summary, we conclude from these experiments that counter-cyclical capital buffers are a useful tool for policymakers that seek to disentangle the financial markets of two economies. Our analysis suggests that targeting credit supply (or demand) at the national level is the most effective option to reduce contagion. A slight caveat of such a policy is that its effect is mainly relevant for short-term correlation, but in the long-run credit market synchronization will still increase with higher levels of gross cross-border capital flows and decrease with the asymmetry of this relationship.

2.6 Conclusion

In this paper, we have introduced a finance co-movement slope that measures the relationship between bilateral capital flows and the synchronization of financial cycles. We show that this slope is increasing with the time horizon over which the synchronization is measured. For the short horizon (8 quarters) the slope for gross capital flows is close to zero and its point estimate may even be negative. For longer horizons (16 quarters) it is significantly positive. The slope for net capital flows, which measure the asymmetry of the bilateral relationship is negative and decreases further with the horizon over which synchronization is measured. In a theoretical exercise, we verified that the empirical finance co-movement slope is reproduced by a model of international capital flows. In particular, the model of Poutineau and Vermandel (2017) reproduces the main properties of the finance co-movement slope and allows us to infer more insights through which markets it operates. This suggested that the short-term effects of cross-border financial flows on financial synchronization are mainly a product of flows through the corporate loans market, while the medium-term effects are likely driven by interbank lending. Finally, we conducted experiments that show how the finance co-movement slope is affected by macroprudential policy and monetary policy. In these exercises we show that countercyclical capital buffers are a good tool for policymakers to dampen the relationship between capital flows and financial synchronization - however, this is not true in the long term.

Given the improving data availability on cross-country capital flows, we believe that this field of research still contains many interesting results that may help policymakers avoid crisis contagion and therefore are worthwhile for future research.

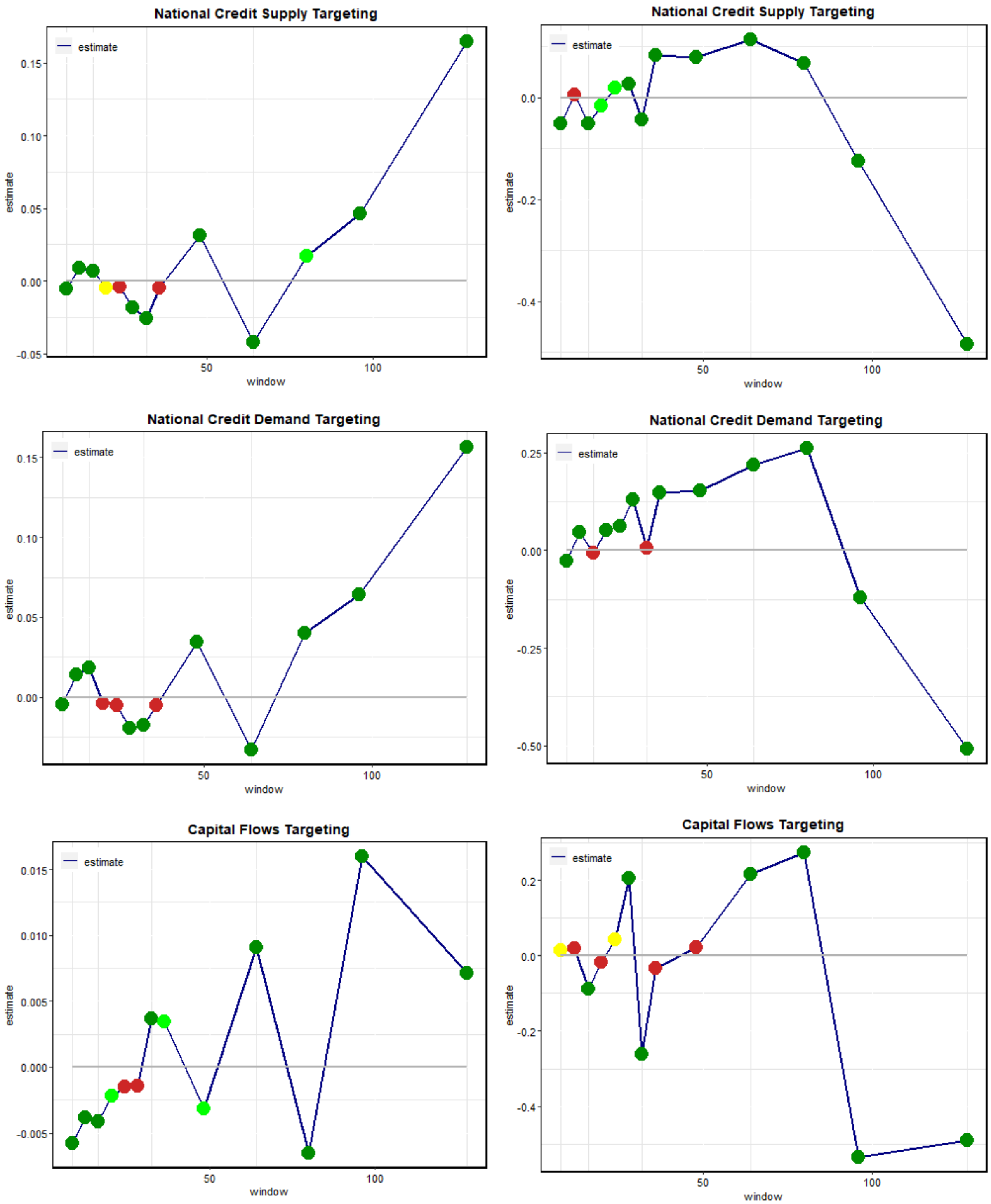


Figure 2.5.1. Policy Experiments

This figure shows the model-implied finance co-movement slopes for the policy counterfactual, when the macro-prudential authorities target credit supply and credit demand at the national level, and when they target cross-border flows directly. The left column shows the estimate for gross flows and the right column the estimate for net flows. The x-axes measure the horizon over which the slope is calculated. The y-axes denote the estimated coefficient.

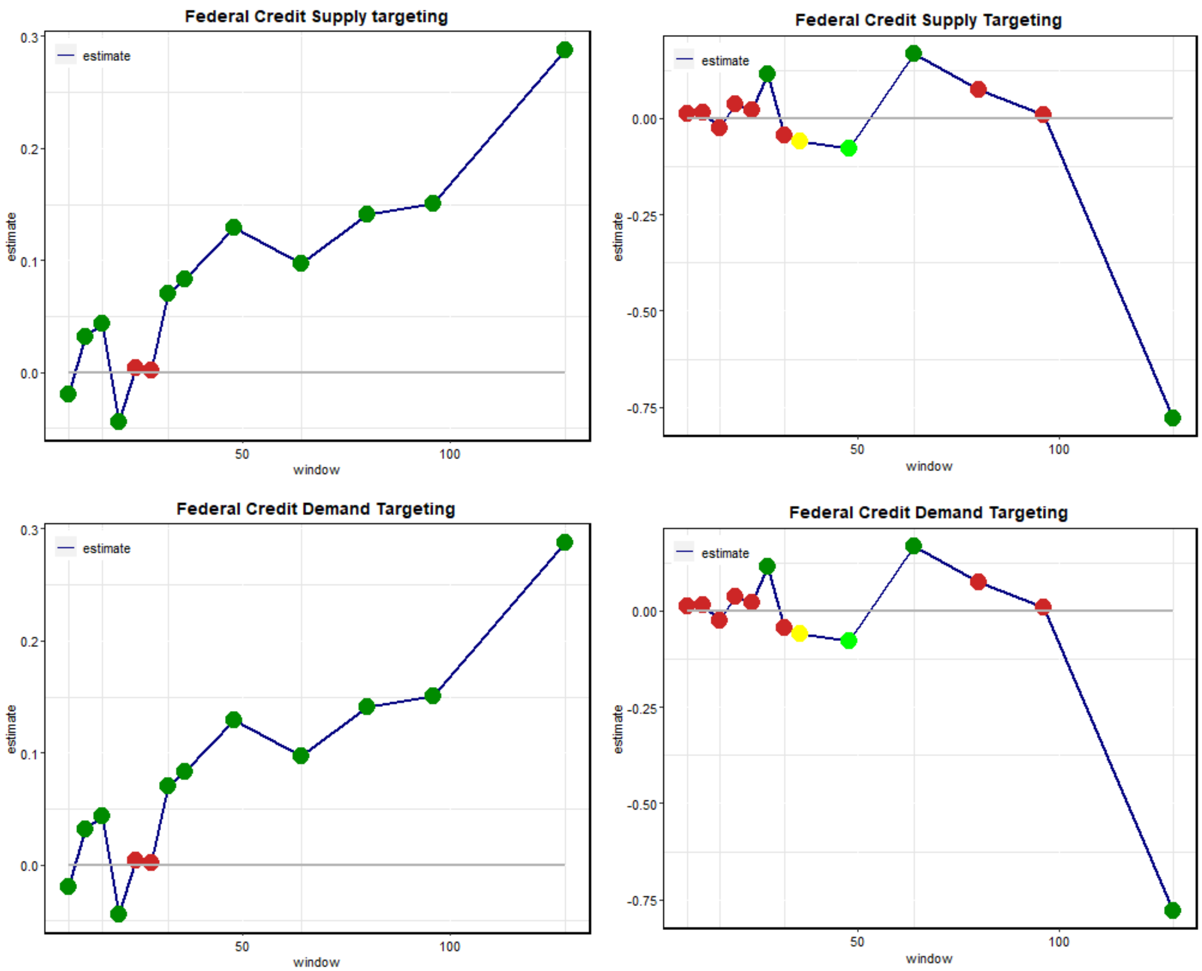


Figure 2.5.2. Policy Experiments

This figure shows the model-implied finance co-movement slopes for the policy counterfactual, when the macro-prudential authorities target credit supply and credit demand at the federal level. The left column shows the estimate for gross flows and the right column the estimate for net flows. The x-axes measure the horizon over which the slope is calculated. The y-axes denote the estimated coefficient.

Appendix

2.A Empirical Results: Robustness checks

The data from the JRC is data where gross financial stocks are used to estimate gross financial flows. This is practically impossible, as the change in gross financial stocks cannot be used to calculate the level of gross financial flows. At best, it can be used to calculate a lower bound for financial flows between the two countries. Assuming that this lower bound is a good proxy for actual bilateral capital flows, we can work with this. We construct the following measures:

- Undirectional intensity of gross capital flows:

$$F_1 = log(\frac{abs(Flows_{i \to j}) + abs(Flows_{j \to i})}{GDP_i + GDP_j}$$

- Undirected intensity of net capital flows

$$F_1 = log(\frac{abs(Flows_{i \to j} - Flows_{j \to i})}{GDP_i + GDP_j}$$

- External Imbalance

$$F_1 = log(\frac{abs(Stocks_{i\ in\ j}) - abs(Stocks_{i\ in\ j})}{GDP_i + GDP_j}$$

The first measure is an undirected measure of gross capital flows. It proxies the overall movements of capital between the two countries, but its construction implies the loss of information in which direction capital is flowing and the share of capital flowing in and out of either country. The second measure is the intensity of net capital flows between the two countries. This reveals how much more capital is flowing from country i to j than in the reverse direction. If one country insures another, it is likely that this becomes very large in response to shocks.

2.A.1 Robustness 1: Alternative measures for capital flows and financial cycle

The following two tables show robustness checks where we use the first principal component of the financial cycle variables (instead of the average). Additionally, we use the maximum instead of the sum of capital flows between two countries as the main regressor.

Table 2.A.1. Regression with principal component as financial cycle

	Dependent variable:							
	Financial Cycle Correlation (1st Principal Component)							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross capital flows	0.019*	0.050***	0.072***	0.104***	0.037	0.098*	0.140**	0.170***
	(0.011)	(0.016)	(0.022)	(0.030)	(0.034)	(0.050)	(0.055)	(0.058)
net capital flows	−0.019*	−0.014	−0.058***	−0.082***	−0.036	−0.046	−0.105*	−0.124**
	(0.010)	(0.016)	(0.021)	(0.029)	(0.033)	(0.053)	(0.057)	(0.056)
Observations	2,559	1,688	1,166	852	791	566	547	522
R^2	0.717	0.796	0.815	0.853	0.874	0.910	0.910	0.920

Here, the financial cycle is defined as the first principal component of the cyclical components of the three financial cycle variables. After this, the correlation of the two countries' principal components is calculated. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 2.A.2. Regression with maximum capital flows

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
Maximum Capital Flows	0.025	0.045*	0.059*	0.117**	0.031	0.131	0.112	0.146
	(0.017)	(0.026)	(0.035)	(0.049)	(0.052)	(0.085)	(0.092)	(0.097)
Net Capital Flows	−0.023*	−0.021	−0.061**	−0.104***	−0.046	−0.081	−0.110	−0.152*
	(0.014)	(0.021)	(0.028)	(0.040)	(0.043)	(0.074)	(0.081)	(0.083)
Observations	2,559	1,688	1,166	852	791	566	547	522
R^2	0.670	0.762	0.779	0.830	0.855	0.890	0.890	0.905

This table shows the regression results when the maximum capital flow is used instead of the sum of flows between the two countries. The regression includes country-pair fixed effects. The financial cycle is calculated as the average of the cyclical components of total credit volume, credit gap and house prices. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

2.A.2 Robustness 2: Subsample Estimates

Table 2.A.3. Regression for EMU countries

	Dependent variable:							
	Financial Cycle correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross capital flows	0.046*	0.087**	0.187***	0.277***	0.202***	0.378***	0.362**	0.450***
	(0.025)	(0.037)	(0.059)	(0.069)	(0.074)	(0.131)	(0.151)	(0.130)
net capital flows	−0.005	−0.046	−0.036	−0.220**	−0.103	−0.114	−0.141	−0.251
	(0.027)	(0.040)	(0.064)	(0.085)	(0.088)	(0.213)	(0.270)	(0.223)
Observations	329	216	148	113	103	68	68	68
R^2	0.845	0.863	0.843	0.891	0.912	0.931	0.929	0.941

This table shows the regression results for the benchmark regression run on the EMU subsample. The regression includes country-pair fixed effects. The financial cycle is calculated as the average of the cyclical components of total credit volume, credit gap and house prices. *p<0.1; **p<0.05; ***p<0.01

Table 2.A.4. Regression for non-EMU countries

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross capital flows	0.019	0.056***	0.088***	0.100***	0.033	0.140***	0.151***	0.129**
	(0.013)	(0.018)	(0.024)	(0.034)	(0.037)	(0.051)	(0.056)	(0.057)
net capital flows	−0.022*	−0.029	−0.077***	−0.091***	−0.033	−0.094*	−0.095	−0.130**
	(0.012)	(0.018)	(0.023)	(0.033)	(0.036)	(0.054)	(0.059)	(0.059)
Observations	2,230	1,447	1,001	758	697	472	453	429
R^2	0.630	0.776	0.789	0.824	0.856	0.913	0.911	0.933

This table shows the regression results for the benchmark regression run on the non-EMU subsample. The regression includes country-pair fixed effects. The financial cycle is calculated as the average of the cyclical components of total credit volume, credit gap and house prices. *p<0.1; **p<0.05; ***p<0.01

Table 2.A.5. Regression for OECD countries

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross capital flows	0.031***	0.051***	0.098***	0.120***	0.039	0.157***	0.184***	0.175***
	(0.012)	(0.018)	(0.025)	(0.033)	(0.038)	(0.056)	(0.062)	(0.062)
net capital flows	−0.024**	−0.029*	−0.079***	−0.080**	−0.050	−0.096	−0.139**	−0.139**
	(0.012)	(0.017)	(0.023)	(0.033)	(0.036)	(0.059)	(0.064)	(0.062)
Observations	2,147	1,419	973	710	665	475	457	446
R^2	0.710	0.789	0.798	0.840	0.863	0.895	0.894	0.909

This table shows the regression results for the benchmark regression specification run on the OECD subsample. The regression includes country-pair fixed effects. The financial cycle is calculated as the average of the cyclical components of total credit volume, credit gap and house prices.*p<0.1; **p<0.05; ***p<0.01

2.A.3 Robustness 3: Inclusion of more regressors

Table 2.A.6. Benchmark Regression with dummy for EMU

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross capital flows	0.023**	0.050***	0.070***	0.107***	0.035	0.114**	0.150**	0.163***
	(0.011)	(0.017)	(0.023)	(0.031)	(0.035)	(0.053)	(0.058)	(0.060)
net capital flows	−0.021*	−0.023	−0.068***	−0.094***	−0.047	−0.069	−0.133**	−0.145**
	(0.011)	(0.016)	(0.022)	(0.030)	(0.033)	(0.056)	(0.060)	(0.058)
monetary union dummy	0.859***	1.048***	0.885***	0.841***	0.867**	1.097**	0.920**	0.920*
	(0.180)	(0.226)	(0.265)	(0.293)	(0.366)	(0.446)	(0.453)	(0.470)
Observations	2,559	1,688	1,166	852	791	566	547	522
R^2	0.671	0.763	0.781	0.832	0.856	0.891	0.893	0.908

This table shows the results from the benchmark econometric model. Financial Cycle correlation, which is calculated over window sizes ranging from 8 to 36 quarters is regressed on gross capital flows, net capital flows and the bilateral imbalance of outstanding financial positions. Additionally, there are country-pair fixed effects and a dummy for country pairs that are within a monetary union. *p<0.1; **p<0.05; ***p<0.01

Table 2.A.7. Regression with dummy for GFC

	Dependent variable:						
	Financial Cycle Correlation						
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters
gross capital flows	0.022*	0.049***	0.067***	0.079***	0.034	0.095*	0.135**
	(0.011)	(0.017)	(0.023)	(0.028)	(0.034)	(0.054)	(0.057)
net capital flows	−0.019*	−0.023	−0.071***	−0.060**	−0.036	−0.041	−0.097
	(0.011)	(0.016)	(0.022)	(0.028)	(0.033)	(0.058)	(0.062)
monetary union	0.886***	1.043***	0.843***	1.021***	0.935***	1.174***	1.069**
	(0.180)	(0.226)	(0.262)	(0.267)	(0.360)	(0.446)	(0.455)
crisis dummy	−0.083***	0.050**	0.112***	−0.234***	−0.096***	0.061*	0.089**
	(0.023)	(0.024)	(0.024)	(0.023)	(0.025)	(0.033)	(0.042)
Observations	2,559	1,688	1,166	852	791	566	547
R^2	0.673	0.764	0.787	0.861	0.860	0.892	0.895

In this model, we also include a dummy for the period in which we have the Great financial crisis to see if there is any kind of reversal of effect. Because this dummy is much more precise in the equations where the time windows are shorter, the estimates of those are more reliable in this context. *p<0.1; **p<0.05; ***p<0.01

Regression with interaction effects

	Dependent variable:						
	Financial Cycle Correlation						
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters
gross capital flows	0.024**	0.053***	0.088***	0.104***	0.054	0.066	0.045
	(0.012)	(0.018)	(0.024)	(0.032)	(0.037)	(0.067)	(0.086)
net capital flows	−0.022*	−0.026	−0.095***	−0.091***	−0.068*	−0.083	−0.012
	(0.012)	(0.017)	(0.024)	(0.032)	(0.037)	(0.071)	(0.094)
monetary union	0.871***	1.051***	0.817***	0.975***	0.856**	0.692	1.074**
	(0.180)	(0.226)	(0.262)	(0.267)	(0.359)	(0.463)	(0.491)
crisis	0.121	−0.016	0.221**	0.003	0.180*	0.568***	0.141
	(0.093)	(0.096)	(0.097)	(0.097)	(0.106)	(0.161)	(0.202)
gross capital flows × crisis	−0.009	−0.031	−0.114**	−0.060	−0.064	−0.061	0.135
	(0.032)	(0.043)	(0.050)	(0.052)	(0.063)	(0.089)	(0.105)
net capital flows × crisis	0.034	0.022	0.123**	0.088	0.096	0.121	−0.124
	(0.033)	(0.044)	(0.051)	(0.054)	(0.065)	(0.093)	(0.109)
Observations	2,559	1,688	1,166	852	791	566	547
R^2	0.673	0.764	0.788	0.863	0.863	0.898	0.897

This regression includes the interaction between capital flows and the Great Financial Crisis to check if there is some sort of reversal effect. Additionally, we add interaction effects between the crisis dummy and the capital flows regressors. In the regressions with crisis dummy, we drop the longest 36 quarter regression, as it is impossible to pinpoint the GFC to either period. These interaction effects are largely insignificant and likely pollute the other estimates. *p<0.1; **p<0.05; ***p<0.01

Table 2.A.8. Regression with outstanding stocks

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross stocks	-0.066^{***}	-0.032	-0.170^{***}	-0.162^{***}	-0.168^{***}	-0.140^{**}	-0.220^{***}	-0.278^{***}
	(0.019)	(0.025)	(0.030)	(0.042)	(0.039)	(0.065)	(0.063)	(0.062)
net stocks	0.011	0.011	0.037^{*}	0.043	0.044	0.094^{**}	0.064	0.074
	(0.012)	(0.016)	(0.020)	(0.027)	(0.028)	(0.046)	(0.047)	(0.046)
monetary union	0.725^{***}	0.849^{***}	0.596^{**}	0.562^{**}	0.689^{**}	0.890^{**}	0.538	0.424
	(0.176)	(0.217)	(0.247)	(0.260)	(0.329)	(0.372)	(0.367)	(0.346)
Observations	2,559	1,688	1,166	852	791	566	547	522
R^2	0.672	0.762	0.787	0.833	0.862	0.891	0.897	0.915

This model uses outstanding capital stocks instead of flows. The procedure to calculate the finance co-movement slope is otherwise exactly as in the tables above. *p<0.1; **p<0.05; ***p<0.01

Table 2.A.9. Regression with stocks and flowss

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross flows	0.017^{*}	0.040^{***}	0.055^{***}	0.065^{***}	0.039	0.091^{**}	0.110^{***}	0.129^{***}
	(0.009)	(0.013)	(0.017)	(0.024)	(0.026)	(0.041)	(0.042)	(0.046)
gross stocks	-0.063^{***}	-0.038^{*}	-0.160^{***}	-0.137^{***}	-0.141^{***}	-0.093^{*}	-0.199^{***}	-0.239^{***}
	(0.016)	(0.020)	(0.025)	(0.033)	(0.030)	(0.054)	(0.048)	(0.046)
monetary union	0.789^{***}	1.036^{***}	0.809^{***}	0.838^{***}	0.820^{**}	1.177^{***}	1.022^{**}	1.020^{**}
	(0.180)	(0.225)	(0.259)	(0.286)	(0.353)	(0.419)	(0.420)	(0.422)
Observations	2,559	1,688	1,166	852	791	566	547	522
R^2	0.672	0.763	0.789	0.835	0.862	0.891	0.899	0.918

This regression uses both stock and flow intensity as regressors. While gross flows exhibit the same properties as in the benchmark regression, gross outstanding stocks significantly decrease financial synchronization. *p<0.1; **p<0.05; ***p<0.01

Table 2.A.10. Regression with higher order moments

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross flows mean	0.017*	0.029**	0.030*	0.037	0.006	0.042	0.036	0.061
	(0.009)	(0.014)	(0.017)	(0.026)	(0.027)	(0.044)	(0.043)	(0.049)
gross flows std.dev.	0.011	−0.017	0.001	−0.016	0.004	−0.016	−0.100*	−0.085
	(0.012)	(0.018)	(0.023)	(0.033)	(0.035)	(0.054)	(0.057)	(0.060)
flows evolution	0.004	−0.003	0.006	−0.001	−0.009	−0.025**	−0.013	−0.019
	(0.005)	(0.006)	(0.007)	(0.009)	(0.008)	(0.012)	(0.014)	(0.015)
monetary union	25.285***	3.945	43.227***	29.045***	25.781***	20.559**	42.141***	38.932***
	(3.290)	(3.983)	(4.898)	(6.456)	(5.421)	(9.165)	(8.568)	(7.508)
year	−0.012***	−0.001	−0.021***	−0.014***	−0.012***	−0.010**	−0.020***	−0.019***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.005)	(0.004)	(0.004)
Observations	2,559	1,688	1,166	852	791	566	547	522
R^2	0.678	0.763	0.798	0.835	0.862	0.894	0.904	0.920

This table shows the results from the regressions when more moments than the average capital flow over each time window is included. As additional regressors, we here have the standard deviation of gross capital flows over the time window and the difference between the last value and the first value (flows evolution). The table shows that these regressors are usually not significant. *p<0.1; **p<0.05; ***p<0.01

Table 2.A.11. Regression with higher order moments for EMU subsample

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross flows mean	0.052**	0.044	0.173***	0.108*	0.140**	0.239*	0.266*	0.307**
	(0.023)	(0.034)	(0.053)	(0.061)	(0.063)	(0.120)	(0.139)	(0.122)
gross flows std.dev.	0.025	−0.045	0.026	−0.182*	0.012	−0.213	−0.089	−0.165
	(0.030)	(0.043)	(0.082)	(0.099)	(0.092)	(0.213)	(0.251)	(0.184)
gross flows evolution	0.006	−0.019	0.007	0.022	−0.037	−0.024	0.028	−0.077
	(0.012)	(0.015)	(0.024)	(0.025)	(0.023)	(0.046)	(0.047)	(0.063)
Observations	329	216	148	113	103	68	68	68
R^2	0.846	0.864	0.843	0.887	0.914	0.936	0.929	0.943
Adjusted R^2	0.819	0.825	0.768	0.803	0.839	0.781	0.760	0.805

This table shows the results from the regressions when more moments than the average capital flow over each time window is included. As additional regressors, we here have the standard deviation of gross capital flows over the time window and the difference between the last value and the first value (flows evolution). The table shows that these regressors are usually not significant.Describe here in detail how all the higher order moments were calculated. This is the subsample with only EU countries. *p<0.1; **p<0.05; ***p<0.01

Table 2.A.12. Regression with higher order moments for non-EMU subsample

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross flows mean	0.004	0.030**	0.029	0.030	0.003	0.054	0.065	0.037
	(0.010)	(0.015)	(0.019)	(0.028)	(0.029)	(0.042)	(0.046)	(0.053)
gross flows std.dev.	0.0004	−0.017	−0.019	−0.030	−0.010	0.003	−0.079	−0.060
	(0.013)	(0.019)	(0.025)	(0.038)	(0.039)	(0.051)	(0.059)	(0.062)
gross flows evolution	0.003	−0.006	0.012	0.002	−0.012	−0.034***	−0.003	−0.019
	(0.006)	(0.006)	(0.008)	(0.009)	(0.009)	(0.012)	(0.014)	(0.016)
Observations	2,230	1,447	1,001	758	697	472	453	429
R^2	0.629	0.776	0.786	0.821	0.856	0.916	0.910	0.932

This table shows the results from the regressions when more moments than the average capital flow over each time window is included. As additional regressors, we here have the standard deviation of gross capital flows over the time window and the difference between the last value and the first value (flows evolution). The table shows that these regressors are usually not significant. This is calculated from the subsample with only non-EMU countries. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 2.A.13. Regression with more variables

	Dependent variable:							
	Financial Cycle Correlation							
	8 quarters	12 quarters	16 quarters	20 quarters	24 quarters	28 quarters	32 quarters	36 quarters
gross capital flows	0.023**	0.050***	0.070***	0.107***	0.035	0.114**	0.150**	0.163***
	(0.011)	(0.017)	(0.023)	(0.031)	(0.035)	(0.053)	(0.058)	(0.060)
net capital flows	−0.021*	−0.023	−0.068***	−0.094***	−0.047	−0.069	−0.133**	−0.145**
	(0.011)	(0.016)	(0.022)	(0.030)	(0.033)	(0.056)	(0.060)	(0.058)
monetary union	0.653***	0.453*	0.559*	0.583*	0.779*	0.688	0.632	0.530
	(0.221)	(0.260)	(0.299)	(0.349)	(0.403)	(0.421)	(0.425)	(0.411)
common border	−0.201	−0.376	−0.351	−0.531	−0.030	−0.160	−0.136	−0.350
	(0.292)	(0.333)	(0.379)	(0.521)	(0.496)	(0.517)	(0.575)	(0.554)
common language	−0.276	−1.295**	−0.645	−0.679	0.065	−0.665	−0.526	−0.922
	(0.451)	(0.505)	(0.590)	(0.840)	(0.805)	(0.913)	(0.928)	(0.931)
geographical distance	0.0001	0.0003***	0.0002	0.0001	0.00005	0.0002	0.0002	0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Observations	2,559	1,688	1,166	852	791	566	547	522
R^2	0.671	0.763	0.781	0.832	0.856	0.891	0.893	0.908

This table shows the results the model when more regressors that capture geographic or cultural characteristics are included. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

2.B Model

2.B.1 Model Description

Time is discrete. There are two countries, home and foreign, indexed $i \in \{h, f\}$. The structure of the economy is identical in both countries, differences only arise from the parameterization. In each country, there are 8 different agents: households, firms, labour unions, retailers, capital producers, entrepreneurs, banks, and macroprudential authorities. Additionally, there is one central bank that sets a policy rate for the monetary union, of which both countries are members.

Households: The households consume final goods, work in the firm and deposit their savings with banks.

$$maxE_t \sum_{s=0}^{\infty} \beta^{\tau} exp(\epsilon^U_{i,t+s} \Big(log(C_{i,t+s} - h^C C_{i,t+s-1}) - \frac{\chi_i}{(1+\sigma_i^H} H_{i,t+s}^{1+\sigma_i^H} \Big)$$

The budget constraint is:

$$w^h_{i,t} H_{i,t} + D^d_{i,t-1} \frac{(1 + R^D_{i,t-1})}{1 + \pi_{i,t}}^C + \Pi_{i,t} = C_{i,t} + D^d_{i,t} + t_{i,t} + p_{i,t} AC^D_{i,t}$$

Its consumption basket is:

$$C_{i,t} = \Big((1 - \alpha_i^C)^{1/\mu} C_{hi,t}^{(\mu-1)/\mu} + (\alpha_i^C)^{1/\mu} C_{fi,t}^{(\mu-1)/\mu} \Big)^{\mu/(\mu-1)}$$

Firms: The firms' production function is:

$$Y_{i,t} = exp(\epsilon^A_{i,t})(K^u_{i,t})^{\alpha}(H^d_{i,t})^{1-\alpha}$$

At first, the firm chooses a value of capital $K^u_{i,t}$ and labour demand $H^d_{i,t}$ to maximize its profits. After this, the firm sets its price by solving a Calvo problem:

$$E_t \sum_{s=0}^{\infty} (\theta_i^P)^s_{i,t+s} \Big[\frac{P^*_{i,t}}{P^C_{i,t+s}} \Pi^S_{k=1} (1 + \pi_{i,t+s+1})^{\xi_i^p} - exp(\epsilon^p_{i,t+s}) mc_{i,t+s} \Big] Y_{i,t+s}$$

Entrepreneurs: Entrepreneurs own the capital stock of the economy and rent it out to the firms. They finance themselves through their own net worth and through loans they receive from the banks. For this, they have to pay an external finance premium a la Bernanke et al. (1999). When the value of an entrepreneur's investment project drops below his net worth, the entrepreneur defaults. The firms' balance sheet is given by:

$$q_{i,t}K_{i,t} = L^H_{i,t} + N_{i,t}$$

where $q_{i,t}$ is the shadow value of capital, $L_{i,t}$ are corporate loans and $N_{i,t}$ is the entrepreneur's net worth. Entrepreneurs hence maximize their profit function by choosing the optimal amount of capital:

$$\Pi^E_{i,t} = E_t\{\eta^E_{i,t+1}[g(\bar{\omega}_{i,t+1})(1 + R^k_{i,t+1})q_{i,t}K_{i,t} - (1 + P^L_{i,t}L^H_{i,t}]$$

where $\bar{\omega}_{i,t+1}$ is the threshold of investment projects which is successful at the steady state.

Capital Goods Producers: Capital producers purchase intermediate goods as investments, which they install and sell as capital goods to the entrepreneurs. The law of motion of capital is:

$$K_{i,t} = (1 - S((exp(\epsilon^I_{i,t})I_{i,t}/I_{i,t-1}))I_{i,t} + (1 - \delta)K_{i,t-1}$$

where $\epsilon^I_{i,t}$ is a shock to installation costs and Poutineau and Vermandel (2017) adopt the adjustment cost function S of Smets and Wouters (2007) which is $S = \chi^I_i(x_t - 1)^2$, with $\chi^I_i > 0$ the adjustment cost. Investment is composed of domestic and foreign goods through the aforementioned CES aggregator. The representative capital supplier then chooses the level of investment $I_{i,t}$ to maximize.

$$max \sum_{s=0}^{\infty} \Lambda_{i,t+s}(q_{i,t+s}(1 - S(exp(\epsilon^I_{i,t})I_{i,t}/I_{i,t-1})) - p_{i,t+s})I_{i,t+s}$$

where $q_{i,t}$ is the shadow value of the investment good. Capital utilization is given by $a'(u_t) = Z_{i,t}$ with

$$a(u_{i,t}) = \bar{Z}(u_{i,t} - 1) + 0.5\psi_i/(1 - \psi_i)\bar{Z}(u_{i,t} - 1)^2$$

Capital installation takes one period so that $K^u_{i,t} = u_{i,t}K_{i,t-1}$.

Banks: Banks raise funds from depositors and give loans to entrepreneurs and to other banks. Additionally, with probability λ, banks have access to funds from the central bank. In this case they are called "liquid". Illiquid banks must instead borrow on the interbank market to raise funds on top of deposits. Liquid and illiquid banks in country i have the following balance sheets:

$$L^s_{i,t} + IB^s_{i,t} = L^{ECB}_{i,t} + BK^{liq}_{i,t} + D_{i,t} + liab^{liq}_{i,t}$$
$$L^s_{i,t} = IB^H_{i,t} + BK^{ill}_{i,t} + D_{i,t} + liab^{ill}_{i,t}$$

Profits of the illiquid banks are:

$$\Pi^{ill}_{i,t} = [1-\mu^B(1-E_t\eta_{i,t+1})](1+R^L_{i,t})L^s_{i,t} - (1+R^D_{i,t})D_{i,t} - (1+P^{IB}_{i,t})IB^H_{i,t}$$
$$- (1+R_t)liab^{ill}_{i,t} - F(rwa^{ill}_{i,t} - \nu_{i,t})BK^{ill}_{i,t}$$

Profits of the liquid banks are:

$$\Pi^{liq}_{i,t} = [1-\mu^B(1-E_t\eta_{i,t+1})](1+R^L_{i,t})L^s_{i,t} - (1+R^D_{i,t})D_{i,t} - (1+P^{IB}_{i,t})IB^s_{i,t}$$
$$- (1+R_t)liab^{liq}_{i,t} - (1+R_t)L^{CB}_{i,t} - F(rwa^{liq}_{i,t} - \nu_{i,t})BK^{liq}_{i,t}$$

$F_i(.)$ denotes the cost function associated with the capital requirement, which is taken from Gerali et al. (2010), defined as $F_i(x) = 0.5\chi^k x^2$ and $rwa_{i,t} = BK_{i,t}/L^s_{i,t}$.

Monetary policy: There is a single central bank that sets the interest rate for both countries. It does so according to the Taylor Rule:

$$R_t - \bar{R} = \rho(R_{t-1} - \bar{R}) + (1-\rho)(\phi^\pi \pi^C_t + \phi^C_t + \phi^{\Delta y}(Y_t - Y_{t-1})) + \epsilon^R_t$$

where ϵ^R_t is a monetary shock and the $\phi^\pi, \phi^{\Delta y}$ are the parameters of the Taylor Rule.

Macro-prudential policy: The macro-prudential policy instrument is a capital requirement $\nu_{i,t}$ that raises the marginal costs of banks. The macro-prudential authority sets this capital buffer according to the following policy rule:

$$\nu_{i,t} = (1-\rho^\nu_i)\bar{\nu} + \rho^\nu_i \nu_{i,t-1} + \phi(T_{i,t} - \bar{T_{i,t}})$$

where $\bar{T_{i,t}}$ is the macro-prudential target. This macro-prudential target can take the form of credit supply $L^s_{i,t}$, credit demand $L^d_{i,t}$ or cross-border capital flows.

Market Clearing: As outlined in Poutineau and Vermandel (2017) the market clearing conditions in the markets for final goods, corporate loans and interbank loans are:

$$Y_{c,t}/\Delta^p_{c,t} = (1-\alpha^c_c C)[P_{c,t}/P^C_{c,t}]^{-\mu} C_{ct} + (1-\alpha^I_c)[P_{c,t}/P^I_{c,t}]^{-\mu} I_{c,t} + (1-n)/n(\alpha^C_p[P_{c,t}/P^C_{p,t}]^{-\mu} C_{p,t} + \alpha^I_p[P_{c,t}/P^I_{p,t}]^{-\mu} I_{p,t})$$
$$+ a(u_{c,t})K_{c,t-1} + g\bar{Y}exp(\epsilon^G_{c,t}) + AC^D_{c,t}$$
$$L^s_{c,t}/\Delta^L_{c,t} = (1-\alpha^L_c)[(1+R^L_{c,t}/(1+P^L_{c,t}]^{-\nu} L_{c,t} + n/(1-n)\alpha^L_p[(1+R^L_{c,t})/(1+P^L_{p,t})]^{-\nu} L_{p,t}$$
$$IB^s_{c,t}/(1-\lambda)/\lambda = (1-\alpha^{IB}_c)[(1+R^{IB}_{c,t}/(1+P^{IB}_{c,t}]^{-\xi} IB^d_{c,t} + n/(1-n)\alpha^{IB}_p[(1+R^{IB}_{c,t})/(1+P^{IB}_{p,t})]^{-\xi} IB^d_{p,t}$$

Stochastic Process: There are 10 country-specific shocks, and the monetary shock that applies to

Table 2.B.1. Persistences and Standard Errors

Parameter	Description	country H	country F
ρ_a	persistence TFP shock	0.9795	0.9885
ρ_g	persistence government spending shock	0.8908	0.5493
ρ_u	persistence utilization shock	0.2197	0.8926
ρ_i	persistence inv. adj. cost shock	0.8741	0.8699
ρ_p	persistence markup shock retailers	0.9965	0.7306
ρ_w	persistence markup shock labor unions	0.3901	0.1365
ρ_n	persistence entrepreneurial net worth shock	0.8703	0.9345
ρ_d	persistence deposit markdown shock	0.8886	0.9001
ρ_b	persistence bank capital shock	0.9580	0.9705
ρ_l	persistence loans markup shock	0.6406	0.6422
ρ_r	persistence monetary shock	0.3828	0.3828
ρ_a	standard error TFP shock	0.8175	0.5143
η_g	standard error government spending shock	1.3901	1.3778
η_u	standard error utilization shock	0.9806	1.0690
η_i	standard error inv. adj. cost shock	3.1964	3.5353
η_p	standard error markup shock retailers	0.0842	0.2802
η_w	standard error markup shock labor unions	0.4394	0.7056
η_n	standard error entrepreneurial net worth shock	0.3161	0.2896
η_d	standard error deposit markdown shock	0.2648	0.5917
η_b	standard error bank capital shock	5.6563	9.0982
η_l	standard error loans markup shock	2.0871	1.8896
η_r	standard error monetary shock	0.0852	0.0852

This table shows the persistences and standard errors parameterization of the model. All values are taken from Poutineau and Vermandel (2017).

both countries. All shocks follow an AR(1) process:

$$\epsilon^s_{i,t} = \rho^S \epsilon^S_{i,t-1} + \eta^S_{i,t}$$

with $\eta^S_{i,t} \sim N(0, \sigma^S_i)$.

Table 2.B.2. Parametrization

Parameter	Description	country H	country F
α	share of capital in production function	0.38	0.38
β	discount factor	0.9901	0.9901
R^D	deposit rate	0.01	0.01
R	Central bank policy rate	0.0142	0.0142
δ	depreciation rate	0.025	0.025
G/Y	steady state government spending	0.24	0.24
χ_D	portfolio adjustment cost	0.07	0.07
μ	substitutability final goods	1.4186	1.4186
μ_L	substitutability loans	1.001	1.001
η_E	leverage ratio entrepreneurs	0.4	0.4
η_B	leverage ratio banks	0.1	0.1
R_L	steady state credit rate	0.0192	0.0192
μ_B	recovery cost	0.1	0.1
ϵ_p	elasticity of substitution goods	10	10
ϵ_w	elasticity of substitution labor	10	10
ω_{min}	minimum bound pareto distribution	0.6	0.6
κ	shape value pareto distribution	2.5	2.5
Q	steady state asset price	1	1
H	hours worked	1	1
n	relative size home country	0.58	0.42
dls	share of deposits in bank liabilities	0.4690	0.4690
bkls	share of capital in bank liabilities	0.1	0.1
ibls	share of interbank loans in bank liabilities	0.55	0.55
shockls	share of unmodeled liabilities	0.25	0.25
ν_L	substitution loan varieties	0.1	0.1
ν_{IB}	substitution interbank varieties	0.1	0.1
χ_K	bank capital adjustment cost	11	11
λ	share of illiquid banks	0.45	0.45
h_C	habit formation consumption	0.5	0.5
h_L	habit formation corporate loans	0.7785	0.9181
h_B	habit formation interbank loans	0.2368	0.0954
χ_I	capital adjustment costs	5.739	5.6657
α_C	share of foreign consumption goods	0.0911	0.1081
α_I	share of foreign investment goods	0.0450	0.0662
α_{IB}	share of foreign interbank loans	0.3780	0.3215
α_L	share of foreign corporate loans	0.0418	0.1152
ρ	Taylor rule smoothing	0.8255	0.8255
ϕ_π	Taylor rule inflation	1.5376	1.5376
ψ	Taylor rule output	0.7151	0.6559
θ_P	Calvo parameter prices	0.7517	0.7309
θ_w	Calvo parameter wages	0.8729	0.8922
θ_L	Calvo parameter loans	0.7391	0.7623
θ_D	Calvo parameter deposits	0.7901	0.7296
ξ_p	Taylor rule output	0.1701	0.1852
ξ_w	Taylor rule output	0.4917	0.1867

This table shows the benchmark parameterization of the model. All values are taken from Poutineau and Vermandel (2017).

2.B.2 Experiment: Market Analysis

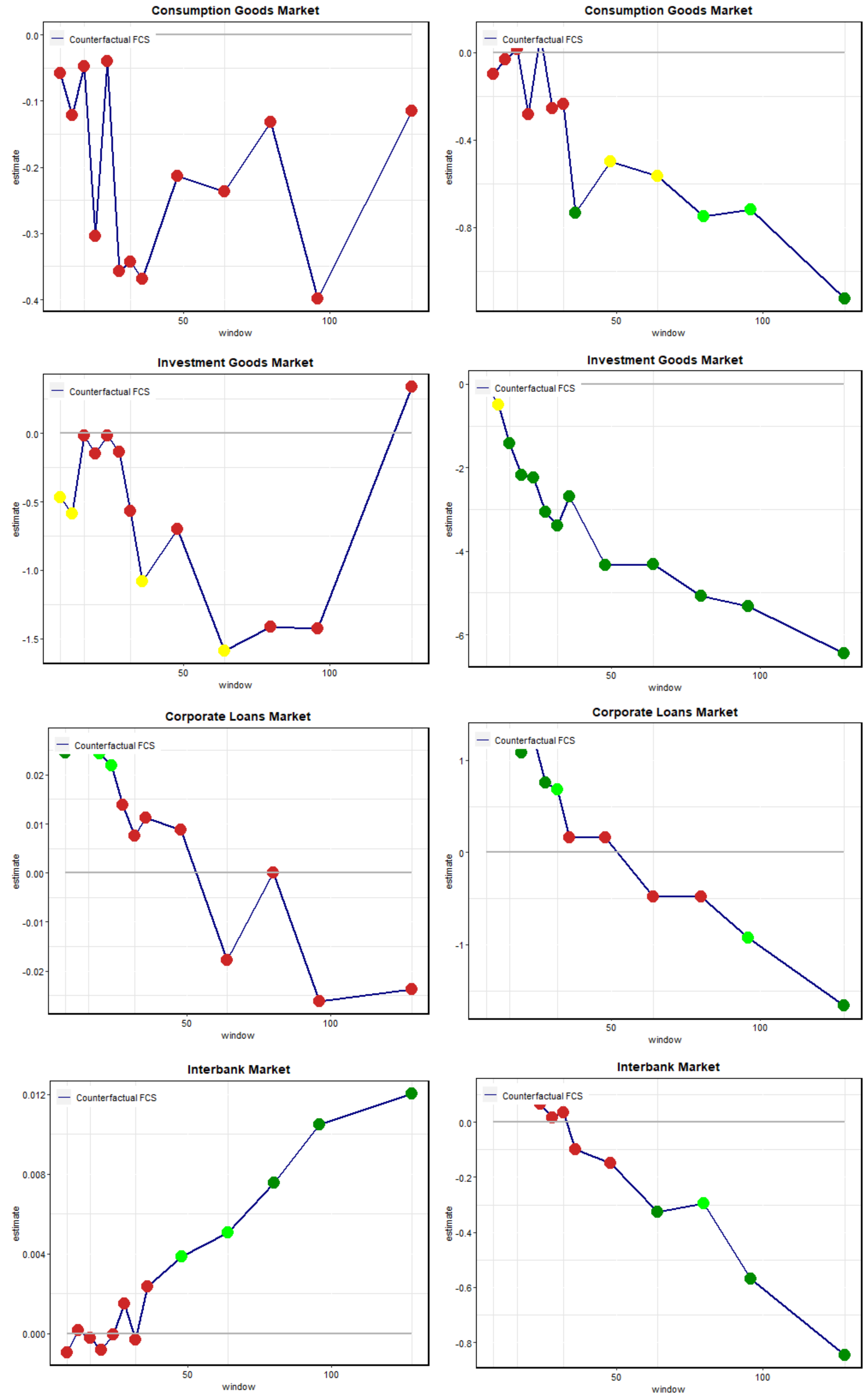


Figure 2.B.1. Model-implied Finance Co-Movement Slopes in different markets

This figure plots the model-implied finance co-movement slopes when only one market is integrated internationally.

2.B.3 Experiment: Shock Analysis

This subsection plots the impulse response functions (IRFs) of the model following the arrival of a specific shock. In each case, we plot only the IRFs of the levels of gross capital flows, net capital flows and financial cycle synchronization. Here, financial cycle synchronization is measured over a window of five periods.

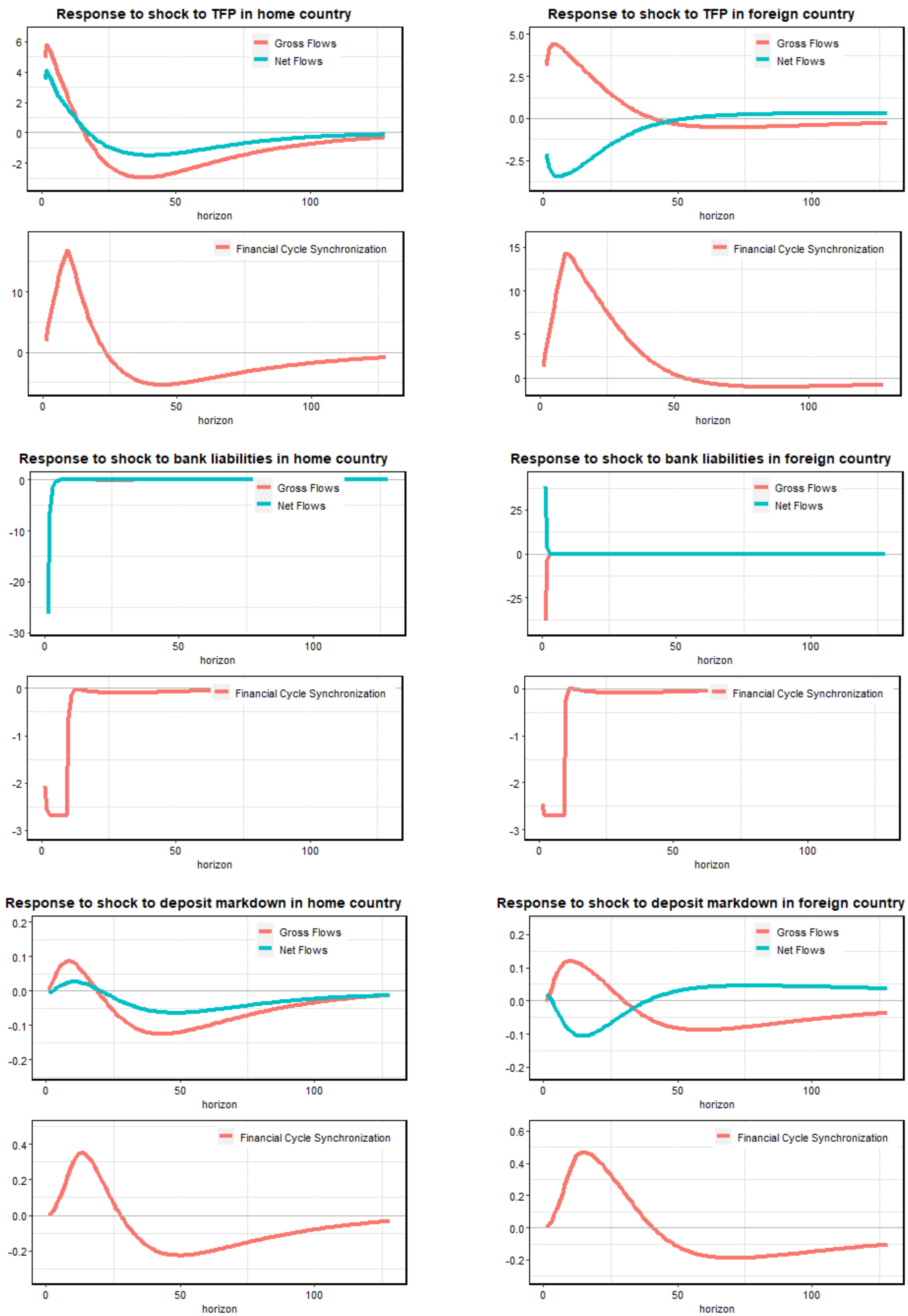


Figure 2.B.2. Shock Analysis 1

These figures plot the evolution of gross and net capital flows (top panel) and financial synchronization following a one-standard-deviation shock to the respective variable. The x-axis measures the time after the arrival of the shock. The y-axis denotes the deviation of the variable from steady state.

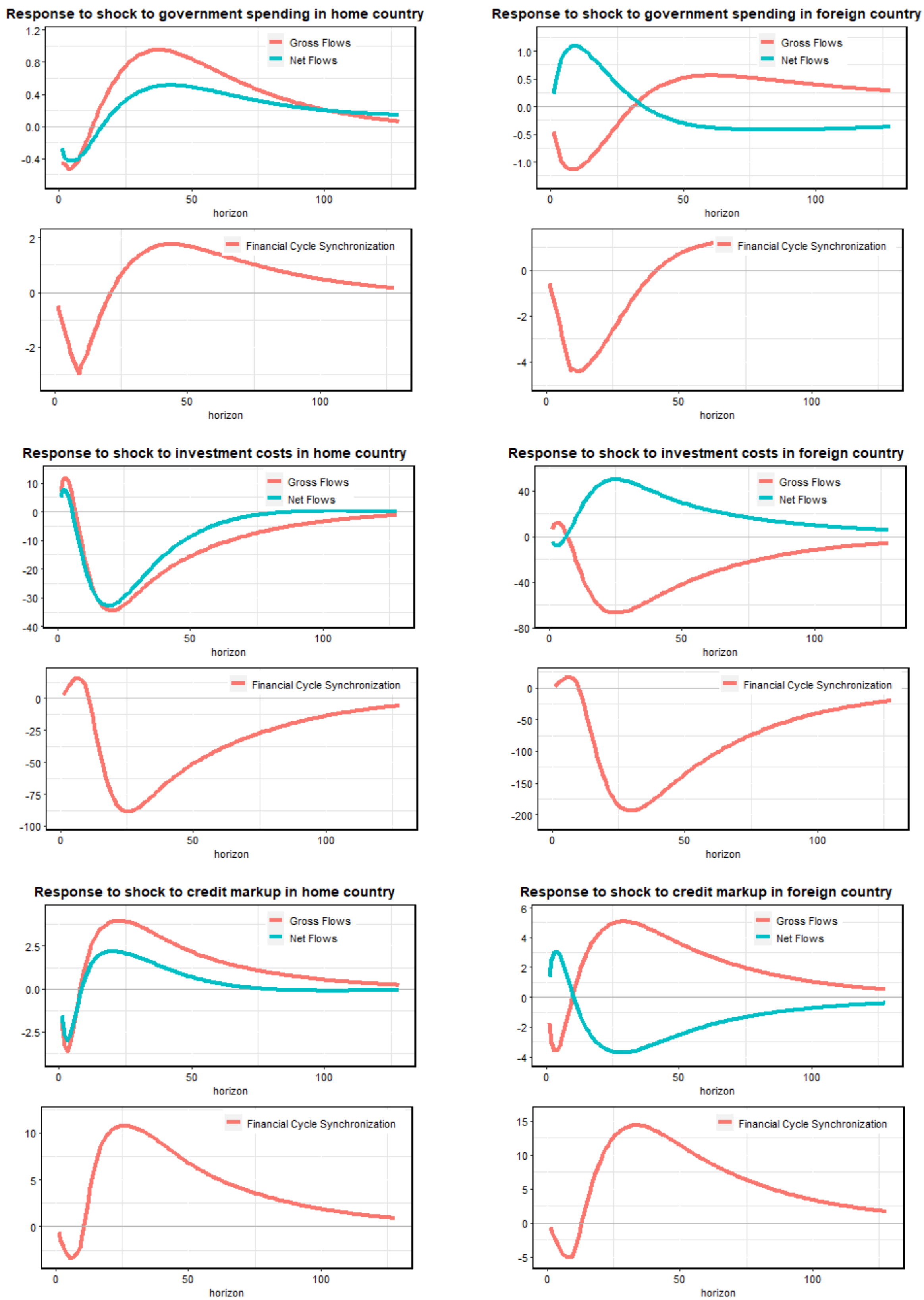


Figure 2.B.3. Shock Analysis 2

These figures plot the evolution of gross and net capital flows (top panel) and financial synchronization following a one-standard-deviation shock to the respective variable. The x-axis measures the time after the arrival of the shock. The y-axis denotes the deviation of the variable from steady state.

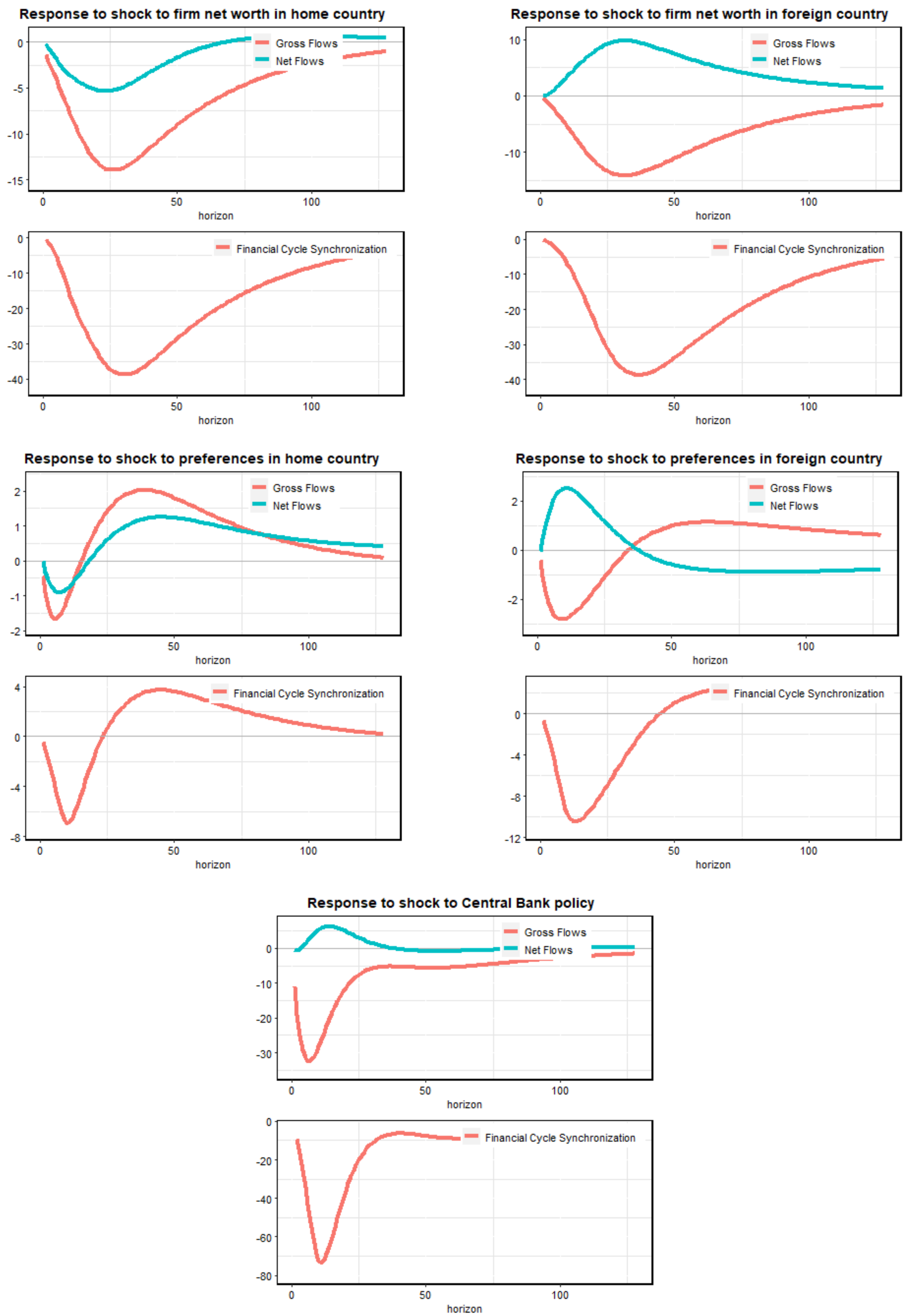


Figure 2.B.4. Shock Analysis 3

These figures plot the evolution of gross and net capital flows (top panel) and financial synchronization following a one-standard-deviation shock to the respective variable. The x-axis measures the time after the arrival of the shock. The y-axis denotes the deviation of the variable from steady state.

Chapter 3

Repeated Bailouts and Austerity

Friedrich Lucke[1,2]

Abstract

This paper studies the incidence of bailouts with the possibility that bailouts may be required repeatedly before the crisis is resolved. I build a model in which two countries engage in a strategic interaction over repeated bailouts and austerity. The strategic interaction ends when the country in crisis has either overcome the crisis or defaulted. Evaluating the properties of the Markov-equilibrium of the model, I show how the rescuing country trades off the costs of bailout with the spillover costs from default. I find that the fundamental conflict of interest over austerity arises over the speed of repayment of the failing country's debt. This finding suggests a new definition for austerity that distinguishes between a solvency and a liquidity dimension of a sovereign debt crisis.

JEL Classifications: E00, H00, H6, C72, C73

Sovereign Debt, Bailouts, Austerity

[1]I thank Fabrice Collard, Patrick Feve and Christian Hellwig, Franck Portier, Martial Dupaigne, Fernando Stipanicic, Philipp Wangner, Alexandre Gaillard and the participants of the TSE macro workshop, the ENTER conference and the CIREQ doctoral students colloquium for their helpful comments. All remaining errors are mine.

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3.1 Introduction

Between 2010 and 2018, Greece was unable to roll over its debt on the international credit market. As a result, to ensure the stability of the Eurozone and insure itself from spillovers, the EU-17 and the IMF put together three loan packages, split into multiple tranches of loans each, to prevent a sovereign default of Greece. During these efforts to stabilize Greece, indebtedness soared from 129% in 2010 to 170% in 2016 before slightly decreasing until 2018. While this rise was mostly associated with a decline in GDP rather than an increase in debt, the combination of the two prevented Greece from regaining enough trust of investors to refinance its debt on the international credit market until August 2018. From this development arises the first question that this paper intends to answer: How does a rescuing country or institution trade off the costs of default of a failing country against the costs of bailout when potentially multiple rounds of bailout are needed?

To limit the number of bailout rounds and achieve a quick recovery, in line with IMF custom, these rescue packages have been tied to structural reform by Greece. This has the aim to generate a primary budget surplus of 1.5%[3], ensure repayment of the loans and prevent the bailout program from turning into a system of transfers. These reforms, called the "Economic Adjustment Program for Greece", are a set of legislative milestones and policy recommendations that were verified before each new bailout tranche was paid out. These milestones are a combination of reductions in government spending, such as a reform of the pension system and a reduction of the bureaucratic apparatus, along with a set of tools to increase public revenue: An increase in the VAT, the privatization of several state enterprises and a number of laws to combat tax evasion, tax fraud, and corruption. Unsurprisingly, the anti-corruption and anti-tax-fraud measures found wide support from the general public. However, the tax increases and the reform of the pension system - which became known as "austerity" in the public debate - came at a cost to the population and were therefore widely criticized. As an alternative way to consolidate its budget, the Greek government asked the EU during the negotiations for investments in Greece - effectively transfers that would boost the Greek economic performance and spur growth. Either measure could pave the way to re-accessing the international credit markets. This leads to the second main question of this paper: What is austerity and who is it good for? The combination of these two questions adds a third interesting component: With each new round of bailout, the rescuer's stake in the crisis gets larger. This means that with each bailout tranche that is given out, his default option gets worse and so does his position to demand austerity measures from the failing country.

This paper builds a model to analyze a sovereign debt crisis in which a neighboring country takes the role of a rescuer. I make two contributions: Firstly, I compute the optimal repeated bailout strategy of a country that is exposed to spillover costs of default. I show how the rescuer trades

[3]Initially, the surplus threshold was 4.5%, but it was adjusted downwards with the implementation of the second bailout package.

off the cost of potentially repeated bailouts against the costs of letting the other country default and facing spillover costs. To the best of my knowledge, I am the first to analyze repeated bailouts in this form, i.e. with an increasing stake of the rescuer with each round. Herein, I show how the rescuer uses different instruments of bailout optimally. Secondly, I use the properties of the non-cooperative equilibrium to suggest a new definition of austerity. This definition splits austerity into two components, that address separately the problem of temporary illiquidity in a sovereign debt crisis, and the problem of long-run solvency issues; and it answers the question formulated above.

Related Literature: This section describes the large literature on sovereign debt, surveyed among others by Aguiar et al. (2014) and Mitchener and Trebesch (2021), and the previous papers that justify the modeling assumptions I use.

In particular, this model in this paper builds on the strand of the literature that studies sovereign debt crises that emerge from failures of sovereigns to roll over their debt in private credit markets, for instance, Arellano (2008). The combination of financial frictions with the strategic behavior of investors lead to self-fulfilling sovereign debt crises (Broner et al. (2010), Mink and De Haan (2013), Broner et al. (2014)). In theory, this literature often assumes sunspots according to which investors refuse to refinance the sovereign (Conesa and Kehoe (2015), Pancrazi et al. (2015) and Aguiar et al. (2014)). In practice, such a refusal leads to a spike in sovereign bond interest rates, which effectively makes a rollover impossible. In context of the European debt crisis Bianchi and Mondragon (2022) show that countries inside a monetary union are particularly vulnerable to this sort of crisis, as they do not have control over their own monetary policy.

When a rollover crisis occurs, three exit scenarios are possible: 1) The country in crisis decides to default or to restructure its debt (usually imposing a haircut on investors) and restarts with a lower debt burden. However, this scenario usually comes with a large output penalty (Furceri and Zdzienicka (2012), Trebesch and Zabel (2017), Borensztein and Panizza (2009)). 2) The country in crisis convinces its investors of its capacity and willingness to repay the debt, through fiscal reforms that increase (future) primary surpluses). If this is sufficient, the sovereign debt crisis can be resolved before it becomes acute. 3) An international third party decides to step in with a bailout. Interestingly, the second and third scenario are what Mitchener and Trebesch (2021) call "debt crises without default" which motivates Pescatori and Sy (2007) to question whether debt crises are accurately defined. I contribute to this literature by explicitly analyzing a looming rollover crisis, distinguishing between the three aforementioned scenarios. Mitchener and Trebesch (2021) describe how the international bailouts by exposed neighboring countries have become more frequent in recent times, beginning with the bailout of Mexico in 1994. The Eurozone crisis in the aftermath of the 2008-2009 financial crisis then renewed researchers' interest in the topic of bailouts and the approaches of the literature on bailouts were as multi-faceted as the bailout programs themselves:

Fink and Scholl (2016) extend the Arellano (2008) framework with the option to participate in an EFSF-type bailout program, that offers loans at better conditions than the financial market does. Roch and Uhlig (2016) propose a different type of bailout that resembles the OMT program of the European Central Bank: by infusing liquidity in the market they manage to kill the "default sunspot equilibrium" that arises in models of self-fulfilling debt crisis. Jeanne et al. (2008) propose another model that highlights the role of the IMF as an emergency lender to countries, that would otherwise have to liquidate profitable projects. Farhi and Tirole (2016) suggest that a bailout of both private and public sector may be necessary to prevent the one from dragging the other into a crisis.

The multitude of suggestions and implemented bailout programs originate from the fact the Greek sovereign debt crisis and the crises of other European countries consisted of several problems that have been widely covered in the sovereign debt literature: If this is the nature of the crisis, a monetary bailout as suggested by Roch and Uhlig (2016) would be appropriate to tackle the problem here.

The other problem, as put forward by Tirole (2015), Dellas and Niepelt (2014) and Farhi and Tirole (2016) is one of wrong incentives to incur debt levels that are unsustainable. In this case, an incentive scheme is required to prevent excessive debt incurrence. An EFSF-type bailout could help here to finance the failing country until the debt has been reduced. A common feature of the papers in this literature is the conditionality of bailout: A constraint on the consumption of the debtor - austerity - is imposed to ensure that sufficient resources are allocated to the repayment of debt.

However, the literature is split over whether bailouts are a good idea in practice and the empirical evidence is mixed: While the Mexican bailout of 1994 was very painless and Mexico evaded a default or debt restructuring, the Greek sovereign debt crisis included a debt restructuring despite the bailouts and came with a severe output reduction of the Greek economy Mitchener and Trebesch (2021). Fittingly, Chamley and Pinto (2011) make the argument that official bailouts that do not increase the present value of fiscal resources of the failing country, tend not to work and only increase the country's indebtedness. This paper incorporates these last points by setting up a scenario in which the sovereign debt crisis may need repeated bailouts that initially increase the country's debt level. Additionally, the resolution of the sovereign debt crisis depends on both bailout and austerity measures. Herefore, we specifically model the incentives of the rescuer - a feature from which the literature largely abstracts: Except for Jeanne et al. (2008), the previously cited papers remain agnostic to who the rescuer is, what its exposure to the crisis is and what intrinsic or extrinsic incentives motivate the bailout. In this paper, I specify that the rescuer is a neighboring country, whose motivation to rescue is to avoid spillover costs from a default. This is well in line with past experiences such as the US bailout of Mexico in 1994 and the EU bailout of

Greece in 2011-2015. This paper focuses on the problem of incentives[4]. Here, the failure of the exact rollover property through the refusal of the international credit market is the key driver of the sovereign debt crisis in my model. Because of a financial friction, a bailout is required, but the incentives of the failing country, along with an austerity constraint, determine how likely a re-access of the international credit market is. The methodology of this paper resembles the two-country model that Guler et al. (2014) propose, which is adapted to incorporate the financial friction and the conflicting interests over austerity and bilateral bailout loans. Hereby, this paper positions itself in the part of the literature that analyzes direct loans from another country or institution to the failing country. The paper also has similarities with Gourinchas et al. (2020).

The two-country analysis also yields the second contribution of the paper - a clearer definition of austerity. The existing literature has proposed defining the austerity as "reduction in consumption below the desired level" Dellas and Niepelt (2014). In this paper, instead, I proposes a two-tier definition of austerity that can distinguish between the solvency and liquidity dimension of the sovereign debt crisis. In its modeling of austerity to speed up recovery, the paper also connects to Muller et al. (2019).

The paper is structured as follows: Section 3.2 sets up the model. Section 3.3 computes the equilibrium and reviews its properties. The fourth section analyzes the implications of the equilibrium on austerity. The fifth section simulates the model and the 3.6 concludes.

3.2 Model

There are two players $i \in \{N, S\}$, the governments of countries North and South; and they play a game of infinite horizon. There is an international credit market whose behavior is entirely exogenous. From the beginning on, it refuses to roll over the debt of the South in every period, until the South reaches a primary budget balance for the first time[5]. If the South ever defaults, the international credit market refuses to roll over the South's debt forever after.

For simplicity, we assume that the North's endowment is constant $Y_t^N = A^N \forall t$ across periods while the South's endowment is volatile. Its endowment follows a Markov process (a, P, π_0) that has the following characteristics: The maximum value of the state-space is one: $max(a) = 1$. Further, the maximum value of the state-space is absorbing so that $P(A_t^S = max(a)|A_{t-1}^S = max(a)) = 1$. Finally, the distribution of initial states π_0 is such that the South does not reach the absorbing state in the first period. Further, the South's income is augmented by a productivity-enhancing transfer K - resources that the North spends in the South rather than at home. This spending of the North in the South, hereafter referred to as "transfer", increases the South's income like a productivity shifter: $Y_t^S = A_t^S(1 + K_t)$. I assume that all government spending (consumption and

[4] and abstracts from monetary mechanisms

[5] This condition can easily be generalized to any desired budget surplus requirement. Important is only that this conditions governs the probability that the South regains access to the credit market.

transfer) is rigid and always has to be set one period in advance. This friction is a key component of the model: It adds an illiquidity dimension to the sovereign debt crisis - by generating a temporary inability of a sovereign to repay creditors (even when the country is willing to repay).

Both countries enter each period observing the current state $X_t = \{b_t, B_t, g_t^N, A_t^S, g_t^S, K_t, Z_t\}$. b_t and B_t are the respective debt of North and South vis-a-vis the rest of the world, that need to be repaid in period t. g_t^N and g_t^S are the respective government spending levels and K_t is the current-period transfer that need to be financed. A_t^S is the productivity shock of the South. $Z_t \in \{0, 1\}$ is a dummy that is equal to 1 if the South has defaulted in any period up to the start of period t. Z starts with a value of 1 and stays at one if both North and South choose to offer and to participate in a bailout program. If the South at any point wants to or has to default, Z takes a value of zero forever after. The last four variables of the state-space jointly determine the events of a period as follows:

States	$A_t^S < \frac{g_t^S}{1+K_t}$	$A_t^S \geq \frac{g_t^S}{1+K_t}$
$Z_t = 0$	South has already defaulted	South has already defaulted
$Z_t = 1$	North needs to bail out South	South regains credit market access

The condition $A_t^S \geq \frac{g_t^S}{1+K_t}$ determines whether the South achieves a primary surplus in period t. As the productivity parameter A_t^S is chosen by nature, this is stochastic. However, the right-hand side of the condition is determined by the choices of North and South. Both a lower level of government spending g_t^S by the South and a higher transfer K_t by the North reduce the right-hand side value and thereby make it more likely that A_t will be sufficiently large.

I assume that if the South defaults, it loses access to credit forever after. When the South has not defaulted yet and it achieves a primary budget surplus, it regains access to the international credit market for the rest of time. If the South has not defaulted yet but does not have a primary budget surplus this period, a new bailout is needed immediately.

Having observed the state and calculated their needs for financing, the players proceed to choosing their actions: The South chooses its next-period spending g_{t+1}^S and the North its spending on consumption g_{t+1}^N and its transfer policy K_{t+1} for the next period. It is assumed that there is no possibility of deviating from these choices in period t+1. After observing these choices, the North chooses $Z_{t+1}^N \in \{0, 1\}$ which contains the decision whether to bail the South out. A bailout implies that the North buys up all the debt that the South needs to sell to finance its pre-set expenditure level. As in Fink and Scholl (2016) it is assumed that the interest rate on these emergency loans is equal to the risk-free rate r. The South chooses to default or to participate in the bailout if one has been offered, choosing $Z_{t+1}^S \in \{0, 1\}$. Then $Z_{t+1} = min(Z_{t+1}^N, Z_{t+1}^S)$, meaning that both players need to participate in a bailout to avoid the default. Once these decisions are made, the consumption and transfer and bailout take place.

Both countries receive an instantaneous utility of $u_t^i = log(g_t^i), i \in \{S, N\}$ from consumption. Additionally, the North pays a utility-denominated cost p whenever it bails out the South. If it does not bailout, the North suffers a utility-denominated spillover cost C in each period thereafter. As in Conesa and Kehoe (2015), the South's penalty of defaulting is that its income is reduced by a fraction $(1-\gamma)$ forever after. Future utilities are discounted with factor β.

To understand the model, it is critical to note the following: Bailout is an autonomous choice of the North while defaulting is an autonomous choice of the South. An offer of bailout does not necessarily rule out a default as it does not necessarily lead to a resolution of the crisis, i.e. a re-accessing of the credit market. It is possible that the North offers a bailout but the South defaults nevertheless. It is further possible that after a bailout today, a new bailout is required tomorrow and the absence of a bailout directly implies a default when the South is unable to repay its debt. On the flip side, the strategic interaction ends with the South reaccessing the international credit market by a choice of nature, a realization of a high-enough productivity value A_t^S.

From the assumption that at least a primary budget balance is required, we can derive the probability of the event that A_t^S is high enough as:

$$P(A_{t+1}^S(1+K_{t+1}) \geq g_{t+1}^S) = P(A_{t+1}^S \geq g_{t+1}^S/(1+K_{t+1})) = 1 - F_a(\frac{g_{t+1}^S}{1+K_{t+1}}) \tag{3.1}$$

where F is the cumulative distribution function of the probability distribution that is described by the transition matrix of the Markov-shock. To be precise, it is the cumulative rowsum of row a of the transition matrix P.

Bearing in mind the setup described above, the problem of each country can be written in four value functions: The value of repaying all outstanding debt "R", the value of defaulting or letting default "D", the value of having the option to do either and the continuation value of the game post-crisis, when the South has re-accessed the credit market "A". For the North "repaying" corresponds to buying up the debt of the South, i.e. offering a bailout and repaying its own debt. Hence, the maximization problem of the North writes:

$$V_O^N(X_t) = \max_{Z_{t+1}^N}(V_R^N(X_t), V_D^N(X_t)) \tag{3.2}$$

$$\begin{aligned} V_R^N(X_t) = \max_{g_{t+1}^N, K_{t+1}} \{ & log(g_t^N) - p + \beta\left(1 - F_a(\frac{g_{t+1}^S}{1+K_{t+1}})\right)E_t[V_A^N(X_{t+1})] \\ & + \beta F_a\left(\frac{g_{t+1}}{1+K_{t+1}}\right)E_t[V_O^N(X_{t+1})]\} \end{aligned} \tag{3.3}$$

$$V_A^N(X_t) = \max_{g_{t+1}^N, K_{t+1}} \{log(g_t^N) + \beta V_A^N(X_{t+1})\} \tag{3.4}$$

$$V_D^N(X_t) = \max_{g_{t+1}^N, K_{t+1}} \{log(g_t^N) - C + \beta V_D^N(X_{t+1})\} \tag{3.5}$$

$$s.t. \quad (BC) \quad A^N + q_b b_{t+1} + B_t = g_t^N + b_t + q_B B_{t+1} + K_t \tag{3.6}$$

As we can see in the budget constraint, the North accounts for its own debt as a liability and the debt of the South as an asset, which it needs to buy when it bails the South out. In periods where a bailout takes place, the probability of transitioning to a state in which no new bailout is needed is $(1 - F_a(.))$. If the crisis ends with re-access "A", or default "D" of the South, it never starts again. I assume that the North never defaults. Meanwhile, the value functions of the South are:

$$V_O^S(X_t) = \max_{Z_{t+1}^S}\{V_R^S(X_t), V_D^S(X_t)\} \tag{3.7}$$

$$V_R^S(X_t) = \max_{g_{t+1}^S}\{log(g_t^S) + \beta\left(1 - F_a(\frac{g_{t+1}^S}{1+K_{t+1}})\right)E_t[V_A^S(X_{t+1})] \tag{3.8}$$

$$+ \beta F_a(\frac{g_{t+1}^S}{1+K_{t+1}})E_t[V_O^S(X_{t+1})]\}$$

$$V_A^S(X_t) = \max_{g_{t+1}^S}\{log(g_t^S) + \beta E_t[V_A^S(X_{t+1})]\} \tag{3.9}$$

$$V_S^D(X_t) = \max_{g_{t+1}^S}\{log(max(g_t^S, \gamma A_t^S)) + \beta E_t[V_D^S(X_{t+1})]\} \tag{3.10}$$

$$s.t. \quad (BC) \quad (1 - Z_t(1-\gamma))A_t^S(1+K_t) + q_B B_{t+1} = g_t^S + B_t \tag{3.11}$$

By the assumptions that the North is financially healthy and cannot default, and that the emergency loans to the South are given at the risk-free interest rate, the bond prices are simply:

$$q_B = \frac{1}{1+r}$$
$$q_b = \frac{1}{1+r}$$

The model is written forward-looking and can be solved numerically.

3.3 Recursive equilibrium

As players can observe each other's past actions, the equilibrium of this dynamic game is a closed-loop one. All strategies are Markovian, i.e. they depend only on information that is encoded in the current state, which itself encodes only payoff-relevant information. The equilibrium hence satisfies all the requirements of a Markov-perfect equilibrium. The algorithm cycles through the states in a fixed order and picks the optimal value and policy for each player, given each possible response of the other player. As the solution is a numerical one, I cannot formally prove existence and uniqueness of the Markov-perfect equilibrium. Here, it is constructed through the following components. There are

- eight value functions $V_O^S, V_R^S, V_A^S, V_D^S$ for the South and $V_O^N, V_R^N, V_A^N, V_D^N$ for the North that solve the Bellman equations 3.2-3.5 and 3.7-3.10.

- eleven associated best-response policy functions that determine $g_{t+1}^{S,resp}(X_t, K_{t+1}), Z_{t+1}^{S,resp}(X_t, K_{t+1})$ for the South and $g_{t+1}^{N,resp}(X_t, g_{t+1}^{S}), K_{t+1}^{resp}(X_t, g_{t+1}^{S}), Z_{t+1}^{N,resp}(X_t, g_{t+1}^{S})$ for the North that maximize the RHS of these equations during crisis, post-crisis and in default. These policy functions show the optimal choice of the respective country, for any action that the other player may choose.

- The equilibrium allocation then consists of the values $g_{t+1}^{N*}(X_t), K_{t+1}^{*}(X_t)$ and $g_{t+1}^{S*}(X_t)$ at which the policy functions intersect, i.e. when both players are in best-response to one another.

$$g_{t+1}^{N*} = g_{t+1}^{N,resp}(X_t, g_{t+1}^{S*}) \tag{3.12}$$

$$K_{t+1}^{*} = K_{t+1}^{resp}(X_t, g_{t+1}^{S*}) \tag{3.13}$$

$$g_{t+1}^{S*} = g_{t+1}^{S,resp}(X_t, K_{t+1}^{*}) \tag{3.14}$$

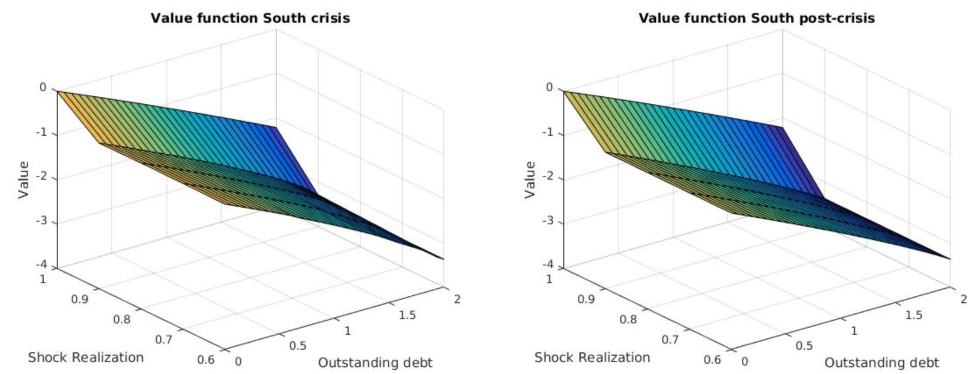
$$Z_{t+1}^{*} = min(Z_{t+1}^{N,resp}(X_t, g_{t+1}^{S*}), Z_{t+1}^{S,resp}(X_t, K_{t+1}^{*})) \tag{3.15}$$

  And the bailout-default choice which takes value one only if both North and South both decide to participate in the bailout. If one of them abstains, it takes the value 0.

Fixing an arbitrary response and arbitrary debt level of the other country, the value functions are illustrated in Figure 3.3.1:

They exhibit the following properties: The South's value increases with a higher realization of the Markov shock. The South's value naturally decreases with its debt level. There is a kink between the highest realization (=1) and the second realization of the shock (=0.8) as the highest state is absorbing; hence the value increases more than proportionally because the South will have the highest income shock forever after. Since there is no direct cost to the South of being in a crisis, the value function does not change if the South regains access to the capital markets. For the North this is not the case: As the North always pays a penalty p when it bails the South out during the crisis, its value of the game during the crisis is substantially lower than its value once the crisis has been resolved. Naturally, the North's value decreases with its own debt. As the North's own income is constant, it does not change with the realization of the income shock in the South after the crisis. But, during the crisis it does, as a higher shock in the South makes a new bailout less likely.

As described above, the policy functions are best-response functions, that include the anticipated action of the other player as a state: The four subfigures above illustrate how the value of the game of the South changes with the transfer from the North and the value of the North changes when the South reduces its consumption. In the two left pictures of Figure 3.3.2, A_t^S is fixed along with B_t and b_t respectively. On the right, both b_t and B_t are fixed. The value of the South is increasing slightly with the transfer of the North.



The value functions of the South

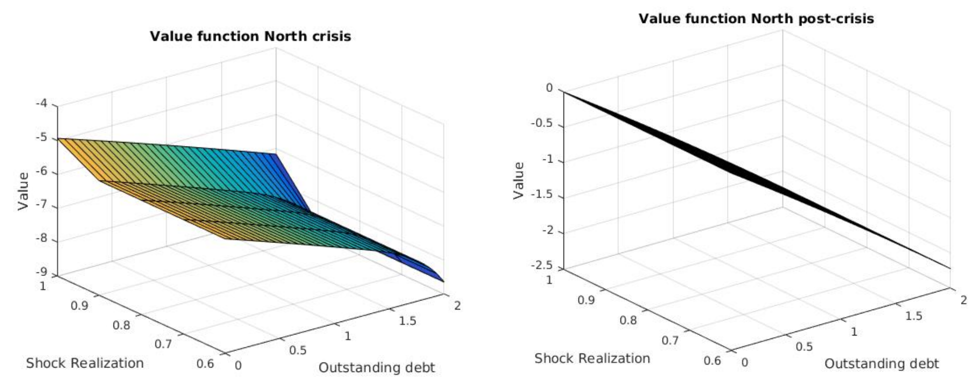
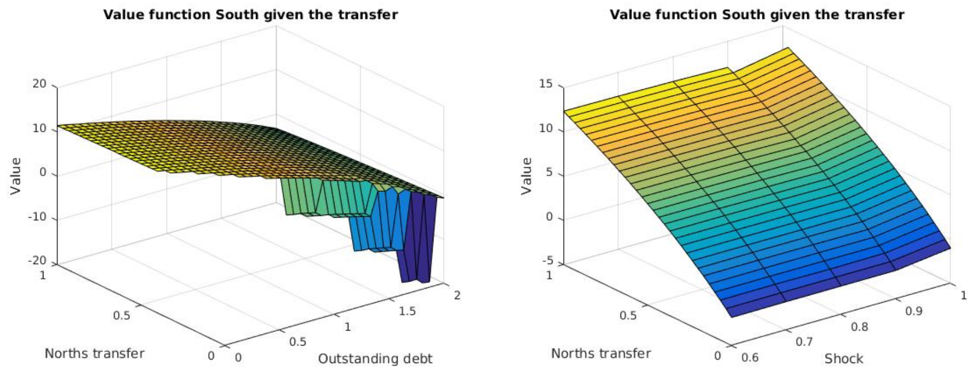


Figure 3.3.1. The value functions of the North

This figure shows the value functions of South and North in a three-dimensional space. The x-axis denotes the outstanding debt. The y-axis denotes the realization of the shock. The z-axis denotes the value to the South (top) and North (bottom) respectively. The left column shows the value function while the crisis is still ongoing, whereas the right column shows the value once the crisis has ended (with market reaccess).



The response dimension of the South

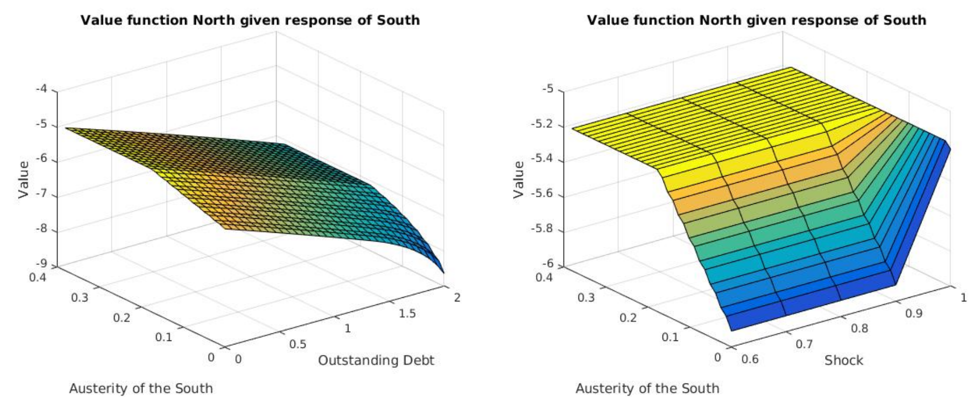


Figure 3.3.2. The response dimension of the North

This figure shows the value functions of South and North in a three-dimensional space. The x-axis measures the outstanding debt. The y-axis shows how the value of the program changes with the action taken by the other country. The z-axis denotes the value to the South (top) and North (bottom) respectively.

The value of the North increases when the South reduces its consumption by more. Holding debt of the North constant, the value increases with reduced consumption in the South up to a threshold, beyond which an additional reduction becomes redundant. This is the case when consumption would be below the lowest level of the state-space of the shock, and hence a further reduction in consumption does not increase the probability of reaching a primary surplus.

The equilibrium allocation that can be derived from the Markov-response functions is displayed in Figure 3.3.3 and it depends crucially on two parameters: The direct utility cost p to bail out the South, which is born by the North; and the cost of abstaining from such a bailout, namely the spillover cost C of a default of the South. The combination (C, p) of these two costs determines the incentives at play in the game: The North trades off the sure costs of a default of the South, with the expected costs of bailout. The latter are subject to the uncertainty that a bailout today may not be enough to end the crisis and a new bailout is needed tomorrow. The right picture of Figure 3.3.3 shows how this trade-off splits the parameter space into three different areas.

On the very left of the picture, the spillover costs of default are high relative to the costs of

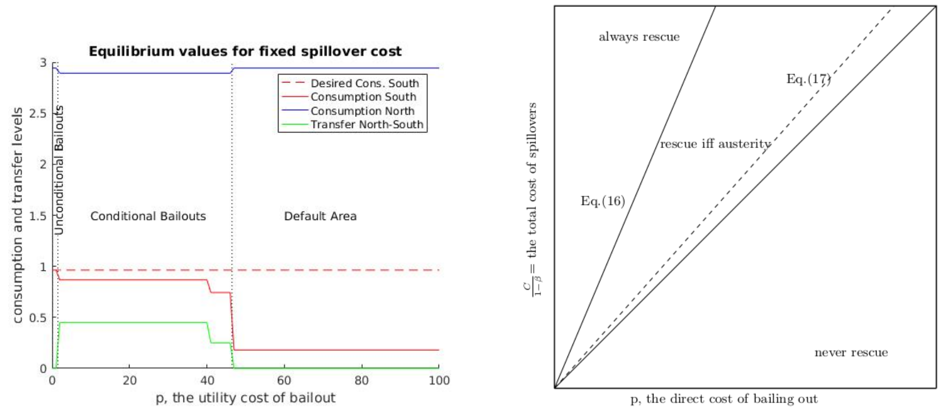


Figure 3.3.3. Three equilibrium regions

This figure shows the three equilibrium regions in which the solution may fall. The left subfigure plots the optimal consumption profiles and the transfer for a fixed spillover cost from default. The x-axis measures the utility penalty of bailout and the y-axis measures the levels of consumption and transfer. The right subfigure sketches the incentive constraint as a function of the utility costs of spillover and bailout.

bailout. Hence, no matter which level of consumption the South chooses, the North will want to rescue it. Then the level that the South chooses, is the highest one that is still compatible with its debt fundamentals. On the other side, on the very right of the picture the spillover costs are very low compared to the costs of bailout. Hence the North will never bail the South out so the South needs to default. In the middle, the North's choice depends on the consumption of the South. When the South sets a high consumption level for the next period, the probability of gaining re-access to the credit market is low. Hence the probability that a new bailout will be needed is high, which drives down the expected value of the North of bailing out the South today. If the South picks a low g^S_{t+1}, the expected value from rescuing is higher than the value of letting the South default. Hence, when the South wants to avoid default, its consumption is constrained by the requirement to that the North's expected value of bailout is greater than the North's value of letting the South default. Let g^{S*}_{t+1} be the consumption level that the South sets if it is rescued for sure and $\bar{g}^S_{t+1}$ the value that is compatible with the North's incentives to bailout. Then there are two constraints that separate the different parameter regions:

$$V^N_R(X_t, g^{S*}_{t+1}) \geq V^N_D(X_t, g^{S*}_{t+1}) \tag{3.16}$$

$$V^N_R(X_t, g^S_{t+1} > \bar{g}^S_{t+1}) \leq V^N_D(X_t, g_{t+1} > \bar{g}^S_{t+1})) \tag{3.17}$$

Note that the constraint that the option value function of the North imposes on the South is an endogenous one, as it depends on both the policy of the North and the policy of the South. It requires that to the North, the value of bailing the South out is greater than the value of abstaining and paying the spillover costs of default - given the consumption of the South.

In the left picture of Figure 3.3.3[6] we see how equilibrium transfer and consumption values change within the parameter space[7]. Holding C constant, for a very low p, North and South consume near their full endowment and there is no transfer. For the South, I call this the "desired consumption", i.e. the level it consumes if it knows that it will be bailed out, whatever its consumption. The North bails out the South, and the latter does not default unilaterally. As p increases, the North increases its transfer and the South needs to reduce its consumption. Beyond a threshold value of p, the North is no longer willing to bail out the South. The South defaults and consumes its endowment. The North also consumes its endowment but does not transfer any more resources to the South.

3.4 Incentives and Austerity

The intuition of the above patterns of consumption and transfer is the following: While the South knows, that the North will agree to bail out, it will not adjust its consumption downward. Hence, even when the North increases the South's income through a transfer, the windfall will first go towards consumption, not towards a reduction of debt and deficit. Thus, the transfer does not increase the likelihood that the South can reaccess the credit market in this region. However, once the costs of bailout rise, the South's consumption is capped by the incentive constraint of the North, equation 3.17. When the South can no longer allocate the resources from the transfer to consumption, a transfer has much stronger effects, i.e. it yields a much higher probability of resolving the crisis. The further the South's consumption needs to be reduced, the more efficient the transfer becomes at paving the South's way towards reaccessing the international credit market. The equilibrium exhibits what I call the "carrots-and-sticks property": The North wants the South's government to reaccess the credit market by reducing its consumption. This adjustment is painful and represents the stick. But in the meantime, as the main finding of this paper, it is optimal for the North in this equilibrium to simultaneously transfer resources to the South, a "carrot", which alleviates the burden of adjustment. Like carrots and sticks should be used together, so should the reduction in consumption and the transfer, from the point of view of the North. At the same time, while the South has still no interest in engaging in austerity, a transfer can ensure the South's participation in the bailout for a range of values, in which the South would otherwise have preferred to default. In other words, the two tools to resolve the crisis are strategic complements in the middle solution area.

The insights from above also propose a new definition of austerity. According to my model, there

[6] Unconditional here means that the North cannot credibly ask for a reduction of consumption beyond what the South does voluntarily. In the opposite case, the bailout can credibly be made conditional on a forced reduction in consumption.

[7] The same picture is included in higher resolution in the appendix.

are two reasons why the South would need to reduce its consumption: The first is a very slight reduction of consumption below the long-run equilibrium to ensure that the present value of all future surpluses is greater or equal to the face value of outstanding debt. In the long run, the South will almost surely hit the absorbing state of its Markov-shock, but while productivity is fluctuating below the absorbing state, the South may need to adjust consumption downward to ensure its own solvency. To be more precise, it will set consumption so as to pay back its outstanding debt as smoothly as possible, given its expectation of when it will hit the absorbing state. Secondly, the model also gives rise to a problem of illiquidity, through the rigidity of public spending, and the refusal of the international credit market to roll over the South's debt. Then, the emergency loans of the North are the only tool that can prevent the South from defaulting. But here, the South needs to do austerity measures that push consumption below the value which would be supported by debt fundamentals, to keep the interest of bailout of the North alive. Hence austerity should be defined as follows: Austerity is a reduction in consumption that is required from a country by its creditor(s), to maintain both short-term and long-term access to funding. The latter is called solvency austerity and it is required by any creditor to the same extent. The former is called liquidity austerity and its magnitude depends on the incentives of last-resort lender to refinance the debt of the failing country.

The insight that austerity has two different components here speaks to the principal question of who benefits from austerity: Both North and South benefit from the austerity that the South undertakes to align its consumption with its debt fundamentals. But only the North benefits from the austerity that is a response to the illiquidity crisis of the South. The model hence answers the question from where the conflicting interests of the two countries regarding austerity arise: The two countries fundamentally disagree over the speed at which the South's debt should be repaid. While the North favors a quick repayment to reaccess the credit market to avoid the costs of bailout, the South does not suffer from the lack of credit market access as long as the North is willing to bailout. Thus, it prefers the smoothest debt repayment possible.

The definition of austerity that the model suggests is different from the one found in the literature: Applying the definition put forward by Dellas and Niepelt (2014), that austerity is the difference between desired consumption and the consumption supported by debt fundamentals, the South needs to do much more than austerity in my model. The former definition is only one that resembles the "solvency austerity" described above. But on top of that, my model requires the South to engage in "liquidity austerity" that is caused by the frictions of the model, namely the rigidity of government spending and the limited willingness of the North to bail the South out.

The value functions of the North address the other main question, if the North can be levered into rescuing the South. The answer is yes: If spillover costs are high and the South knows it, the North will bail the South out without demands of reducing consumption. The incentives to bail out the South are even stronger when the North already has a stake in the South's debt. The

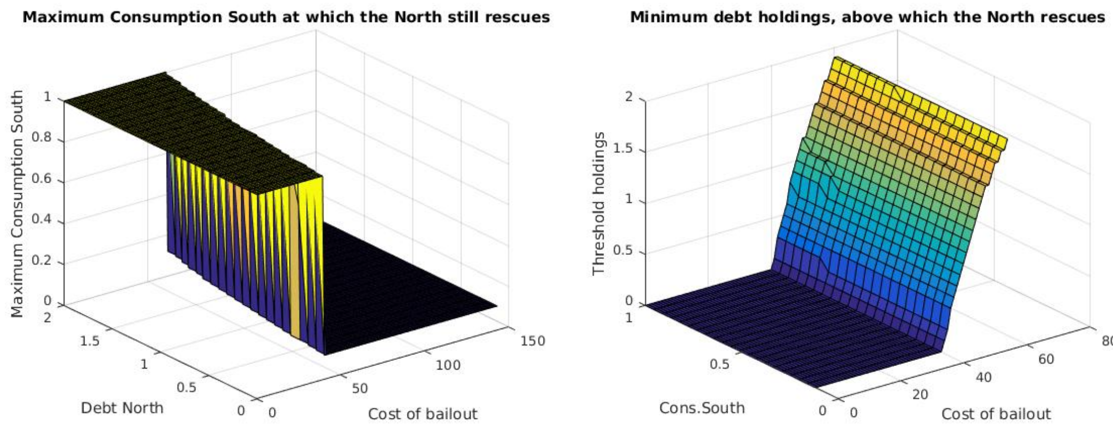


Figure 3.4.1. Bailout Thresholds

This figure shows the maximum consumption of the South at which the north will still offer a bailout, and the minimum debt holdings of the South, above which the North offers a bailout.

problem here is that the North becomes more exposed with each round of bailout, in which it buys up more debt of the South. If the South defaulted after multiple rounds of bailout, the North would lose the value of all the previously bought up debt on top of the spillover costs C. This property puts the North in a weaker position to ask for austerity. More precisely, if the North has a larger stake in the South's debt, the solution area in which the South has to do austerity kicks in at higher levels of the bailout cost p. This shift can be seen in figure 3.4.1: The left picture shows the maximum consumption that the South can allow itself, given the costs of bailout and the debt exposure of the North to a default. Clearly, at higher levels of the South's debt that the North already holds, the South can allow itself more consumption, given a fixed cost of bailout p close to the bailout/let-default threshold of the North. Conversely, the higher the costs of bailout are, the more emergency loans the North needs already to have paid out, should it still want to bail out the South. This can be seen in the right picture of figure 3.4.1. But beyond a certain value of p, no level of debt exposure still justifies a bailout[8]. As a consequence of the exposure to spillover costs, the North find itself forced to rescue the South repeatedly in this framework. In the model, this does not pose a great problem, as the fact that the productivity in the South will almost surely hit its absorbing state at one point, guarantees the repayment of the bailout loans. However, at this point, we need to remark on one important caveat of the model: The fact that both the costs of spillover from default and the costs of bailout are assumed to be exogenous and time-invariant in this model. This may present a significant departure from reality, in which rescue packages often have the purpose of "buying time" to reduce the exposure to spillover costs. This is especially important when the spillover cost capture an exposure of the North's banking system, which can be mitigated when banks have time to increase their capital buffers, or when the exposure comes

[8]Here: No level of debt that is still within the limits of the grid

from trade integration and firm have time to adjust their supply chains. Hence, in reality, the indirect costs of spillover are likely to decrease through repeated bailouts, which would strengthen the North's position and prevent it from being levered into offering repeated bailouts. At the same time, if the non-monetary cost of bailout p represents a "political cost" in the North, this is likely to rise during repeated bailouts (which are usually unpopular). This would sway the North's incentives further away from offering bailouts and enable it to ask for even more liquidity austerity.

3.5 Simulating the model

To illustrate the model's behavior, I simulate the model over the first T=10 periods. Therefore, I impose a set of initial values and a shock sequence and let the model evolve from there. The pictures in Figure 3.5.1 show the results of simulations for two different parameter combinations. Further simulations are provided in the appendix. The crisis resolution line takes a value of zero as long as the South is shut out from the international credit market. When it regains access, its value moves to one. The bailout default line assumes a value of one as long as neither North nor South decide that the South should default - then it moves to zero. The left picture uses the parameter combination $C = 2$, $p = 0.25$. The cost of bailout is small compared to the cost of spillovers. The South has initial debt and the North does not. The North decides to bail the South out three times. During this time, it carries the debt of the South and pays the cost of bailout p three times. The South only reduces its consumption in accordance with its solvency constraint, i.e. it slightly reduces it because of its increasing debt level. In period 4, the productivity shock in the South is high enough for the South to reach a primary surplus. Consequently, the South regains access to the credit markets and the crisis is resolved. For this parameter combination, the South did not have to engage in illiquidity austerity as it was in the interest of the North to rescue anyway.

The picture on the right illustrates the case when the cost of bailout are substantially higher: C=2, p=2.5. The North is still willing to rescue the South, but the South reduces its consumption by more than in the previous case. It engages in illiquidity austerity. This incentivizes the North to make a transfer in period 1. Because of the transfer, the South achieves a primary budget surplus in period 1 despite the low productivity shock of this period. For the North, the utility costs from making a transfer assuming this parameter combination were cheaper than the risk of having to bail out multiple periods. In fact, for all parameter combinations which fall into the middle region, where bailout depends on the consumption of the South, that I have tried, the North chooses a transfer that is high enough to resolve the crisis right away. This result hinges on the assumptions on the productivity shock, specifically on the minimum of its state-space. But it is worth noting, that the model indicates, that when the North bears sufficiently high costs of rescue,

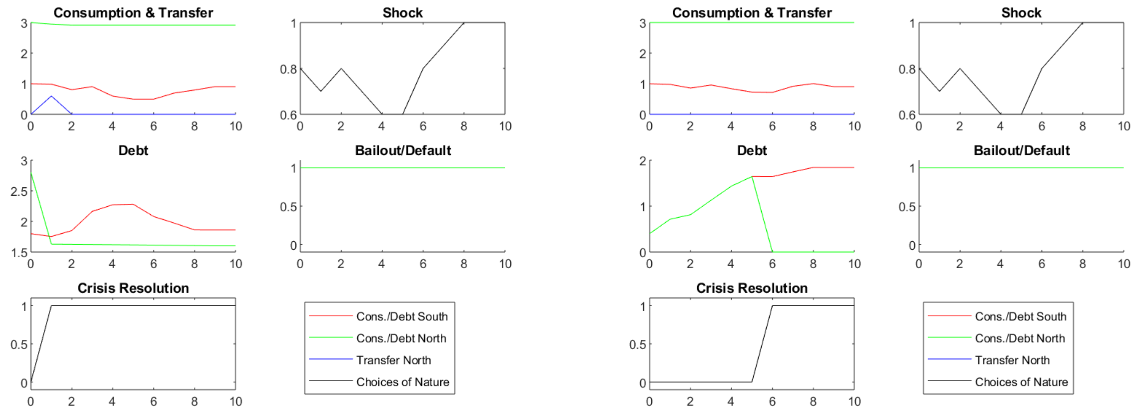


Figure 3.5.1. Simulations 1

This figure shows exemplary paths for debt, consumption and the South's productivity shock. The x-axis denotes the evolution of time, the y-axis denotes the values of the variables of interest.

its optimal strategy is to avoid repeated bailouts. This behavior of the North limits the extent to which it can slip into a trap of being levered into rescuing the South repeatedly. On top of this we can remark the following: in this simulation, the decision to default will always come from the South and never from the North: the reason for this is simply that the bailout-if-austerity incentive constraint ensures that the North is willing to rescue the South if consumption is reduced enough. Then it is the South that decides if, given the required consumption level, it is worth participating in the bailout.

I run several robustness checks that are noteworthy: firstly, I allow the productivity enhancing transfer to affect the output of the South for multiple periods. While the transfer in the above specification depreciates right away, I can include K_t in the state space and add a law of motion for capital $K_{t+1} = (1-\delta)K_t + T_t$ where T_t is the current transfer and K_t the accumulated transferred resources. This does not change the nature of the results. This is because the North will make transfers large enough to almost ensure re-access to the credit market immediately, but the benefit of undepreciated capital only arises one period later. A slowly-depreciating transfer from North to South can be more easily interpreted as, for example, an investment into the South's infrastructure. Secondly, the nature of the results also remains the same when examining a "direct" transfer, $Y_t = A_t + K_t$ that feeds into the South's output as a lump-sum transfer rather than as a productivity-shifter. Finally, I can confirm that the results of the paper are unaffected by changes to the grid size.

3.6 Conclusion

This paper built and solved a model of bailouts and austerity in a sovereign debt crisis. The equilibrium of the model highlights the interplay of austerity, bailout loans, and monetary transfers to the failing country. The result depends on in which of three parameter regions the case falls: There exists a parameter region in which through an incentive constraint of the rescuing country, which limits the consumption of the failing country, austerity and transfer complement each other. Given the assumptions of the model, it is austerity that boosts the returns from a transfer. At the same time, it is the transfer that ensures the participation of the failing country in the bailout. As a qualifier of the result, it has to be mentioned that the specification of the South's income, and thereby the effect of the transfer are very restrictive. A further weakness of the model is the modeling of the direct utility costs of bailout and spillover. Thereby, the model also rules out any scenario in which the initial bailout mainly serves the purpose of "buying time", to control and potentially reduce the spillover cost of a sovereign default. While in the model in its current form, the costs of sovereign default to the rescuer can only increase through new rounds of bailout, the ability to reduce the spillover cost could fundamentally change the optimal strategies computed in this paper. However, incorporating a dynamic spillover cost requires a micro-foundation, that would come at the expense of a much more complex model. The model also suggests a new definition of austerity with two components, that tackle the solvency and the liquidity dimension of a sovereign debt crisis. This definition is new to the literature and helpful to analyze the multiple problems and conflicts of interest in a sovereign debt crisis. The model does not address the hotly debated question of which way austerity affects growth but assumes that there is no effect of government spending on output. Assuming that austerity represses economic activity in the South, or even increases output as put forward by Blanchard (1990), so-called expansionary austerity could drastically change the results of this paper.

Turning back to the motivating example of this paper, we can use its results to rationalize the negotiations over bailouts between the Eurogroup and Greece: Following the insights from the model, these negotiations should be interpreted as follows: The Eurogroup argues, that Greece has a solvency problem. Long-run consumption may be lower than Greece assumed, as the real process that underlies the evolution of productivity is, in reality, unknown. Hence, Greece should reduce its consumption and reaccess the credit markets as quickly as possible by undertaking sufficient austerity measures. Meanwhile, Greece argues that its long-run income is high enough, the current crisis is merely one of illiquidity caused by frictions in the international financial market. Thus, the North should invest in Greece (transfer resources, which shift its productivity upwards) if it wants a quicker recovery of Greece. The definitions of austerity put forward by this model fit well with reality, as we saw that it was not the international financial market, but only the pressure of the Eurogroup that could motivate Greece to do substantial austerity measures. This may either be because the financial market did not leave Greece sufficient time to reduce its consumption, or because with the Eurogroup a lender of last resort existed which made the threats of the financial markets lose their bite. In the model, the North's exposure to spillover cost can lead to the situation in which the North finds itself obliged to repeatedly bail out the South. As mentioned before, the consequences in the model are mild, because the emergency loans will ultimately be repaid when the productivity shock hits the absorbing state. In reality, repeated bailouts may have harsher consequences, as the income process and the behavior of international creditors are unknown. Anyhow, it is clear that if a quick reaccess of the international credit market is the goal, a rescuer with no exposure to spillover cost, at best an independent institution like the IMF, has an advantage over the Eurogroup. The lower the costs of spillovers to the rescuer, the easier it is to push the failing country into liquidity austerity. So far, the nature and the specification of the spillover costs from default, and the direct costs of bailout are the most unrealistic feature of the model. Both were assumed as entirely exogenous. The former could be identified through trade relations or cross-country bank relationships in a general equilibrium framework. The latter was used to introduce a non-monetary cost of bailout - motivated by the observation that despite the debt-financed bailout packages in the North, interest on the Northern countries' bonds declined to near zero[9]. The utility cost p could be interpreted as the cost of political discords over the bailouts in the North. Micro-founding either goes beyond the scope of this paper, whose focus was on the incidence of bailout and the relation between bailouts and austerity. Regarding austerity, its effect on growth is a particularly pressing question. There may be no clear answer, as the effects vary a lot from crisis to crisis. Some of these crises interact with capital flight or doom loops with the private sector or others. In other cases, countries engaged in solvency austerity in the absence of a liquidity crisis. All of the aforementioned points may be fruitful directions for future research.

[9] I hypothesize that this development was caused by characteristics of the world's financial crisis unrelated to sovereign debt - a safe asset shortage for example.

Appendix

3.A Further Simulations, Illustrations of Policy Function and Equilibrium

This section shows further simulation results for all three cases: Repeated bailouts without austerity, one-time bailouts with austerity and transfer, and defaults. The Markov process were generated randomly and the parameters that were used can be seen in the table below.

Figure	B_0	b_0	C	p
Figure 3.A.1	$B_0 = 0.6$	$b_0 = 0$	2	8.75
Figure 3.A.2	$B_0 = 0.6$	$b_0 = 0$	2	7.5
Figure 3.A.3	$B_0 = 0.6$	$b_0 = 0$	2	4.75
Figure 3.A.4	$B_0 = 0.6$	$b_0 = 0$	2	0.25
Figure 3.A.5	$B_0 = 1.8$	$b_0 = 0$	2	0
Figure 3.A.6	$B_0 = 0.6$	$b_0 = 0$	2	0

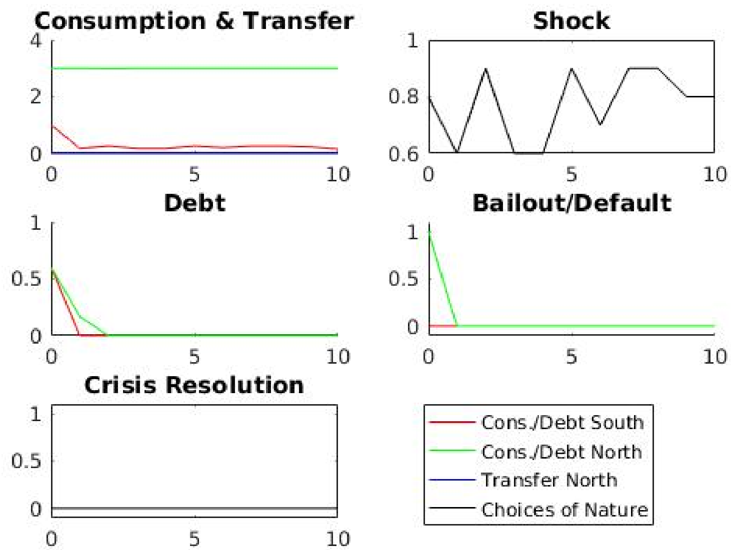


Figure 3.A.1. Default

This figure shows a simulation of the model when the North has no incentives to offer a bailout. Hence the South defaults and suffers a loss in output for all subsequent periods. The x-axis denotes the number of periods after the beginning of the crisis.

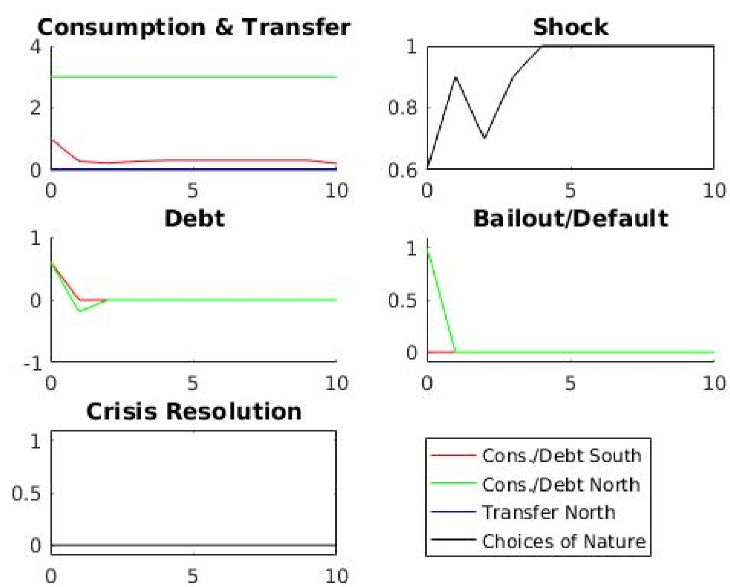


Figure 3.A.2. Default

This figure shows a simulation of the model when the North has no incentives to offer a bailout. Hence the South defaults and suffers a loss in output for all subsequent periods. The x-axis denotes the number of periods after the beginning of the crisis.

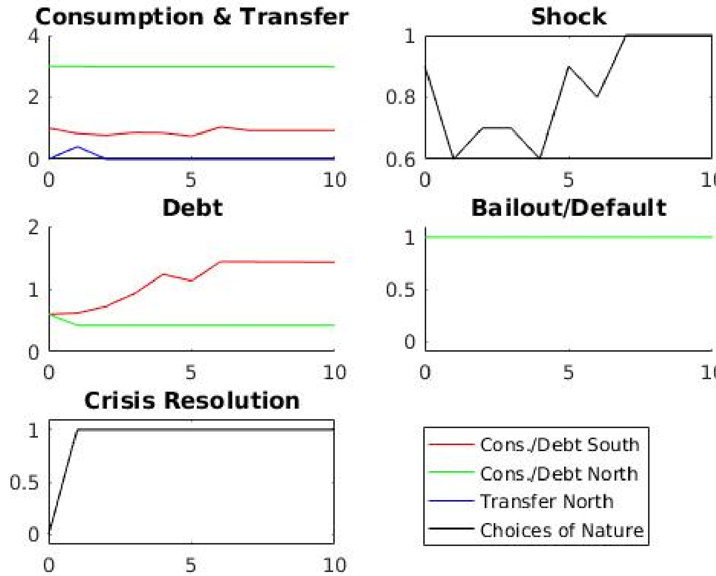


Figure 3.A.3. One-time rescue

This figure shows a simulation of the model when the North has incentives to provide a transfer and the South must engage in liquidity austerity. In this case, the crisis is resolved after one period due to the reduction of the South's consumption and the North's transfer, despite a low productivity shock in that period. The x-axis denotes the number of periods after the beginning of the crisis.

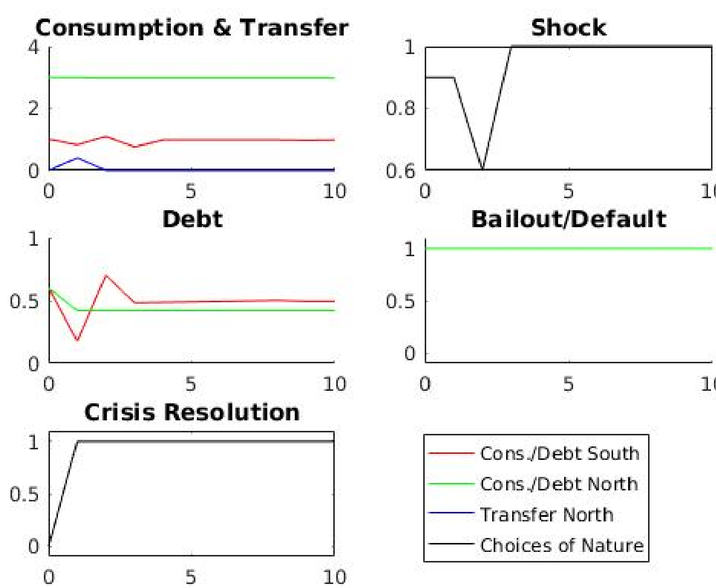


Figure 3.A.4. One-time rescue

This figure shows a simulation of the model when the North has incentives to provide a transfer and the South must engage in liquidity austerity. In this case, the crisis is resolved after one period due to the reduction of the South's consumption and the North's transfer. The x-axis denotes the number of periods after the beginning of the crisis.

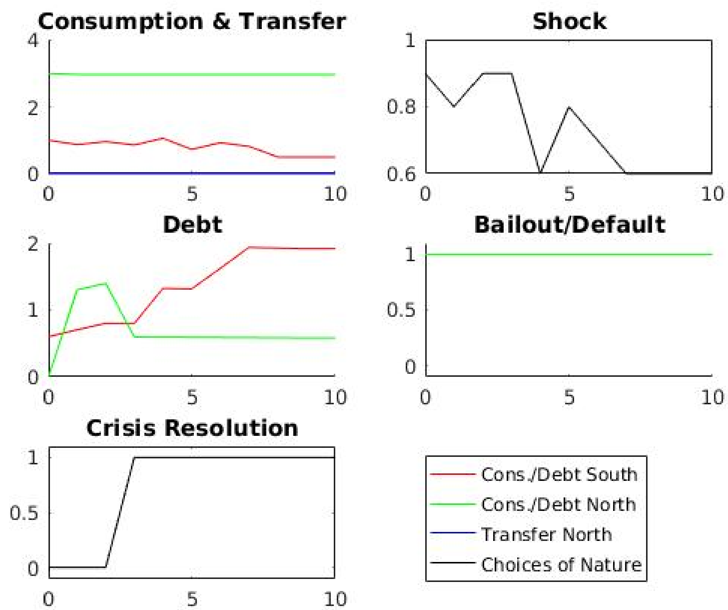


Figure 3.A.5. Repeated bailouts

This figure shows a simulation of the model when bailouts can occur repeatedly, as the North has no incentives to provide a transfer. In this case, the crisis is resolved by the arrival of a high productivity shock after three periods of crisis. The x-axis denotes the number of periods after the beginning of the crisis.

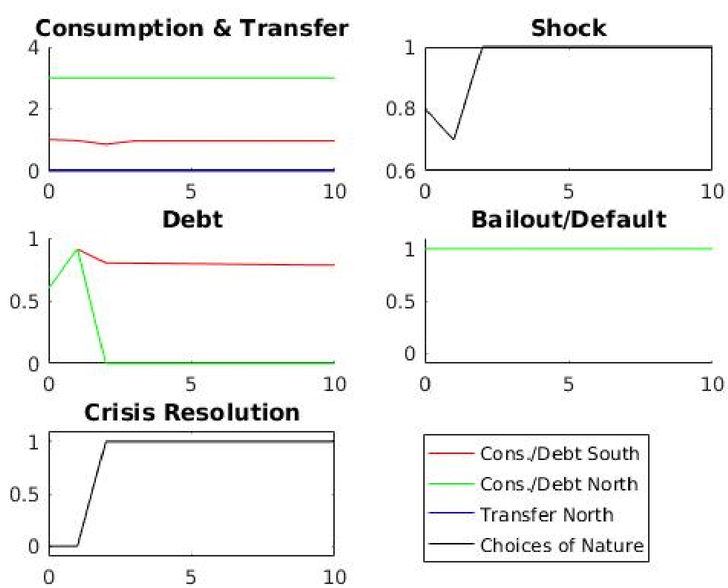


Figure 3.A.6. Repeated bailouts

This figure shows a simulation of the model when bailouts can occur repeatedly, as the North has no incentives to provide a transfer. In this case, the crisis is resolved by the arrival of a high productivity shock after two periods of crisis. The x-axis denotes the number of periods after the beginning of the crisis.

3.B Value Functions

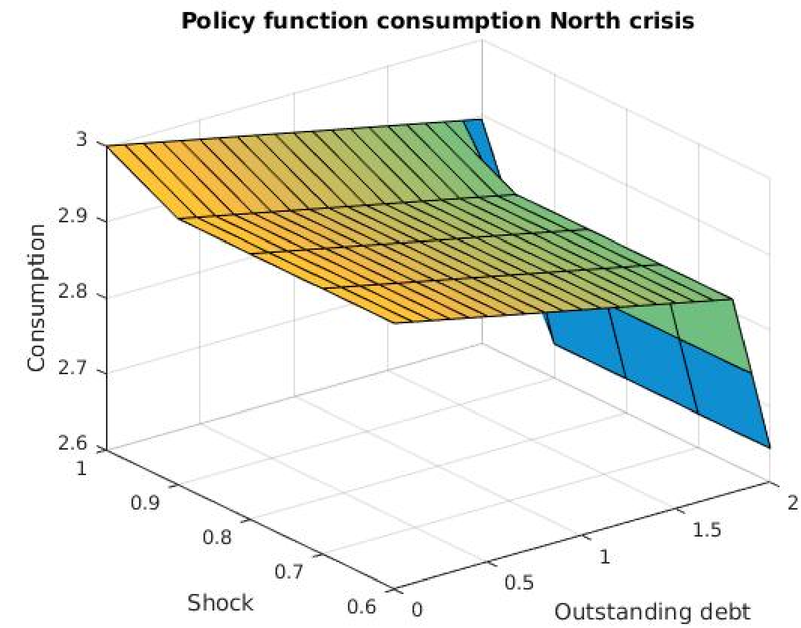


Figure 3.B.1. Policy function North crisis

This figure shows the policy function of the North during the crisis. The x-axis measure the outstanding debt of the South. The y-axis measures the realization of the productivity shock. The z-axis denotes the level of consumption that the North chooses. The level of consumption of the North is lower when the productivity shock realizes a value below one, because the North gives a transfer. The level of consumption is lower when the South's debt is very high, as the South would default in this case.

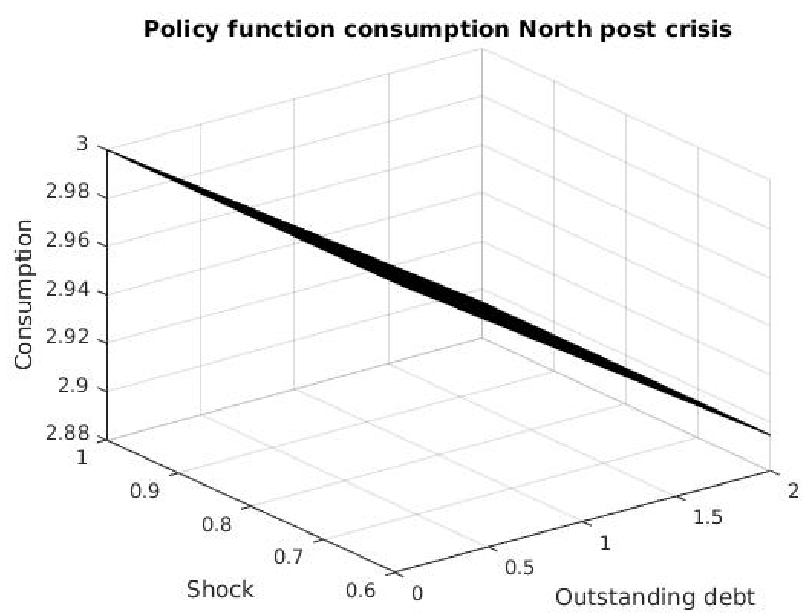


Figure 3.B.2. Policy function North post-crisis

This figure shows the policy function of the North after the crisis has been resolved. The x-axis measure the outstanding debt of the South. The y-axis measures the realization of the productivity shock. The z-axis denotes the level of consumption that the North chooses.

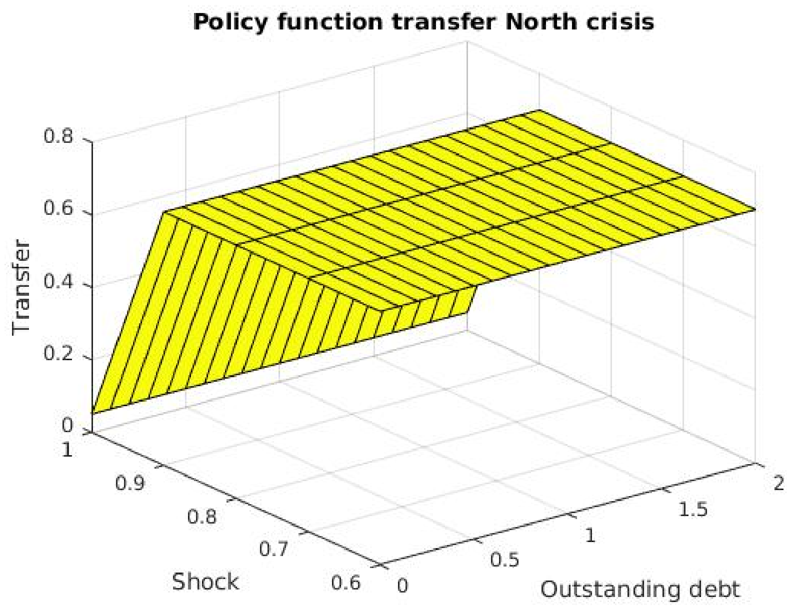


Figure 3.B.3. Policy function

This figure shows the policy function of the North with respect to whether or not it grants a transfer to the South. The x-axis measure the outstanding debt of the South. The y-axis measures the realization of the productivity shock. The z-axis denotes the level of transfer that the North chooses.

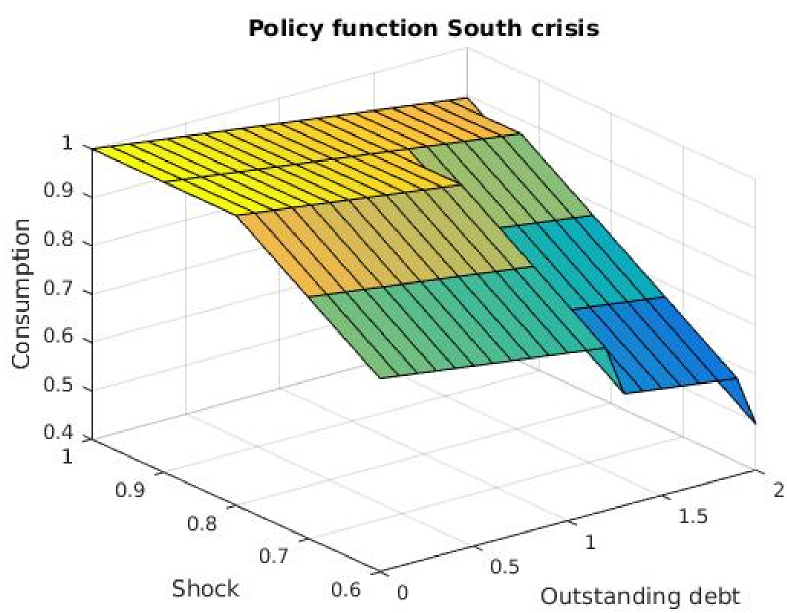


Figure 3.B.4. Policy function South Rescue

This figure shows the policy function of the South during the crisis. The x-axis measures the outstanding debt of the South. The y-axis measures the realization of the productivity shock. The z-axis denotes the level of consumption that the South chooses.

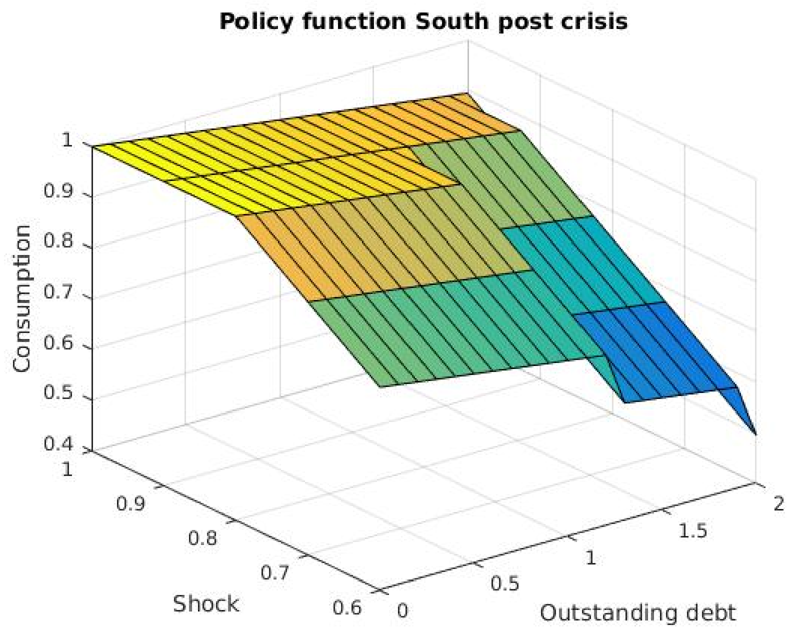


Figure 3.B.5. Policy function South post-crisis

This figure shows the policy function of the South after the crisis has been resolved. The x-axis measures the outstanding debt of the South. The y-axis measures the realization of the productivity shock. The z-axis denotes the level of consumption that the South chooses.

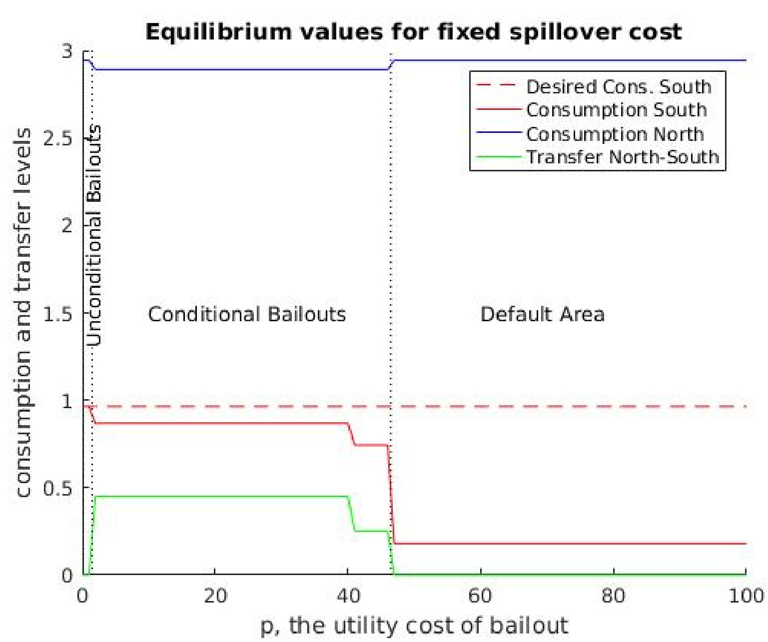


Figure 3.B.6. Figure 3.3.3-left in better resolution

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