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Abstract

The global financial crisis of 2007-2009 spread through different channels from its origin in the United States to large parts of the world. In this paper we explore the financial and the trade channel in a unified framework and quantify their relative importance for this transmission. Specifically, we employ a DSGE model of an open economy with an internationally operating banking sector. We investigate the transmission of the crisis via the collapse of export demand and through losses in the value of cross-border asset holdings. Calibrated to German data, the model predicts the trade channel to be twice as important for the transmission of the crisis than the financial channel. In the UK, the latter dominates due to higher foreign-asset holdings, which, at the same time, serve as an automatic stabilizer in case of plummeting foreign demand. The transmission via the financial channel triggers a much longer-lasting recession relative to the trade channel, resulting in larger cumulated output losses and a prolonged crisis particularly in the UK. Stricter enforcement of bank capital requirements would have deepened the initial slump while simultaneously speeding up the recovery. The effects of higher capital requirements depend on the way banks' balance sheets adjust to this intervention.

JEL-Codes: F440, F410, E320.

Keywords: financial crisis, international transmission, international business cycles, global banks.

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1. Introduction

The financial crisis of 2007-2009 started in a small segment of the US financial market and spread rapidly around the world, infecting in particular the large and globalized banking systems of advanced economies. It soon spilled over to the real economy, leading to a global recession. Alternative narratives attribute important roles for its international transmission to the observed collapse in international trade (trade channel), or to losses in cross-border asset holdings (financial channel, as defined in this paper). It is, however, neither empirically nor theoretically clear which of the two dominated the global transmission of the crisis. As the nature and the importance of the financial channel have changed during the financial globalization of the recent decades, this question is particularly relevant for forming an understanding of international linkages nowadays and in the future.

In this paper, we therefore investigate the effects of the trade and the financial channel in a unified framework and assess which of the two was more important in the transmission of the crisis. For this purpose, we put forward a model that features both channels in order to assess their isolated relevance. Their correlation and mutual interdependence complicate purely empirical analyses. A deeper investigation of the transmission channels by means of a structural model seems hence necessary and worthwhile.

Our international business cycle model features a small open economy integrated with the rest of the world through trade in goods and holdings of international financial assets in the banking sector. The assumption of a small open economy allows us to treat the specific origin of the last crisis as exogenous to the economy in question. Put differently, we are interested in foreign developments only to the extent as they arrive at the border of the domestic country. Without the need to take a stand on how the financial crisis originated, caused massive losses, and led to the collapse of global trade, the applicability of the theoretical results is broadened to generic financial and trade crises. In the model, the transmission through the financial channel works via losses on foreign assets that destroy a part of banks' capital.[1] The bank uses some of its own funds to finance loans and consequently reacts by restricting lending, leading to long-lasting declines in investment and output. The transmission via the trade channel entails that foreign demand for home goods falters, leading to a reduction in exports and output. Calibrating the magnitudes of the two channels, i.e., losses on foreign bank assets and a reduction in external demand, to the recent financial crisis, we can analyze how the economy reacts to each shock and assess which of them has the greater share in the output decline. Furthermore, the model allows us to investigate how policy measures affect the shock transmission.

We proceed by calibrating the model to German and UK data. We take Germany and the UK as insightful cases on the receiving side of the crisis transmission as they are well integrated with the rest of the world. In particular, trade *and* financial links between Germany and the UK on one side and the US on the other side are strong, where Germany is a traditionally strong exporter, while the

[1] While there is no unique definition of the financial channel, we focus on the transmission via losses on cross-border holdings on banks' balance sheets. These played a major role in the recent financial crisis, as shown below. In Section 2 we define our concept of the financial (and trade) channel in detail.

UK has established London as a global financial center. They hence lend themselves to investigate the relative importance of both channels. Furthermore and in line with the model, the financial crisis was arguably exogenous to Germany and the UK, which both featured robust growth before the crisis. Germany did not experience a housing or financial asset bubble, while falling house prices in the UK only had a minor autonomous impact on real activity.[2]

In order to obtain empirical counterparts to the model predictions, we estimate a Structural Vector Autoregression (VAR) featuring international trade and financial data as well as domestic variables from either Germany or the UK. We identify two shocks that have the highest contribution to the forecast error variance of external demand and financial stress, respectively. We find that shocks to external demand have a significant impact on financial stress and vice versa, which underlines the mentioned difficulties in disentangling the two channels empirically. We hence look at the crisis impact of both simultaneous shocks, obtaining an approximation for the joint effect of the financial and trade channel. We find that they played a major role for the recessions in Germany and the UK during the financial crisis episode. Comparing the model predictions to our empirical VAR results, we estimate that the model can explain half of the empirically estimated maximum GDP decline for Germany, and four fifths for the UK over a 4-quarter horizon following the onset of the crisis.[3] Regarding the relative contributions, it turns out that the trade channel is twice as important as the financial channel for the GDP decline in Germany. For the UK the relative contributions almost reverse, with the financial channel explaining 1.7 times as much as the trade channel. This difference can be explained to a large degree by the higher presence of foreign assets in the UK banking sector, making the British economy more vulnerable to the transmission via the financial channel. At the same time, however, the depreciation of the terms of trade that follows a reduction in external demand increases the value of foreign assets in domestic currency, improving banks' balance sheets. Banks are hence relatively more able to create loans, such that foreign-asset holdings serve as an automatic stabilizer as regards the trade channel.

The transmission via the trade channel triggered a relatively short recession in both countries. The financial channel, in contrast, had longer-lasting effects. This channel is thus crucial in accounting for the fact that German output in the last quarter of 2010 was still below its level two years before, and even more so in the UK. This finding is in line with general results established by Reinhart and Rogoff (2009) and others, showing that financial crises generally lead to protracted recessions.[4] We additionally explore the effects of a stricter banking regulation in the forms of either higher costs for violating the capital requirement or a higher capital requirement. The former policy turns out to have procyclical effects by frontloading the recession, i.e., the GDP drop is simultaneously deeper and shorter. The

[2] In particular, Germany's house prices were flat for an extended period before the crisis. The UK experienced a larger increase in housing prices, but the construction of new units and employment in the construction sector remained modest due to strict planning laws. The following reduction in house prices, which turned into an upswing in 2009, is hence likely to have had relatively minor effects on aggregate activity, compared to, e.g., the US, Spain or Ireland. See International Monetary Fund (2010b).

[3] We attribute the remaining part to additional transmission channels and/or shocks that are captured in our empirical estimates but not in the model.

[4] The Bank for International Settlements (2014) also finds that balance-sheet recessions are followed by slower recoveries.

same is true for higher capital requirements, if they leave the size of banks' balance sheets unaffected. Frontloading the recession, however, has a negative impact on the welfare of workers, the largest group of agents in the model. If banks react to higher capital requirements by shrinking the balance sheet, the recession is shorter and flatter with a lower steady-state level of GDP.

Within the theoretical literature, our analysis is particularly related to studies analyzing the international transmission of financial shocks via a global banking sector. Using a one-good two-country model, Kollmann et al. (2011) show how a banking sector subject to a bank capital requirement can transmit a loan default shock originating in one country. Kollmann (2013) estimates this model on US and euro-area data and finds that a version with a bank capital constraint outperforms a version without it. Attributing a prominent role to the banking sector fits well to the UK and Germany, as firms there rely more heavily on bank lending as in, e.g., the US. In comparison to Kollmann et al. (2011), we study a two-good model, which enables us to analyze the transmission via the trade channel in more detail, in addition to the transmission via the banking sector. We furthermore abstract from the foreign economy and instead model a small open economy, thereby avoiding a detailed specification of the origins of the crisis. Lastly, while Kollmann et al. (2011) focus on the effects of loan losses in one of the two countries in the model, we consider losses on foreign assets held by domestic banks. These are much more volatile than loan losses, giving them a larger role in shaping business cycles. Other contributions with global banking sectors include Ueda (2012), who shows how financial constraints and the net worth of creditors contribute to business cycle synchronization in a two-country model similar to Kollmann et al. (2011), but with a two-good setup as in the present paper. Analyzing a model with financial constraints, Mendoza and Quadrini (2010) show how financial contagion can spread across countries through shocks to bank equity. They do not consider business cycles, though.

Related to our research question, several papers in the empirical literature investigate the transmission of the 2007-2009 financial crisis, including the trade and financial channel.[5] Abate et al. (2016) study the transmission of US financial shocks to a set of advanced economies, using a factor-augmented VAR. They find that the recent negative shock was large compared to previous financial shocks. While they are not able to cleanly disentangle how the financial shock was transmitted via the different channels, they can show that both trade and financial channels contributed to the transmission. Other studies analyze whether the cross-country variation in crisis incidence - measured by severity and duration of the output decline as well as business cycle correlations - can be attributed to pre-crisis indicators. Several empirical papers find that advanced economies were hit harder by the crisis (Lane and Milesi-Ferretti, 2011; Rose and Spiegel, 2011; Claessens et al., 2010) and that financial variables, such as credit growth, are linked to the crisis intensity. The results of Olafsson and Pétursson (2011) show that relatively large banking sectors and strong global financial linkages—together with macro variables like inflation reactions, current account deficits, and a leveraged private sector—played an important role for the propagation of the US shock, whereas there is little evidence for the transmission via trade.

[5] Other transmission channels involve, e.g., a global increase in risk aversion and reliance on foreign finance (Lane and Milesi-Ferretti, 2011) as well as a macro channel represented by macroeconomic vulnerabilities and imbalances, and an institutional channel (Olafsson and Pétursson, 2011).

On the other hand, Rose and Spiegel (2011) identify few consistent results linking pre-crisis indicators and crisis intensity. Furthermore, considering the transmission to financial variables like credit default swap premia, bank stock prices or equity portfolios, there is little direct evidence that US exposure or external exposure via trade or financial openness led to higher contagion (Bekaert et al., 2014). Given the relatively inconclusive results of the empirical literature, and the need for counterfactual simulations to clearly disentangle the two channels, we think that our analysis through the lens of an appropriate international dynamic stochastic general equilibrium model is worthwhile.

The remainder of the paper is organized as follows. The next section defines the channels under investigation. Section 3.1 presents unconditional time-series on how the German and UK economies fared through the financial crisis, while Section 3.2 identifies external trade- and financial-channel shocks and their joint effects. Section 4 describes the model setup and its calibration. Section 5 discusses the predictions of the model, while Section 6 inspects the underlying mechanism. In Section 7 we discuss the tradeoffs faced by stricter financial regulation, and Section 8 concludes. Appendix A presents data sources and Appendix B shows further figures and tables for additional intuition.

2. The trade and the financial channel

Before investigating the transmission of the financial crisis in more detail, we first define the specific channels that we seek to quantify. Taking the financial channel as an example, unforeseen developments may emerge in the foreign financial sector, transmit via international financial linkages, and/or spread via the domestic financial sector. Each of these elements can by itself be called 'financial channel'. Depending where the relevant origin (from the perspective of the receiving country) of these developments is located, the distinction between shocks and channels is blurred as well. When investigating the domestic economy, it may suffice to treat all unexpected developments arriving at the border as shocks, although they have their origin in structural shocks hitting foreign economies.

Figure 1 illustrates alternative definitions of the trade and the financial channel. Our understanding of the transmission in a setting where two countries are linked via trade in goods and financial assets is the following. In the foreign country, structural shocks affect the trade and/or the financial sector (arrow A), where a single shock can affect both sectors simultaneously. These shocks may change export demand and the valuation of foreign assets of Home banks (arrow B), which, in turn, affect the home country via the domestic financial and export sector (arrow C). Both sectors also interact with each other and influence the real economy.

In this paper, we want to measure the effect of foreign developments via a specific financial channel (the valuation of foreign assets of Home banks) and foreign export demand (the trade channel), i.e., arrow B. That is, we do not aim to measure the effects of individual foreign shocks, but the effects of changes in these two variables. They summarize the effects of foreign developments as they arrive at the border of the receiving country via the two transmission channels. We capture these developments by introducing the corresponding 'channel shocks' in our model: a financial-channel shock reduces

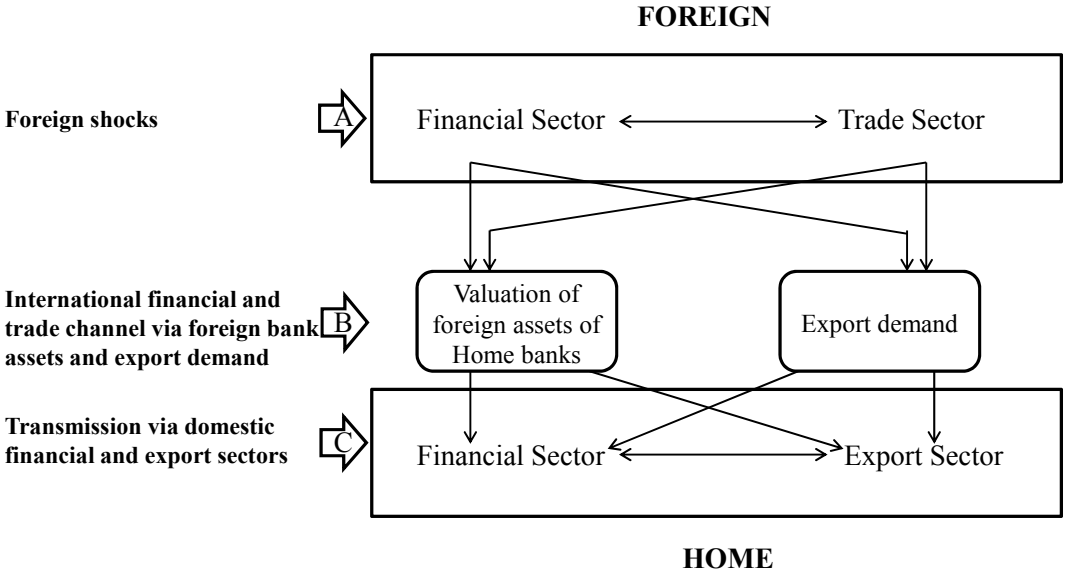

Figure 1: Schematic representation of specific transmission processes.

the valuation of foreign assets of Home banks, while a trade-channel shock lowers export demand. Both are exogenous to the economy of the domestic country. As we discuss in more detail in Section 3.2, the channels are not independent in the data, which makes an empirical investigation of their isolated effects very difficult. We therefore use a structural model to disentangle the two.

While arrows A and C deliver valid, alternative definitions of the transmission channels, we think that our approach has the following advantages. 1) It answers our research question: to what extent was the financial crisis transmitted to Germany and the UK via these two narrowly and well-defined channels? Analyzing, for example, the transmission via domestic sectors (arrow C) answers the question to what extent the financial and the export sector were responsible for transmitting the crisis within the domestic economy. As both variables in B, valuation of foreign assets and export demand, affect both sectors, this is a different question.[6] In our definition, the trade channel is associated with a reduction of foreign export demand, instead of all factors that affect the domestic export sector (such as availability of credit etc.). 2) Changes in the valuation of foreign assets and export demand are easier to measure in the data and hence to calibrate. If we were to model the shocks (arrow A) in the foreign country, which would require additional and potentially controversial assumptions, we would have to make sure that they affect the variables at arrow B as empirically observed. As we aim to isolate the effects of the transmission channels instead of the impact of different foreign structural shocks, we can skip this step and move directly to arrow B. 3) Our approach has a broad application. Without the need to model foreign structural shocks, the model is applicable to many different situations in which the value of foreign assets and/or export demand change for various reasons.

[6] We have also investigated the transmission via the domestic financial and trade sector, i.e., arrow C. Conclusions are similar to those of our analysis of arrow B. Results are available upon request.

3. The German and UK economies during the financial crisis

In the following we present empirical observations related to the two channels as defined in the previous section. We first discuss unconditional developments during the crisis and then turn to reactions conditional on adverse developments transmitted via the two channels.

3.1. Unconditional developments during the crisis

Some important aspects of the crisis for the UK and Germany are captured in figures 2 - 4. For Germany, Figure 2 shows the unprecedented nature of the recent recession, considering the post reunification period in Germany.[7] In 2009, German GDP fell annualized by 4.7%, with a year-on-year (yoy) growth rate of -6.9% in the first quarter. The growth decline in UK was only slightly smaller than in Germany. While German GDP had almost returned to its pre-crisis level by the end of 2010, the growth rebound in the UK was much smaller, reaching only half of its pre-crisis GDP growth.

Related to the trade channel, German exports experienced a similarly unprecedented downturn. Total exports fell yoy by almost 20% (Figure 2, right panel) in the first quarter of 2009. The UK, starting from mostly smaller export growth rates before the crisis, was affected somewhat less. Nevertheless, exports dropped by around 12% in the beginning of 2009. The massive reduction in German and UK exports goes hand in hand with the major slump in global trade hitting the world by the end of 2008 and the beginning of 2009. The global trade collapse was considerably larger than the accompanying world output decline, which has sparked an ample search for the underlying reasons.[8] The key factor explaining the massive trade collapse is suspected to be a deterioration in global demand (Behrens et al., 2013; Bussière et al., 2013). Besides a faltering exogenous demand, the reduction in exports is also driven by an endogenous reaction to terms-of-trade adjustments and various other factors.

Next, we turn to the developments in the banking sector. Both, the UK and German banking sectors were hit hard by the financial crisis. Laeven and Valencia (2014) identify a systemic banking crisis in the UK, starting in 2007, and in Germany, starting in 2008. They base their identification on various banking policy intervention measures. The banking sectors faced massive write-downs on their loans and securities holdings (discussed below), draining the capital position and leading inter alia to failure or the need for some kind of assistance. The estimations of Laeven and Valencia (2014) show that total assets of failed and government assisted banks in Germany amounted to 7% and 29% of total banking assets, respectively, and in the United Kingdom to 25% and 4%.

The substantial losses led to strains on banks' balance sheet, forcing them to deleverage. One way to accomplish this is to restrict lending, thereby transmitting the financial shock to the real economy. Figure 3 shows that the growth rates of the loan volume to non-financial corporations over GDP

[7] Although not strictly comparable due to methodological differences, the growth decline was also the largest considering the time after the second world war (see Statistisches Bundesamt, 2009).

[8] Real world GDP fell by 7.9% (annualized) in the first quarter of 2009, while real world trade contracted by 15% in the same period (Bems et al., 2010).

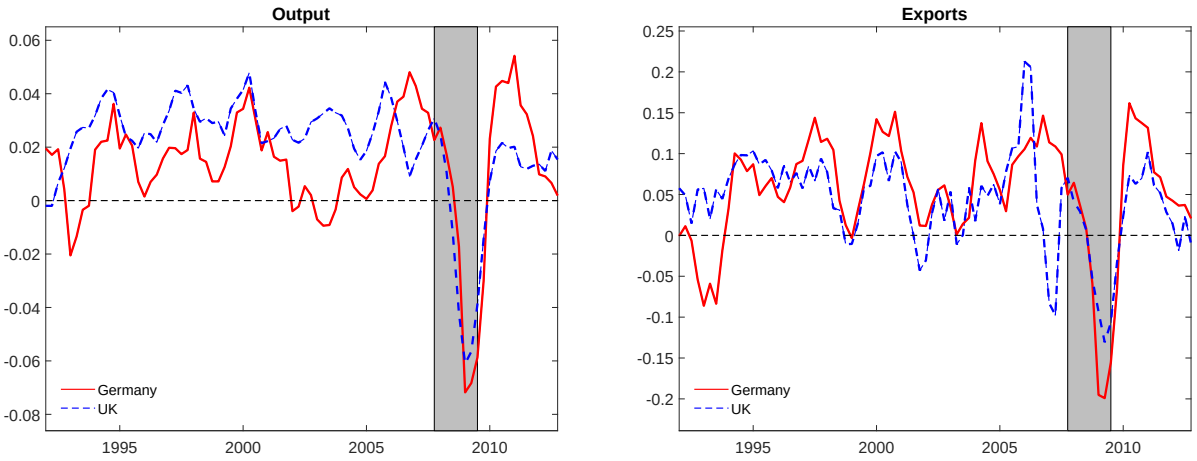

Figure 2: Growth rates of GDP and exports.
Left panel shows yoy growth of German GDP (solid line) and of UK GDP (dashed line). Right panel shows yoy growth rates of German exports (solid line) and of UK exports (dashed line). Shaded area indicates the latest NBER-dated recession for the US.

also exhibited pronounced falls, albeit later in Germany than in the UK (dashed line, right axis). Furthermore, loan growth in Germany first increased and then declined a few quarters later than GDP and export growth.[9] In the UK, loans had already started a downward trend before the crisis. The strongest decline happened in 2010. However, the decreasing loan volume can either be an expression of bank-sided factors that lead banks to restrict their loan supply or it can stem from the demand side, with firms demanding lesser loans during times of faltering exports and GDP growth. We therefore also display in Figure 3 how the spread between loan and deposit rates has reacted during the financial crisis. Specifically, it widened strongly, increasing from an all-time low in early 2008 by approximately 2 percentage points in Germany and the UK (solid line, left axis). During times of high loan-rate spreads, loan growth was very small or negative and vice versa.

Both the UK and the German banking sectors operate on a global scale with claims on non-residents amounting to over 100% of GDP, making them vulnerable to adverse financial developments in the rest of the world. At the same time, UK and German bank portfolios differed in size and composition. The UK had the higher foreign loan and securities holdings (UK: 3.19 trillion US$ vs. 1.49 trillion in Germany) due to London's role as a financial center. In particular, the UK was the second largest holder of United States long-term corporate asset-backed securities, owning a total amount of 142 billions US dollars right before the crisis in June 2007 (Department of the Treasury, 2008). Of these, 63% constituted mortgage-backed securities. While smaller, the German banking system also held a considerable amount of US long-term corporate asset-backed securities, namely 42 billion US dollars, of which 80% were mortgage-backed securities. That is, German banks concentrated on more vulnerable foreign assets.[10] Figure 4 shows the development of claims on non-residents by

[9] Explanations involve drawing of previously contracted credit lines and their slow re-negotiations or banks' initial reduction of other assets, such as interbank assets or equities, before reducing lending (Blaes, 2011).

[10] Lane and Milesi-Ferretti (2011) observe that several industrial countries with heavily affected financial institutions held large amounts of asset-backed securities.

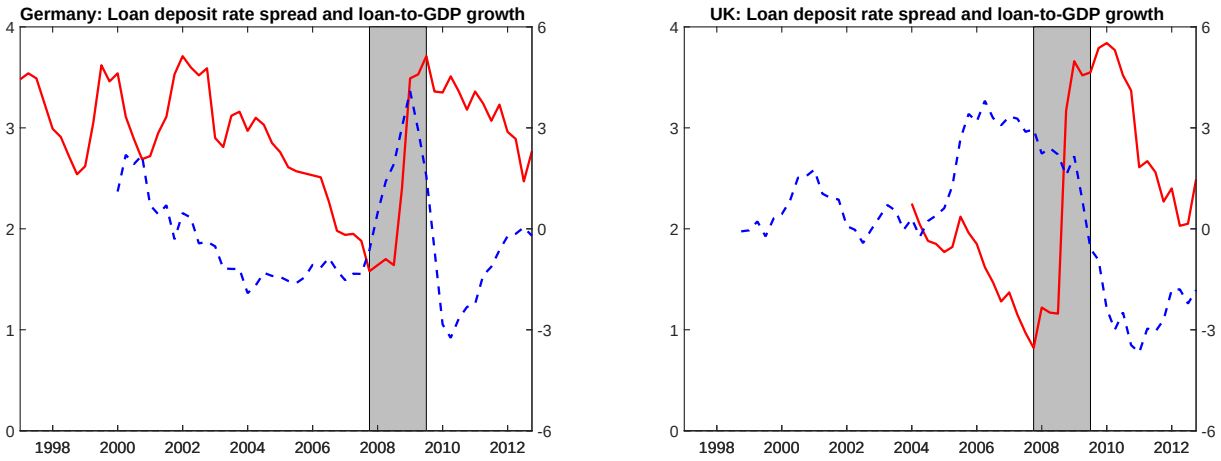

Figure 3: Change of loan-deposit rate spread and loan-to-GDP growth. Spread between the loan and deposit rates (solid line, left axis, percentage points) and yoy growth rates of loans to non-financial corporations over GDP (dashed line, right axis, percentage points).

German and UK banks. German claims on all countries increased until an all-time high of 134% of GDP in the third quarter of 2007 and have since been mostly declining (left panel). Considering yoy growth of one segment of foreign claims, namely holdings of US securities (right panel), shows where large parts of the losses arose, given that these assets fell substantially during the crisis years. The International Monetary Fund (2010a) estimates that German banks faced cumulative write-downs on their total loans and securities portfolio of 314 billions US dollars between 2007-10. For foreign loans and securities this amounts to an implied cumulative loss rate of 10%. Developments in the UK were somewhat distinct, as foreign claims on all countries first continued to increase during the crisis. They took a hit, however, in 2009. Similarly, yoy growth of US security holdings was positive longer compared to Germany, before collapsing. UK banks faced an amount of 455 billion US dollars of cumulative write-downs on total loans and securities, with a large part being foreign loans and securities (loss rate of 7.25% on foreign loans and securities, International Monetary Fund 2010a).

3.2. Conditional responses via the trade and financial channel

In this section we identify reactions of the German and UK economies to adverse developments transmitted via the trade and financial channel (arrow B in Figure 1). As laid out in Section 2, these developments can be considered as external shocks from the perspective of the receiving countries. However, an empirical identification of shocks that activate a single channel, leaving the other inactive, is inherently complicated since such shocks are unlikely to exist in reality. As we will discuss below, shifts in one channel are indeed accompanied by changes in the other channel. This is not surprising, given that the reasons that activate one channel, i.e., shocks in foreign economies, are likely to activate the other channel as well. For example, developments in the foreign financial sector (arrow A in Figure 1) might be transmitted not only via the financial channel but can also have a bearing on foreign demand. As we aim to investigate each channel in isolation, the other channel should ideally

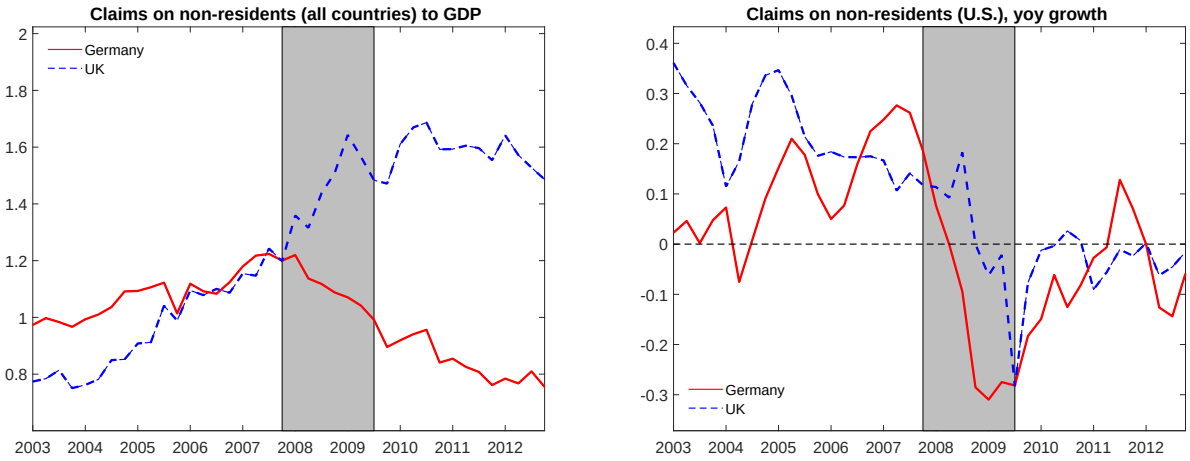

Figure 4: Foreign claims by German and UK banks. Left panel shows claims on non-residents (all countries) as a ratio to GDP. Right panel shows claims on non-residents (US securities), yoy growth.

remain constant, i.e., inactive. Because of their correlation, however, we cannot accurately disentangle the transmission channels empirically, which is one motivation behind the development of our theoretical model.

Despite these difficulties, we propose an empirical procedure that allows us to gauge the *joint* impact of the transmission of the crisis via the trade and financial channel on the German and UK economies. We identify 'crisis shocks' that are linked to these two channels and estimate their contribution to the recession in both countries. Given the interdependence of the channels, we use a set of relatively unrestrictive identification assumptions which capture the different developments that might transmit via the two channels. Trade-channel shocks are defined as those shocks that are responsible for the bulk of unexpected changes in external demand, that is, they have the largest contribution to the respective one-period ahead forecast error of the below specified Vector Autoregression (VAR).

Unfortunately, we are missing the corresponding data equivalent for the financial channel. We will use write-downs of German and UK banks during the crisis as a direct measure of the financial contagion for the calibration of our model. This variable matches closest our definition of the financial transmission channel. As no sufficient time series are available for this variable, we use the US excess bond premium as provided by Gilchrist and Zakrajšek (2012). This variable has proven to be highly correlated with financial stress, which itself is tightly linked to losses of financial assets by internationally operating banks (e.g., the excess bond premium and write-downs both increased significantly during the financial crisis). We hence estimate separate VARs for Germany and the UK, including the log of domestic GDP, the log of a global demand measure (overall imports of a large country sample, including the respective ten largest trading partners, see Section 4.5), and the US excess bond premium.[11]

[11] Details on the data can be found in Appendix A.

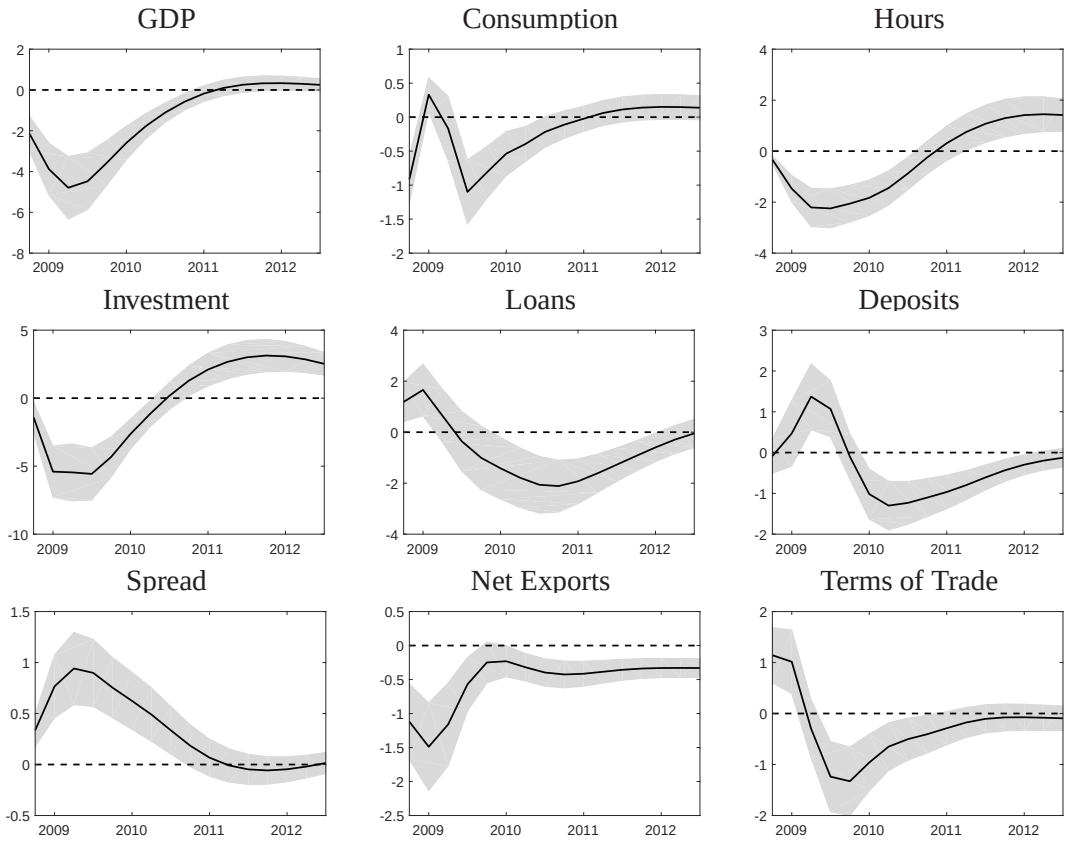

Figure 5: Germany: Impulse responses to identified 'crisis shocks'. Solid lines indicate point estimates, shaded areas 90% confidence bounds obtained by bootstrap sampling (1000 repetitions). Horizontal axes: years. Vertical axes: percentage points for spread and net exports, percentage deviations from trend otherwise.

The VAR takes the form

$$\tilde{Y}_t = \sum_{i=1}^{L} A_i \tilde{Y}_{t-i} + B\nu_t,$$

where $\tilde{Y}_t$ is a vector containing the mentioned three variables and ν_t represents i.i.d. shocks with unitary variances. L denotes the number of lags. Based on the Akaike Criterium we choose 3 lags. We employ the sample 1991Q1-2012Q4 for Germany and 1993Q1 (after UK's exit from the European Exchange Rate Mechanism) until 2012Q4 for the UK. We also include a constant and a linear time trend. To identify the shocks, we employ the strategy that was outlined above. We find the rotation of the impact matrix B that maximizes the sum of the contribution of the trade-channel shock to the forecast error variance of our global demand measure plus the contribution of the financial-channel shock to the forecast error variance of the excess bond premium.[12] With this procedure, we identify

[12] We first decompose the variance-covariance matrix Ω via a Cholesky-decomposition into $\tilde{B}\tilde{B}'$. Given that any matrix $\hat{B}=\tilde{B}\hat{r}$, where $\hat{r}$ is an orthonormal rotation matrix, fulfills the restriction $\hat{B}\hat{B}'=\tilde{B}\hat{r}\hat{r}'\tilde{B}'=\Omega$, we can search for the rotation $B=\tilde{B}r$ that meets the described identification assumption. This amounts to finding the maximum of $B(i,i)^2+B(j,j)^2$, where the index i denotes the position of external demand and, simultaneously, of the trade-channel shock, while j is the index for the excess bond premium and the financial-channel shock. See, e.g., Angeletos et al. (2014) for a related approach. Both shocks remain the main drivers of external demand and the excess bond premium, as they together account for more than 85% of the forecast error variance for these variables at a one-year horizon for both countries.

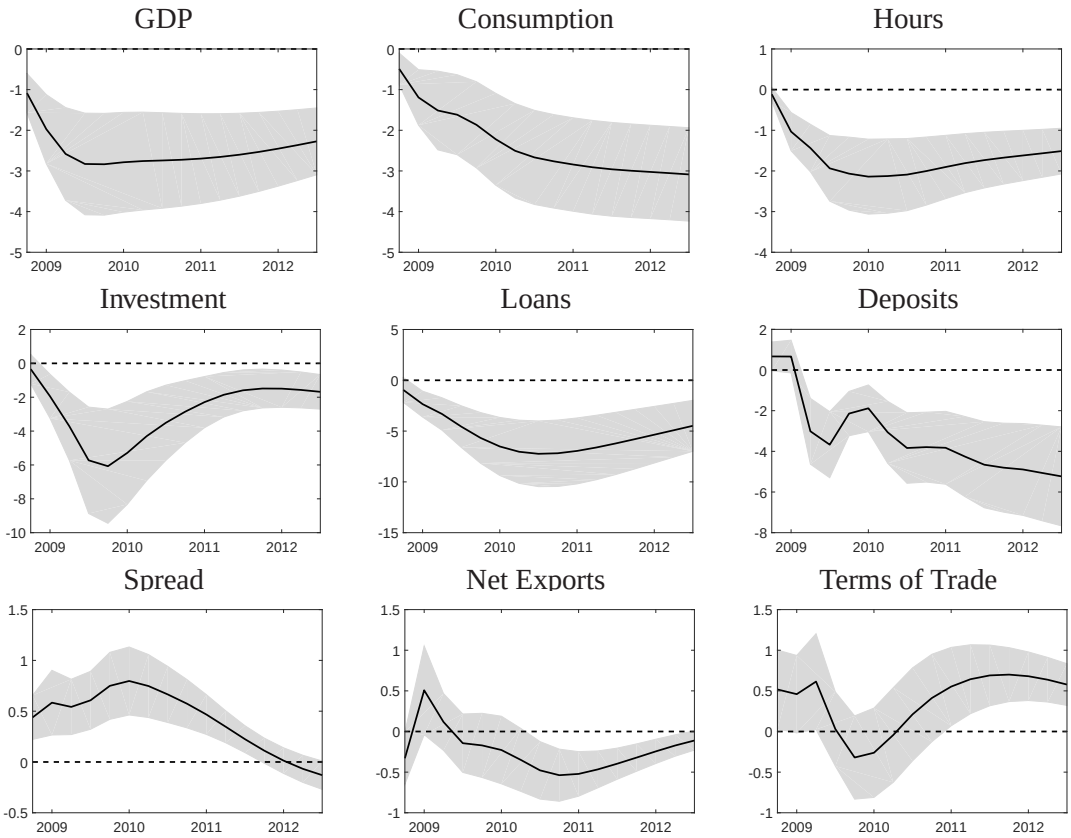

Figure 6: UK: Impulse responses to identified 'crisis shocks'. See Figure 5 for description.

two shocks that are closely related to international trade and financial developments. We need to maximize the sum of both contributions, as maximizing the contribution of each shock separately would result in two different impact matrices. The forecast error variance is calculated at horizon 1, i.e., we consider the effects of the shocks on impact. Additionally, we impose that the remaining, unidentified shock to domestic GDP (or other domestic variables added below) has no contemporaneous impact on the foreign variables global demand and the US excess bond premium. Analyzing the impact of each shock in isolation confirms our above conjecture that the channels are not activated individually: external demand moves significantly after a shock to the excess bond premium and vice versa.[13] For this reason, we will analyze simultaneous occurrences of both shocks as observed in the financial crisis, yielding a measure of the joint contribution of both channels. In this way we do not need to isolate 'pure' individual channel shocks. We will use our theoretical model to do so.

In the following, we estimate the VAR once for Germany and a second time for the UK and feed in both the identified trade- and financial-channel shocks of 2008Q4 and 2009Q1 in the initial period (with no more shocks occurring afterwards). These periods featured the largest shocks in absolute value according to our VAR, such that they come closest to representing the 'crisis shocks'. We

[13]The shocks account for between 8 and 25% of the one-year ahead forecast error variance of the respective other variable.

also add other domestic variables of interest to the VAR, one at a time. We display empirical impulse-response functions to these shocks for Germany and the UK in Figures 5 and 6, respectively.[14] Shaded areas depict 90% confidence intervals, generated by standard bootstrapping. We observe that the two shocks had a considerable impact on all variables under consideration. Most real variables fell in reaction to the shocks, while the interest rate spread increased. The terms of trade depreciated on impact. Figure 5 shows the initial positive reaction of loans (and deposits) in Germany, potentially due to pre-negotiated credit lines. Net exports fell quickly and significantly in the case of Germany, but only with a delay in the UK.

We also note that the trade- and financial-channel shocks were indeed important for the transmission of the global financial crisis. Performing a historical decomposition, we find that all shocks together triggered declines in GDP in 2008Q4 and 2009Q1 (that is, changes in percentage deviations from trend) of 2.24 and 4.96 percentage points, respectively, for Germany. If we feed only the identified trade- and financial-channel shocks into the VAR, we obtain drops of 1.80 and 3.04 percentage points.[15] The corresponding statistics for the UK are GDP drops of 2.55 and 1.94 percentage points in 2008Q4 and 2009Q1, with 1.42 and 1.41 percentage points explained by the two shocks. This shows that our two identified shocks were important, if not the main drivers of economic activity during the financial crisis episode in Germany and the UK.

4. The Model

We use a small open economy variant of the model in Kollmann et al. (2011). The economy is inhabited by a representative worker, an entrepreneur, and a bank.[16] There are two goods, a home intermediate good produced by the entrepreneur and a foreign intermediate good produced in the rest of the world. Both intermediate goods are combined into a final good that is used for consumption by the three agents and for investment by the entrepreneur. The economy is connected to the rest of the world through trade in intermediate goods representing the trade channel and through trade in foreign assets representing the financial channel.

4.1. The Worker

The worker's utility depends on consumption of the final good C_t, bank deposits D_{t+1} and hours worked N_t:

$$U_t = E_t \sum_{s=0}^{\infty} \beta^s \left[\frac{(C_{t+s} - \psi_w C_{t+s-1})^{1-\sigma_w} - 1}{1-\sigma_w} + \Psi^D \frac{(D_{t+1+s})^{1-\sigma_w} - 1}{1-\sigma_w} - \Psi^N N_{t+s} \right], \quad (1)$$

[14] Net exports are measured towards the country sample that is used for the construction of the external demand series.

[15] Specifically, we subtract the counterfactual level of GDP that is obtained if no shocks are fed into the estimated VAR—i.e., the level of GDP that is explained by the constant, the trend, and initial conditions—from the levels of GDP that are obtained if we either feed in all identified shocks or only the two mentioned shocks.

[16] We assume entrepreneurs and households to be separate in order to obtain a role for borrowing and lending (with equal discount rates). Introducing bankers as separate agents, on the other hand, is a modelling device to obtain a sensible description of bank behavior regarding the interest rate spread and lending activities.

where β is the subjective discount factor, $\sigma_w > 0$ governs the worker's intertemporal elasticity of substitution, and Ψ^D, $\Psi^N > 0$ are preference parameters. The consumers have habits in consumption, where ψ_w measures the degree of internal habit persistence.[17] Additionally to paying interest, deposits provide liquidity services to the worker. That way the worker can have the same subjective discount factor as the entrepreneur (and the banker) and still hold positive deposits. The budget constraint of the representative worker in terms of the final good, which is used as the numéraire, is

$$C_t + p_t^a D_{t+1} = p_t^a W_t N_t + p_t^a D_t R_{t-1}^D. \tag{2}$$

The household earns income from supplying labor to the entrepreneur and from interest payments on deposits held with the bank. The wage rate W_t is measured in terms of the home intermediate good. Thus, labor income in terms of the final good is $p_t^a W_t N_t$, where p_t^a is the relative price of the home intermediate good. R_{t-1}^D is the gross interest rate on deposits made last period, D_t, measured in terms of the home intermediate good as well. The worker either consumes her income or saves in new deposits D_{t+1}. Maximizing the worker's utility subject to her budget constraint yields the following first-order conditions:

$$\lambda_{w,t} p_t^a W_t = \Psi^N \tag{3}$$

$$(C_t - \psi_w C_{t-1})^{-\sigma_w} - \psi_w \beta \left(C_{t+1} - \psi_w C_t\right)^{-\sigma_w} = \lambda_{w,t} \tag{4}$$

$$\Psi^D \left(\frac{D_{t+1}^{-\sigma_w}}{\lambda_{w,t}}\right) + \beta E_t \left[p_{t+1}^a R_t^D \left(\frac{\lambda_{w,t+1}}{\lambda_{w,t}}\right)\right] = p_t^a, \tag{5}$$

where $\lambda_{w,t}$ is the multiplier on the budget constraint. The first equation shows the trade-off between consumption and labor. The third first-order condition is the Euler equation. It differs from a standard Euler equation through an additional term representing liquidity services provided by deposits.

4.2. The Entrepreneur and Final Good Production

The entrepreneur produces the home intermediate good a_t by combining capital and labor provided by the worker via a Cobb-Douglas production function:

$$Y_t = z_t K_t^{\alpha} N_t^{1-\alpha}, \tag{6}$$

where α is the capital share and z_t is total factor productivity following an AR(1) process:

$$\log(z_t) = \rho_z \log(z_{t-1}) + \varepsilon_{z,t}. \tag{7}$$

The capital stock, owned by the entrepreneur, depreciates with rate δ and increases through gross investment I_t:

$$K_{t+1} = (1 - \delta) K_t + I_t, \tag{8}$$

[17] Consumption habits are often assumed in the literature, as they bring consumption volatility closer to the data.

The entrepreneur uses the final good for investment. However, it cannot be transformed costlessly into capital. Instead, to produce investment I_t, the amount $\xi(I_t)$ of final goods is needed:

$$\xi(I_t) = I_t + 0.5\Xi \left(\frac{I_t}{I_{t-1}} - 1 \right)^2, \ \Xi > 0. \tag{9}$$

To finance parts of her operations, the entrepreneur borrows from the bank one-period loans L_t, on which she has to pay the gross loan rate R^L_{t-1}. The entrepreneur's budget constraint is

$$p^a_t L_t R^L_{t-1} + \xi(I_t) + p^a_t W_t N_t + d^E_t = p^a_t L_{t+1} + p^a_t Y_t, \tag{10}$$

where d^E_t is the entrepreneur's dividend income. She derives utility from consuming this income according to the following utility

$$U_t = E_t \sum_{s=0}^{\infty} \beta^s \left[\frac{\left(d^E_{t+s} - \psi_E d^E_{t+s-1} \right)^{1-\sigma_E} - 1}{1-\sigma_E} \right]. \tag{11}$$

The entrepreneur's risk aversion differs from the risk aversion of the worker. Below we will fix σ_E to be lower than σ_w, making the entrepreneur less risk averse than the worker (implying that less risk-averse people are more likely to become entrepreneurs). The subjective discount factor β, however, is the same for all agents. Like the worker, the entrepreneur has habits in consumption, with the prameter ψ_E. The first-order conditions of the maximization of the entrepreneur's utility (11), taking into account the constraints (8)-(10), are:

$$(1-\alpha) z_t \left(\frac{K_t}{N_t} \right)^{\alpha} = W_t \tag{12}$$

$$\beta E_t \left[\left(\frac{\lambda_{E,t+1}}{\lambda_{E,t}} \right) \left(p^a_{t+1} \alpha z_{t+1} \left(\frac{K_{t+1}}{N_{t+1}} \right)^{\alpha-1} + \xi'(I_{t+1}) (1-\delta) \right) \right] = \xi'(I_t) \tag{13}$$

$$\beta E_t \left[\frac{p^a_{t+1}}{p^a_t} \left(\frac{\lambda_{E,t+1}}{\lambda_{E,t}} \right) R^L_t \right] = 1 \tag{14}$$

$$\left(d^E_t - \psi_E d^E_{t-1} \right)^{-\sigma_E} - \psi_E \beta \left(d^E_{t+1} - \psi_E d^E_t \right)^{-\sigma_E} = \lambda_{E,t}.$$

The final good F_t used for consumption and investment is bundled from home and foreign intermediate goods, a_t and b_t, via the following CES-aggregator:

$$F_t = \left(\omega^{\frac{1}{\theta}} (a_t)^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}} (b_t)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}},$$

where θ is the elasticity of substitution between home and foreign goods and $0 \leq \omega \leq 1$ is the share of the home intermediate good used for the final good in case of equal prices. $\omega > 0.5$ corresponds to a home bias in consumption and investment. A cost-minimization argument yields the demand functions for a_t and b_t with p^b_t denoting the relative price of foreign intermediate goods in terms of the final good:

$$a_t = \omega \left(p^a_t \right)^{-\theta} F_t, \qquad\qquad b_t = (1-\omega) \left(p^b_t \right)^{-\theta} F_t.$$

4.3. The Bank

The bank collects deposits from the worker, makes loans to the entrepreneur, and trades foreign assets with the rest of the world. Foreign assets A_{t+1} are measured in terms of foreign intermediate goods.[18] The value of foreign assets in terms of the home intermediate good is therefore $p_t A_{t+1}$, where $p_t = p_t^b/p_t^a$ are the terms of trade defined as the ratio of import to export prices. p_t^b is set constant due to our small open economy assumption. As in Kollmann et al. (2011), the bank faces a capital requirement. The capital in period t, $L_{t+1} + p_t A_{t+1} - D_{t+1}$, should not be below a fraction γ of the bank's assets $L_{t+1} + p_t A_{t+1}$. When the bank does not meet the capital requirement, i.e., excess capital $x_t = (1-\gamma)(L_{t+1} + p_t A_{t+1}) - D_{t+1}$ is negative, it incurs a cost. These costs might be imposed by the regulators or by market discipline and depend in an increasing manner on the amount of capital falling short of the requirement. The cost function $\phi(x_t)$ has the following convex form:[19]

$$\phi(x_t) = \phi_1 x_t + \frac{\phi_2}{2}(x_t)^2.$$

If capital is below the requirement the bank faces positive costs, whereas holding more capital than required reduces the chance of falling below the constraint, thereby easing market operations and reducing operation costs by adding $\phi(x_t) > 0$.[20] All bank operations - collecting deposits from workers, handing out loans to entrepreneurs, and holding foreign assets - lead to linear operation costs Γ. The bank's budget constraint is:

$$\begin{aligned} p_t^a \left(L_{t+1} + D_t R_{t-1}^D + \Gamma(D_{t+1} + L_{t+1} + A_{t+1}) + \phi(x_t) + \frac{\chi_A}{2}\left(A_{t+1} - \bar{A}\right)^2 \right) \\ + p_t^b A_{t+1} + d_t^B = p_t^a \left(L_t R_{t-1}^L + D_{t+1} \right) + p_t^b A_t R_t^A Q_t, \end{aligned} \tag{15}$$

where d_t^B is the banker's dividend income. To induce stationarity we assume that the foreign assets are subject to quadratic portfolio adjustment costs (see Schmitt-Grohé and Uribe, 2003). Specifically, holding foreign assets that are different from their steady-state value $\bar{A}$ is costly. The foreign asset pays a risky return. We differentiate between two components that determine this return. In normal times, the return is autocorrelated and subject to a shock with a comparable low variance. That is, the expected gross return of foreign assets accumulated in period $t-1$, denoted by R_t^A, is exogenous and

[18] Actually, more than half of the claims by German banks on non-residents are denominated in Euro. However, here we focus on financial developments originating in the US financial market and the vast majority of German banks' claims on the US are denominated in US dollar, on average around 90%. The same percentage applies to overall claims on non-residents by UK banks.

[19] This form guarantees that the bank has an incentive to return to the steady-state bank capital after shocks in the linearized model. Note that an approximation of ϕ', which plays an important role in the bank's first-order conditions below, features ϕ_2 times excess capital. The parameter ϕ_2 hence determines the effects of bank capital deviating from its target on the bank's costs.

[20] Note the difference between our setup and models that emphasize nonlinearities, such as Akinci and Queralto (2014). These authors assume an occasionally binding leverage constraint for banks. The bank in our model faces a similar constraint that becomes stronger, the further it falls below a certain capital-asset ratio. Given that banks were still paying dividends in the crisis, we think that an increasingly stricter constraint is a good description for the restrictions that banks were facing during the crisis.

follows an AR(1) process:

$$\log(R_t^A) = (1-\rho_R)\log(\bar{R}^A) + \rho_R \log(R_{t-1}^A) + \varepsilon_{R,t}.$$

In addition, the stock of foreign assets $A_t Q_t$ with $Q_t = 1+\varepsilon_{F,t}$ may be subject to an unpredictable i.i.d. shock, which represents fundamental re-evaluations, such as write-downs. In normal times, $\varepsilon_{F,t} = 0$, while a large negative value represents the financial-channel shock, as defined in Section 2. We make this distinction due to the unprecedented nature of the last financial crisis and the high write-downs on loans and assets (as discussed in Section 3.1). The results are identical whether we use the valuation shock as the crisis shock or calibrate R_t^A to the size of the valuation shock and assume ρ_R to be zero during the crisis. The missing autocorrelation corresponds to the singularity of the crisis and allows us to study the impact of the realized, unexpected write-downs. The longer-lasting effects of the financial-channel shock (see Section 5) are hence not mechanically induced by an assumed positive autocorrelation.

The banker consumes her dividend income and maximizes her utility function

$$U_t = E_t \sum_{s=0}^{\infty} \beta^s \left[\frac{\left(d_{t+s}^B\right)^{1-\sigma_B} - 1}{1-\sigma_B} \right]$$

by choosing $L_{t+1}, A_{t+1}, D_{t+1}$, subject to the budget constraint (15). The first-order conditions are:

$$\beta E_t \left[\frac{p_{t+1}^a}{p_t^a} \left(\frac{d_{t+1}^B}{d_t^B} \right)^{-\sigma_B} R_t^L \right] = 1 + \Gamma + \phi'(x_t)(1-\gamma), \tag{16}$$

$$\beta E_t \left[\frac{p_{t+1}^b}{p_t^b} \left(\frac{d_{t+1}^B}{d_t^B} \right)^{-\sigma_B} R_{t+1}^A Q_{t+1} \right] = 1 + \frac{\Gamma}{p_t} + \phi'(x_t)(1-\gamma) + \frac{\chi_A}{p_t}\left(A_{t+1} - \bar{A}\right), \tag{17}$$

$$\beta E_t \left[\frac{p_{t+1}^a}{p_t^a} \left(\frac{d_{t+1}^B}{d_t^B} \right)^{-\sigma_B} R_t^D \right] = 1 - \Gamma + \phi'(x_t). \tag{18}$$

4.4. Market clearing and definitions

We assume that the costs incurred by the bank are paid in terms of the home intermediate good. The bank has to buy these resources from the entrepreneur. Thus, market clearing for the home intermediate good requires

$$Y_t = a_t + a_t^* + \phi(x_t) + \Gamma(D_{t+1} + L_{t+1} + A_{t+1}) + \frac{\chi_A}{2}\left(A_{t+1} - \bar{A}\right)^2, \tag{19}$$

where a_t^* is the amount of the home intermediate good exported to the rest of the world.

It is determined by (see, e.g., Justiniano and Preston, 2010)

$$a_t^* = (1-\omega)\left(p_t^{*a}\right)^{-\theta} Y_t^*. \tag{20}$$

Exports depend on the relative price for the home intermediate good in the rest of the world p_t^{*a}, which is inversely related to the terms of trade p_t, and on foreign demand Y_t^* that follows an AR(1) process

$$\log(Y_t^*) = \rho_Y \log(Y_{t-1}^*) + \varepsilon_{T,t}, \tag{21}$$

where $\varepsilon_{T,t}$ represents our trade-channel shock. Net exports scaled by GDP are

$$nx_t = \frac{a_t^* - p_t b_t}{Y_t}. \tag{22}$$

Finally, market clearing for the final good requires that its production equals aggregate consumption, which is the sum of worker, entrepreneur and banker consumption, plus goods used for investment:

$$F_t = C_t + d_t^E + d_t^B + \xi(I_t). \tag{23}$$

4.5. Calibration

The model is calibrated to match properties of the German and UK economies. An overview of the calibration exercise is shown in Table 1. If not specified otherwise, the sample period runs from the first quarter of 1991 to the fourth quarter of 2012.[21] A detailed description of all data sources and availability can be found in Appendix A. A period in the model corresponds to one quarter. Our aim is to make the calibration as specific to each country as possible. That is, we try to capture the different economic structures by setting those parameters to country-specific values for which sufficient data exist. In the following sections, we will then asses the role of crucial differences in economic structures across the two countries for the transmission of the financial crisis.

In the table, we first list the parameters which are set equally for Germany and the UK. The elasticity of substitution between home and foreign goods θ is fixed at a standard value in the literature (Backus et al., 1994). Physical capital depreciates with a rate of $\delta = 0.025$ per quarter. Similar to Davis (2010), the parameter governing portfolio adjustment costs is assumed to take a small value, $\chi_A = 0.005$. We follow Kollmann et al. (2011) and assume log utility for the worker and the banker and almost risk-neutral entrepreneurs.[22] As in Gerali et al. (2010), entrepreneurs and workers have

[21] Our following results do not change significantly if we end the sample in 2007Q4.

[22] Besides the positive influence of lower risk aversion on the decision to become entrepreneurs, the implied higher volatility of entrepreneurial consumption is in line with the empirical finding of a higher consumption volatility of wealthier people, see Parker and Vissing-Jørgensen (2009) for evidence based on the US Consumer Expenditure Survey. Similarly, Vissing-Jørgensen (2002) shows that the implied intertemporal elasticity of substitution of stock holders is much higher than that of non-stock holders. Ait-Sahalia et al. (2004) document that sales of high-end luxury goods are an order of magnitude more volatile than aggregate consumption. More importantly, we also obtain sensible predictions for bank behavior. There is widespread evidence that banks were reluctant to cut dividends during the financial crisis, despite accumulating losses. See, for example, Acharya et al. (2011) for US and non-US banks, Floyd et al. (2015) for the US, and Acharya et al. (2016) for Europe. Setting $\sigma_B = 1$ gives predictions in line with these observations.

Table 1: Calibration

Parameter		GE	UK	Target/Source
Trade price elast.	θ	1.5	1.5	BKK (1994)
Depreciation rate	δ	0.025	0.025	Annual δ
Portfolio adj. cost	χ_A	0.005	0.005	Davis (2010)
IEOS	$\sigma_B = \sigma_w$	1	1	Log utility
Entrepreneur IEOS	σ_E	0.01	0.01	Risk neutral
Utility parameter	$\psi_w = \psi_E$	0.85	0.85	Gerali et al. (2010)
Convexity of costs	$\phi''(0)$	0.25/Y	0.25/Y	Kollmann et al. (2011)
St. st. slope of costs	$\phi'(0)$	-0.0037	-0.0027	$r_D = 2.69\%$ (GE), 3.73% (UK)
Labor Supply	Ψ^N	2.46	3.18	L/Y$= 33\%$ (GE), 25% (UK)
Preference for deposits	Ψ^D	0.021	0.019	$x = 0$
Discount factor	β	0.986	0.985	$r_L = 5.6\%$ (GE), 5.91% (UK)
St. st. A/L	A/L	0.58	1.37	GE/UK data
Home bias	ω	0.63	0.71	GE/UK data
Capital share	α	0.30	0.35	”
Investment adj. costs	Ξ	0.0324	0.0221	$\sigma_I/\sigma_Y = 2.16$ (GE), 3.32 (UK)
St. st. capital/asset ratio	γ	0.0435	0.065	GE/UK data
Operation costs	Γ	0.0035	0.0026	Spread $= 2.91\%$ (GE), 2.18% (UK)
Autocorr. trade	ρ_{Y^*}	0.95	0.96	SUR estimation
Std. Dev. trade		1.53%	1.51%	”
Autocorr. TFP	ρ_z	0.76	0.93	”
Std. Dev. TFP		1.05%	0.64%	”
Autocorr. for. return	ρ_R	0.097	0.076	”
Std. Dev. for. return		4.37%	4.46%	”
Corr. TFP & trade	Corr(ε_z,ε_{Y^*})	0.39	0.46	”
Corr. TFP & for. return	Corr(ε_z,ε_R)	0	0.28	”
Corr. trade & for. return	Corr(ε_{Y^*},ε_R)	0.28	0.27	”
Crisis Shocks				
Financial-channel shock	ε_F	-10%	-7.25%	For. write-downs
Trade-channel shock	ε_T	-10.76%	-10.35%	For. demand
Autocorr. trade-ch. shock	ρ_{Y^*}	0.53	0.53	yoy ΔY^*

the same consumption habits. As demonstrated in detail in Kollmann et al. (2011) and supported by micro evidence cited therein, the value for the curvature of the excess cost function is consistent with the empirical relation between loan-to-deposit ratios and interest rate spreads.

The following parameters are matched to data from the UK and Germany. We set the parameter ω such that trade openness in the model $1 - \omega$ matches the average trade openness of Germany and the UK during the sample period. The capital shares in production α correspond to the average capital shares in Germany and the UK over the sample period. We use the investment adjustment cost parameter Ξ to match the relative volatility of investment of the model, i.e., the standard deviation of investment relative to the standard deviation of GDP (see tables 2 and 3). To calculate the relative investment volatility, we simulate the model including all shocks simultaneously, see below.

The approximate capital ratio (γ) of German banks, i.e., the ratio of bank equity to total bank assets (not risk-weighted), was 4.35%, whereas for the UK this ratio was 6.5%. The steady state deposit

and loan rates correspond to their respective averages. The resulting spreads in steady state are 2.91% and 2.18%, implying specific values for Γ. Excess capital in steady state is zero. Together with the bank's costs Γ for handling deposits, loans, and foreign assets, ϕ_1 determines the deposit and loan rates, and hence the spread. These parameters are therefore set to match both interest rates (see above) for both countries. The loans to physical capital ratio, which together with $x = 0$ determines Ψ^N and Ψ^D, is set such that the ratio of loans to annual GDP in steady state matches the mean of the empirical counterparts for Germany and the UK. We set the A/L ratio equal to US securities to domestic loans. The loan interest rate also determines the subjective discount factor, which results from the Euler equation of the entrepreneur.[23]

The foreign demand process is approximated using a series aggregating trade-weighted total imports of a broad set of trading partners for Germany and the UK, including the respective top 10 trading partners. Since the trade weights differ between Germany and the UK, we obtain two slightly different series for Germany and the UK (see Appendix A for details). Because this measure consists of overall imports, it mainly reflects developments in the trading partners, instead of events in Germany or the UK, respectively. The AR(1) process for TFP is estimated on linearly detrended German log TFP and similarly for the UK. For the return process of foreign assets we combine data on stock and corporate debt returns, see Appendix A for details. We also match the empirical correlations between the three data series via a SUR estimation. The correlation between the returns to foreign assets and home TFP shocks for Germany is not significantly different from zero. For the UK, on the other hand, it is 0.28.

5. Theoretical predictions

5.1. Business Cycle Statistics

Before we analyze with our model how the financial crisis was transmitted, we first examine whether it is able to capture features of normal German and UK business cycles. For this purpose, we compare second moments of HP-filtered German and UK data for the period 1991Q1-2012Q4 with unconditional HP-filtered moments of the model. For all simulations, we linearize the model around the steady state.[24] For the three shock processes for TFP, trade and foreign-asset returns, we use the fitted AR(1) processes as described in the previous section. The valuation shock does not play a role under normal circumstances. Hence, we only include the shock process for 'normal' foreign asset returns.

Tables 2 and 3 present moments of the data (Column 1), of the model with all shocks (Column 2), and of the model including TFP, trade, and foreign asset return shocks individually (columns 3-5).

[23] We also note that the consumption share of the worker in the model is 71.3% for Germany and 67.0% for the UK in steady state. Subtracting their interest income (from deposits), we obtain 70.4% (Germany) and 65% (UK) as the labor share. Although not calibration targets, these values are close to the average observed labor shares of 63% in Germany and 66% in the UK (averages over 1991-2012 from the AMECO data base of the EU, corresponding values without crisis period: 64% for Germany and 66% for the UK).

[24] We use a smoothing coefficient of 1600 and take logs of all variables before filtering, except for net exports and the interest rate spread, as these variables are already expressed in percentage points. We also employed a second-order approximation, yielding virtually identical results for all experiments in the paper.

Table 2: Business cycle statistics of German data and the model

	Data	Model				
		All	TFP	Trade	FA ret.	No fin. fric
	(1)	(2)	(3)	(4)	(5)	(6)
Std. dev. output	1.56	1.81	1.71	0.04	0.61	1.66
Relative standard deviations						
Consumption	0.46	0.70	0.58	2.79	1.35	0.56
Investment	2.16	2.16	1.96	9.76	2.82	2.16
Hours	0.43	0.63	0.45	1.49	1.41	0.42
Deposits	0.95	0.81	0.43	7.36	1.84	0.52
Loans	1.53	1.64	1.03	8.89	4.19	0.95
Interest rate spread	0.38	0.12	0.03	0.86	0.38	0.00
Terms of Trade	0.76	0.67	0.63	22.42	0.68	0.66
Net Exports	0.48	0.35	0.20	7.15	0.74	0.26
Correlation with GDP						
Consumption	0.42	0.74	0.81	0.51	0.80	0.79
Investment	0.88	0.92	0.96	-0.95	0.75	0.96
Hours	0.68	0.83	0.92	0.95	1.00	0.91
Deposits	0.09	0.10	0.17	-0.82	-0.02	0.21
Loans	0.00	-0.11	-0.13	0.26	-0.16	-0.08
Interest rate spread	-0.39	-0.44	-0.96	-0.82	-0.97	-0.65
Terms of Trade	0.31	0.56	0.95	0.81	0.33	0.61
Net Exports	0.24	0.21	0.24	-0.69	-0.46	0.41

The model is able to replicate many features of German and UK business cycles. GDP volatility generated by the model including all shocks is somewhat higher for the UK calibration than the one in the data. However, the volatilities of the other variables relative to GDP and their correlations with GDP are matched well. As in the data, aggregate consumption is less volatile than GDP, in particular for Germany. Investment adjustment costs were calibrated such that relative investment volatility matches the data exactly. Loans show a higher relative volatility than deposits in the model, similar to the empirical observations. Deposits and loans are a lot more volatile in the UK than in the German data. The model successfully replicates this difference. While it is not able to generate the negative correlation between deposits and GDP for the UK and loan acyclicality in Germany, the signs for all remaining variables are matched correctly for both countries. The terms of trade—typically difficult to match for international business-cycle models, see, e.g., Enders and Müller (2009)—are also predicted to be procyclical in both countries. The most striking difference between Germany and the UK in terms of correlations is the opposing sign for the correlation of the net export-to-GDP

Table 3: Business cycle statistics of UK data and the model

	Data	Model				
		All	TFP	Trade	FA ret.	No fin. fric.
	(1)	(2)	(3)	(4)	(5)	(6)
Std. dev. output	1.15	2.17	1.27	0.18	1.53	1.22
Relative standard deviations						
Consumption	0.83	0.92	0.62	1.25	1.11	0.56
Investment	3.32	3.32	2.73	1.80	3.57	3.32
Hours	0.58	1.13	0.53	1.44	1.48	0.49
Deposits	2.05	1.38	0.82	0.86	1.69	0.89
Loans	3.73	3.95	2.38	5.25	4.95	2.30
Interest rate spread	0.46	0.26	0.05	0.43	0.36	0.00
Terms of Trade	1.21	0.42	0.46	4.67	0.29	0.57
Net Exports	0.87	0.35	0.13	1.21	0.48	0.18
Correlation with GDP						
Consumption	0.78	0.84	0.82	0.95	0.88	0.72
Investment	0.76	0.91	0.93	-0.03	0.90	0.93
Hours	0.68	0.94	0.96	1.00	0.99	0.96
Deposits	-0.18	0.03	0.16	-0.72	-0.03	0.22
Loans	0.42	0.01	0.11	-0.07	-0.03	0.17
Interest rate spread	-0.66	-0.84	-0.96	-0.96	-0.97	-0.25
Terms of Trade	0.16	0.02	0.94	0.95	-0.22	0.19
Net Exports	-0.25	-0.72	-0.56	-0.98	-0.91	-0.07

correlation, which is correctly generated by the model.

Considering the three shocks individually shows that the model including only the TFP shock underpredicts the relative volatilities of the financial variables and net exports. It also generates a too large correlation between deposits and GDP. This underlines the importance to include also the trade- and financial-channel shocks to account for business-cycle moments. The trade-channel shock contributes relatively little to output fluctuations. However, it is not only the main driver of relative net exports and the terms of trade, but has also a large impact on investment and deposits (in Germany) and loans (in both countries). On the other hand, its predictions for the correlations of deposits and loans with GDP are quite far away from the empirical values. The return shock brings these correlations closer towards the data. It is furthermore responsible for a large part of the fluctuations in loans and deposits, and generates volatilities of the spread that are in line with the data.

We also demonstrate the importance of the financial friction in this model. The introduction of a bank with a capital requirement introduces a distortionary wedge between the lending and the deposit

rate. In the steady state, the effects of this wedge are well-understood: the marginal product of capital does not correspond to the marginal rate of substitution, thereby lowering consumption and output. The effects of a time-varying spread, however, are less straightforward. To analyze those, we conduct simulations in which we leave the steady-state distortion as in the baseline calibration, but set $\phi_2 = 0.0001$.[25] Up to a first-order approximation, the bank has no incentive to return to the required bank capital. Hence, the spread does not depend on the level of bank capital in the linearized model, eliminating the effect of the financial friction on the model dynamics. Column (6) in tables 2 and 3 shows the results. They are close to those obtained if only TFP shocks occur. We conclude that the financial friction is important in generating realistic business cycle fluctuations in our model.[26] We discuss the importance of the financial frictions for the transmission of the crisis in Section 6.

One main difference between Germany and the UK is the structure of banks' balance sheets. While German banks are traditionally very engaged in providing loans to domestic entrepreneurs (with a loan-to-GDP ratio of 33% compared to 25% in the UK), banks in the UK invested much more in foreign financial assets.[27] The resulting difference in the A/L ratio is responsible for a large part of the differences between the simulated German and UK economies. We discuss the resulting changes in business cycle statistics in Appendix B, while Section 6 analyzes the importance of the different calibrations for the transmission of the crisis.

5.2. Crisis Transmission

In this section, we assess whether the model economy can replicate characteristics of the German and UK downturns during the financial crisis. In particular, we are interested in how the theoretical prediction for the effects of the trade and financial channel, as defined in Section 2 and formalized in Section 4, relates to the empirical estimate of their combined effect in Section 3.2. Remember that for the reasons explained there, it is inherently difficult to disentangle the two shocks empirically. Once we are confident that the model is able to key aspects of the crisis episode, we will investigate both transmission channels in isolation. The magnitudes of the shocks are chosen to match the observed declines in trade and bank asset values. The financial-channel shock for Germany is set to -10% to match the estimated losses on foreign loans and securities incurred by German banks, for the UK it is -7.25%.[28] Hence, foreign assets are hit by a one-time valuation shock $\varepsilon_{F,t}$ of -10% or -7.25%, respectively. The trade-channel shock is set to -10.8% for Germany and -10.4% for the UK, based

[25] We thereby avoid a unit root. Investment adjustment costs are re-set to generate the observed investment volatilities.

[26] Contrary to us, Kollmann et al. (2011) find a more limited role for financial frictions during normal business cycles in a distinct but related model. This can be explained by the different types of financial shocks considered. While they focus on loan-default shocks, which were at the center of the financial crisis in the US, we consider variable returns on foreign asset holdings, as they were an important transmission channel from the US to financially connected countries. These returns are much more volatile than losses on loans. Furthermore, write-downs on domestic loans are equivalent to transfers to domestic entrepreneurs in Kollmann et al. (2011). In our model, the lost resources have a stronger effect as they do not appear in other agents' budget constraints, given that they represent transfers to the foreign country.

[27] In this paper, we take these differences in economic structures as given. Explaining those is the subject of a large literature, see, among others, Tilly (1989), Allen and Gale (2000), and Sylla and Wright (2004).

[28] Using write-downs instead of changes in asset values allows us to disentangle actual losses from, e.g., sales. See Appendix A for all calculations and data sources.

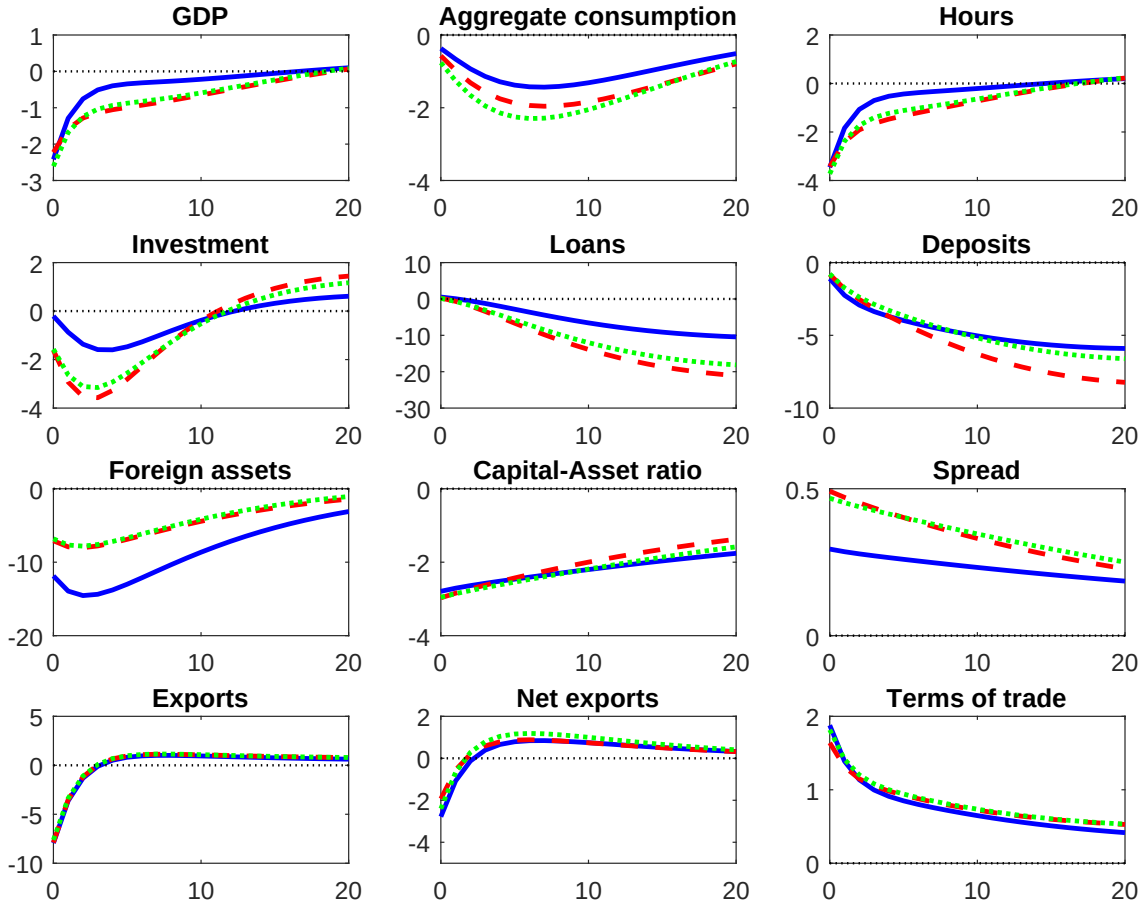

Figure 7: Impulse-response functions to simultaneous trade- and financial-channel shocks. Solid lines represent IRFs for Germany, dashed lines for the UK, dotted lines for German calibration with shocks and A/L ratio of UK. Variables are expressed in percentage deviations from steady state, except spread (in percentage points p.a.), capital-asset ratio, and net exports over GDP (both in percentage points).

on our measure of external demand, see Section 4.5. Its autocorrelation is adjusted to 0.53 for both countries. We hereby intend to capture the relatively short length of depressed demand in the crisis, compared to normal times.

Figure 7 displays the impulse responses to a negative trade- and a simultaneous negative financial-channel shock for Germany (solid line) and the UK (dashed line).[29] As shown in the graph, the model predicts reductions in output, investment, exports, banks' foreign assets, bank capital, loans, and an increase in the loan-deposit interest rate spread, all in line with our empirical observations in Section 3.2. Additionally, also consumption, deposits, and hours worked are predicted to fall, while the terms of trade depreciate. The main differences between Germany and the UK occur in the responses of foreign assets, loans, deposits, the spread, and investment. The initial impact on GDP following the simultaneous shocks is slightly higher for Germany, while the UK suffers from a more

[29] Here and in the following we simulate the model either for simultaneous or for isolated occurrences of the financial- and/or the trade-channel shock. We set the correlation between shocks to zero, such that the other shock (in the case of isolated shocks) and TFP remain constant.

Table 4: Model responses Germany

	Maximum response				Cumulative response		
	Data	Both	TC	FC	Both	TC	FC
Output	-4.79	-2.42	-1.79	-0.87	-5.37	-1.38	-3.99
Consumption	-1.10	-1.29	0.26	-1.35	-4.39	0.89	-5.27
Investment	-5.57	-1.60	1.75	-2.57	-5.63	5.77	-11.40
Hours	-2.25	-3.46	-2.56	-1.17	-7.59	-2.13	-5.46
Deposits	-0.10	-3.70	-2.17	-1.59	-13.33	-9.04	-4.29
Loans	-1.01	-2.01	1.49	-3.50	-3.19	6.23	-9.42
Interest rate spread	0.94	0.29	-0.08	0.37	1.40	-0.37	1.77
Terms of Trade	1.14	1.88	1.97	0.10	6.31	6.18	0.14
Net exports	-1.49	-2.78	-3.05	0.58	-2.94	-5.35	2.41

First column displays maximum responses in the four periods following the shock as estimated in Section 3.2. Other columns show results from simulation of the model, with either both shocks (second and fifth column), only the trade-channel shock (third and sixth column) or only the financial-channel shock (fourth and seventh column) operating.

sluggish recovery. We will provide intuition for these results when discussing the reactions to the individual shocks in Section 6.

In order to systematically compare the model predictions with the data, we use the estimated reactions in both countries to the 'crisis shocks', as identified in the VAR of Section 3.2. Table 4 compares the maximum responses of the empirical impulse-response functions in Figure 5 to those predicted by the model (Figure 7) for the German calibration, while Table 5 presents results for the UK calibration and the empirical counterparts of Figure 6. Column (1) shows the maximum responses of the empirical reactions, Column (2) the model predictions after the occurrence of both shocks. The maximum responses are calculated in the four quarters following the shocks in both cases. The model is able to replicate 51% of the estimated output decline following the crisis shocks for Germany. This might be an indication that our empirical estimates are correlated with further negative shocks, such as uncertainty shocks, and/or transmission channels that are not subject of this paper. Nevertheless, the model predicts the sign and value of most other variables fairly well, as discussed below. The UK estimates are closer to the predictions of the model, which cover 79% of the estimated maximum output decline after the crisis shocks.

Importantly, the tables also display the reactions triggered by each channel individually. For Germany, the trade channel in the model (Column 3) explains around 37% of the estimated drop of output in the VAR, while for the UK the number is 34%. The isolated financial channel (Column 4) triggers a reduction in output of 18% and 57% of the estimated output drop for Germany and the UK, respectively. The fraction of the total output decline predicted by model that can be attributed to each channel is hence almost opposite for both countries. While in Germany the trade channel alone generates an output drop of 74% of the decline generated by both channels together (resulting from -1.79%/-2.42%),

Table 5: Model responses UK

	Maximum response				Cumulative response		
	Data	Both	TC	FC	Both	TC	FC
Output	-2.84	-2.23	-0.97	-1.62	-7.28	0.30	-7.58
Consumption	-1.87	-1.75	0.39	-2.00	-6.18	1.65	-7.83
Investment	-6.07	-3.57	3.00	-5.64	-14.92	9.01	-23.93
Hours	-2.07	-3.42	-1.50	-2.36	-10.86	0.14	-11.00
Deposits	-3.67	-3.69	-1.13	-2.72	-11.98	-4.60	-7.39
Loans	-5.67	-5.03	3.25	-8.28	-10.80	12.24	-23.04
Interest rate spread	0.75	0.49	-0.15	0.65	2.27	-0.71	2.97
Terms of Trade	0.61	1.64	1.67	0.25	6.14	5.26	0.88
Net exports	-0.33	-1.93	-2.39	0.80	-0.90	-4.44	3.54

See Table 4 for description.

the financial channel triggers 36% of this response.[30] For the UK, the proportions are 43% for the trade channel and 73% for the financial channel.

The trade channel is the driving force behind the developments in the external sector of both countries. The depreciation of the terms of trade is predicted relatively well for Germany, mainly attributable to the trade channel. German net exports are predicted to fall substantially, although more than in the data. Because of Germany's larger trade dependency, hours worked, and deposits, are also influenced strongly by the trade channel. The financial channel plays a smaller role for the output drop in Germany, but is essential to bring about a decline in loans and an increase in the spread. It also has a much more detrimental effect on investment than the trade-channel shock, although the model strongly underpredicts the investment slump. Arguably, risen uncertainty after the crisis, which might have been correlated with the identified empirical shocks but is not present in the model, might have contributed to this extreme response in the data. The drop in deposits is overpredicted, but note that the empirical response reaches lower levels after the initial 4 periods.

For the UK, the two channels combined played a larger role for the reaction to the crisis. The drop in output is relatively similar to the empirical counterpart, which is mostly caused by the financial channel. The fall in investment is again underpredicted, but less than in the German case. Deposits drop similarly in the model and in the data. Loans, as in the data, are predicted to fall more than in Germany. The trade-channel shock is again the main driver of the terms of trade and the trade balance, whose response is, despite being too large, correctly predicted to be less strong compared to Germany. The financial-channel shock, on the other hand, is more dominant for the UK than for Germany. It exerts strong negative pressure on consumption, investment, deposits, hours worked, and loans. It also pushes up the spread in the crisis.

To summarize, the model does well in predicting the reactions of important variables in the crisis,

[30] The numbers add up to more than 100% for some variables, as the maximum responses following shocks through each channel can occur at different times.

with some exceptions. In particular, the model responses show a decline in macroeconomic activity, with output, consumption, investment, and hours decreasing following the shocks. Similarly, deposits, loans, and net exports fall, while the interest rate spread rises.[31] The model hence predicts the correct signs for all of these variables if compared to our estimates from Section 3.2. To account for the impact of the financial crisis on Germany and the UK, it turns out to be crucial to consider the simultaneous occurrence of the trade- and financial-channel shocks. The simulation also highlights the role of each channel for specific variables, particularly the dominance of the trade channel for Germany and the financial channel for the UK.

6. Inspecting the mechanism

To gain more insights into the dynamic responses triggered by the two shocks, we display the impulse-response functions for the financial- and the trade-channel shock separately in figures 8 and 9 and provide intuition. The responses in Germany are again depicted by blue solid lines, while red dashed lines represent UK responses. The shocks have the same magnitudes as before. Both lead to a decline in output and hours, where the financial-channel shock is triggering hump-shaped responses. The reactions of other variables, in particular bank capital and exports, differ more starkly across shocks. As already seen in tables 4 and 5, we find that the developments in Germany and the UK can only be explained by a combination of the trade- and the financial-channel shock. Both shocks would predict the wrong sign for key variables if they occurred in isolation.

In the case of the financial-channel shock, the deteriorating value of foreign assets leads to a decline in bank capital. Interestingly, the relatively lower write-downs on UK foreign asset holdings, resulting from the better portfolio choice of UK banks relative to their German counterparts, translate into a larger drop of the capital-asset ratio because of the much larger ratio of foreign assets to loans (and to GDP) in the UK. Correspondingly, the spread increases more strongly and the output drop is more pronounced in the UK. Specifically, the shock sets off an increase in the loan-deposit rate spread by about 0.4 percentage points for the German model and by about 0.7 percentage points for the UK, which translates into a fall of loans and deposits. The losses and the larger increase in the spread reduces domestic demand, that is aggregate consumption and investment, relatively more in the UK, which lowers prices of domestically produced goods. The resulting depreciated terms of trade increase exports slightly, by less than 0.5% over four years, while imports fall. Germany, on the other hand, experiences an even smaller depreciation of the terms of trade as its higher openness implies that a larger part of the reduction in demand falls on foreign goods. We hence obtain a relatively subdued expansion of exports.

In contrast, bank capital increases in the case of the trade-channel shock, putting downward pressure on the spread. This is driven by a positive response of loans and a reduction of deposits during the first

[31] Since the considered shocks are idiosyncratic to the foreign country, they naturally have stronger effects on relative variables than common shocks. They also generate co-movement between Germany and the UK as those economies are hit by similar external shocks.

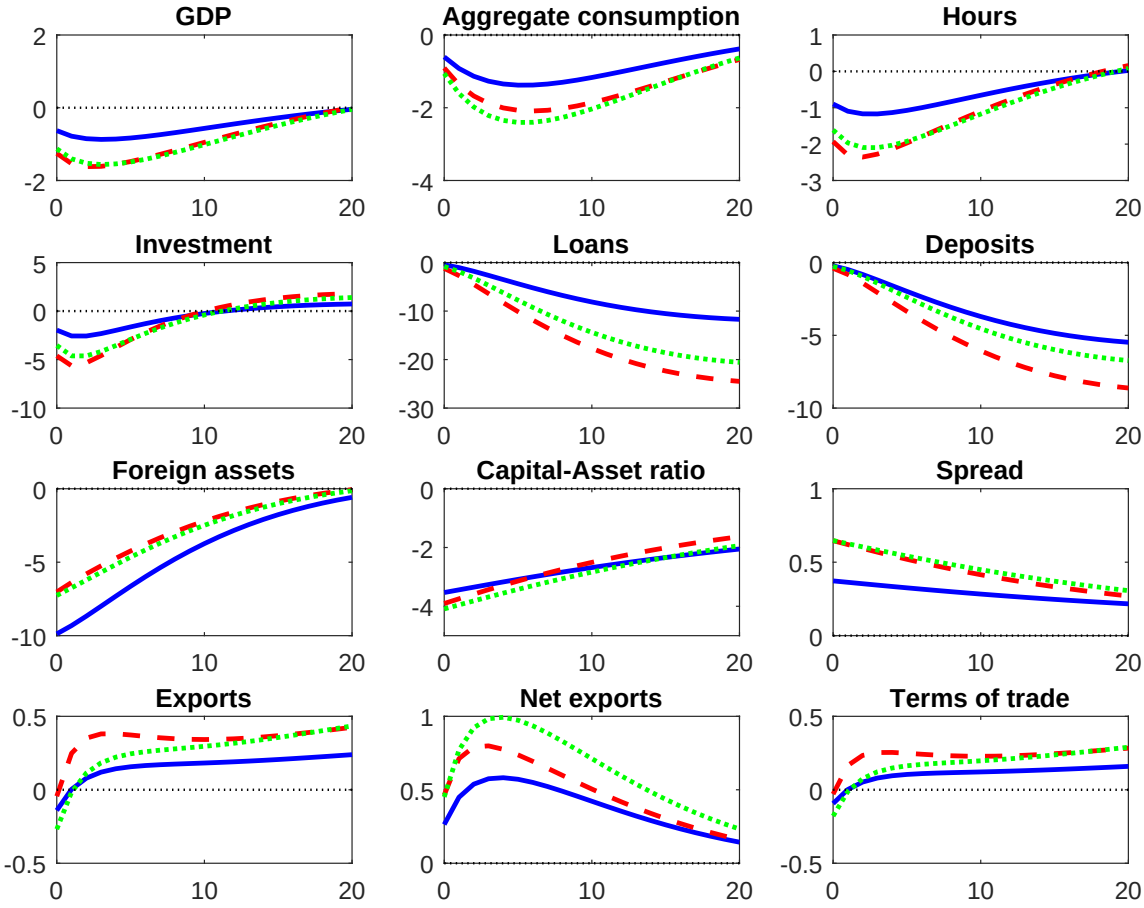

Figure 8: Impulse-response functions to financial-channel shock. See Figure 7 for descriptions.

few quarters. Deposits are reduced by workers to smooth out the impact of the shock on consumption, while loans increase due to a lower loan rate. The latter results from an expected appreciation of the terms of trade, i.e., back towards the steady state after the initial depreciation that follows the reduction in demand. Expected returns on foreign assets in domestic currency hence fall and by arbitrage also domestic loan rates. Foreign assets in domestic currency (plotted) decline despite the depreciation, as they become less attractive. Instead, the bank shifts its assets towards loans until expected returns are equalized. The initial slight increase of aggregate consumption following a trade-channel shock is mainly driven by consumption of entrepreneurs because of intertemporal consumption shifting, triggered by the reduced loan rate. Since they are almost risk neutral, entrepreneurs react strongly to interest-rate movements.[32] Bankers' consumption also increases because of rising income from lending activities and the increasing domestic value of foreign assets, but its share in aggregate con-

[32] While the positive consumption response might seem counterfactual at first sight, note that we consider the effects of a very temporary reduction in foreign demand. In the model, it is known to all agents that external demand will recover fairly quickly, such that negative wealth effects are limited. We thereby exclude elements that could reduce consumption and investment, such as uncertainty about the future development of external demand. The exclusion of this and related channels is in line with our analysis, as we are merely interested in the narrowly defined trade channel. Setting $\sigma_E = 1$ eliminates the positive consumption response without significantly changing the remaining responses.

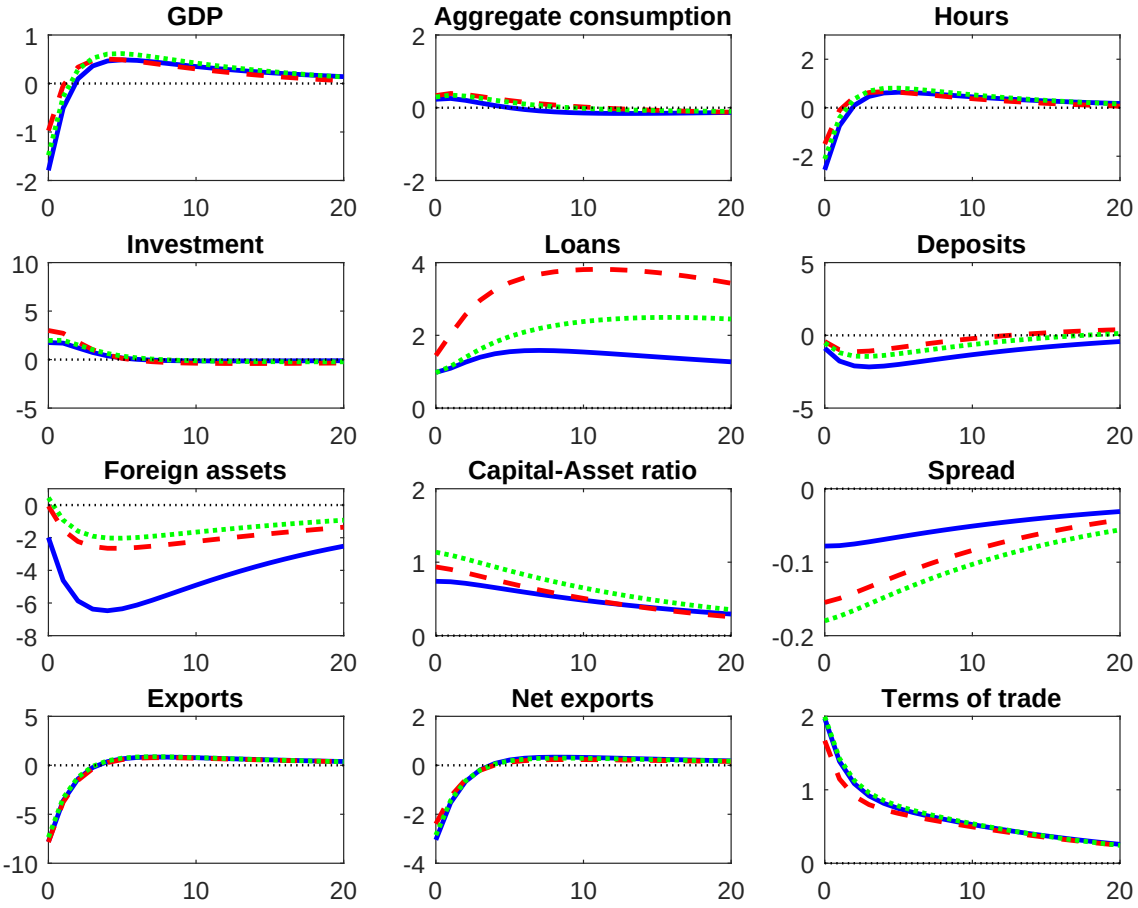

Figure 9: Impulse-response functions to trade-channel shock. See Figure 7 for description.

sumption is very low. On the other hand, consumption of workers, which constitutes the largest part of aggregate consumption, falls. Lower interest rates and higher net exports, which turn into a surplus because of the continued depreciation of the terms of trade, lead to a quick and overshooting recovery of GDP. The main difference between the German and the UK reaction to the trade-channel shock is again due to the larger foreign-assets-to-loans ratio in the UK. The depreciation of the terms of trade increases the value of UK foreign assets in terms of domestic goods relatively more, such that bank capital rises more than in Germany.[33] The resulting larger reduction in the spread stimulates the economy more in the UK. The large exposure to foreign assets, which leads to detrimental effects in case of the financial-channel shock, hence serves as an automatic stabilizer after a trade-channel shock.

Comparing the output responses for the two shocks shows that the initial impact of the trade-channel shock is higher relative to the financial-channel shock for Germany and vice versa for the UK. However, in both cases output needs much longer to recover from the financial-channel shock. Given that

[33] Remember that bank capital in period t is $L_{t+1} + p_t A_{t+1} - D_{t+1}$, where the terms of trade p_t unexpectedly rise following a trade-channel shock. Asset returns typically fall in times of lower external demand because of deteriorating economic situations abroad, another factor that links falling external demand to negative wealth effects. This effect is deliberately not captured in the trade, but in the financial channel of our model.

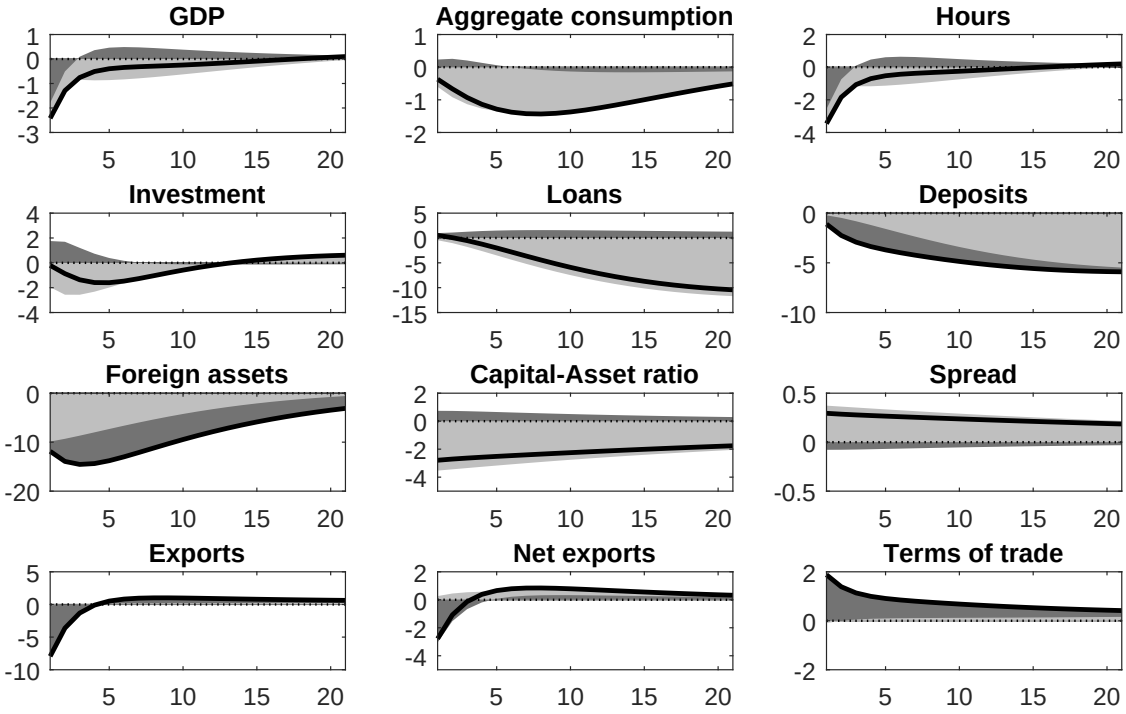

Figure 10: Relative impact of trade- and financial-channel shock for Germany. Dark grey areas represent effects of the trade-channel shock, light grey areas show effects of the financial-channel shock. Thick lines depict aggregate response. Variables are expressed in percentage deviations from steady state, except the spread (in percentage points p.a.), capital-asset ratio, and net exports over GDP (both in percentage points).

German and even more so UK output in the third quarter of 2010 was still below its level two years before, the financial-channel shock plays an important role in explaining the prolonged recovery. To visualize these aspects, we plot the relative contributions of both shocks in Figure 10 for Germany and Figure 11 for the UK. The dark grey area depicts the contribution of the trade-channel shock, the light grey area represents the contribution of the financial-channel shock, while the thick black line plots the aggregate response. As the figure shows, the trade-channel shock explains almost all of the movements of net exports and the terms of trade, while the financial-channel shock is responsible for most of the reactions of consumption and the financial variables. Deposits in Germany and foreign assets in both countries, however, are also driven to a non-negligible amount by the trade-channel shock. Concerning GDP, the trade-channel shock's relative influence is largest on impact, especially in Germany. Longer horizons, on the other hand, are dominated by the financial-channel shock. This is also reflected in the cumulative responses, presented in Columns (5)-(7) of tables 4 and 5. We accumulate the quarterly values of individual responses over the course of the year following the shocks. In both countries, the financial channel has the stronger accumulated, contractionary impact on almost all variables, except for net exports and the terms of trade that are predominantly depressed/depreciated by the trade-channel shock. Moreover, deposits in Germany are also more strongly affected by the trade-channel shock over time. This is due to the stronger fall in the spread in the UK (see above), which dampens the reduction in deposits.

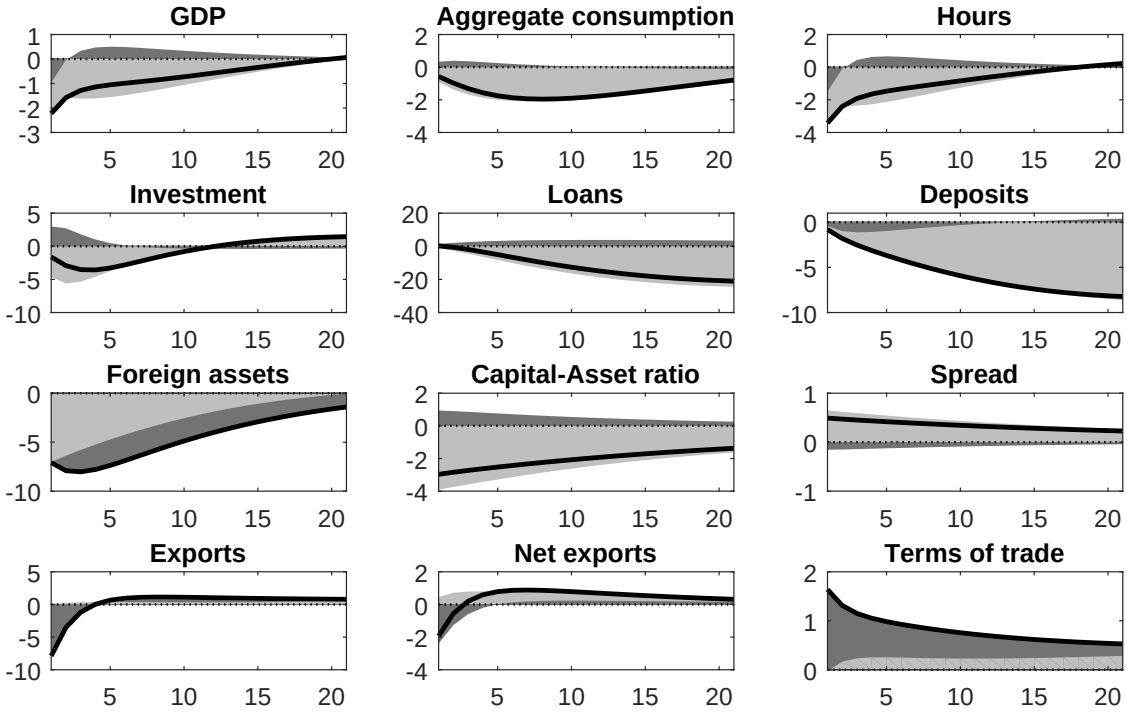

Figure 11: Relative impact of trade- and financial-channel shock for the UK. See Figure 10 for description.

Next, we want to highlight the importance of different structures in the UK and Germany for the transmission of the shocks, in particular the composition of banks' balance sheets. To do so, we conduct the following counterfactual simulation. We take the model calibrated to the German economy, but change the A/L ratio to the higher value observed in the UK. As crisis shocks, we also use those of the UK. We hence obtain a hypothetical crisis path for a German economy with parts of the financial structure of the UK and the crisis shocks as experienced in the UK. Results are plotted as green dotted lines in figures 7 - 9. Any remaining differences between this scenario and the UK responses (red dashed lines) hence stem from other differences in the calibration.

Consider first the financial channel, shown in Figure 8. Remember that the UK experienced lower write-downs than Germany during the financial crisis (in percentage terms, but larger in absolute terms). If we equalize the A/L ratio and the size of the financial-channel shock, foreign assets fall similarly in the hypothetical German and the actual UK economy. Because of the higher A/L ratio, most hypothetical German responses are much closer to their UK counterparts, compared to the baseline.[34] Using the asset-to-loan ratio of the UK value hence amplifies most responses relative to the German calibration with German shocks, despite the lower reduction in foreign assets. Intuitively, as the shock is applied to a larger stock of foreign assets, bank capital falls by more than in the original German calibration. This triggers a larger increase in the spread and hence stronger reductions in loans and deposits. The largest remaining differences to the UK calibration lie in the external sector. Because

[34] Figures B.1 and B.2 in Appendix B show the responses for the unchanged German calibration with shocks as estimated for the UK (blue solid lines). Considerable differences to the UK remain.

Germany is more engaged in international trade, the reduction in demand falls to a larger extent on foreign goods. As a result of the smaller weight on domestic goods, net exports increase more, the terms of trade depreciate less, and exports are lower compared to the UK. Adjusting the export share of Germany to the UK value results in more similar responses of exports, net exports, and the terms of trade. The green dotted lines in Figure B.1 in Appendix B depict the corresponding impulse-response functions for the financial-channel shock. As for the UK responses (red dashed lines in the same figure), we now also obtain a quick depreciation and a simultaneous increase in exports.

The green dotted lines in Figure 9 represent the hypothetical German responses to a trade-channel shock, if we set the shock size and the calibrated A/L ratio to the UK value. Again, the responses are closer to the UK responses compared to the original German calibration. As discussed above, the terms-of-trade depreciation has a positive effect on the domestic value of the foreign asset, counteracting to some degree the reduced demand. A larger stock of foreign assets increases this effect, such that bank capital rises more strongly and the spread falls by more. With a higher A/L ratio, a smaller share of foreign assets has to be transformed into loans to satisfy the increased loan demand; the reduction in foreign assets is hence dampened further. Given the larger steady-state export share of Germany, the negative GDP response is nevertheless stronger for the hypothetical German response than for the UK. The largest remaining difference is the behavior of loans. The larger steady-state stock of loans in Germany leads to a stronger wealth effect for entrepreneurs, as their debt-service payments decline with lower loan rates. Their expenditures can hence be financed to a larger degree out of own funds instead of loans. Imposing equal financial structures, i.e., setting also the German steady-state L/Y and capital-asset ratios to the UK values in addition to the A/L ratio, reduces this difference significantly. The green dotted lines in Figure B.2 in Appendix B depict the corresponding impulse-response functions for the trade-channel shock, which are very close to the UK responses (red dashed lines in the same figure). We conclude that the financial structures are important also for the transmission of the trade-channel shock, while trade openness plays a large role for the transmission of the financial-channel shock as well.

Lastly, the green dotted lines in figures 12 and 13 plot important responses for the transmissions via the financial channel, the trade channel, and a simultaneous transmission for a model without (dynamic) financial frictions. In this case, neither regulators nor market discipline force the bank to return to a certain capital ratio after disturbances, implying a constant spread.[35] Bank capital reduces due to the write-downs in the case of a financial-channel shock, but stays relatively flat afterwards. The constant spread causes the deposit rate to fall by less compared to the baseline, leading to lower worker consumption and hence higher labor supply. The resulting lower wages depreciate the terms of trade and increase exports. As a result, GDP increases slightly for a couple of periods.

The responses to a trade-channel shock are changed less. The initial reaction of loans and deposits is very similar to the baseline. As the spread remains constant, however, there is a slightly smaller

[35] As we simulate a one-time shock, we can set $\phi''=0$ despite the resulting unit root, different to the business-cycle simulations above. The steady-state interest-rate spread is left at its baseline value in order to compare scenarios with equal steady states.

positive effect of a falling spread on GDP (and consumption). This effect is stronger for the UK since its spread falls by more in the baseline scenario. If both shocks happen simultaneously, the relative positive effects of the financial channel dominate: GDP and consumption are higher relative to the baseline. Furthermore, note the different long-run implications. Given that bank capital is free to remain at any given level, we obtain a unit root in the model. Bank capital is determined by loans and deposits, besides foreign assets. Their values represent relative wealth positions of the entrepreneur, the worker, and the banker. As usual in models with incomplete markets, they do not return to the initial steady-state (in absence of a special mechanism for that purpose). The resulting aggregate long-run effects, however, are quantitatively very small.

Considering the simulation results for normal business cycles (tables 2 and 3) and those for the transmission of the crisis, we find that the financial friction is important for certain variables during normal business cycles. Its largest effect, however, arises in the aftermath of a negative shock that arrives via the financial channel. Here, it reduce GDP (and consumption) considerably.

7. Policy intervention: stricter capital regulation

As a response to the crisis, some authors have asked for stricter capital regulations.[36] In this section, we increase the costs a bank incurs when deviating from the mandatory capital requirement. This can be interpreted as being consistent with the strengthening of supervision after the financial crisis (see, e.g., BCBS 2015) or the observation that since the financial crisis capital markets pay more attention to banks' compliance with capital regulation. Alternatively, we also analyze higher mandatory capital requirements, as called for in the wake of the financial crisis (see, e.g., Admati and Hellwig 2013). These can loosely be interpreted as being in line with the tighter capital requirements introduced with Basel III (BCBS 2010). For example, the higher quality of capital required by Basel III would play the same role as a higher capital ratio in our model, since we do not distinguish different types of capital. Our aim, however, is not to quantitatively evaluate the consequences of specific suggestions, but to assess the tradeoffs that regulators might face in the context of adverse spillovers via the trade and financial channel. In particular, we are interested if these measures can contribute to a lower and/or shorter recession after the considered external shocks.

So far, the parameter for the bank capital cost function was set at $\phi_2 = 0.25/Y$. A stricter enforcement would lead to larger punishments for violations of the requirement. We explore the implications of these larger punishments by doubling ϕ_2 to $= 0.5/Y$. Figure 12 shows how output, bank capital, the loan-deposit spread and deposits react for the German case, while Figure 13 depicts the UK scenario. The initial response of the capital-to-asset ratio to simultaneous financial- and trade-channel shocks (Column 1) or to either one (Columns 2 and 3) is almost the same in the case of a stricter enforcement

[36] Bank capital requirements that generally affect the fraction of liabilities that banks can lend and the resulting credit spreads have been analyzed by a number of studies, see for example Quint and Rabanal (2014), Angelini et al. (2015), and Brzoza-Brzezina and Makarski (2015). The exact specification of the bank capital requirement depends on the model and the question asked.

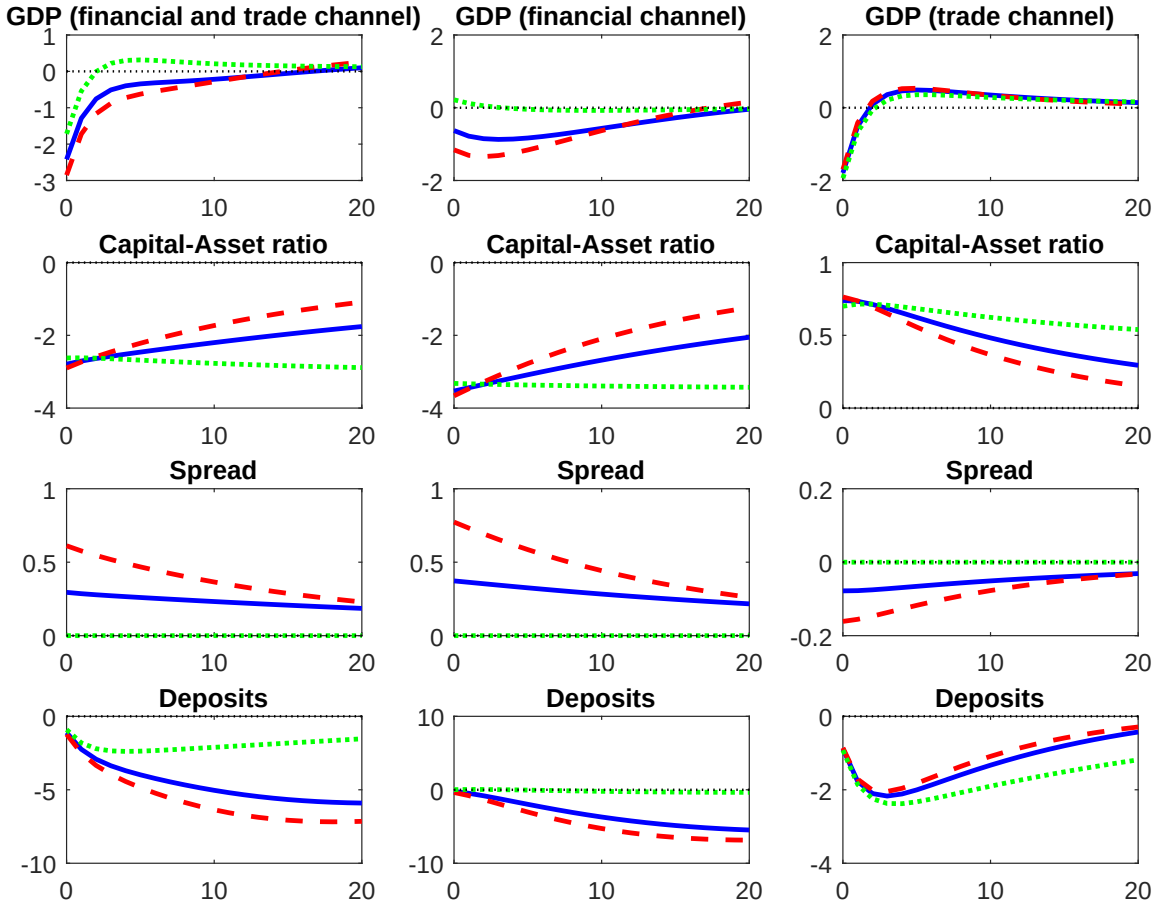

Figure 12: Germany: Impulse-response functions to financial- and trade-channel shocks, different bank capital costs. Responses for $\phi_2 = 0.25/Y$ (solid line), those for $\phi_2 = 0.5/Y$ (dashed line), and for $\phi_2 = 0$ (dotted line). Variables are expressed in percentage deviations from steady state, except spread (in percentage points p.a.), capital-asset ratio, and net exports over GDP (both in percentage points).

compared to the baseline calibration. However, the spread increases by more in order to revert bank capital faster back to its steady-state value. The negative GDP response is hence shifted forward, i.e., a stronger initial response is followed by a quicker recovery. Mainly responsible for this procyclical effect is the altered reaction to the financial-channel shock. In case of the trade-channel shock, the responses of real variables hardly change. For both shocks together, the German responses are slightly less affected by a stricter regulation, given the relatively lower importance of the financial-channel shock for Germany. The reaction of the spread after simultaneous shocks doubles, while the initial output decline increases from 2.42% to 2.85%. The duration of the recession shortens by 2 quarters (16 vs. 18 periods of GDP below trend). The initial output drop in the UK is 2.80% with stricter regulation, compared to 2.23% before. Responsible for the stronger reaction is again the spread, which more than doubles. As bank capital returns to normal values quicker, the recession is 3 periods shorter (17 against 20).

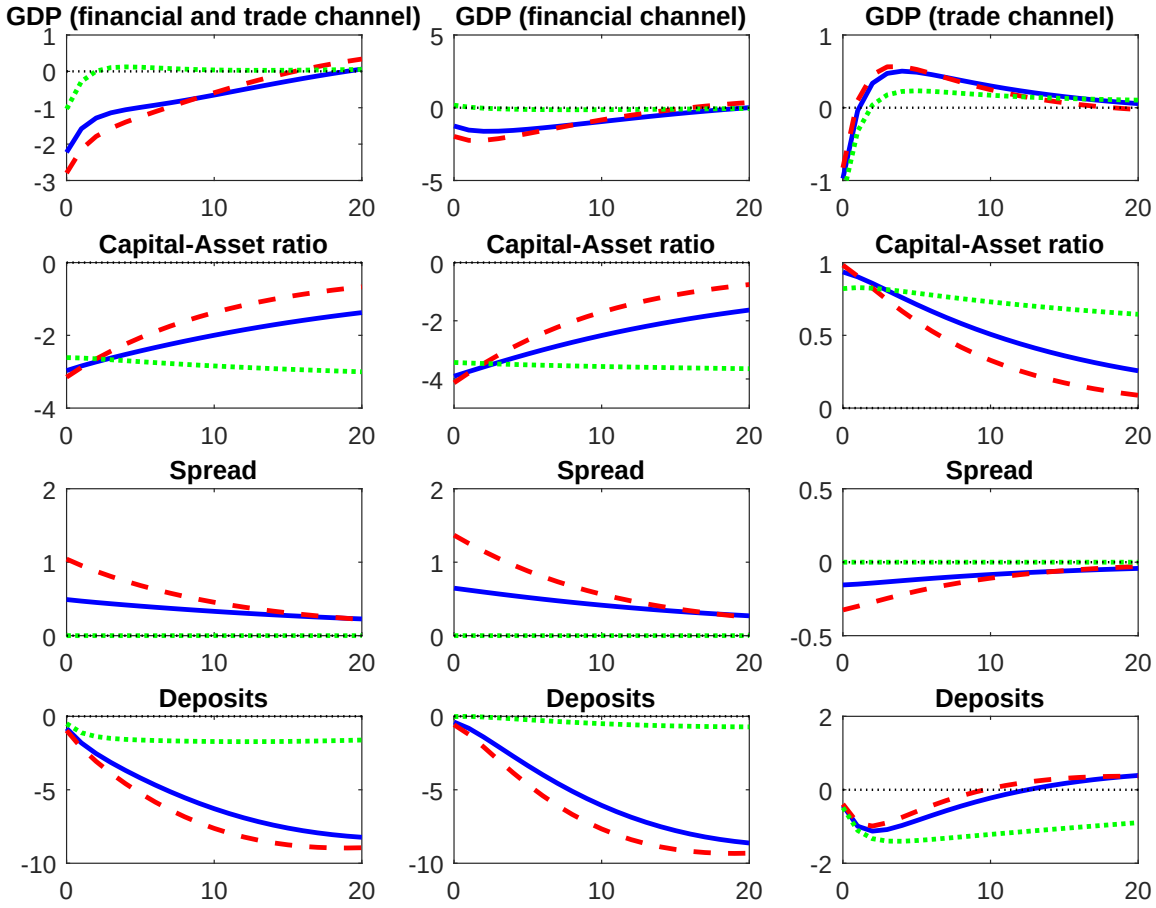

Figure 13: UK: Impulse-response functions to financial- and trade-channel shocks, different bank capital costs. See Figure 12 for description.

As a second approach to stricter banking regulations we consider a higher capital requirement.[37] In the baseline calibration, we have targeted the long-run loan-to-GDP ratio in both countries. Since it is not clear a priori how the balance sheets of banks react to higher capital requirements, we will evaluate two extreme cases: one where the size of bank balance sheets remain unchanged and one where bank capital is constant but the balance sheet adjusts to meet the higher required capital.

In the former case banks' liabilities consist of more equity but less deposits. To demonstrate the effects intuitively, we require banks to hold a higher capital share by doubling the steady-state bank capital γ relative to its baseline value. Steady-state GDP is hardly altered under this calibration. We depict the hypothetical responses for Germany and the UK with the red dashed lines in Figures 14 and 15. We observe similar effects as with the stricter enforcement discussed above: the recession is frontloaded compared to the baseline. Given the lower stock of deposits, the bank cuts the deposit rate by more in order to restore its capital after an adverse financial-channel shock. The resulting higher spread has a negative impact on GDP. The recovery, however, is again faster compared to an economy

[37] We evaluate this measure in isolation, i.e., ϕ_2 is set back to its baseline value

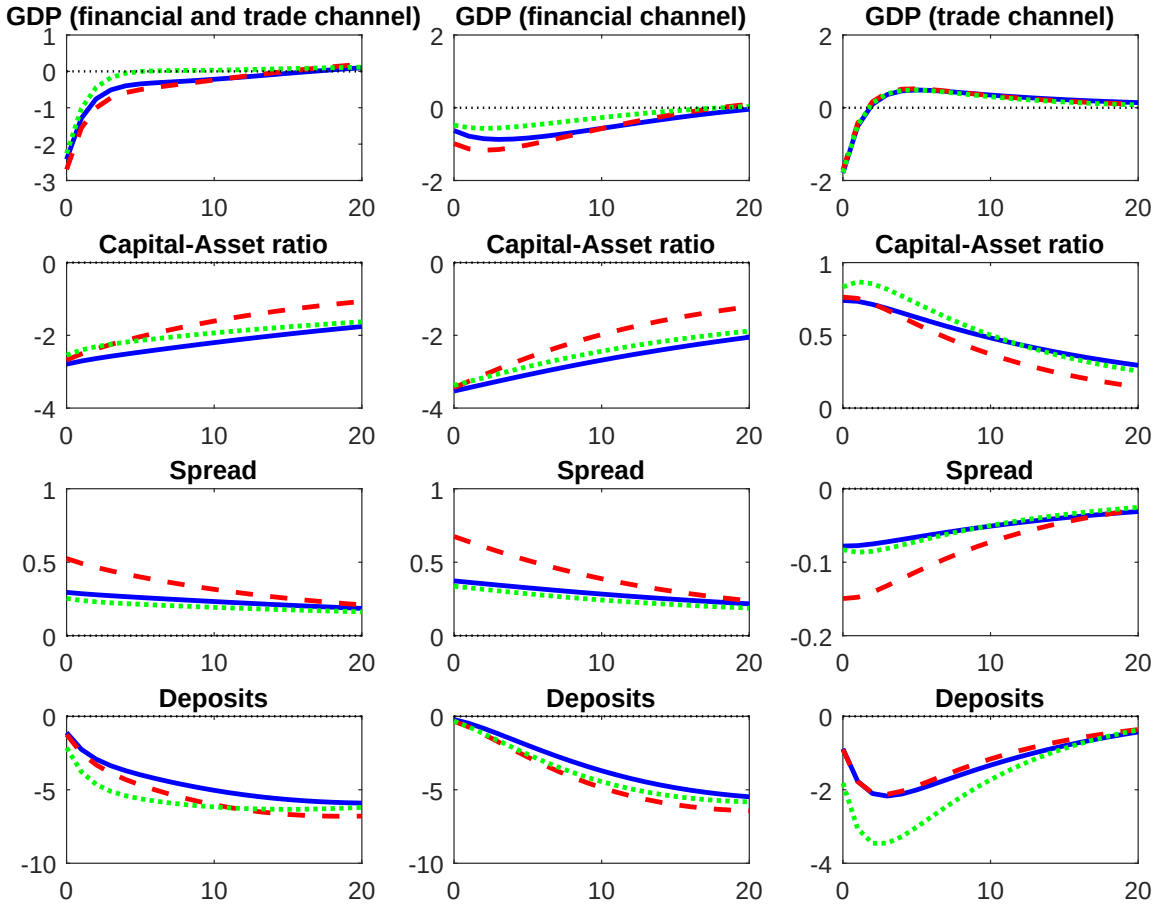

Figure 14: Germany: Impulse-response functions to financial- and trade-channel shocks, different bank capital requirement. Responses for capital requirement (γ) of 4.35% (solid line), those for $\gamma = 8.7\%$ with constant balance-sheet size (dashed line), and with constant absolute capital (dotted line). Variables are expressed in percentage deviations from steady state, except spread (in percentage points p.a.), capital-asset ratio, and net exports over GDP (both in percentage points).

with lower bank capital in steady state. The falling consumption profile of workers induced by the lower deposit rate lets wages fall below the baseline response, while hours worked rise above it. For simultaneous trade- and financial-channel shocks, the effects of the new regulation on the financial channel dominate, as the reaction of real variables to a trade-channel shock is hardly altered after the policy intervention. In terms of numbers, the initial GDP drop amounts to 2.70% for Germany and 2.52% for the UK, while the recession lasts 16 quarters in Germany and 18 in the UK.

In the alternative experiment, we assume that banks keep the size of their capital constant and thus shrink their balance sheet in order to comply with the higher capital requirement. That is, we double the steady-state bank capital γ, but also adjust the steady-state loan-to-GDP ratio downwards.[38] We

[38] We hence need to change Ψ^N in the utility function. Considering this parameter invariant implies that a constant size of the balance sheet after a required higher bank capital is the more likely outcome. In response to the Basel III reforms that introduced tighter capital requirements, banks have indeed increased their absolute levels of capital (see, e.g., the Basel III Monitoring Report of September 2017).

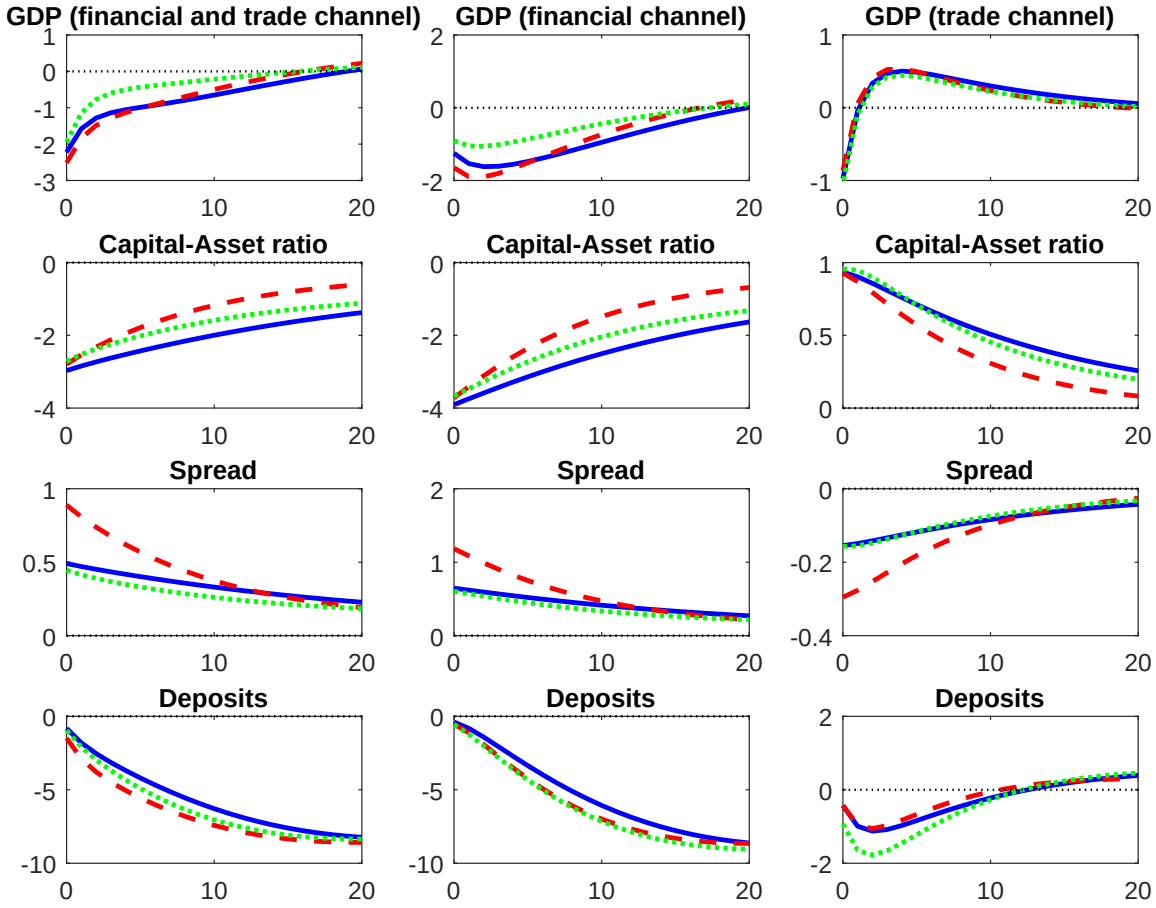

Figure 15: UK: Impulse-response functions to financial- and trade-channel shocks, different bank capital requirement. Responses for capital requirement (γ) of 6.5% (solid line), those for $\gamma = 13\%$ with constant balance-sheet size (dashed line), and with constant absolute capital (dotted line). See Figure 14 for further description.

also obtain a new steady-state level of GDP, around 1.7% below baseline, demonstrating the adverse effects of a lower supply of loans. The responses are shown with the green dotted lines in figures 14 and 15. Intuitively, the smaller balance sheet features less international assets and hence reduces banks' exposure to foreign losses. The resulting absolute reduction in bank capital after a financial-channel shock relative to the stock of deposits is comparable to the baseline case, such that the spread rises by a similar amount. The lower absolute loss also translates into a quicker recovery (only 7 quarters in Germany and 17 in the UK) and a smaller negative impact on GDP (2.26% in Germany and 1.95% in the UK, relative to the new steady state), even compared to the baseline. Due to the higher foreign asset holdings, this positive effect is more pronounced for the UK. We conclude that the reaction of banks (and their customers) is important for the effects of imposing a higher capital ratio. While in both cases the recession is shorter, its depth can be larger or smaller relative to the baseline. Thus, the consequences of this policy can only be evaluated taking further assumptions.

To summarize, all considered policy interventions induce a shorter recession in reaction to financial-

channel shocks. Note, however, that workers' relative welfare—expected lifetime utility compared to the baseline—falls by more in the case of a simultaneous shock transmission with both, a stricter capital regulation and a higher equity requirement with a constant balance sheet size.[39] Higher financial frictions, resulting in a higher spread, induce relative low investment and GDP. Given that we do not consider financial stability issues (risks of bank failure), however, we hesitate to give policy recommendations based on these results only.

8. Conclusion

In this paper, we have analyzed how the recent financial crisis was transmitted internationally. For this purpose, we have employed a quantitative business cycle model featuring trade with the rest of the world as well as a globally acting banking sector. Calibrated to German and UK data, the model can account for key features of empirical regular German and UK business cycles. In order to compare the model predictions for the crisis episode to the data, we estimate a VAR that identifies the effects of external trade- and financial-channel shocks on Germany and the UK. The theoretical predictions replicate important aspects of the effects of the estimated crisis shocks. In particular, the predicted signs and relative strengths of a variety of variables are as observed empirically.

Analyzing the relative importance of the two transmission channels shows that the trade channel was more important for the transmission of the crisis to Germany, due to its larger trade openness. The financial channel, on the other hand, played a stronger role for the UK. Specifically, the German banking system had to write down a larger share of its foreign assets, but the resulting effects were less severe due to the relatively smaller holdings of foreign assets. This underlines the greater vulnerability of the UK economy to the kind of financial-channel shocks considered here, i.e., losses on foreign assets. In case of a trade-channel shock, however, larger holdings of foreign assets serve as an automatic hedge because of the induced terms-of-trade depreciation.

Since the transmission via the financial channel has longer-lasting effects than the trade channel, it is responsible for the prolonged recessions that followed the financial crisis, in particular in the UK. By the same token, the cumulated effects of the financial channel are more contractionary than for the trade channel, except for the reaction of international trade. Regarding possible policy experiments, we consider the effects of two forms of stricter bank capital regulation. It turns out that a stricter implementation of existing requirements would frontload the recession, as banks increase the spread by more to rebuild capital quicker. The effects of higher capital requirements depend on the way how banks' balance sheets adjust to this regulation.

[39] If the balance sheet shrinks in reaction to the regulation, workers' welfare in reaction to the crisis shocks falls by less relative to the respective steady states if compared to the baseline. This is again due to the reduced stock of foreign assets that is hit by the financial-channel shock. However, steady-state GDP and welfare are lower.

Appendix

A. Data construction and sources

- **Shock processes and crisis shocks:** For the calibration, we use the series for the log of TFP, the log of global demand, and the foreign asset returns in a SUR regression with one lag from 1991Q1-2009Q1 to estimate the AR(1) shock processes in 'normal times'. Log-variables were detrended with a linear trend before estimation. We insert a dummy in 2009Q1 and use its impact on global demand as the crisis shock of the trade channel. The autocorrelations for the trade-channel shock are set to values that imply the same recoveries after one year (in percentage terms) as the observed recoveries of our global demand measures for Germany and the UK, respectively. The crisis shock for the financial channel corresponds to the write-downs on foreign loans and securities between 2007 and 2010 as estimated in International Monetary Fund (2010a). For Germany we assume that the ratio of foreign to domestic loans and securities, both for holdings and for write-downs, is equal to the euro area average, as a breakdown in foreign and domestic loans and securities is not available. Data on write-downs are only available for the period of the financial crisis.

- **Empirical maximum responses:** To compare the model predictions with empirical data, we use the results from the VAR in Section 3.2. Specifically, we feed the identified trade- and financial-channel shocks for 2008Q4 and 2009Q1 as shocks in the first period in the estimated VAR. We denote the minimum over the following 4 periods (the maximum for the spread and the terms of trade) as the maximum response.

- **GDP, its components, and hours worked:** We use quarterly German and UK data for GDP, gross fixed capital formation, consumption of households and non-profit institutions serving households, exports and imports of goods and services, Hours worked per employee, and total employment from the OECD Economic Outlook. We employ data from 1991Q1 to 2012Q4.

- **Loans, deposits, interest rates, and bank capital:** We use data on loans and deposits from the Bundesbank and the Bank of England. The data on loans to domestic non-financial corporations (private non-financial corporations for the UK) starts in 1999Q1 for Germany (series ID: BBK01.OXA8A4) and 1997Q4 for the UK (series ID: LPMBC57). Deposits for Germany (deposits from domestic non-banks) has the series ID: BBK01.OU0220. Data for the UK (deposit liabilities, series ID: BSI.M.GB.N.A.L20.A.1.U6.2300.Z01.E) is taken from the ECB.
  For the German interest rate spread, we combine data on deposit and loan rates from the Bundesbank (1997-2003) and the ECB (from 2003 onwards). Deposit rate: average rate on savings deposits with higher rates of returns, with agreed notice of 3 months and a duration of up to and including 1 year (Bundesbank, series IDs: BBK01.SU0527); annualized agreed rate on

deposits with agreed maturity up to 1 year from households and non-profit institutions serving households (ECB, series ID: MIR.M.DE.B.L22.F.R.A.2250.EUR.N). Loan rate: effective interest rate on long-term fixed-rate loans to enterprises and self-employed persons of 500000 and up to 5 million Euro (Bundesbank, series IDs: BBK01.SU0509); annualized agreed rate on loans other than revolving loans and overdrafts, convenience and extended credit card debt to nonfinancial corporations with a maturity of at least 1 and up to 5 years of up to and including 1 million Euro (ECB, series ID: MIR.M.DE.B.A2A.I.R.0.2240.EUR.N).

The UK interest spread is calculated on the basis of data from the ECB, which is available from 2004 onwards. Deposit rate: annualized agreed rate on deposits with agreed maturity up to 1 year from households and non-profit institutions serving households (series ID: MIR.M.GB.B. L22. F.R.A.2250.GBP.N). Loan rate: annualized agreed rate on loans other than revolving loans and overdrafts, convenience and extended credit card debt to nonfinancial corporations with a maturity of at least 1 and up to 5 years (series ID: MIR.M.GB.B.A20.I.R.A.2240.GBP.O).

The 'Bank capital to assets ratio (%)' for Germany and the UK is taken from the World Bank (FB.BNK.CAPA.ZS), available 2000-2011 for Germany and 2000-2010 for the UK.

- **Claims on non-residents and Claims on non-residents (US) by German and UK banks:** For claims on non-residents (left panel of Figure 4) and non-residents (US) (right panel of Figure 4) by German and UK banks we use data from the BIS consolidated banking statistics (Foreign Claims, Immediate Borrower Basis, Tables 9B), with quarterly data starting in 2002.

- **Global demand and trade data:** We construct the global import series by aggregating overall imports obtained from the OECD Economic Outlook (MGSV: Imports of goods and services, volume) of Australia, Austria, Belgium, Canada, China, Finland, France, Ireland, Italy, Japan, Netherlands, Norway, Poland, Spain, Sweden, Switzerland, and the United States, as well as Germany for the UK aggregate and vice versa. These countries include the top ten trading partners for the UK and Germany. In order to avoid national basis effects, we construct the global import series by first calculating quarterly growth rates of overall real imports of goods and services for each trading partner and then aggregating the weighted series. Weights are calculated as the time-varying percentage shares of trade (merchandise imports+exports, obtained from the OECD Monthly Statistics of International Trade) with the respective country (lagged four quarter rolling window). The aggregated growth rates are then cumulated from the normalized base year in order to transform the series into levels. Given that imports of goods and services are not available for China, we use imports of goods (value) for China and the GDP deflator for the United States to obtain volumes, both from the OECD Main Economic Indicator database. Values for imports of goods for 1991, which were still quite low, are extrapolated from later observations, starting in 1992. Net exports over GDP of Germany and the UK are calculated as the net exports towards the same set of countries.

- **Foreign asset returns:** We construct the return process for foreign assets using data on US stock prices and the value of US corporate debt. For the former, we use data of the S&P 500

total return index (from Bloomberg), while for the latter we use the Bank of America Merrill Lynch US Corp Master Total Return Index Value that tracks investment grade rated corporate debt, taken from the FRED database. The two series are deflated with the US GDP deflator and weighted by the average share of equity and corporate debt in German and UK long-term portfolio holdings of US securities. The data for German and UK long-term portfolio holdings of US securities is taken from various reports on foreign portfolio holdings of US securities published by the Department of the Treasury together with the Federal Reserve Bank of New York and the Board of Governors of the Federal Reserve System.

- **TFP:** To construct the TFP measure, we use the following quarterly data from the OECD Economic Outlook: Gross domestic product, volume, market prices; Total Employment; Hours worked per employee, total economy. The UK capital share, which is also used in the calibration, is calculated by employing averages of nominal GDP, compensation of employees, and gross self-employment income received by households from the same source. Because of missing data for self-employed workers, the German capital share is calculated on the basis of corresponding data from the Federal Statistical Office. Because of a lack of data for the capital stocks, we set capital to a constant in both estimations.

B. Additional figures and tables

Table B.1 shows the business cycle statistics for the German calibration, where the A/L ratio is replaced by the higher UK value. We note that in this case the return shock generates much larger fluctuations, i.e., volatility of GDP due to the return shock increases substantially, while other volatilities and correlations remain relatively unaffected (net export's and terms of trade's correlations with GDP decline, see below). The intuition is straightforward: as the fluctuations in returns now affect a larger stock of foreign assets, their impact is amplified. Shocks to total factor productivity have similar effects as with the original A/L ratio, while we observe some notable differences in the reactions to trade-channel shocks. As explained in more detail in Section 6, the higher A/L ratio dampens the effects of shocks via the trade channel. A reduction in external demand depreciates the domestic currency and hence lifts the value of foreign assets in domestic currency. The increase in bank capital counteracts the negative effects of the negative trade-channel shock to some extent. Hence, relative volatilities of all variables decline. Output falls less on impact after a trade-channel shock, but turns stronger positive after some periods, such that its volatility increases. Importantly, the correlation between net exports and GDP counterfactually turns negative, due to the trade and return shocks. After a negative trade-channel shock, GDP recovers more quickly with a higher A/L ratio, although net exports still remain negative for some periods. Following a return shock, net exports increase by more during the slump, as the stronger impact through a larger stock of foreign assets reduces import demand and depreciates the terms of trade further.[40]

[40] The difference in the NX/GDP correlation between the UK and Germany following TFP shocks under the baseline calibration is driven by the different autocorrelation of TFP: the larger value in the UK increases the wealth effect and hence boosts imports.

Table B.1: Business Cycle Statistics of German data and model
(German calibration with A/L value of UK)

	Data	Model				
		All	TFP	Trade	FA ret.	No fin. fric.
	(1)	(2)	(3)	(4)	(5)	(6)
Std. dev. output	1.15	2.40	1.98	0.13	1.45	1.74
Relative standard deviations						
Consumption	0.46	0.95	0.59	1.23	1.38	0.56
Investment	2.16	2.53	2.02	2.04	3.09	2.22
Hours	0.43	0.95	0.60	1.37	1.39	0.48
Deposits	0.95	0.84	0.29	1.01	1.33	0.27
Loans	1.53	2.71	1.21	4.35	4.31	1.02
Interest rate spread	0.38	0.23	0.06	0.62	0.38	0.00
Terms of Trade	0.76	0.56	0.63	6.95	0.35	0.64
Net Exports	0.48	0.42	0.20	2.12	0.63	0.26
Correlation with GDP						
Consumption	0.42	0.79	0.82	0.91	0.91	0.79
Investment	0.88	0.91	0.96	-0.72	0.89	0.96
Hours	0.68	0.89	0.95	1.00	1.00	0.92
Deposits	0.09	-0.02	-0.07	-0.89	-0.04	0.14
Loans	0.00	-0.09	-0.16	-0.02	-0.08	-0.10
Interest rate spread	-0.39	-0.70	-0.97	-0.96	-0.96	-0.69
Terms of Trade	0.31	0.46	0.95	0.96	0.09	0.64
Net Exports	0.24	-0.27	0.21	-0.95	-0.84	0.41

Figures B.1 and B.2 provide some additional intuition for the model dynamics. We plot the responses under the German calibration, but feed in the shocks estimated for the UK (blue solid lines). Given that the trade-channel shock is very similar for both countries, differences to the baseline responses for Germany arise mainly for the financial channel. The shape and qualitative responses do not change with the alternative shocks. The effects of the financial channel, however, become smaller, as the German financial channel was characterized by larger losses on foreign assets (measured in percentage terms). Remember that many banks, in particular the 'Landesbanken', were quite 'unlucky' in their investment decisions. As a result, the financial variables, such as the interest-rate spread, react less after the financial-channel shock. This causes a somewhat less strong decline in output relative to the baseline.

The green dotted lines in Figure B.1 depict the case of the same A/L ratios and export shares across the two countries for a financial-channel shock. In particular, we still feed the UK shock into the model

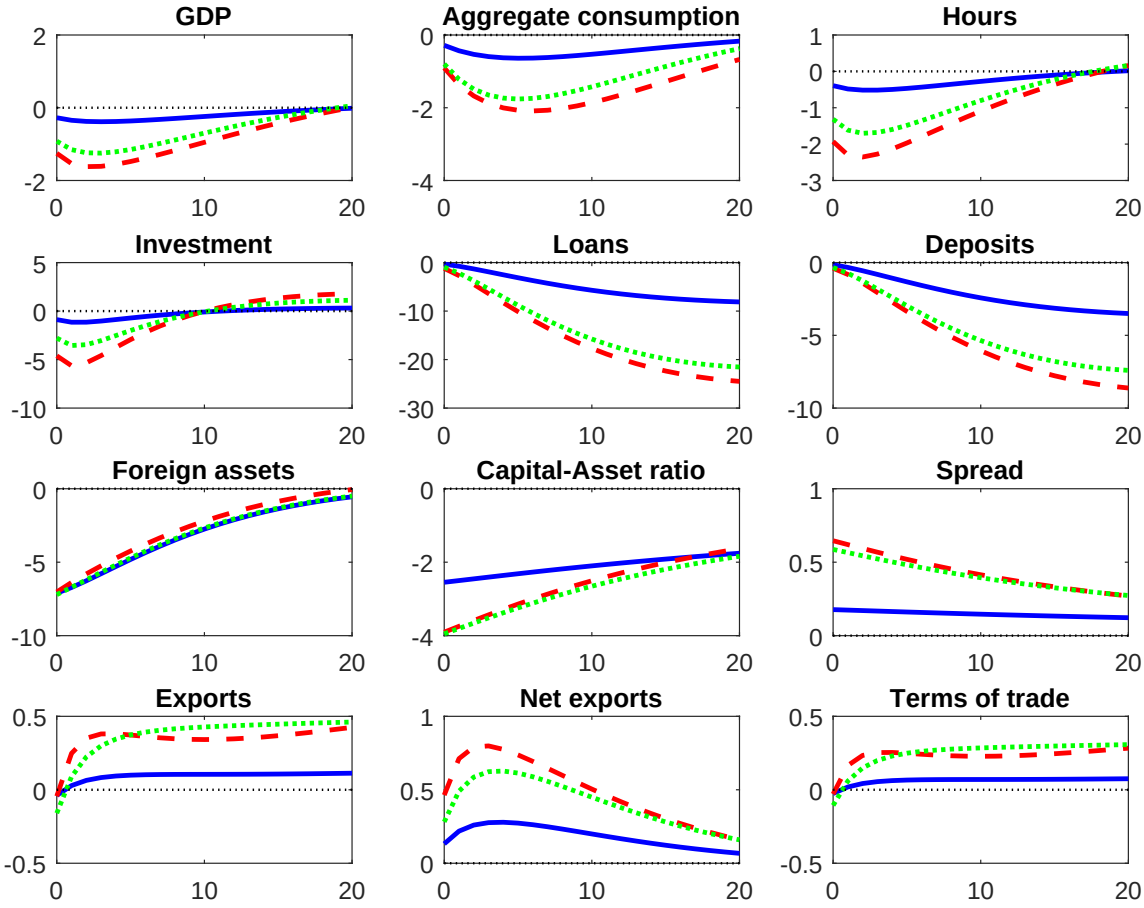

Figure B.1: Impulse-response functions to financial-channel shock, for equal shocks and the same assets-to-loan ratio and export share. All lines represent reactions to shock values as estimated for the UK. Solid lines represent IRFs for the German calibration, dashed lines for the UK, dotted lines for the German calibration with steady-state A/L and steady-state export share of the UK. Variables are expressed in percentage deviations from steady state, except spread (in percentage points p.a.), capital-asset ratio, and net exports over GDP (both in percentage points).

calibrated to the German economy, but set the A/L ratio and the export share to the UK values. As discussed in the main text, this brings about an immediate terms-of-trade depreciation and a simultaneous rise in exports in the hypothetical German responses, as in the UK responses (red dashed lines). In fact, both variables react stronger than under the UK calibration. This difference stems from the different steady-state bank capital in both countries. A given loss of foreign assets results in a stronger reduction of the capital-asset ratio for German banks, given their lower steady-state value (remember that we plot changes in the capital-asset ratio expressed in percentage points. German banks hence loose relatively more for similar decreases in the plots). Setting the steady-state capital-asset ratio to the UK value gives very similar impact responses (results are available from the authors upon request). The green dotted lines in Figure B.2 depict the case of equal financial structures in both countries for a trade-channel shock. As above, we still feed the UK shock into the model calibrated to the German economy, but now set the A/L ratio, the L/Y ratio, and the steady-state bank capital-asset

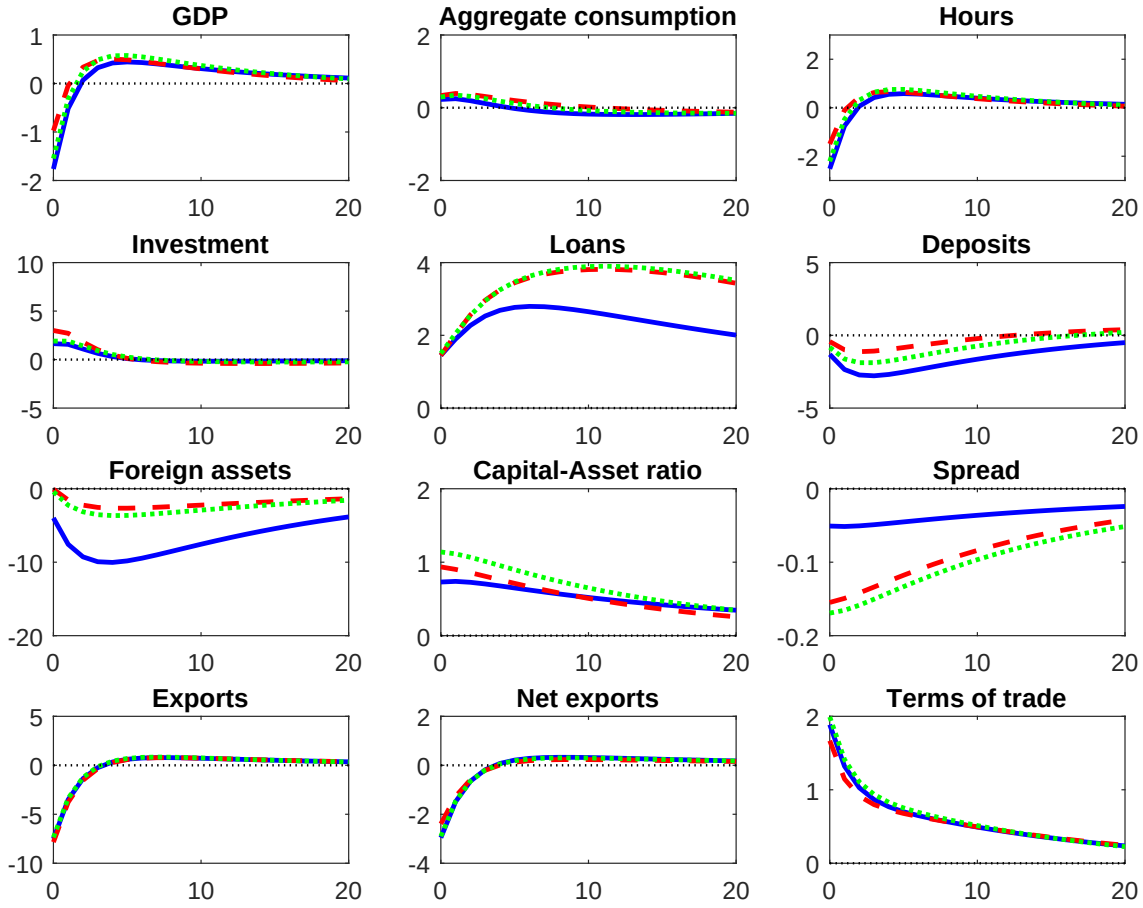

Figure B.2: Impulse-response functions to trade-channel shock, for equal shocks and the same financial structures. See Figure B.1 for description, except dotted lines: German calibration with steady-state A/L, steady-state loan to GDP ratio and bank capital-to-assets ratio of the UK.

ratio to the UK values. As discussed in the main text, most responses are then very close to their UK counterparts (red dashed lines). The largest remaining difference lies in the stronger fall of deposits. Since Germany is more affected by the trade-channel shock due to its higher openness, workers reduce deposits more to smooth consumption. Setting equal export shares yields a virtually identical behavior of deposits (results are available from the authors upon request).

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