BANK OF ENGLAND

Working Paper No. 479
Financial factors and the international transmission mechanism

Abigail Haddow and Mariya Mileva

August 2013

Working papers describe research in progress by the author(s) and are published to elicit comments and to further debate.
Any views expressed are solely those of the author(s) and so cannot be taken to represent those of the Bank of England or to state Bank of England policy. This paper should therefore not be reported as representing the views of the Bank of England or members of the Monetary Policy Committee or Financial Policy Committee.

BANK OF ENGLAND

Working Paper No. 479
Financial factors and the international transmission mechanism

Abigail Haddow[(1)] and Mariya Mileva[(2)]

Abstract

The aim of this paper is to investigate theoretically how financial factors affect the international transmission mechanism. We build a two-country dynamic stochastic general equilibrium model with sticky prices and financial frictions. To add to the literature we extend the model to include two types of credit spread shocks that are micro-founded; a mean preserving shock to the dispersion of firms idiosyncratic productivity (risk shock) and a shock to financial agents net worth (financial wealth shock). We find that the source of the shock to the credit spread matters; credit spread shocks of equivalent size, but driven by different innovations, have different consequences for output and inflation in the home and foreign economy. In general risk shocks generate more realistic spillovers to activity than a financial wealth shock.

Key words: International transmission mechanism, financial frictions, financial shocks, DSGE model.

JEL classification: E37, F41, F42, F44.

---

(1) Bank of England. Email: abigail.haddow@bankofengland.co.uk
(2) Kiel Institute for the World Economy. Email: mariya.mileva@ifw-kiel.de

The views expressed are those of the authors and do not necessarily reflect those of the Bank of England or members of the Monetary Policy Committee or Financial Policy Committee. We are grateful to Emilio Coregudo-Fernandez, Giancarlo Corsetti, Luca Dedola, Matthias Paustian and Jumana Saleheen for useful comments. This paper was finalised on 15 July 2013.

The Bank of England's working paper series is externally refereed.

Information on the Bank's working paper series can be found at
www.bankofengland.co.uk/publications/Pages/workingpapers/default.aspx

Publications Group, Bank of England, Threadneedle Street, London, EC2R 8AH
Telephone +44 (0)20 7601 4030 Fax +44 (0)20 7601 3298 email publications@bankofengland.co.uk

© Bank of England 2013
ISSN 1749-9135 (on-line)

Summary

Two striking features of the Great Recession of 2008-09 are the speed and synchronicity of the collapse in world output and trade in the wake of the sub-prime crisis. These observations provide compelling evidence that spillovers of shocks across national boundaries can be large. But standard macroeconomic models are unable to account for such strong linkages in real activity across countries. There is also little consensus in previous work on the impact that financial market shocks have on real activity and how they might spill over from one country to another. The aim of this paper is therefore to investigate theoretically the impact that financial frictions have on the transmission of shocks across countries and to investigate if incorporating financial factors into an open economy model could help these models to account for the large and synchronised declines in cross-country real activity, often observed following financial crises, not only the recent one. It also analyses how the nature of financial market shocks affect the way that shocks spill over to real activity.

To investigate the impact of financial factors on the transmission of shocks across countries we build a two-country model, with sticky prices and financial frictions. Our analysis is twofold. First we build a shadow version of the model without financial frictions that is used in conjunction with the baseline friction model to analyse how financial frictions affect the way that shocks propagate across countries. Then we introduce two financial market shocks that affect the premium which borrowers pay on their loans, the credit spread, to study how the source of the shock to this credit spread affects its impact on real activity. We introduce a risk shock and financial wealth shock that are calibrated to match the increase in credit spreads seen in the United States over the recent financial crisis period. These are used to consider whether the model's predicted movements in macroeconomic variables are similar to the rapid cross-country declines in output and trade seen over the recent recession period.

Using this modelling framework, we find that the international spillovers of shocks are driven by movements in the real exchange rate and terms of trade. Both the real exchange rate and terms of trade determine the responses of real international economic variables to shocks, such as exports and imports. Under certain conditions, we find that introducing financial frictions can magnify movements in these international relative prices and therefore the spillovers of shocks to real international economic variables. The source of the shock to the credit spread also matters. Results suggest that credit spread increases of equivalent size, but driven by different shocks, have different consequences for output and inflation in the Home and Foreign economy.

Our model can generate synchronised declines in output across the two economies, similar to that seen after financial crises such as the Great Recession, but the international spillovers following all shocks are relatively small. In addition, there is little evidence that financial variables across countries tend to move together in this model, even in response to shocks which are financial in nature. To generate spillovers more in line with the 2007-10 period the model requires a coincident widening of the credit spread across the two economies. This could be interpreted in two ways. On one hand, a richer framework that incorporates direct international linkages between financial sectors is needed to analyse how financial shocks spillover to activity across economies. On the other hand, our results could be consistent with the view that the global reach of the recent Great Recession is due to a common international shock rather than a contagious spread of a country-specific event.

1 Introduction

The Great Recession has challenged academics and policy makers to understand better inter-linkages across economies and between financial and real variables. Standard New Open Economy models have struggled to account for the speed and severity of the cross-country declines in output and trade seen in the wake of the subprime crisis through standard international transmission channels. There is also little consensus in the theoretical literature on the impact that financial market shocks have on real activity. These are important issues for policy makers, not least because of the implications they have for the transmission of shocks across economies.

This paper addresses two questions; first in a simple theoretical model it investigates how financial frictions affect the transmission of shocks to the real economy, both domestically and across economies, second, it explores the transmission of country-specific credit market shocks. There is a vast literature in this area; many studies focus on resolving some of the well known "output co-movement puzzle" by introducing a greater role for financial factors in the transmission mechanism. Our paper adds to that literature in its examination of the impact of financial frictions on the international transmission mechanism. It also extends the current knowledge on how financial factors affect economic fluctuations by investigating how the source of shocks to the credit spread affect the way that shocks propagate to the real economy which, as far as we are aware, has not been done in an open economy model before.

In order to address these questions we build a two-country Dynamic Stochastic General Equilibrium (DSGE) model with financial frictions and sticky prices. In our simulation three separate shocks are introduced to the Home economy; a total factor productivity (TFP) shock and two credit spread shocks. The dynamic responses of the Home and Foreign economy variables to a TFP shock in the Home economy are compared in the model with financial frictions turned on and off. These are used to investigate the effect that financial frictions have on the propagation of shocks.

Next we compare the way that two credit market shocks propagate to the real economy. The first shock that we introduce is a "risk shock" that increases the dispersion of returns on investment; it affects the current state of investment risk in the economy and therefore influences financial intermediaries propensity to lend. The second is a "financial wealth" shock that changes the value of financial agent's total wealth. Both shocks are calibrated so that the increase in credit spreads match the quarterly increase seen in the United States over the recent financial crisis period. The purpose of this exercise is to investigate the strength of the international propagation channels in the model. We analyse the model's ability to generate an endogenous international transmission mechanism that is sufficiently strong to produce a large and synchronised decline in cross-country financial variables and real activity in response to an asymmetric credit spread shock that originates in one country.

The results of our analysis suggest that movements in international relative prices are a key channel for the propagation of shocks to the real economy. In the model's framework international spillovers of shocks are driven by movements in the real exchange rate and terms of trade, which determine the responses of real international economic variables to shocks (exports and imports). Financial frictions tend to magnify movements in international relative prices and therefore increase international spillovers following asymmetric TFP shocks but there are some signs of sensitivity to the specification of financial contracts. The source of the shock to the credit spread also matters. Results suggest that credit spread increases of equivalent size, but driven by different innovations, have different consequences for output and inflation in the Home and Foreign economy. In our model framework movements in the credit spread driven by a risk shock lead to more realistic spillovers to activity in both the Home and Foreign economy, than shocks to financial wealth. That said, whilst the model can account for the positive cross-country output co-movement seen after financial crises such as the Great Recession, the international spillovers following the three shocks remain small. There is also limited co-movement in cross-country financial variables, so a widening of credit spreads in one economy does not generate a significant widening of credit spreads in the other. To generate spillovers in line with the 2007-2010 period the model requires a coincident widening of credit spreads across the two economies. This could be interpreted in two ways. On one hand, a richer framework that incorporates direct international linkages between financial sectors is needed to analyse financial shocks in the context of an open-economy macroeconomic model. On the other hand, our results could be consistent with the view that the global reach of the Great Recession is due to a common international disturbance rather than a contagious spread of a country-specific event.

A number of researchers have studied the impact of introducing financial factors to New Open Economy models. These have predominantly focused on examining how the financial sector propagates shocks originating in the real sector (Gertler and Kiyotaki (2010), Goodfriend and MacCallum (2007), Faia (2007)). The paper most closely related to ours is Faia (2007) who also incorporates a financial accelerator into a two-country DSGE model. Faia (2007) aims to explain why business cycles are more correlated among countries that have similar financial structures. Her analysis shows that cross-country output, consumption and investment co-movement increase when financial parameters are similar. In contrast, our analysis explores how financial factors affect the transmission mechanism. Our contribution to this strand of the literature is to develop a shadow version of the model without financial frictions and explicitly compare its results to the ones implied by the model with financial frictions in order to investigate the effect of financial frictions on the international transmission mechanism.

A newer literature also investigates the impact of introducing more complex cross-country financial linkages, through stock market and cross-country balance sheet exposure (Dedola and Lombardo (2012)). But these have focused less on how the nature of financial disturbances affect spillovers to the real economy and across economies. One explanation for the recent recession is that financial market shocks drove declines in investment and activity implying financial factors may drive business cycle fluctuations. And there is empirical evidence that shocks to the US banking system during the recent financial crisis had consequences for lending and activity in advanced and emerging economies (Cetorelli and Goldberg (2012)).

There has been little research to investigate the macroeconomic impact of direct disturbances to the financial sector in open economy frameworks. Christiano et al (2010) use a version of the Bernanke et al. (1999) model, BGG henceforth, to consider the importance of financial disturbances for business cycle fluctuations. They estimate that financial factors are responsible for a substantial proportion of economic fluctuations, accounting for more than one third of the volatility in euro area investment and 60 percent in the US but these are in a closed economy framework. The results of Christiano et al.(2010) suggest that financial factors are critical for business cycle fluctuations both in the US and the Euro area which suggests that understanding how financial factors spill over to foreign economies is an important question. To investigate how credit market shocks propagate to the real economy both domestically and internationally we introduce two shocks to the credit spread which are analogous to the risk and net worth shock of Christiano et al. Previous studies by Dedola and Lombardo (2012) and Christiano et al (2010) suggests that credit spread shocks generate a quantitatively significant effect on real activity. However, there is little understanding to how the different types of shocks spillover to foreign activity. For example, there is some evidence that shocks to financial wealth can be sensitive to model set up.

Financial frictions are introduced via a “financial accelerator” mechanism along the lines of BGG (1999). Investors pay an external finance premium (EFP) to borrow funds from households via financial intermediaries. Collateral constraints, of the type introduced by Kiyotaki and Moore (1997), have also been used to capture financial accelerator effects in open economy DSGE models (Devereux and Sutherland (2011)). Whilst these may better capture balance sheet effects associated with the process of financial deleveraging, we are interested in finding a model which replicates data observations. Brzoza-Brzezina et al(2010) suggest EFP type constraints outperform collateral constraints in data fit so we favour using an EFP in our model.

The paper is structured as follows: Section 2 presents the model, including the processes that drive our economy; section 3 discusses the calibration of the model parameters before presenting the key results and sensitivity analysis and section 4 concludes.

2 Model overview

This section outlines the baseline DSGE model that we use in our analysis. It closely resembles Faia (2007), but it is modified in two dimensions. First, we consider the impact of financial factors on the propagation of shocks by building a shadow version of the model that excludes financial frictions; second, we consider the role of credit spread shocks. The model comprises of two countries and two-traded goods. The Home (H) and Foreign (F) economy are symmetric but are subject to asymmetric shocks. Each economy comprises optimising households; monopolistic intermediate goods producing firms that can set prices in Calvo fashion and final goods producing firms that are perfectly competitive; capital producers that transform output into unfinished capital goods; entrepreneurs that purchase this capital, rent it to firms and are subject to a financial friction; financial intermediaries that channel household savings into loans for entrepreneurs; and a policy maker that sets interest rates. Variables for the foreign economy are denoted with an asterisk. International linkages are between final good firms who produce and sell a continuum of domestic varieties to households and entrepreneurs in both economies. Households engage in the international trade of risk-free real bonds. In what follows we consider the problems faced by each agent.

2.1 Model

2.1.1 Households

The household maximises its expected discounted sum of utility obtained from consumption and hours worked:

$$\max E_t \left\{ \sum_{i=0}^{\infty} \beta_i U_t \left(\frac{C_{t+i}^{1-\sigma}}{1-\sigma} - \frac{H_{t+i}^{1+\phi}}{1+\phi} \right) \right\} \tag{1}$$

where β is the discount factor, σ is the coefficient of risk aversion, ϕ the Frisch elasticity of wages with respect to the labour supply, H_t total hours worked and C_t the final goods consumption basket.

The consumption index (C_t) is defined by $C_t = \left[(1-\gamma)^{\frac{1}{a}} C_{f,t}^{\frac{a-1}{a}} + \gamma^{\frac{1}{a}} C_{h,t}^{\frac{a-1}{a}} \right]^{\frac{a}{a-1}}$ where $C_{h,t}$ and $C_{f,t}$ are the amounts of domestic and imported Foreign goods the household consumes. γ is the home bias parameter and a the elasticity of substitution between the two goods.

Households spend their resources on consumption $(P_t C_t)$ and saving in the form of real domestic deposits (D_t) and risk-free real bonds denominated in Home currency $(B_{h,t})$ and in Foreign currency $(B_{f,t})$. They also pay fees for adjusting their holding of international bonds $\frac{\zeta}{2} P_t \left(B_{h,t}\right)^2 + \frac{\zeta}{2} \frac{P_t}{e_t^r} \left(B_{f,t}\right)^2$. We assume convex fees for international portfolio adjustment in order to ensure that our model has a unique steady state and is stationary.[1] Funds are comprised of labour income $(W_t H_t)$ and financial income obtained from real deposit holdings $(D_{t-1} R_{t-1}^D)$, international Home bonds holdings $(R_{t-1} B_{h,t-1})$ and international Foreign bond holdings $(R_{t-1}^* B_{f,t})$ held from the previous period, dividend income (Π_t) from owning firms and an international bond fee rebate $P_t \tau_{h,t}$. Accordingly the budget constraint is given by:

$$\begin{aligned} & P_t C_t + P_t D_t + P_t B_{ht} + \frac{P_t B_{f,t}}{e_t^r} + \frac{\zeta}{2} P_t \left(B_{h,t}\right)^2 + \frac{\zeta}{2} \frac{P_t}{e_t^r} \left(B_{f,t}\right)^2 \leq W_t H_t + P_t R_{t-1}^D D_{t-1} \\ & + P_t R_{t-1} B_{h,t-1} + P_t R_{t-1}^* \frac{B_{f,t-1}}{e_t^r} + \Pi_t + P_t \tau_{h,t} \end{aligned} \tag{2}$$

where e_t^r and e_t are the real and nominal exchange rate, $e_t^r = \frac{e_t P_t}{P_t^*}$, $e_t = \frac{P_{h,t}^*}{P_{h,t}} = \frac{P_{f,t}^*}{P_{f,t}}$ and $\tau_{h,t} = \frac{\zeta}{2} \left(B_{h,t}\right)^2 + \frac{\zeta}{2} \frac{1}{e_t^r} \left(B_{f,t}\right)^2$ is the rebate of international bond adjustment fees. The nominal and real exchange rate are defined the UK way so a rise in e^r represents an appreciation of the Home currency.

The household maximises 1 subject to 2 in the standard way in order to choose quantities $\{C_t, B_{h,t}, B_{f,t}, D_t, H_t\}_{t=0}^{\infty}$ taking prices $\left\{P_t, R_t, R_t^*, R_t^D, W_t\right\}_{t=0}^{\infty}$ and the initial wealth endowments $(D_{t-1}, B_{h,t-1}, B_{f,t-1})$ as given. The optimal conditions that govern the behaviour of households follow:

$$\frac{H_t^{\phi}}{C_t^{-\sigma}} = \frac{W_t}{P_t} \tag{3}$$

$$\beta E_t \left(R_t^D \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} \right) = 1 \tag{4}$$

$$(C_t)^{-\sigma} (1 + \zeta B_{ht}) = \beta R_t E_t (C_{t+1})^{-\sigma} \tag{5}$$

$$(C_t)^{-\sigma} (1 + \zeta B_{ft}) = \beta R_t^* E_t \left[(C_{t+1})^{-\sigma} \left(\frac{e_t^r}{e_{t+1}^r} \right) \right] \tag{6}$$

They include a labour supply condition (3) which equates the real wage to the marginal rate of substitution between leisure and consumption and three Euler conditions that determine the saving decisions on deposits (4), international Home (5) and Foreign (6) bond holdings.

[1] International asset markets are incomplete as only risk-free bonds are traded across countries. This implies indeterminacy of steady state net foreign assets and non stationarity. To solve this problem we assume that agents must pay fees when adjusting their holdings of both Home and Foreign bonds. We assume that these fees are a quadratic function of the stock of bonds, where $\frac{\zeta}{2} \left(B_{h,t}\right)^2$ is the fee paid on Home bonds and $\frac{\zeta}{2} \left(B_{f,t}\right)^2$ on Foreign bonds. ζ is a parameter that describes how sensitive these costs are to changes in the stocks of bonds. These pin down the steady state and deliver stationary model dynamics in response to temporary shocks. Realistic choices of parameter values for ζ imply that the cost of adjusting bond holdings has a very small impact on model dynamics. Revenues from bond-adjustment fees are rebated to domestic households each period as a lump transfer $\tau_{h,t}$.

2.1.2 Firms

There are two stages to production in each economy. Intermediate firms produce an identical input which final goods firms differentiate at no extra cost to obtain a tradeable final good.

Intermediate firms

Intermediate firms operate in a perfectly competitive environment. They use capital (K_t) and labour (N_t) which they rent from entrepreneurs at rental rate (R_t^k) and hire at a nominal wage (W_t) and (W_t^e) from households and entrepreneurs. Labour is a function of hours worked by households (H_t) and entrepreneurs(H_t^e)[2]:

$$N_t = (H_t^e)^{\eta} (H_t)^{1-\eta} \tag{7}$$

where η is the fraction of entrepreneurial labour. Production technology displays constant returns to scale:

$$Y_t^w = A_t K_t^{\alpha} N_t^{1-\alpha}. \tag{8}$$

Y_t^w is the gross output of the firm. A is a total factor productivity (TFP) shock which follows an AR(1) process with persistence parameter ρ_A and standard deviation σ_A. Intermediate goods are sold at price P_t^w, so profit maximisation implies the following optimal conditions:

$$\frac{R_t^k}{P_{h,t}} = \frac{P_t^w}{P_{h,t}} \alpha \left(\frac{Y_t}{K_t} \right) \tag{9}$$

$$\frac{W_t}{P_{h,t}} = \frac{P_t^w}{P_{h,t}} (1-\eta)(1-\alpha) \left(\frac{Y_t}{H_t} \right) \tag{10}$$

$$\frac{W_t^e}{P_{h,t}} = \frac{P_t^w}{P_{h,t}} \eta (1-\alpha) \frac{Y_t}{H_t^e}. \tag{11}$$

Final goods firms

Final goods producers are monopolistically competitive and use a Calvo pricing mechanism, where ω denotes the fraction of firms who cannot change their prices in a given period. The optimisation problem is standard and delivers the following rule for the optimal price:

$$P_{h,t}^o(i) = \frac{b}{(b-1)} E_t \left\{ \frac{\sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{-\sigma} P_{t+i}^w (P_{h,t+i})^b \left(X_{h,t+i} + X_{h,t+i}^* \right)}{\sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{-\sigma} (P_{h,t+i})^b \left(X_{h,t+i} + X_{h,t+i}^* \right)} \right\}.$$

The law of one price is assumed to hold for each variety of good, which can be aggregated for the home and foreign goods sector so that $P_{h,t}^* = e_t P_{h,t}$ and $P_{f,t}^* = e_t P_{f,t}$.

2.1.3 Unfinished capital producers

A competitive sector of capital producers combines investment and depreciated capital stock to produce unfinished capital goods. The capital producers purchase final goods for investment I_t both from Home and Foreign final producers. We assume that they combine the home and foreign goods in the same aggregate good basket as households such that:

$$I_t = \left[(1-\gamma)^{\frac{1}{a}} I_{f,t}^{\frac{a-1}{a}} + \gamma^{\frac{1}{a}} I_{h,t}^{\frac{a-1}{a}} \right]^{\frac{a}{a-1}}.$$

The production of unfinished capital is subject to physical adjustment costs. Unfinished capital producers have a constant returns to scale production function $\phi\left(\frac{I_t}{K_{t-1}}\right) K_{t-1}$, where $\phi(.)$ is increasing and convex in the investment to capital ratio. We assume a quadratic functional form $I_t - \frac{\phi}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 K_{t-1}$, which implies the following capital accumulation equation:

$$K_t = (1-\delta) K_{t-1} + I_t - \frac{\phi}{2} \left(\frac{I_t}{K_{t-1}} - \delta \right)^2 K_{t-1}. \tag{12}$$

[2] In calibrations we keep the share of income going to entrepreneurs small (of the order 0.01) so this modification does not have a significant effect on the results. This deviates from Faia(2007) setup but is in line with BGG(1999).

Defining Q_t as the re-sell price of the capital good, capital producers maximize their profits $Q_t\left[I_t - \frac{\phi}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 K_{t-1}\right] - P_t I_t$ and choose how much to invest based on the following optimal condition:

$$\frac{Q_t}{P_t} = \left(1 - \phi\left(\frac{I_t}{K_t} - \delta\right)\right)^{-1}. \tag{13}$$

2.1.4 Entrepreneurs

To introduce financial frictions we follow BGG (1999). There is a continuum of risk neutral entrepreneurs, indexed by j, who purchases unfinished capital from the capital producers at the price $q_t = \frac{Q_t}{P_t}$, and transforms it into finished capital with linear production technology, $(a_e(j)\,K_t(j))$, that is subject to idiosyncratic productivity shocks $a_e(j)$. The idiosyncratic productivity shocks are assumed to be independently and identically distributed (i.i.d) across entrepreneurs and time, and to follow a log normal distribution, namely $a_e(j) \sim \log N(1, \sigma_a^2)$, with cumulative distribution function denoted by $F(a_e)$. Notice that, for the solution of the entrepreneurial problem, we take the variance of a_e as a given parameter. But, as we show in section 2.1.7, allowing for time variation in σ_a^2 will constitute a major source of shock in our model. This is Christiano et al. (2010) risk shock.

To finance the purchase of unfinished capital entrepreneurs employ internal funds, their net worth (NW_t), but they also need to acquire an external loan (L_t) from the financial intermediary;

$$q_t K_t(j) = L_t(j) + N_t W_t(j) \tag{14}$$

where $K_t(j)$ is the amount of capital purchased.

To characterise the entrepreneurs' problem we first define the expected gross return from holding one unit of finished capital. In period t the entrepreneur buys one unit of capital at price (q_t) and at period $t+1$, he gets income from renting it out to intermediate producers at rental rate $\frac{R_t^k}{P_t}$ and from re-selling the un-depreciated capital to capital producers at price q_{t+1}. So the expected gross return is the sum of rental income and the capital gain from reselling undepreciated capital:

$$E_t\left(R_{t+1}^e\right) = E_t\left[\frac{q_{t+1}(1-\delta) + \frac{R_t^k}{P_t}}{q_t}\right]. \tag{15}$$

2.1.5 The optimal loan contract

The financial contract between the entrepreneur and financial intermediary assumes the form of an optimal debt contract, based on Gale and Hellwig (1985). Specifically, the idiosyncratic shock to entrepreneurs is private information for the entrepreneur. To observe this, the lender must pay an auditing cost that is a fixed proportion $\mu \in [0,1]$ of the realised gross return to capital held by the entrepreneur. The optimal loan contract will induce the entrepreneur to not misreport his earnings and will minimise the expected auditing costs incurred by the lender. The contract lasts one period and is renegotiated every period.

The optimal contract can be described in terms of the amount of capital produced and the cut off level of productivity at which the entrepreneur defaults. The entrepreneur is able to repay the loan at the contractual rate (R_t^L) if the return from investment is higher than the amount they must repay on their loan, $R_{t+1}^e a_{t+1}^e q_t K_t > R_{t+1}^L(q_t K_t - NW_t)$, or if their productivity is higher than some cut-off value for the idiosyncratic productivity shock, $\overline{a}_{t+1}^e$,defined as:

$$\overline{a}_{t+1}^e = \frac{R_{t+1}^L\left(q_t K_t - NW_t\right)}{R_{t+1}^e q_t K_t}. \tag{16}$$

The participation constraint that ensures the financial intermediary enters the market is:

$$\int_{\overline{a}_{t+1}^e}^{\infty}\left[R_{t+1}^L L_t\right] dF\left(\overline{a}_{t+1}^e\right) + (1-\mu)\int_0^{\overline{a}_{t+1}^e}\left[R_{t+1}^e q_t K_t a_{t+1}^e\right] dF\left(a_{t+1}^e\right) \geq R_t^D L_t \tag{17}$$

where μ is the monitoring cost, intuitively speaking 17 states that the financial intermediary will only participate if their expected return from lending is equal to the opportunity cost of finance.

The contract maximises the expected return to entrepreneurs subject to 17 and gives an optimal pair of $\{\bar{a}^e_{t+1}, K_{t+1}\}$. [3]

Aggregating yields a wedge between the gross return on capital for entrepreneurs and the risk free real interest rate. This is the external finance premium (EFP), or credit spread over the risk free rate, that entrepreneurs pay to borrow funds from financial intermediaries, where $efp_t \equiv E_t\left(\frac{R^e_{t+1}}{R^D_t}\right)$. The optimal conditions for the contract problem imply:

$$efp_t = \frac{1}{\left[(\Gamma'_t - \mu G'_t)(1-\Gamma_t)/\Gamma'_t + (\Gamma_t - \mu G_t)\right]},\ efp'_t(\bar{a}^e_t) > 0, \tag{18}$$

where $\Gamma_t = \int_0^{\bar{a}^e_t} a^e_t dF(a^e_t) + \bar{a}^e_t \int_{\bar{a}^e_t}^{\infty} dF(a^e_t)$ is the expected gross share of profits going to the lender and $\mu G_{t+1} = \mu \int_0^{\bar{a}^e_t} a^e_t dF(a^e_t)$ - the expected monitoring costs. Another optimal condition relates the entrepreneurs' leverage ratio $\left(\tau_t \equiv \frac{q_t K_t}{NW_t}\right)$ to the productivity distribution of entrepreneurs:

$$\tau_t = 1 + \frac{\left[\Gamma'_t(\Gamma_t - \mu G_t)\right]}{\left[(\Gamma'_t - \mu G'_t)(1-\Gamma_t)\right]},\ \tau'_t(\bar{a}^e_t) > 0. \tag{19}$$

Combining equations 18 and 19 allows us to write the credit spread as an increasing function of the leverage ratio:

$$efp_t = v_t(\tau_t). \tag{20}$$

Note that equation 20 implies a negative relationship between net worth and credit spreads. Intuitively, an increase in net worth causes a decrease in the leverage ratio which reduces the optimal cut-off value, as shown by equation 19. As a result, the fraction of defaulting entrepreneurs falls which lowers the bankruptcy costs and the credit spread.

2.1.6 The evolution of net worth

To ensure that entrepreneurs do not accumulate enough funds to finance their expenditures on capital entirely with net worth, we assume that they have a finite lifetime. In particular, we assume that each entrepreneur survives to the next period with probability $s_t\chi$. Entrepreneurs who "die" in period t are not allowed to purchase capital, but instead consume their accumulated resources and depart the market. The net capital gain that entrepreneurs obtain from investing in capital is:

$$V_t = R^e_t q_{t-1} K_{t-1} - \left[R^D_{t-1} + \frac{\mu \int_0^{\bar{a}^e_t} a_{e,t} dF(a_{e,t}) q_{t-1} R^e_t K_{t-1}}{(q_{t-1}K_{t-1} - NW_{t-1})}\right](q_{t-1}K_{t-1} - NW_{t-1}). \tag{21}$$

So entrepreneurs who survive will accumulate net worth at the end of period t according to the following equation:

$$NW_t = s_t \chi V_t + \frac{W^e_t}{P_t}. \tag{22}$$

2.1.7 Source of shocks in the model

There are three processes which drive the model economy. As is standard in the literature, we assume that TFP follows an autoregressive process that is subject to shocks:

$$A_t = \rho^A A_{t-1} + \sigma^A \varepsilon^A_t \tag{23}$$

where ε^A_t follows a $N(0,1)$ process and the parameter σ^A controls the size of the TFP shock which drives our economy. In addition to the TFP shock, we assume that two additional exogenous processes affect the credit spread, or EFP, charged to entrepreneurs and that these forces drive our model economy; a risk and financial wealth shock.

[3] We assume capital production and monitoring technology are linear which makes aggregation possible since marginal costs are constant.

The risk shock affects the dispersion of entrepreneurs' idiosyncratic productivity. Following Christiano et al. (2010) we allow the variance of the idiosyncratic productivity shocks to change over time. This shock is used to proxy for a sudden re-appreciation of market risk, similar to that seen over the recent financial crisis period.

Each period entrepreneurs face an idiosyncratic productivity shock which converts their purchase of unfinished capital goods into final capital, $(a_e(j)K_t(j))$. We introduce a positive shock f_t that changes the dispersion of productivity across entrepreneurs. The shock is AR(1) with persistence parameter ρ_f and standard deviation σ_f. It is mean preserving so the average productivity of the entrepreneur does not change, but the number of entrepreneurs with the likelihood of very high or low productivity increases. A change in f_t therefore has an impact on the conditions in the entrepreneurial loans markets. An increase in f_t implies a higher probability that entrepreneurs go bankrupt. Figure 1 displays the effect of an increase in the dispersion of the productivity distribution of the entrepreneurs. For illustrative purposes we increase the dispersion of entrepreneurs productivity from its steady state level of $\sigma_a = 0.35$ to $\sigma_a = 0.45$. The immediate impact is that the tails of the productivity distribution become fatter. For a given steady state cut-off productivity of $\bar{a}_e = 0.52$, this implies an increase in the probability of default of about four percent. The yellow area to the right of the cut-off productivity line and under the shifted distribution represents this increase in the default probability. Given the information asymmetry between banks and entrepreneurs, this affects the level of the loans rate and, therefore, capital demand.

The second credit spread shock affects the net worth of entrepreneurs and therefore the total financial wealth of the model economy. It is a shock to the survival rate of entrepreneurs, so it affects the number of entrepreneurs exiting the market each period. A random and time varying fraction of entrepreneurs, $(1 - s_t\chi)$, exit the market each period and an equal fraction enter. s_t is a shock to the survival rate, it follows an AR(1) process with a persistence parameter ρ_s and standard deviation σ_s. A negative realisation reduces the survival probability of entrepreneurs and means that there are fewer entrepreneurs who produce finished capital. This type of shock to the credit spread has two effects on the economy; first there is an immediate increase in entrepreneurial consumption, as the dying entrepreneurs consume their net worth. An intuitive way to think of this is that dying entrepreneurs pay an equity dividend in the last period which is used for consumption. Second, over the longer term, the shock reduces the aggregate net worth of entrepreneurs because they become more impatient and consume more today which affects the credit spread, or EFP, that entrepreneurs must pay for loans.

2.1.8 Monetary policy and market clearing

Monetary policy follows a Taylor rule with interest rate smoothing:

$$\frac{R_t^n}{R^n} = \left(\frac{R_{t-1}^n}{R^n}\right)^{\gamma_r} \left[\left(\frac{1+\pi_t}{1+\pi}\right)^{\gamma_\pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{\gamma_y}\right]^{1-\gamma_r} \tag{24}$$

where γ_r reflects the persistence of interest rate changes and γ_π and γ_y are the weights on output and inflation volatility. Note that the Fisher equation implies the following relationship between the nominal interest rate and the real interest rate paid on deposits:

$$R_t^D = E_t\left(\frac{R_t^n}{1+\pi_{t+1}}\right).$$

The following market clearing conditions hold in equilibrium. Home and Foreign final goods imply the following resource constraints:

$$X_{h,t} + X_{h,t}^* = Y_t \tag{25}$$
$$X_{f,t} + X_{f,t}^* = Y_t^*. \tag{26}$$

Note that total demand includes household consumption, entrepreneurial consumption, demand for investment goods and goods demanded by financial intermediaries for monitoring $X_t = C_t + C_t^e + I_t + \mu\int_0^{\overline{a}_t^e} a_{e,t} dF(a_{e,t}) Q_{t-1} R_t^e K_{t-1}$. Net trade in international bonds must be zero in equilibrium:

$$\begin{aligned} B_{h,t} + B_{h,t}^* &= 0 \\ B_{f,t} + B_{f,t}^* &= 0. \end{aligned} \tag{27}$$

Note that the Home current account is defined as:

$$CA_t = B_{h,t} - B_{h,t} + (B_{f,t} - B_{f,t-1})/e_t^r. \tag{28}$$

Finally the loanable funds market requires that the real quantity of deposits equals the volume of loans, both at Home $D_t = L_t$ and at Foreign $D_t^* = L_t^*$.

2.2 Method

2.2.1 Parameterisation and solution of the model

Parameters associated with the real sector of the economy are mostly calibrated based on Faia (2007) but parameters pertaining to the financial sector are calibrated differently. Structural parameter values are reported in Table A. One period in the model is one quarter. We assume that the fraction of firms allowed to adjust prices every period is 0.6 which implies an average price duration of 2.5 quarters. Note that we assume home bias on international trade in final goods ($\gamma = 0.7$) which implies that purchasing power parity does not hold in our model and the real exchange rate deviates from unity. Another important parameter is ζ, which determines the sensitivity of international adjustment on bond fees to the stock of bonds. We set it at 0.0025 in line with Ghironi and Melitz (2005), a low value that does not affect our results but high enough to stationarise the model. Finally, we assume that the inverse of the Frisch labour supply elasticity ϕ is 1/3, which implies an elasticity of 3. This is high but it follows BGG (1999) and is in line with macroeconomic studies.

Another difference in our model compared to Faia is that the entrepreneurs work and receive a wage. The fraction of hours η of entrepreneurial labour in total labour employed by intermediate firms is 1%. In Faia's model this is a lump sum transfer to entrepreneurs but here we follow BGG (1999) to ensure that the entrepreneurs' income fluctuates with the business cycle. We set the three parameters that govern the behaviour of the financial sector variables to closely match the long-run developed countries estimates for credits spreads, default rates, leverage ratios and elasticity of the credit spreads with respect to leverage. The monitoring cost parameter μ is 0.105, the volatility of the productivity distribution of entrepreneurs σ_a is 0.35, and the survival rate of entrepreneurs χ is 0.966. These values imply a steady state credit spread of about 123 basis points which is close to the 187 basis points used by Carlstrom and Fuerst (1997). The steady state leverage ratio $\left(\tau = \frac{QK}{NW}\right)$ is 2.1 which is close to the value first used in BGG (1999) and henceforth, became standard for financial friction models. The steady state probability of default for entrepreneurs is 3% and the elasticity of the credit spread to the leverage ratio $\left(el = \frac{\partial epf}{\partial \tau} \frac{\tau}{efp}\right)$ is 0.05, a value also in line with BGG (1999). In quarterly space the standard deviations of the shocks to the credit spread are calibrated in order to generate an increase in the spread of 37 basis points on impact which is broadly consistent with the rise in US corporate credit spreads seen over the initial stages of the recent financial crisis. The persistence of the credit spread shocks are based on Christiano et al. (2010) who estimate a financial frictions model on US and Euro area data.

Key steady state values are reported in Table B. The nonlinear model is linearised around the steady state to the first order. The first order linearisation does not detract from the dynamic analysis of responses to financial shocks because the financial accelerator mechanism creates first order effects which spill over from the EFP to the net worth of entrepreneurs, hence from the financial to the real sector of the economy. The linearization and the dynamic simulation are executed with DYNARE.

3 Results

3.1 The effect of financial frictions on the international transmission mechanism

Before looking at the effects of credit spread shocks, we investigate how financial frictions effect the transmission of shocks to real activity in both the Home and Foreign economy. Figure 2 shows the impulse responses of Home and Foreign economy variables to a one standard deviation shock to TFP in the Home economy with (solid lines) and without (dashed lines) financial frictions. The impulse responses are reported as deviations from the steady state in units of the respective variables. Only variables measured in percentage points are converted to basis points.[4]

As in standard models the TFP shock propagates to the Home economy as a supply shock. Home output falls and inflation increases, reflecting reduced productivity and rising marginal costs. The fall in wealth, associated with the fall in output, results in weaker consumption and investment demand. Rising inflation at Home prompts an increase in the policy rate and an appreciation of the Home real exchange rate.

[4] A list of the non-linear equations describing the shadow model without financial frictions can be found in the Appendix.

In our model the international spillovers to Foreign output and inflation operate via net trade and the terms of trade. Changes in the terms of trade reduce Foreign supply which is only partially offset by a boost to output from net trade, so overall Foreign output falls and inflation rises.

The rise in Home inflation makes Foreign goods relatively more competitive which results in a boost to Foreign net trade. But the Foreign economy terms of trade also depreciates because the price of Foreign imports rise relative to their exports. The depreciation in Foreign terms of trade reduces the value of the marginal products of Foreign capital and labour in terms of Home output which prompts a fall in Foreign producers demand for capital and labour. As a result there is a supply contraction in the Foreign economy, so Foreign output falls and inflation rises.

Comparing the dashed lines to the solid lines summaries the impact of financial frictions on these responses. We use an EFP to introduce financial frictions, which generate a financial accelerator type effect. In the friction world the Home TFP shock causes a fall in asset prices and the net worth of entrepreneurs which pushes up on their costs of borrowing, shown by the rise in the EFP. This leads to an accelerator effect so that both investment and output fall by more than in the non friction world. This result is in line with standard BGG type models.

As in the non friction world the negative TFP shock reduces supply in the Home economy; Home output falls and inflation rises, which causes an appreciation of the real exchange rate. There is a larger crowding out of exports, as both the real exchange rate and terms of trade adjust by more when financial frictions are present. As a result international prices play a greater role in the adjustment process after the TFP shock in the financial friction world. The response of the Foreign variables to the Home TFP shock remain similar to those in the non-friction world, but the shift in the foreign aggregate supply curve is larger with financial frictions because the international terms of trade effect is magnified by the presence of the financial accelerator.

3.2 Credit spread shocks

Next we introduce two credit spread shocks to the model. These are used to examine how the source of the shock to the credit spread effects the transmission mechanism and its effect on key variables. The shocks are calibrated to match the rise in spreads seen in the US over the recent financial crisis period because we also want to examine whether the model can generate a large and synchronised decline in financial and real activity as often observed following financial crises, such as the Great Recession. One notable feature of that period is the high cross-country correlation between real and credit markets variables. Panel A and B in figure 3 plot a measure of annual GDP growth and credit spreads for the UK, US and Euro Area, which show the high degree of synchronisation across countries. In the following analysis we compare cross-country correlations between output and credit spreads, as a proxy for these measures, to see how the model performs relative to the recession period as well as examining the transmission mechanism.

3.2.1 Risk shock

Figure 4 presents the impulse responses associated with an idiosyncratic productivity shock, or "risk shock", at Home. The risk shock operates via reducing demand for (capital) investment and then propagates to the rest of the Home economy as a demand shock, via sticky prices, and to the Foreign economy as a net trade shock, via the real exchange rate.

The 'risk shock' at Home increases the dispersion of the entrepreneurs' productivity, which means there is an increase in the dispersion of returns to investment. This is consistent with a re-appreciation of market risk, so financial intermediaries' propensity to lend falls because more entrepreneurs may default on their loans. Over the recent financial crisis period there was a similar fall in financial intermediaries' desire to lend because of a re-appreciation of general market risk. Consistent with that our model predicts that credit conditions tighten in the Home economy in response to the re-appreciation of market risk and the EFP charged on loans rises from 123 basis points in steady state to 160 basis points on impact. These are quarterly increases so they are consistent with a 150 basis point rise in the annualised credit spread which we saw in the initial stages of the financial crisis.

Focusing first on the impact on the Home economy: as expected we find a financial multiplier effect which operates mainly through the capital market. The increase in the dispersion of the entrepreneurs' productivity raises the probability of entrepreneurial default and, due to asymmetric information, increases the EFP charged by Home financial intermediaries. Capital demand from entrepreneurs falls because it is more costly to acquire funds to purchase new capital, which pushes down on the capital stock and the asset price of capital[5]. In addition falling asset prices reduce the entrepreneurs' net worth. The decline in capital demand results in lower investment expenditure. The capital stock in the economy falls slowly over time as investment is lower for a number of periods and the existing capital stock depreciates. Weaker investment spending results in a decline in output and hence, demand which via sticky prices pushes down on inflation. It is notable that the overall fall in Home aggregate demand response is small compared to the fall in output observed over the recent financial crises across a number of economies, in our model the peak fall in output is 0.1% compared to steady state.

What are the spillover effects to the Foreign economy? Our results suggest that the international transmission is dominated by changes in the real exchange rate and net trade. Falling Home inflation makes Home goods relatively less expensive and leads to a depreciation in the terms of trade and real exchange rate. Declining real interest rates in the Home economy also support a depreciation of the real exchange rate, via UIP. The depreciation of the exchange rate means Home export prices (denominated in foreign currency) fall but import prices rise acting to boost Home net exports, so that the demand for Foreign goods falls. The Foreign economy experiences a fall in aggregate demand because of the decline in their exports to the Home economy which pulls down on Foreign output and inflation. So the risk shock leads to output co-movement across the two economies, although it is notable that the foreign economy output response is small compared to the Home economy. The generated correlation in output and inflation across the two economies is also low compared to that seen during the crisis period (table C).

There is very little co-movement in EFPs across the two economies as the Foreign EFP is unaffected by a risk shock in the Home economy. Capital markets are closed in this model which means that entrepreneurs in the Home economy do not borrow from the Foreign financial intermediary. Therefore a rise in default risk at Home has no impact on Foreign financial intermediaries behaviour or the Foreign EFP. So in our framework the main international spillover is dominated by the movements in international relative prices and financial spillovers are limited.

3.2.2 Financial wealth shock

Figure 5 shows the impulse responses associated with a shock to the survival rate of entrepreneurs in the Home economy. A reduction in the survival rate of entrepreneurs means that there are fewer entrepreneurs who produce finished capital. As a result there is an increase in the number of entrepreneurs who exit the market for finished capital. This change in behaviour has a significant impact on the aggregate net worth of entrepreneurs who determine aggregate financial wealth in the Home economy. So this shock operates like a financial wealth shock in the Home economy and propagates to the Foreign economy as an exchange rate shock, via net trade.

As expected, financial wealth falls at Home in response to the shock to the entrepreneurs' survival rate. The net worth of exiting entrepreneurs is redistributed towards consumption; this is analogous to entrepreneurs paying an equity dividend to themselves when they exit the market that they spend on consumption rather than finished capital goods. So the aggregate net worth of entrepreneurs and, therefore, aggregate financial wealth fall as fewer entrepreneurs wish to produce finished capital.

The fall in financial wealth propagates to the Home economy via aggregate demand channels. But this shock generates some counter intuitive results in the first few periods. On impact aggregate demand rises because dying entrepreneurs consume their equity which creates upward pressure on inflation. In the first few periods production increases enough to support the rise in entrepreneurs' consumption but it is not enough to support investment and household consumption which is crowded out in response to the higher real interest rates.

After a few periods the positive boost to the entrepreneurs' consumption dies away, as the shock to the survival rate dissipates, but the negative effects of the financial wealth shock persist so overall aggregate demand at the Home economy begins to fall.

Entrepreneurs' net worth continues to fall for a few periods as declines in the asset price of capital reduce the value of entrepreneurs' assets. This leads to financial accelerator type effects. The EFP rises in response to the declines in net worth which results in weaker (capital) investment demand because it is more costly to borrow funds for investment purposes. The capital stock in the economy falls slowly over time as investment is lower for a number of periods and the existing capital stock depreciates over several periods.

It is notable that the impact of the financial wealth shock is large; its effects on activity are quantitatively larger than those of the risk shock. This is partly driven by the magnitude of the associated wealth shock. To generate a 37 basis point increase in the credit spread the financial wealth of agents falls by around 13% on impact.

[5] There is evidence that investment is sensitive to credit spread shocks as the impulse responses are large in comparison to the overall movement in output.

Again, this analysis suggests that movements in international relative prices are a key channel for the propagation of asymmetric financial shocks to the real economy. The financial wealth shock spills over to the Foreign economy via net trade due to movements in international relative prices. Rising Home inflation makes Home goods relatively more expensive and leads to an appreciation in the terms of trade and real exchange rate. Rising real interest rates in the Home economy also support an appreciation of the real exchange rate, via UIP. The appreciation of the exchange rate means Home export prices rise but import prices fall acting to reduce Home net exports, so that the demand for Foreign goods rises. The Foreign economy experiences a rise in aggregate demand because of an increase in their exports to the Home economy which pushes up on Foreign output and inflation.

There is little evidence of co-movement across financial variables in response to the financial wealth shock. The response of Foreign financial variables is muted in comparison to the Home economy and Foreign spillovers are driven via movements in international prices.

3.2.3 Comparison of the credit spread shock to the observations over the recent financial crisis

Table C compares moments under the two different credit spread shocks relative to those observed in the data. It shows that the financial wealth shock generate variable responses that are much larger than the risk shock. Consistent with this, the volatilities of Home and Foreign output and the EFP after the two shocks are much larger in response to the financial wealth shock. Output correlations after the financial wealth shock are also more similar to those observed in the data over the recession period. That said, in the previous section we showed that the negative risk shock leads to more realistic spillovers to real activity since there is a negative response of both Home and Foreign output which is consistent with the large cross-country declines in output following the financial crisis. In contrast Home and Foreign output rise in response to the negative financial wealth shock. In addition the results for the financial wealth shock show some signs of instability.

More generally, it is striking that both the credit spread shocks are unable to generate output and credit spread responses that are of a similar magnitude to those observed during the recent financial crisis and ensuing recession. The magnitude of the declines in output and rise in the credit spread and the volatility of the variables following the shocks are much smaller than observed over this period. This could be attributed to the fact that at the steady state the financial friction is calibrated to match long-run developed countries estimates for key financial variables. In closed economy model with a financial accelerator Gilchrist and Zakrajsek (forthcoming) show that the response of the real sector following a credit spread shock increases in size when the strength of the financial friction doubles. Our sensitivity analysis also suggests that increasing the strength of the financial imperfections increases the response of output to credit spread shocks at least in the Home economy. However, we need a large increase in the strength of the financial imperfection in order to generate significant change in the quantitative response of output.

3.3 Sensitivity analysis

Our results suggest that movements in international relative prices are a key channel for the propagation of asymmetric financial shocks to the real economy. In particular, the response of the exchange rates and terms of trade to country-specific shocks determines the international spillovers to the Foreign economy, and therefore affect the labour supply decisions of agents. Given the importance of the labour supply decision for the propagation of shocks, we now examine how sensitive the results are to different values for the Frisch elasticity. We also analyse the sensitivity of our results to different parameterisations of the financial friction to see how these affect the propagation of the credit spread shocks. And, finally, we explore the effect of an alternative specification of the financial contract on our results. More recent papers from Christiano et al. (2010) and von Heideken (2009) suggest the specifying debt contracts in nominal terms can introduce a powerful Fisher debt deflation mechanism that, under certain conditions, can reduce the amplification effect associated with financial frictions. So we explore this hypothesis in our two-country framework.

Frisch elasticity We assume a Frisch labour supply elasticity of 3 which is in line with macro studies but high relative to some studies based on micro-level data. The Frisch elasticity governs the response of labour supply to changes in the wage rate so it is an important parameter in our model. The most recent paper, Dyrda et al. (2012), claims that a Frisch elasticity of 0.7 is in line with micro-evidence. We check the sensitivity of our results to a lower assumed Frisch labour supply elasticity. Results of this exercise are shown in Figure 6. We find that reducing the Frisch elasticity does not impact the direction of our results, but does affect the quantitative response of key variables. A lower Frisch elasticity implies that hours become less responsive to wage fluctuations, figure 6 shows that hours in both the Home and the Foreign economy vary less in response to all three shocks. But the effect of this on the responses of output varies depending on the source of the innovation.

In the case of the TFP shock a lower Frisch elasticity results in a larger decline in output because the increase in home labour supply is dampened. Home labour supply increases in response to the negative TFP shock because the reduction in consumption raises the marginal utility of consumption relative to leisure. With standard preferences, this means that there is a substitution effect as households substitute away from leisure towards consumption and supply more labour. With a lower Frisch elasticity hours are less responsive so there is less of an increase in the labour supply which leads to a smaller offset against the overall decline in output. In contrast output in the Foreign economy declines by less because the fall in Foreign labour demand, driven by the reduction in the terms of trade, is dampened under the low elasticity case.

The responses of both Home and Foreign output are smaller at lower levels of Frisch elasticity in the case of both credit spread shocks. This is because both credit shocks spill over to Home and Foreign real sectors as aggregate demand shocks. In the case of the risk shock, household consumption rises due to falling real interest rates which lowers the labour supply via a substitution effect. In the low elasticity case the fall in hours is dampened which translates into a smaller response in Home output. A similar argument explains the dampened fall in Foreign output. Under the financial wealth shock, rising entrepreneurial consumption crowds out household consumption which leads to an increase in households' supply of labour, via the substitution effect, because the marginal utility of consumption is rising. The rise in labour hours is dampened in the low elasticity case so Home output rises by less. Foreign output also declines by less for similar reasons.

Strength of the financial friction Given the nature of our credit spread shocks, it is also important to check the sensitivity of the results to the size of the financial friction. We compare our results following the two credit spread shocks under two scenarios; our baseline calibration and a calibration where the financial friction is greater. Table D presents the structural parameters and steady state values for the key financial variables under the two scenarios. Comparing our results in response to the two credit spread shocks, our general finding is that the direction of the results does not change with different parameterisations of the financial friction. Quantitatively the response of output is somewhat larger but not significantly changed while the response of financial sector variables is magnified.

Figure 7 shows that in the case of the risk shock Home and Foreign output respond by relatively similar amounts despite the larger financial frictions. But financial sector variables are more responsive to the shock when financial frictions are larger. Christiano et al. (2010) note that leverage plays a large role in the transmission of credit spread shocks. Table D highlights that there is very little change in the leverage ratio when we recalibrate the model with larger financial frictions so it is not surprising that these result in small changes in the response of output to credit spread shocks.

A similar pattern emerges for the responses to the net worth shock; financial variables become more responsive to shocks when financial frictions are larger but there is a more muted impact on real variables. In this case, when financial frictions are larger it mean that there is a greater increase in the elasticity of the credit spread for a given change in net worth. So the financial net worth shock generates a larger credit spread response when financial frictions are greater than in our baseline calibration. This speeds up the adjustment of the real and financial variables to the shock and explains the faster decline in the credit spreads.

Fisher deflation effect In section 3.1 we show that the presence of the financial accelerator mechanism amplifies the effect of a TFP shock. This is in line with previous studies that use a BGG framework and debt contracts denominated in real terms (see Gilchrist (2003)). However, more recent papers suggest that the inflation response to shocks can have powerful debt deflation effects when debt contracts are denominated in nominal terms. Christiano et al (2010) and von Heideken (2009) suggest that when debt contracts are denominated in nominal terms there are two factors which impact the cost of entrepreneurs' borrowing; first the cost of borrowing fluctuates with the flow of entrepreneurial earnings and through capital gains and losses on entrepreneurial assets. This is the standard channel highlighted in BGG which tends to magnify the economic impact of a shock that affects economic activity. But they also highlight a second mechanism where entrepreneurs' obligation to pay debt varies because inflation can ex post alter the real burden of debt. This second effect is referred to as a 'Fisher debt deflation' impact.

Christensen and Dib (2008) and Christiano et al. (2010) suggest that the Fisher debt deflation and accelerator type mechanisms tend to reinforce each other in the case of shocks that move the price level and output in the same direction, and they tend to be offsetting in the case of shocks which move the price level and output in opposite directions. Furthermore, in estimated models they reject models without a Fisher deflation effect in favour of models that include them. So in the following analysis we investigate how introducing a debt deflation channel impacts our results.

To do this the financial contract is respecified in terms of the nominal interest rate, where $R_t^d = R_t^n/(1 + E_t\pi_{t+1})$, which means that the interest that entrepreneurs have to repay on loans taken in the previous period is now denominated in nominal terms. Figure 8 plots the impulse responses to the same asymmetric negative TFP shock originating in the Home economy as shown in our original analysis in section 3.1. The non friction model is unchanged from the previous analysis so the responses are the same as previously (shown by the dashed line) but we now compare these to the responses in new financial friction model with a Fisher deflation effect (shown by the solid line). As expected, the presence of a Fisher debt deflation channel tends to cancel out the amplification impact of the financial accelerator mechanism. The negative TFP shock reduces aggregate supply and pushes inflation and output in opposite directions. The fall in output pulls down on asset prices and entrepreneurial earnings which pushes up on the cost of borrowing but this is offset by the impact of inflation on entrepreneurs' real debt burden which reduces the cost of borrowing. Debt contracts are agreed in nominal terms a period in advance, so the rise in inflation in response to the TFP shock reduces the real value of entrepreneurs' outstanding debt. As a result, the EFP falls because entrepreneurs' leverage falls as their real debt levels are eroded. The fall in the EFP pushes down on borrowing costs and dampens the negative impact of the supply shock on investment. Thus, the Fisher deflation effect offsets the amplification effect of the financial accelerator. As a result we find that the fall in aggregate supply in the Home economy is similar to the model without financial frictions when we include a Fisher debt deflation channel in our model. And since the impact of the TFP shock at Home is similar, the spill over to the Foreign economy is also similar in magnitude. This suggests that the specification of the debt contract has important implications for the size of the amplification effect associated with financial frictions when the economy is subject to supply shocks. These observations suggest another important question for the subject of future research is around the sensitivity of amplification effects to alternative specifications of both the debt contract and parameterisations of financial frictions but this is beyond the scope of this paper.

4 Conclusions

The aim of this paper is to investigate theoretically how financial factors affect the international transmission mechanism and the transmission of country-specific credit market shocks. To do so we build a two-country model with financial frictions and sticky prices and analyse the effect of financial frictions on the transmission of TFP shocks to real activity in the Home and Foreign economy. We also analyse the effect of two credit spread shocks, driven by different innovations, and investigate how these shocks propagate to real activity in both the Home and Foreign economy.

Our results are twofold. First, we find that movements in international relative prices are a key channel for the propagation of shocks to the real economy. In the model's framework international spillovers of shocks are driven by movements in the real exchange rate and terms of trade, which determine the response of real international economic variables to shocks. Under certain conditions financial frictions amplify movements in both the terms of trade and real exchange rate and therefore generate larger supply and demand responses in the Foreign economy increasing cross-country spillovers.

Second, our analysis reveals that different sources of shock to the credit spread generate significantly different spillovers to activity and operate via different propagation channels. Financial wealth shocks generate quantitatively larger impacts on activity in both the Home and Foreign economy than risk shocks. But our analysis of the propagation channels of asymmetric wealth shocks reveal some counter intuitive results on impact. This is because the model generates some unrealistically large responses in the entrepreneurial sector. Asymmetric risk shocks generate more realistic spillovers to activity in both the Home and Foreign economy.

Our theoretical exercise reveals that further investigation of the impact of financial factors on the international transmission mechanism is required. There is evidence that the specification of debt contracts has important implications for cross-country spillovers which required further investigation. But more generally, our theoretical exercise has revealed some limitations of the DSGE framework with a financial accelerator. We find that whilst the model can account for the positive cross-country output co-movement seen during the recent financial crisis period international spillovers remain quantitatively small. To generate spillovers in line with the 2007-2010 period the model requires a coincident widening of credit spreads across the two economies. This could be interpreted in two ways. On the one hand, our results could be consistent with the view that the global reach of the recent financial crisis is due to a common international disturbance rather than a contagious spread of a country-specific event[6]. Whilst this is a plausible hypothesis for the crisis it is impossible to ignore the significant rise in cross-border financial flows and period of increased financial liberalisation preceding the recent financial crisis. So another interpretation of our results is that, a richer framework that incorporates direct international linkages between financial sectors is needed to analyse financial shocks in the context of an open-economy macroeconomic model. This observation leads to another question: could we obtain larger cross-country spillovers if more direct international financial linkages were added to the model, for example through the capital market. Given a significant short coming of the current model is that it generates limited co-movement across international capital markets because there are no direct international linkages across financial agents.

The main implication of our analysis is that financial factors have a significant impact on the international transmission mechanism and affect the propagation of shocks across economies. A logical next step for future work is to incorporate more direct financial linkages to the current version of the model, along the lines of Devereux and Sutherland (2011) and Dedola and Lombardo (2012), to see how this affects results and to estimate the model to see how it performs against the data.

[6] In further analysis, not included in the paper due to space constraints, we find that introducing a common risk and wealth shock to both economies leads to greater co-movement across countries in both real and financial variables.

5 Tables and figures

Figure 1: Effect of a risk shock

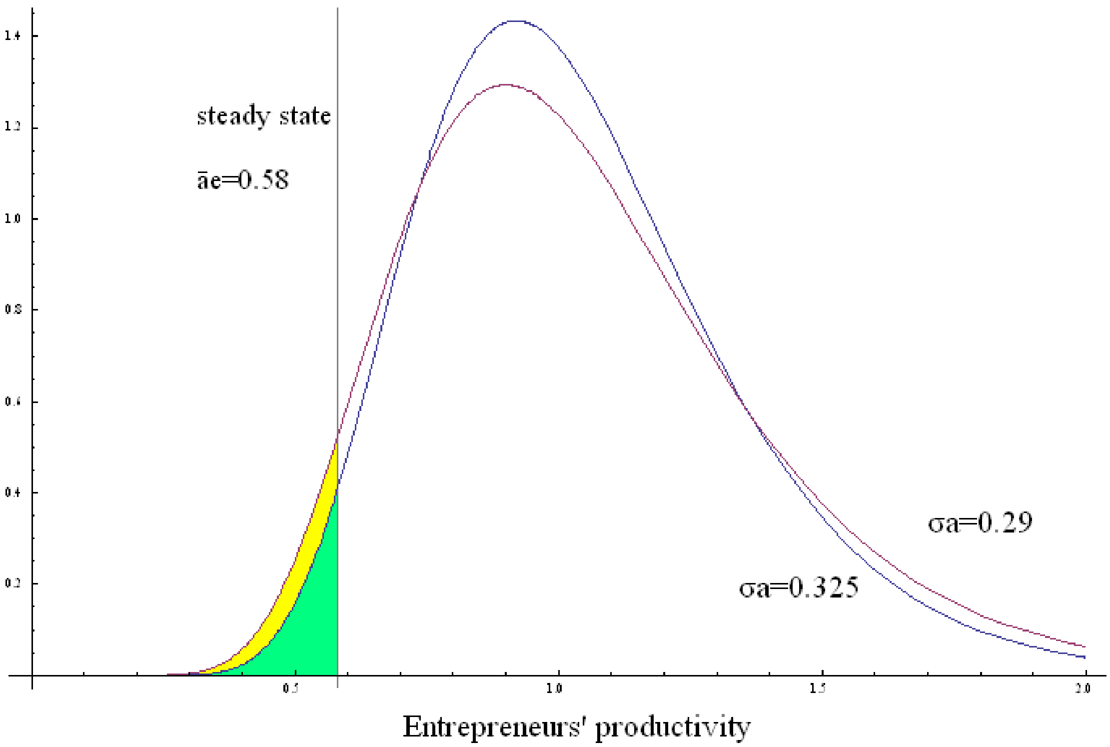
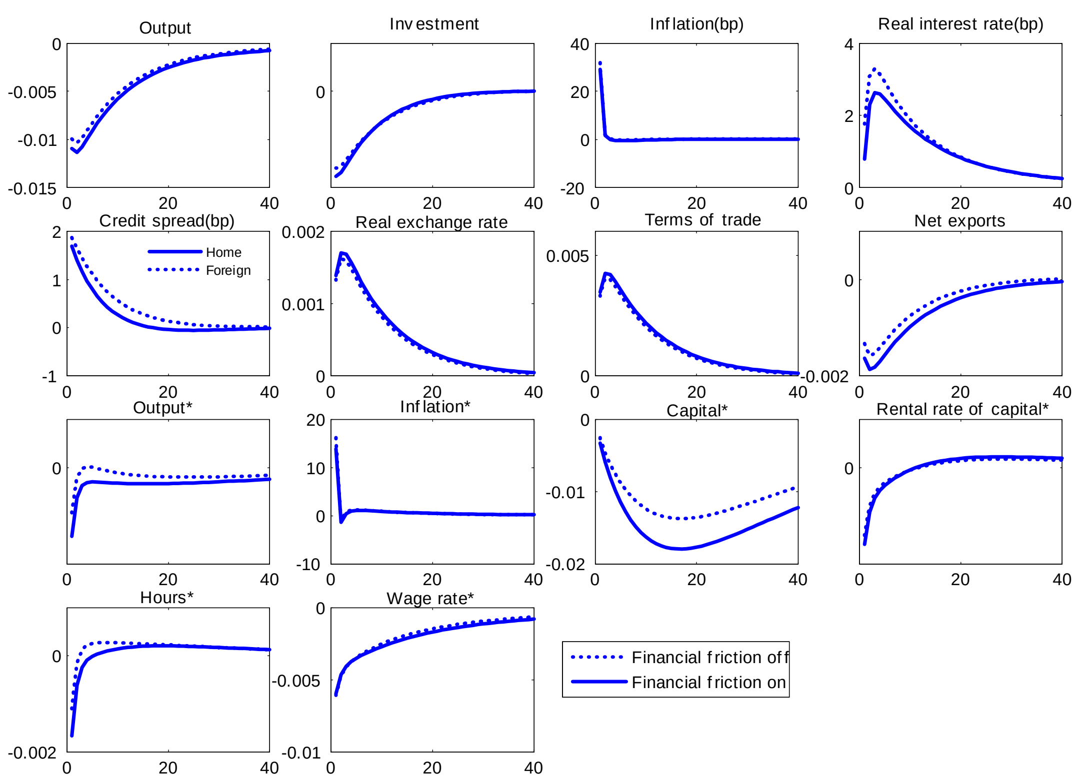
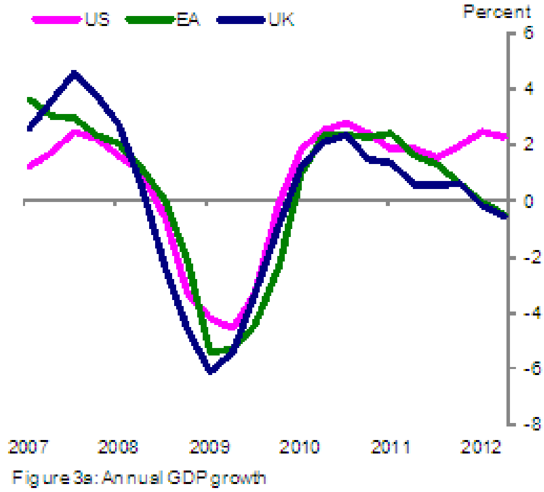


Figure 2: Effect of total factor productivity shock on key variables[7]



[7] Foreign variables are denoted with an asterisk.

Figure 3: GDP and credit spreads over the Great Recession



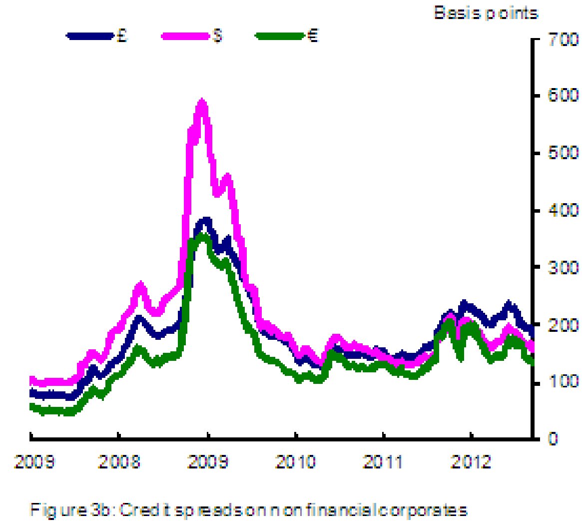
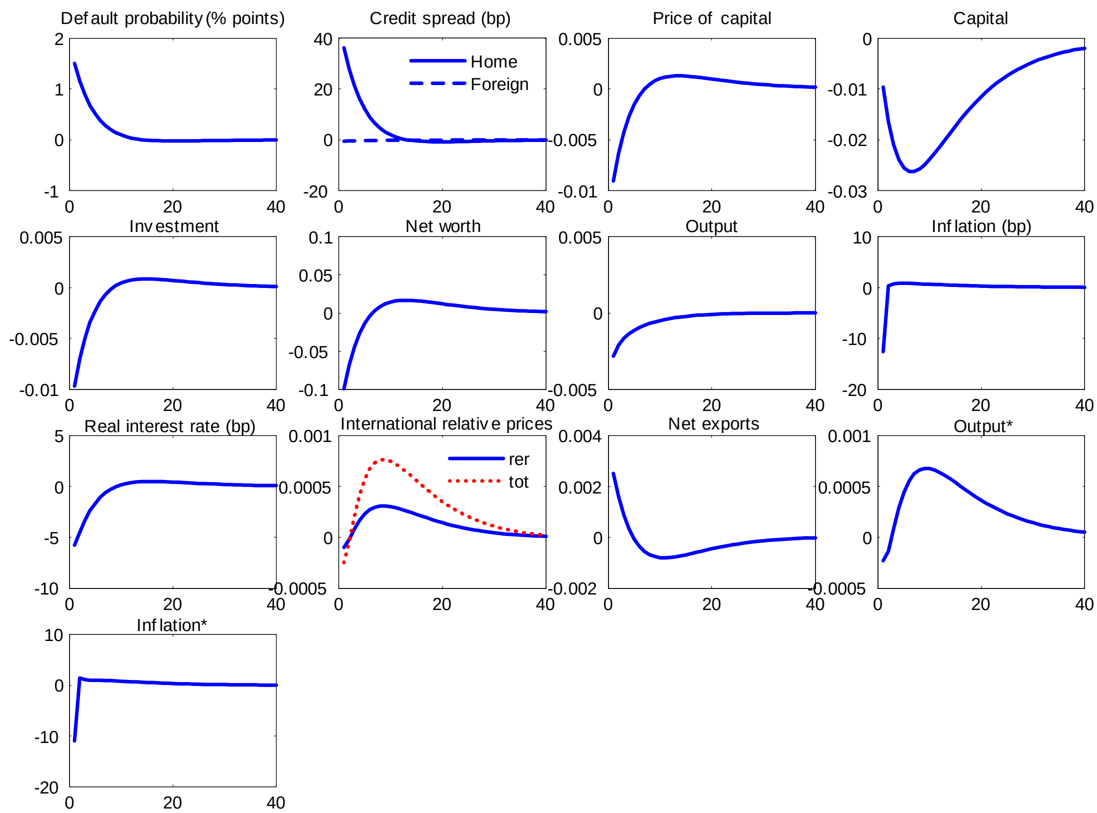
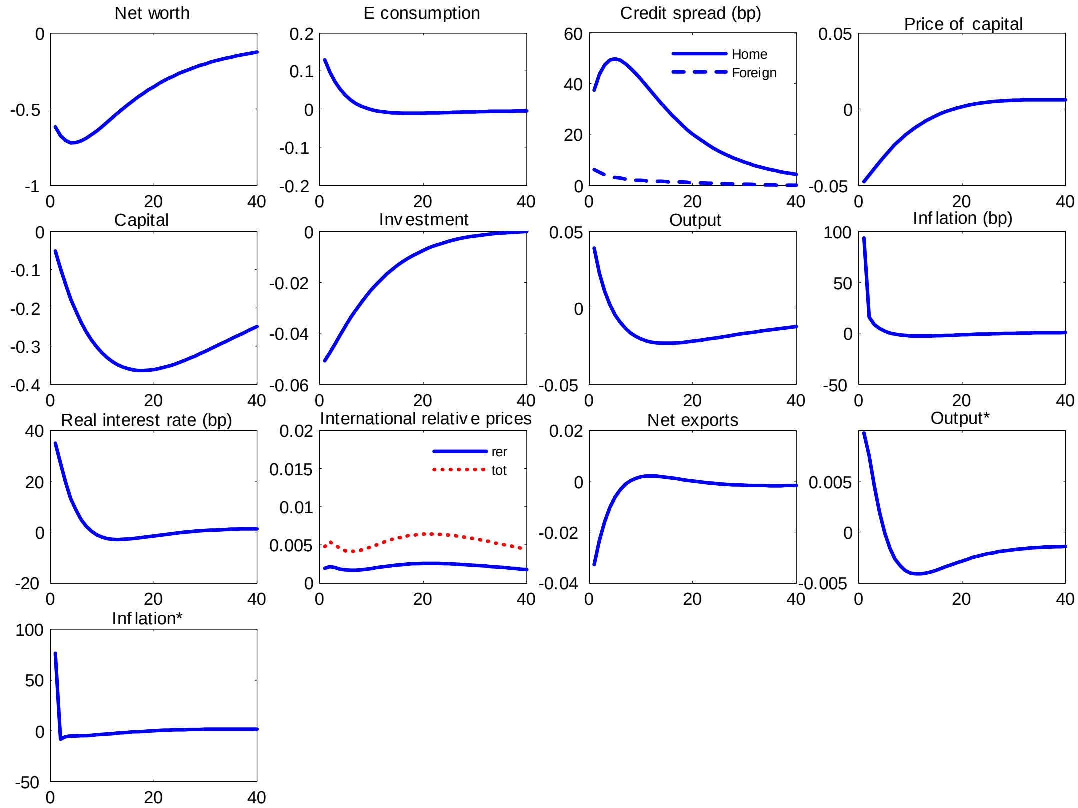


Figure 4: Effect of a risk shock on key variables[8]



[8] Foreign variables are denoted with an asterisk.

Figure 5: Effect of a financial wealth shock on key variables[9]



[9] Foreign variables are denoted with an asterisk.

Figure 6: Sensitivity of results to changes in the Frisch elasticity

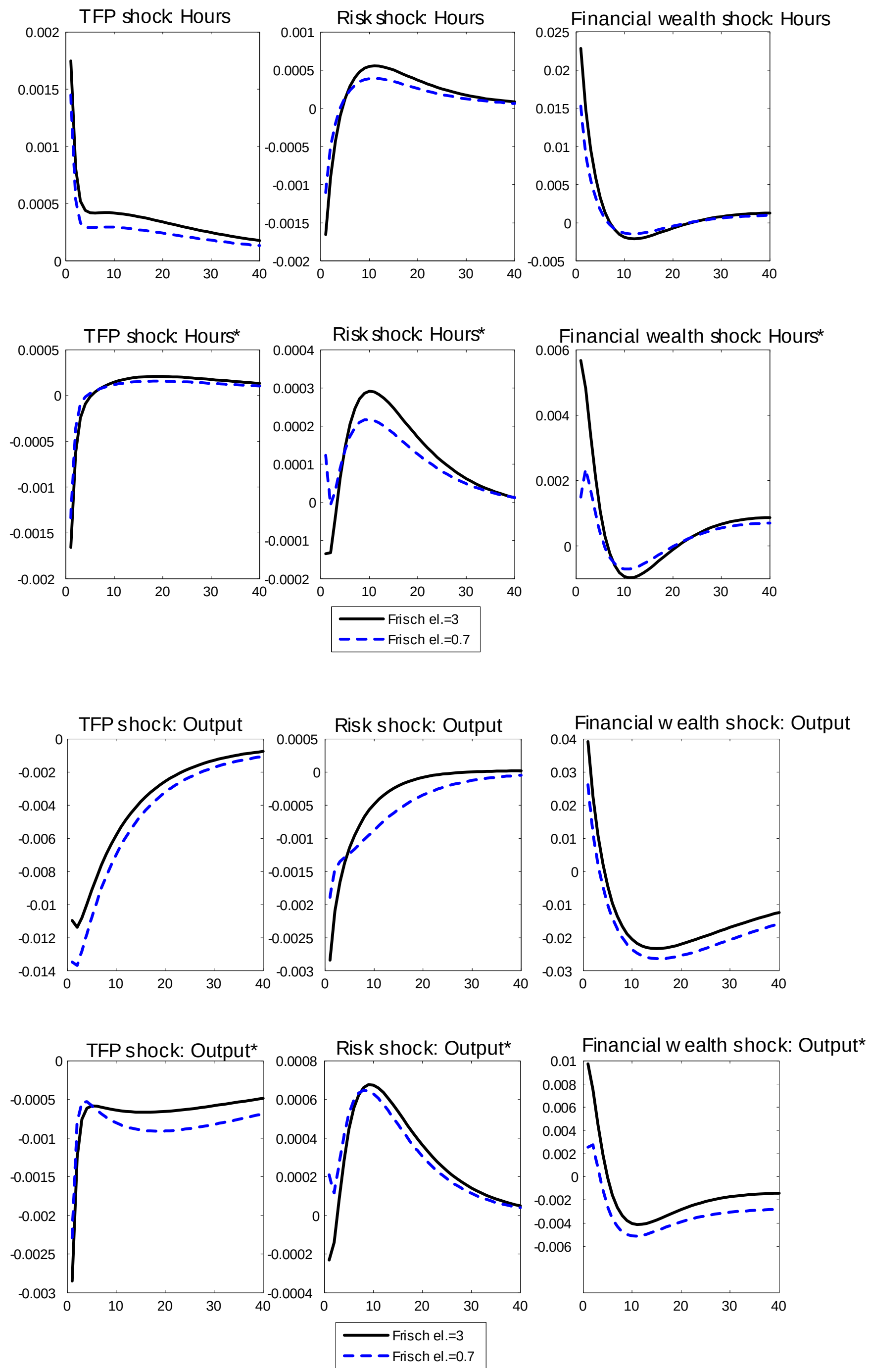
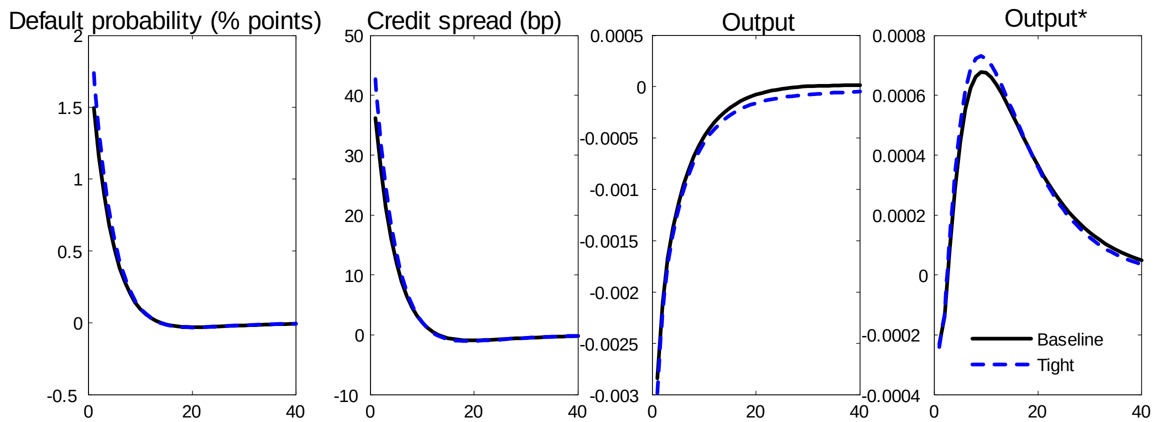


Figure 7: Sensitivity of results to parameterisations of the financial friction
Responses to a risk shock



Responses to a financial wealth shock

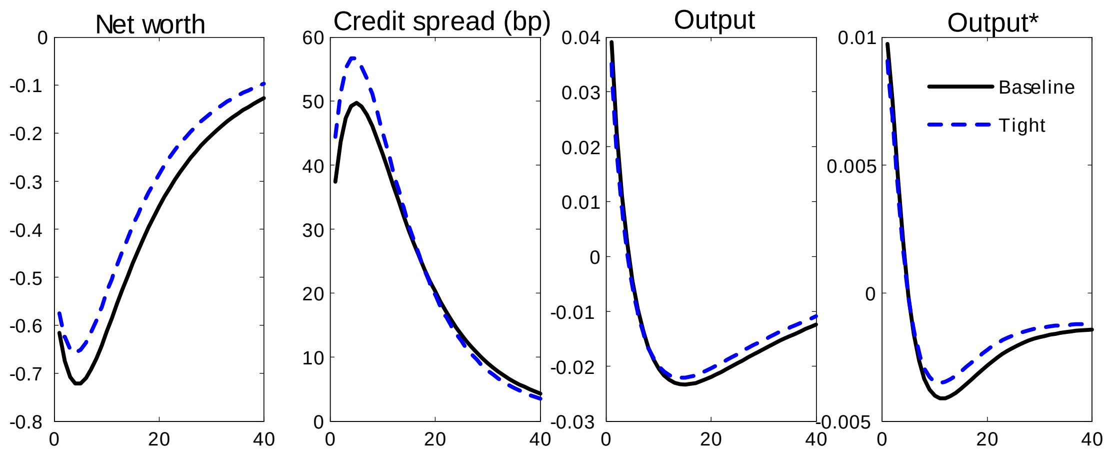


Figure 8: Sensitivity of results to debt deflation effect

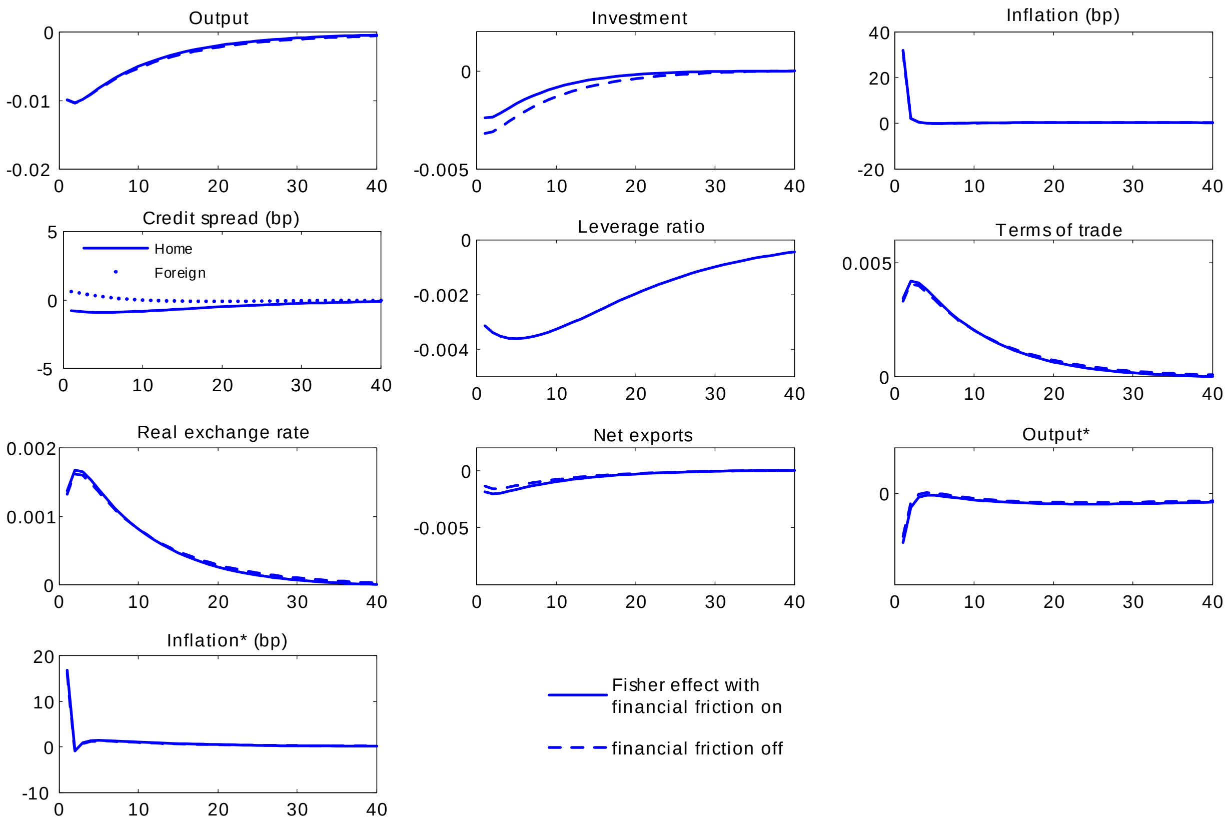


Table A: Calibration of parameters

Parameter	Description	Baseline value
γ	Home bias	0.7
ε	Substitution elasticity of varieties	6
ϕ	Inverse of Frisch labour supply elasticity	1/3
β	Discount factor	0.99
σ	Risk aversion	2
δ	Depreciation rate	0.025
α	Capital share in production	0.35
η	Entrepreneurial share in total hours	0.01
ϕ	Investment adjustment cost parameter	10
ζ	Parameter for international bond adjustment cost	0.0025
χ	Survival probability	0.966
μ	Monitoring cost	0.105
σ_{a^e}	Volatility of entrepreneur shock	0.35
a	Elasticity of substitution between home and foreign goods	1.5
ω	Fraction of firms allowed to adjust prices every period	0.6
γ_{r^n}	Persistence of nominal interest rate in monetary rule	0.8
γ_π	Weight on inflation	1.5
γ_{r^n}	Weight on output	0.5
ρ_A	Persistence of productivity shock	0.9
ρ_f	Persistence of financial shock to entrepreneurs' riskiness	0.8
ρ_s	Persistence of survival probability shock	0.8
σ_A	Standard deviation of productivity shock	0.008
σ_f	Standard deviation of risk shock	0.093
σ_s	Standard deviation of financial wealth shock	0.029

Table B: Calibration of steady state values

Steady state variable	Description	Value
el	elasticity of efp to τ	0.05
$F(\bar{a}^e)$	default probability	0.03
efp	external finance premium (gross)	1.0123
$\tau = qK/NW$	leverage ratio	2.1
$\bar{a}^e$	cut-off productivity	0.528
e^r	real exchange rate	1
TOT	terms of trade	1
CA	current account	0
C/Y	consumption output ratio	0.74
I/Y	investment output ratio	0.15
C^e/Y	E consumption output ratio	0.1

Table C: Table of moments

	Risk shock	Financial wealth shock
Output correlation	0.316	0.801
Home output volatility	0.007	0.228
Foreign output volatility	0.002	0.043
EFP correlation	0.771	-0.916
Home EFP volatility	0.006	0.023
Foreign EFP volatility	0.000	0.001
Terms of trade volatility	0.003	0.063
Exchange rate volatility	0.001	0.025
Observations over the Great Recession (2008Q2 - 2012Q4):		
UK & US output correlation	0.957	
UK & EA output correlation	0.928	
UK & US credit spread correlation	0.924	
UK & EA credit spread correlation	0.959	
Exchange rate volatility £/$	0.125	
Exchange rate volatility £/Euro	0.055	

Table D: Sensitivity analysis of financial frictions

	Parameters	Implied steady state
Baseline friction	$\sigma_a = 0.35$ $\mu = 0.105$ $\chi = 0.966$	$efp = 1.0123$ $el = 0.05$ $F(\bar{a}^e) = 0.03$ $\tau = 2.1$
Tight friction	$\sigma_a = 0.38$ $\mu = 0.12$ $\chi = 0.96$	$efp = 1.0161$ $el = 0.06$ $F(\bar{a}^e) = 0.04$ $\tau = 2.09$

6 References

Bernanke, B, Gertler, M and Gilchrist, S (1999), 'The financial accelerator in a quantitative business cycle framework', in *Handbook of Macroeconomics*, ed. by Taylor, J and Woodford, M, Vol. 1, Chap. 21, pages 1341-1393. Elsevier.

Brzoza-Brzezina, M, Kolasa, M and Makarski, K (2001), 'The anatomy of standard DSGE models with financial frictions', *National Bank of Poland working papers*, No. 80, National Bank of Poland.

Carlstrom, C, and Fuerst, T, (1997), 'Agency costs, net worth, and business fluctuations: A computable general equilibrium analysis,' *American Economic Review*, American Economic Association, vol. 87(5), pages 893-910, December

Cetorelli, N and Goldberg, L, (2012), 'Follow the money: quantifying domestic effects of foreign bank shocks in the Great Recession', *American Economic Review*, American Economic Association, Vol. 102(3), pages 219-18.

Christensen, I and Dib, A (2008), 'The financial accelerator in an estimated New Keynesian model', *Review of Economic Dynamics*, Vol. 11., pages 155-178.

Christiano, L, Motto, R and Massimo, R (2010), 'Financial factors in economic fluctuations', *European Central Bank Working Paper Series*, No. 1192, May.

Dedola, L and Lombardo, G (2012), 'Financial frictions, financial integration and the international propagation of shocks', *Economic Policy*, Vol. 27, pages 319-359.

Devereux, M and Sutherland, A (2011), 'Country portfolios in open economy macro-models', *Journal of the European Economic Association*, Vol. 9(2), pages 337-369.

Dyrda, S, Kaplan, G and Ríos-Rull, J (2012), 'Business cycles and household formation: The micro vs the macro labor elasticity,' *NBER Working Papers* 17880, National Bureau of Economic Research.

Faia, E (2007), 'Finance and the international business cycle', *Journal of Monetary Economics*, Vol. 54(4), pages 1018-1034.

Gale, D and Hellwig, M (1985), 'Incentive-compatible debt contracts: the one-period problem', *The Review of Economic Studies*, Vol. 52, No. 4, pages 647-663.

Gertler, M and Kiyotaki, N (2010), 'Financial intermediation and credit policy in business cycle analysis', in *Handbook of Monetary Economics*, Vol. 3A, ed. Friedman, B and Woodford, M, North Holland.

Ghironi, F and Melitz, M (2005), 'International trade and macroeconomic dynamics with heterogenous firms' , *The Quarterly Journal of Economics,* vol. 120(3), pages 865-915.

Gilchrist, S (2003), 'Financial markets and financial leverage in a two-country world-economy', *Working Papers Central Bank of Chile* 228, Central Bank of Chile.

Gilchrist, S and Zakrajsek, E (forthcoming), 'Credit Supply Shocks and Economic Activity in a Financial Accelerator Model' , in Rethinking the Financial Crisis, ed. by Blinder, A, Lo, A and Solow, R. Russell Sage Foundation.

Goodfriend, M and MacCallum, B(2007), 'Banking and interest rates in monetary policy analysis: A quantitative exploration', *Journal of Monetary Economics*, Vol. 54(5), pages 1480-1507.

Hall, R (2001), 'The stock market and capital accumulation', *American Economic Review*, Vol. 91(5), pages 1185-1202.

Kiyotaki, N and Moore, J (1997), 'Credit cycles', *Journal of Political Economy*, Vol. 105, pages 211-248.

Von Heideken, V (2009), 'How important are financial frictions in the United States and the Euro Area?', *Scandinavian Journal of Economics*, Vol. 111(3), pages 567-596.

7 Appendix A: The shadow model without financial frictions

We list only the structural equations describing the behaviour of the home country and pertaining to international trade. The Foreign country structural equations are symmetric and are not listed for brevity. Note that the model steady state of the shadow model has the same steady state as implied by the financial accelerator model.

$$\frac{H_t^{\phi}}{C_t^{-\sigma}} = \frac{W_t}{P_t} \tag{29}$$

$$\beta E_t R_t^D \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} = 1 \tag{30}$$

$$(C_t)^{-\sigma}\left(1+\zeta B_{ht}\right) = \beta R_t E_t \left(C_{t+1}\right)^{-\sigma} \tag{31}$$

$$(C_t)^{-\sigma}\left(1+\zeta B_{ftt}\right) = \beta R_t^* E_t \left[\left(C_{t+1}\right)^{-\sigma}\left(\frac{e_t^r}{e_{t+1}^r}\right)\right] \tag{32}$$

$$\begin{aligned} &P_t C_t + P_t B_{ht} + \frac{P_t B_{f,t}}{e_t^r} + \frac{\zeta}{2} P_t \left(B_{h,t}\right)^2 + \frac{\zeta}{2}\frac{P_t}{e_t^r}\left(B_{f,t}\right)^2 \le W_t H_t \\ &+ P_t R_{t-1} B_{h,t-1} + P_t R_{t-1}^* \frac{B_{f,t-1}}{e_t^r} + \Pi_t + P_t \tau_{h,t} \end{aligned} \tag{33}$$

$$Y_t = A_t K_t^{\alpha}\left(H_t^{1-\eta}\right)^{1-\alpha}. \tag{34}$$

$$\frac{R_t^k}{P_{h,t}} = \frac{P_t^w}{P_{h,t}}\alpha\left(\frac{Y_t}{K_t}\right) \tag{35}$$

$$\frac{W_t}{P_{h,t}} = \frac{P_t^w}{P_{h,t}}(1-\eta)(1-\alpha)\left(\frac{Y_t}{H_t}\right) \tag{36}$$

$$K_t = (1-\delta) K_{t-1} + I_t - \frac{\phi}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 K_{t-1} \tag{37}$$

$$q_t = \left(1 - \phi\left(\frac{I_t}{K_t} - \delta\right)\right)^{-1} \tag{38}$$

$$R_t^e \equiv \frac{q_t(1-\delta) + \frac{R_t^k}{P_t}}{q_{t-1}} \tag{39}$$

$$E_t\left[\frac{R_{t+1}^e}{R_t^D}\right] = s^{10} \tag{40}$$

$$P_{h,t}^o(i) = \frac{b}{(b-1)} E_t\left\{\frac{\sum_{i=0}^{\infty}\omega^i\beta^i C_{t+i}^{-\sigma} P_{t+i}^w \left(P_{h,t+i}\right)^b \left(X_{h,t+i} + X_{h,t+i}^*\right)}{\sum_{i=0}^{\infty}\omega^i\beta^i C_{t+i}^{-\sigma}\left(P_{h,t+i}\right)^b\left(X_{h,t+i} + X_{h,t+i}^*\right)}\right\} \tag{41}$$

$$P_{h,t}^{1-\theta} = (1-\omega)\left(P_{h,t}^o\right)^{1-\theta} + \omega P_{h,t-1}^{1-\theta} \tag{42}$$

$$P_t^{1-a} = (1-\gamma) P_{f,t}^{1-a} + \gamma P_{h,t}^{1-a} \tag{43}$$

$$\frac{R_t^n}{R^n} = \left(\frac{R_{t-1}^n}{R^n}\right)^{\gamma_r}\left[\left(\frac{1+\pi_t}{1+\pi}\right)^{\gamma_\pi}\left(\frac{Y_t}{Y_{t-1}}\right)^{\gamma_y}\right]^{1-\gamma_r} \tag{44}$$

$$R_t^D = E_t\left(\frac{R_t^n}{1+\pi_{t+1}}\right)$$

$$X_t = C_t + I_t + C^e + \mu\int_0^{\bar{a}^e} a_e dF(a_e) Q_{t-1} R_t^e K_{t-1} \tag{45}$$

[10] s as well as $\bar{a}^e$ and C^e are steady state values for the corresponding financial accelerator model variables. However, they are treated as constants in the shadow model and have no dynamic response to shocks.

$$X_{h,t} = \gamma \left(\frac{P_{h,t}}{P_t} \right)^{-a} X_t \tag{46}$$

$$X_{f,t} = (1-\gamma) \left(\frac{P_{f,t}}{P_t} \right)^{-a} X_t \tag{47}$$

$$TOT_t = \frac{P_{h,t}}{P_{f,t}} \tag{48}$$

$$RER_t = \frac{e_t P_t}{P_t^*} \tag{49}$$

$$P_{h,t} e_t = P_{h,t}^* \tag{50}$$

$$P_{f,t} e_t = P_{f,t}^* \tag{51}$$

$$B_{h,t} + B_{h,t}^* = 0 \tag{52}$$

$$B_{f,t} + B_{f,t}^* = 0 \tag{53}$$

$$X_{h,t} + X_{h,t}^* = Y_t \tag{54}$$

$$X_{f,t} + X_{f,t}^* = Y_t^* \tag{55}$$

$$CA_t = B_{h,t} - B_{h,t-1} + \left(B_{f,t} - B_{f,t-1} \right) / e_t^r \tag{56}$$

$$NX_t \equiv P_{h,t} X_{h,t}^* - P_{f,t} X_{f,t} \tag{57}$$