

Aggregate Volatility and Current Account Dynamics. Credit Supply Matters.

Pedro Gete* and Givi Melkadze†

This Draft: February 2016

Abstract

Changes in country-specific aggregate volatility are positively correlated with current account dynamics while negatively correlated with investment, output and credit flows. An International Real Business Cycle model with time-varying aggregate uncertainty, through a precautionary savings channel, can account for the positive correlation but implies counterfactual comovements for the other variables. Adding a credit supply channel with default and lenders exposed to aggregate risk allows the model to match all the facts. Higher volatility contracts credit supply. The current account turns to surplus because savings increase, but also because investment collapses.

Keywords: Uncertainty; current account; precautionary savings; credit supply.

JEL Classification: F32, G21.

*Corresponding author. Georgetown University and IE Business School. 37th and O Sts., NW Washington, DC, 20057, USA. Telephone: 202-687-5582. Email: pg252@georgetown.edu.

†Georgetown University. 37th and O Sts., NW Washington, DC, 20057, USA. Email: gm737@georgetown.edu.

1 Introduction

Time-varying uncertainty about macroeconomic conditions (usually measured as realized output volatility) is an important determinant of the evolution of the net foreign asset position. Fogli and Perri (2015) document this fact for OECD countries over the period 1970–2012 and Hoffmann et al. (2014) document it for 84 developing countries over the period 1980 to 2007. Both papers explain the correlation using an International Real Business Cycle model (IRBC) with a precautionary savings channel: when countries become more volatile than their partners, their households save and run a current account surplus.

In this paper we use OECD data from the period 1970–2014 to document four other related facts: when the volatility of GDP increases in a country, then investment, credit flows and output fall, while the spread between the country’s government bond and the German bond increases.¹ An IRBC model with only the precautionary savings channel is unable to simultaneously get right all the previous correlations. In the model, investment and output increase in the more volatile country. The reason is an application of Jensen’s inequality: due to convex returns from investment, higher volatility leads to higher investment, capital, output and employment.²

We show that an IRBC model correctly predicts all the previous correlations if it is expanded with a credit supply mechanism in which countries have domestic credit markets with default and lenders exposed to aggregate risk. Moreover, with a credit supply channel, the model generates current account dynamics more consistent with data because higher uncertainty induces both an investment collapse and a surge of savings.

We study a two-country IRBC model with incomplete markets extended with a costly state verification friction à la Bernanke et al. (1999) between domestic entrepreneurs and domestic lenders.³ However, a crucial difference from Bernanke et al. (1999) is that in our financial contract lenders are exposed to both aggregate and idiosyncratic credit risk. That is, the lender’s return is not predetermined. If lenders are not exposed to aggregate risk, then the financial accelerator of Bernanke et al. (1999) generates the same counterfactual predictions as the standard IRBC model.

Our mechanism works as follows: higher aggregate uncertainty increases the probability of

¹These facts are consistent with evidence documented by other authors for different samples and countries. See for example, Bloom (2009), Bloom et al. (2007), Cesa-Bianchi et al. (2014) or Ramey and Ramey (1995).

²Cho et al. (2015) and Lester et al. (2014) analyze how higher uncertainty leads to higher investment in real business cycle models with variable productive inputs.

³Households deposit with banks that lend to a continuum of entrepreneurs, who use the funds to buy capital that they then rent to the firms.

entrepreneurs' default and, because banks are exposed to aggregate risk, this leads to a contraction of credit supply even if banks' cost of funds remains constant. Moreover, when banks' credit risk increases then the risk of losses on banks' deposits is also higher and households, who would like to avoid the riskier deposits, require a higher risk premium to finance the banks.⁴ The combined effect is that higher aggregate uncertainty induces a large contraction of credit supply and lending rates to entrepreneurs soar. Since entrepreneurs need credit to finance investment the credit crunch leads to an investment collapse. Less investment lowers capital, employment and output. Moreover, the current account reacts strongly and moves towards a surplus since the precautionary savings channel is accompanied by an investment collapse.

Quantitative simulations of our model show that our channel is consistent with the data. That is, following volatility shocks, the credit crunch dominates the convex returns from investment that lead to the counterfactual predictions of the IRBC model. Moreover, the cross-country evidence on credit flows and spreads that we show in Section 2 is consistent with our credit channel: more volatile countries see a reduction in credit towards the private non-financial sector and an increase in credit spreads.

Our paper is related to the literature studying the effects of changes in aggregate uncertainty in open economies. For example, Fernandez-Villaverde et al. (2011) show that changes in the volatility of international interest rates have significant negative effects on small open economies. Fogli and Perri (2006) pioneered the importance of volatility changes and precautionary motives for current account dynamics. Fogli and Perri (2015) and Hoffmann et al. (2014) further study the topic. Our paper complements these papers because we show that the precautionary savings channel needs to be combined with a credit supply mechanism to capture all dimensions through which uncertainty affects current account dynamics. Gourio et al. (2013) show that a complete markets IRBC model can account for several exchange rate puzzles if countries differ in terms of their exposure to disaster shocks. Disaster shocks are shocks that, if realized, alter both TFP and the stock of capital. Their model implies the counterfactual result that more volatile countries should have lower interest rates. Our credit mechanism avoids that counterfactual. Gourio et al. (2015) document that aggregate stock market return volatilities forecast capital flows. Seoane (2014) analyzes sovereign spread variability in a small open economy with shocks to the level and volatility of its income process.

Our paper contributes to the emerging literature that analyzes credit frictions as a channel through which volatility fluctuations affect macroeconomic outcomes (Arellano et al. 2012, Christiano et al. 2014, Chugh 2016, Gilchrist et al. 2014, Zeke 2015). So far the literature has

⁴We solve the model using third-order perturbation to capture these risk premiums and aggregate uncertainty shocks.

focused on closed economies and shocks to the cross-sectional dispersion of firms' productivity. In this paper we explore the international implications and analyze aggregate uncertainty shocks.

Concerning the empirical correlations that we document in the next section we complement several papers. For example, Fogli and Perri (2015) and Hoffmann et al. (2014) document the correlation between volatility and current account dynamics. Ramey and Ramey (1995) show that, across countries, volatility has negative effects on GDP growth, and Bloom et al. (2007) document that it also hinders investment. To our knowledge, the link between uncertainty, spreads and credit has not been documented across countries. Gilchrist et al. (2014) document that in the U.S. fluctuations in idiosyncratic uncertainty across-firms (measured from high-frequency stock market data) affect credit spreads. Baum et al. (2009) and Jo (2012), using U.S. bank data, show that aggregate uncertainty is a driver of credit supply.

The rest of the paper is organized as follows. Section 2 documents the empirical correlations. Section 3 presents the model. Section 4 discusses how volatility affects credit supply. Section 5 calibrates the model and contains the main results. Section 6 contains the conclusions of the paper. The appendix explains our data sources. An online appendix contains the algebra.

2 Facts

In this section, we document that, for OECD countries, macroeconomic volatility is positively associated with the net foreign asset position (NFA) and with interest rate spreads. It is negatively associated with investment, GDP and credit.

Tables 1 to 6 regress the different variables on our measure of aggregate volatility.⁵ Using the same methodology as Fogli and Perri (2015), we measure volatility as the realized standard deviation of real GDP growth in a given time interval. That is, we define the volatility variable $\sigma_{i,t}^n$ for country i in period t for a time-window of length $2n + 1$ periods as:

$$\sigma_{i,t}^n = \sqrt{\frac{\sum_{j=-n}^{j=n} (g_{i,t+j} - \bar{g}_{i,t})^2}{2n + 1}}, \quad (1)$$

where $g_{i,t+j}$ is the quarterly growth rate (in percentages) of real GDP in period $t + j$, and $\bar{g}_{i,t}$

⁵We interpret the results as correlations since we lack an identification mechanism to think on causality.

is the mean growth rate over the time-window,

$$\bar{g}_{i,t} = \frac{\sum_{j=-n}^{j=n} g_{i,t+j}}{2n+1}. \quad (2)$$

For example, when $n = 20$, the length of the window around period t is 10 years. Tables 1 to 6 experiment with volatility measures computed over 5, 10 and 15 year rolling windows (i.e. $n = 10, 20$, and 30, respectively).

Table 1 confirms the results of Fogli and Perri (2015). Countries with higher macroeconomic volatility run current account surpluses (a positive change in net foreign assets). Tables 2 and 3 focus on the growth rate of real GDP and investment. Both variables fall when volatility is larger. In our sample, a one percentage point increase in volatility is associated with around a 0.3 percentage point decrease in the real investment growth rate, and a 0.2 percentage points decrease in real GDP growth. An IRBC model with only a precautionary savings channel can generate the correlation sign of Table 1, but it implies the opposite signs for the correlations that we find in Tables 2 and 3.

Table 4 shows the regression results for credit spreads. We define the spread in a given country as the difference between the yield of a domestic government bond and the yield of German government bonds. A one percentage point increase in volatility is associated with about a 2 percentage point increase in spreads.

Finally, Tables 5 and 6 show the connection between aggregate volatility and credit supply. Tables 5 focuses on total credit extended to the private non-financial sector both from domestic sources as well as from non-residents. Table 6 analyzes credit to the private non-financial sector extended only by domestic banks. In both cases, we find a statistically significant negative relationship between volatility and credit flows. Interestingly, domestic banks seem less sensitive to aggregate volatility.

3 Model

We study a two-country IRBC model extended by a costly state verification friction with lenders exposed to aggregate risk. This is the crucial new element. When the credit channel is removed the model becomes an IRBC model with only the precautionary savings channel. We compare across models to illustrate the mechanisms. Each country is inhabited by households, entrepreneurs, banks, firms producing goods and capital. The two countries trade consumption

goods and risk-free bonds. Domestic entrepreneurs can default and their default costs are borne by the domestic households.

3.1 Households

In each country ($i = 1, 2$) there is a continuum of homogeneous households who maximize the present discounted value of utility over consumption (C_t^i) and hours worked (H_t^i). Households save by investing in one-period risky domestic deposits (D_t^i) and in riskless international bonds (B_t^i). The representative household maximizes expected discounted utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(C_t^i, H_t^i), \quad (3)$$

subject to a sequence of budget constraints

$$C_t^i + B_t^i + D_t^i = W_t^i H_t^i + R_{f,t-1} B_{t-1}^i + R_{D,t}^i D_{t-1}^i - \phi_B (B_t^i - \bar{B})^2 - T_E^i + \Pi_t^i + \Pi_{c,t}^i, \quad (4)$$

where W_t^i is the wage in country i and Π_t^i and $\Pi_{c,t}^i$ are the profits of the producers of goods and capital respectively. T_E^i are lump-sum transfers to the domestic entrepreneurs to ensure that they have positive equity. $R_{f,t-1}$ is the gross return on last period holdings of the international bond. To induce a well-defined steady state and stationary equilibria we impose small adjustment costs (ϕ_B) on international bond holdings.

$R_{D,t}^i$ is the gross return on bank deposits of country i , which is state-contingent because banks may suffer credit losses and be unable to repay their borrowings (banks are 100% deposit financed in the model). Thus, households of country i are exposed to the credit risk of their financial system. This assumption is consistent with the recent experiences of Ireland, Iceland, Portugal and Spain during the 2008 financial crisis. These countries had deposit insurance systems in place but, when their local banks suffered major credit losses, the countries were unable to honor all the borrowings of their domestic financial systems (Santos 2014, Zeissler et al. 2015). Households in those countries either suffered losses on their deposits (Iceland), experienced higher taxes, or their government debt increased to fund the bailout of their domestic banks.⁶ Thus, the recent Euro crisis supports the theory that households are exposed to the credit risk of their domestic banks. This is a crucial assumption for our results as we discuss later.

⁶Moreover, the financial repression which followed the crisis has translated into limits on banking competition and low returns on deposits. Reinhart (2012) refers to this as a tax or partial default on depositors.

The households' optimality conditions imply:

$$-\frac{u_H(C_t^i, H_t^i)}{u_C(C_t^i, H_t^i)} = W_t^i, \quad (5)$$

$$\mathbb{E}_t [M_{t+1}^i R_{f,t}] = [1 + 2\phi_B(B_t^i - \bar{B})], \quad (6)$$

and

$$\mathbb{E}_t [M_{t+1}^i R_{D,t+1}^i] = 1, \quad (7)$$

where

$$M_{t+1}^i \equiv \beta \frac{u_C(C_{t+1}^i, H_{t+1}^i)}{u_C(C_t^i, H_t^i)} \quad (8)$$

is the household's stochastic discount factor.

3.2 Entrepreneurs, banks and financial contracts

In each country there is a continuum of mass one of risk-neutral entrepreneurs. In period t , the net worth of an entrepreneur j in country i is $N_{j,t}^i$. Each entrepreneur borrows $L_{j,t}^i$ from the domestic banks and buys domestic capital at price Q_t^i :

$$Q_t^i K_{j,t}^i = N_{j,t}^i + L_{j,t}^i. \quad (9)$$

After borrowing and purchasing the capital, each entrepreneur experiences an idiosyncratic shock ω_j such that $K_{j,t}^i$ units of capital generate $\omega_j K_{j,t}^i$ units of effective capital. Next period, the entrepreneur rents her effective capital to domestic firms at the country-specific rental rate r_{t+1}^i , and then sells the undepreciated capital, $\omega_j(1-\delta)K_{j,t}^i$, at price Q_{t+1}^i . Thus, an entrepreneur with idiosyncratic productivity ω_j has a rate of return $\omega_j R_{K,t+1}^i$, where

$$R_{K,t+1}^i = \frac{r_{t+1}^i + Q_{t+1}^i(1-\delta)}{Q_t^i} \quad (10)$$

is the rate of return on capital in country i .

The idiosyncratic productivity shocks ω_j create profitable and unprofitable entrepreneurs. These shocks are i.i.d. both across entrepreneurs and across time. They are not observable when the financial contract is signed. They are drawn from a log-normal distribution, the same for both countries, with a cumulative density function $F(\omega)$ with mean one and standard deviation σ_ω .

In each country there is a continuum of perfectly competitive banks who collect deposits from domestic households and promise them a gross rate of return ($R_{D,t+1}^i$) to be paid in the next period. The banks then lend these funds to the entrepreneurs. Since banks make zero profits, the return on loans equals the return on deposits. Our setup follows Bernanke et al. (1999) with one change: lenders return is not predetermined. Thus, banks' revenue fluctuates with aggregate risk and the return on deposits is risky.

At time t , the financial contract between a bank and an entrepreneur j specifies a loan amount, $L_{j,t}^i$, and the state-contingent interest rate $R_{L,t+1}^i$. If the entrepreneur has idiosyncratic productivity below the default threshold $\hat{\omega}_{t+1}^i$ defined by

$$\hat{\omega}_{t+1}^i R_{K,t+1}^i Q_t^i K_{j,t}^i = R_{L,t+1}^i L_{j,t}^i, \quad (11)$$

then the entrepreneur defaults and her assets are seized by the bank after paying a share μ of entrepreneur's assets as monitoring and default costs.

The financial contract maximizes the entrepreneur's expected next period profits:

$$\mathbb{E}_t \int_{\hat{\omega}_{t+1}^i}^{\infty} [\omega R_{K,t+1}^i Q_t^i K_{j,t}^i - R_{L,t+1}^i L_{j,t}^i] dF(\omega), \quad (12)$$

subject to equation (7), which specifies the banks' ability to raise funds when the return on deposits will be:

$$R_{D,t+1}^i L_{j,t}^i = \int_{\hat{\omega}_{t+1}^i}^{\infty} R_{L,t+1}^i L_{j,t}^i dF(\omega) + (1 - \mu) \int_0^{\hat{\omega}_{t+1}^i} \omega R_{K,t+1}^i Q_t^i K_{j,t}^i dF(\omega). \quad (13)$$

That is, the first integral on the right hand-side of (13) is the banks' revenue from borrowers who can repay. The second integral is the revenue collected from those borrowers who default.

It is convenient to follow the notation of Bernanke et al. (1999) and define the function $\Gamma(\hat{\omega}_{t+1}^i)$ to denote the expected gross share of outcome going to the bank,

$$\Gamma(\hat{\omega}_{t+1}^i) \equiv \int_0^{\hat{\omega}_{t+1}^i} \omega dF(\omega) + \hat{\omega}_{t+1}^i \int_{\hat{\omega}_{t+1}^i}^{\infty} dF(\omega), \quad (14)$$

the function $G(\hat{\omega}_{t+1}^i)$ to denote expected monitoring costs,

$$G(\hat{\omega}_{t+1}^i) \equiv \int_0^{\hat{\omega}_{t+1}^i} \omega dF(\omega), \quad (15)$$

and κ_t^i to denote entrepreneur's leverage,

$$\kappa_t^i \equiv \frac{Q_t^i K_{j,t}^i}{N_{j,t}^i}. \quad (16)$$

Then, the financial contract is a pair of leverage ratio κ_t^i and state-contingent default threshold $\widehat{\omega}_{t+1}^i$ which solves:

$$N_{j,t}^i \max_{\{\kappa_t^i, \widehat{\omega}_{t+1}^i\}} \mathbb{E}_t \left[[1 - \Gamma [\widehat{\omega}_{t+1}^i]] R_{K,t+1}^i \kappa_t^i \right], \quad (17)$$

subject to

$$\mathbb{E}_t \left[M_{t+1}^i \kappa_t^i R_{K,t+1}^i (\Gamma [\widehat{\omega}_{t+1}^i] - \mu G [\widehat{\omega}_{t+1}^i]) \right] = \kappa_t^i - 1, \quad (18)$$

where M_{t+1}^i is defined by (8). We obtained (18) by combining (7) and (13). Equation (18) is the credit supply equation. Since lending rates are not predetermined, it includes households' stochastic discount factor because banks' ability to raise funds depends on households' willingness to provide them at the risky deposit rate.

Because of constant returns to scale and risk neutrality, an entrepreneur's net worth $N_{j,t}^i$ does not affect the above maximization problem. Therefore, all entrepreneurs will choose the same leverage ratio κ_t^i and face the same borrowing rate $R_{L,t+1}^i$ regardless of their individual net wealth. Thus, the default threshold $\widehat{\omega}_{t+1}^i$ is unique in each country. Aggregation is easy as we only need to keep track of the leverage ratio and the aggregate equity of the entrepreneurs:

$$N_t^i = \int_0^1 N_{j,t}^i dj.$$

It is useful to discuss the difference between (17) and (18) and the financial contract of Bernanke et al. (1999). In that financial contract, banks' return is predetermined and equation (18) holds state by state of nature. That is, banks are insured from aggregate risk and receive the same risk-free payments from the entrepreneurs no matter the state of nature (for example, for aggregate shocks worse than expected the entrepreneurs who do not default pay higher interest rates to ensure that banks break-even). Therefore, banks can pay a predetermined risk-free rate on deposits. Thus, Bernanke et al. (1999) version of equation (18) has no expectation operator. We depart from Bernanke et al. (1999) because for volatility shocks to alter credit supply we need lenders to be exposed to aggregate risk. Since banks hold no capital and their revenue is not risk-free then in our model neither deposit rates are risk-free. For this reason, equation (13) defines the return on deposits and we need to combine it with households' Euler equation to obtain the supply of deposits (18).

As is standard in the financial frictions literature, to ensure that the entrepreneurial sector never accumulates enough equity to avoid the need for external financing, we assume that at the end of each period entrepreneurs die with an exogenous probability $(1 - \gamma_E)$ and consume their net worth:

$$C_{E,t}^i = (1 - \gamma_E) [1 - \Gamma(\widehat{\omega}_t^i)] R_{K,t}^i Q_{t-1}^i K_{t-1}^i. \quad (19)$$

The aggregate equity of the entrepreneurs is their earnings, net of those passing away, plus a transfer T_E^i to guarantee non-zero equity,

$$N_t^i = \gamma_E [1 - \Gamma(\widehat{\omega}_t^i)] R_{K,t}^i Q_{t-1}^i K_{t-1}^i + T_E^i. \quad (20)$$

3.3 Capital producers

There is a representative capital producer in each country. It is owned by the domestic households. It buys goods $(I_{g,t}^i)$ from the firms, and the undepreciated capital $(1 - \delta)K_{t-1}^i$ from the entrepreneurs to produce capital stock according to the law of motion

$$K_t^i = (1 - \delta)K_{t-1}^i + I_{n,t}^i, \quad (21)$$

where $I_{n,t}^i$ is the net investment and $I_{g,t}^i$ is the gross investment,

$$I_{n,t}^i = I_{g,t}^i - \phi_K K_{t-1}^i \left(\frac{I_{g,t}^i}{K_{t-1}^i} - \delta \right)^2. \quad (22)$$

The parameter ϕ_K controls the capital adjustment cost. This adjustment cost ensures that the price of capital is not one and varies endogenously affecting entrepreneurs' net worth. The capital producer sells the capital to the entrepreneurs at price Q_t . Its profits each period are

$$\Pi_{c,t}^i = Q_t^i K_t^i - Q_t^i (1 - \delta) K_{t-1}^i - I_{g,t}^i. \quad (23)$$

The capital producer chooses investment and capital to maximize the present discounted value of its profit streams:

$$\max_{\{I_{g,t}^i, K_t^i\}} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t u_C(C_t^i, H_t^i) \Pi_{c,t}^i,$$

subject to

$$K_t^i = (1 - \delta)K_{t-1}^i + I_{g,t}^i - \phi_K K_{t-1}^i \left(\frac{I_{g,t}^i}{K_{t-1}^i} - \delta \right)^2. \quad (24)$$

3.4 Firms producing goods

Firms producing final goods use labor (H_t^i) and capital (K_{t-1}^i) according to the production function

$$Y_t^i = e^{A_t^i} (K_{t-1}^i)^\alpha (H_t^i)^{1-\alpha}. \quad (25)$$

A_t^i is the country-specific aggregate productivity that follows an AR(1) process with time-varying volatility,

$$A_t^i = \rho_A A_{t-1}^i + e^{V_t^i} \varepsilon_t^i, \quad (26)$$

$$V_t^i = (1 - \rho_V) V^{ss} + \rho_V V_{t-1}^i + \eta_t^i, \quad (27)$$

where ε_t^i is a Gaussian white noise shock to the TFP level with standard deviation σ_ε common across countries. The cross-country correlation of the TFP shocks is denoted by ϑ . The country-specific η_t^i shocks alter the variance of the TFP level. These are the volatility shocks on which we will focus. They are Gaussian white noise, with standard deviation σ_η common across countries. The volatility shocks are uncorrelated across countries. V^{ss} controls the steady state level of volatility.

The representative firm hires labor and rents capital to maximize profits

$$\Pi_t^i = Y_t^i - W_t^i H_t^i - r_t^i K_{t-1}^i, \quad (28)$$

which, because of the constant returns to scale production function, will be zero in equilibrium.

3.5 Market clearing

There is a market for physical capital in each country in which the supply by the capital producer equals the aggregate demand from the entrepreneurs,

$$K_t^i = \int_0^1 K_{j,t}^i dj.$$

International bonds are in zero net supply across countries,

$$B_t^1 + B_t^2 = 0. \quad (29)$$

In each country, households' supply of deposits must equal the borrowings by the entrepre-

neurs,

$$D_t^i = L_t^i = \int_0^1 L_{j,t}^i dj. \quad (30)$$

Also, from the balance sheets of the entrepreneurs, the value of the capital stock of country i equals the holdings of debt and equity of the entrepreneurs:

$$Q_t^i K_t^i = L_t^i + N_t^i. \quad (31)$$

The net foreign asset position for country i is

$$NFA_t^i = B_t^i, \quad (32)$$

and the current account, Ω_t^i , is the change in the net foreign asset position,

$$\Omega_t^i = B_t^i - B_{t-1}^i. \quad (33)$$

Finally, all numeraire goods available in country i (output plus gross return on international bonds) are used for investment, consumption, new bond purchases and resource costs from monitoring and adjustments costs:

$$Y_t^i + R_{f,t-1} B_{t-1}^i = C_t^i + C_{E,t}^i + I_{g,t}^i + B_t^i + \mu G(\widehat{\omega}_t^i) R_{K,t}^i Q_{t-1}^i K_{t-1}^i + \phi_B (B_t^i - \bar{B})^2. \quad (34)$$

4 Volatility and credit supply

In this section, to build intuition for the mechanism of the model, we analyze credit supply in partial equilibrium while keeping households' stochastic discount factor exogenous and constant. We show that higher aggregate uncertainty contracts credit supply, especially when leverage is high. The next section solves the full general equilibrium model and contains the quantitative results.

Figure 1 plots the credit supply equation (18) in a partial equilibrium setting for two levels of aggregate uncertainty. That is, first we rewrite (18) as

$$\mathbb{E}_t \left[M_{t+1}^i \kappa_t^i R_{K,t+1}^i \left[\Gamma \left(\frac{R_{L,t+1}^i \kappa_t^i - 1}{R_{K,t+1}^i \kappa_t^i} \right) - \mu G \left(\frac{R_{L,t+1}^i \kappa_t^i - 1}{R_{K,t+1}^i \kappa_t^i} \right) \right] \right] = \kappa_t^i - 1, \quad (35)$$

where $\widehat{\omega}_{t+1}^i$ has been explicitly replaced using (11). Then, we set M_{t+1}^i at its steady state value

and assume that $R_{K,t}^i$ follows an AR(1) process with time-varying volatility:

$$\log\left(\frac{R_{K,t}^i}{R_K^{ss}}\right) = \rho_A \log\left(\frac{R_{K,t-1}^i}{R_K^{ss}}\right) + e^{V_t^i} \varepsilon_t^i, \quad (36)$$

where V_t^i follows (27). V^{ss} governs the long-run level of aggregate risk. We compare two values of V^{ss} . Using a third-order approximation to (35) we solve for the leverage ratio κ_t^i in the stochastic steady-state for different lending rates $R_{L,t+1}^i$.⁷ Figure 1 plots the resulting credit supply curves, that is, the rates that lenders require to lend at a given leverage level. Higher aggregate volatility (higher V^{ss}) increases entrepreneurs' default risk and contracts credit supply. For the same leverage ratio, when aggregate volatility is higher in the country, lenders require more expensive credit to compensate them for bearing higher default risk. This effect is increasing in the entrepreneurs' leverage ratio because for a given negative shock, default is more likely when leverage is higher. Thus, lending rates react more to increases in aggregate volatility when the entrepreneurs have higher leverage.

As we will discuss in the next section, the previous result is stronger in general equilibrium because households are risk-averse and their deposits are exposed to credit risk. Higher aggregate volatility makes bank deposits riskier, and households require larger risk premiums to supply bank deposits. The higher cost of raising deposits is another factor pushing lenders to raise their lending rates.

5 The IRBC model with and without credit channel

In this section we compare two IRBC models, one with the credit channel presented in section 3 and another without it. First, we discuss the calibration of the model, then the impulse responses and simulation results. As is standard in the literature on uncertainty shocks, we solve the model using a third-order approximation to capture the effects of volatility shocks while keeping the level of TFP unchanged. Fernandez-Villaverde et al. (2011) show that this is the minimum order of approximation for volatility shocks to appear independently in the policy functions, and that model dynamics are unaffected to adding higher order terms to the approximations.

⁷We set the steady state and parameter values as in the full general equilibrium model discussed in the next section. The results are robust to changes in parameters.

5.1 Calibration

We set a period in the model to be one quarter. We use GHH preferences common in international literature to avoid wealth effects on labor supply,

$$u(C, H) = \frac{1}{1 - \gamma} \left(C - \theta \frac{H^{1 + \frac{1}{\xi}}}{1 + \frac{1}{\xi}} \right)^{1 - \gamma}, \quad (37)$$

where ξ is the Frisch elasticity of labor supply and γ controls risk aversion. We set $\gamma = 2$ and $\xi = 0.5$, which are standard values in the literature. We choose the value of θ so that the long-run mean of hours worked equals $\frac{1}{3}$. The discount factor β is 0.99, which implies a 4% annual deposit rate in the stochastic steady state.⁸

We use the usual capital share in production ($\alpha = 0.36$) and depreciation rate ($\delta = 0.025$). For the cost of changing the holdings of international bonds we select a very small number ($\phi_B = 0.0005$) as in Fernandez-Villaverde et al. (2011) to ensure a well-defined steady state and stationary dynamics. The parameter controlling the capital adjustment cost (ϕ_K) is calibrated for investment to be 2.95 times more volatile than output. This is what we observe in our data sample.

We follow Fogli and Perri (2015) to assign values to the shock processes. The standard deviation of TFP level shocks (σ_ε) is 0.01, the persistence of these shocks (ρ_A) is 0.9999, the standard deviation of the volatility shocks (σ_η) is 0.048, their persistence (ρ_V) is 0.9999, their mean (V^{ss}) is zero, the cross-country correlation of TFP innovations (ϑ) is 0.4 and the volatility shocks are uncorrelated across countries. Baxter and Crucini (1995) show that the standard IRBC model with incomplete markets needs the TFP process with persistence close to unit root to match the comovements and cross-country correlations of business cycle quantities.

Concerning the financial frictions, we set the monitoring cost (μ) to 0.63, the cross-sectional standard deviation of idiosyncratic productivity (σ_ω) to 0.25, the survival rate of entrepreneurs (γ_E) to 0.95 and the transfer payments to entrepreneurs (T_E) to 0.005. These parameters imply long-run means for entrepreneurs' leverage ratio (κ^i) of 2, annual credit spread ($R_L^i - R_f$) of 150 basis points and an annual default rate of 2.20%. These values are in the range of those

⁸With high-order perturbations, deterministic steady state values of endogenous variables are in general different from their long-run means. We characterize the long-run values of the endogenous variables following what Juillard and Kamenik (2005) denote as the stochastic steady-state. This is the point where agents decide to stay when they expect future shocks but current realizations of innovations are zero. To compute the stochastic steady-state we simulate the model for many periods with zero innovations of exogenous shocks until the economy converges to a point where all the endogenous variables are constant. Following Fernandez-Villaverde et al. (2011), we use this stochastic steady state as the initial point for computing the impulse response functions.

common in the literature on financial frictions, like Bernanke et al. (1999) or Christiano et al. (2014).

Table 7 contains our calibrated parameters for the model with credit channel. When we calibrate the standard IRBC model, we use all the same parameter values except for the capital adjustment cost. We choose this parameter so that the IRBC model without a credit channel also matches the relative volatility of investment of 2.95.

5.2 Impulse Responses

Figures 2 and 3 compare impulse responses to an unanticipated aggregate volatility shock in country 1. One line is the model with the credit channel presented in Section 3, the other line is the standard IRBC model analyzed by Fogli and Perri (2015). Figure 2 focuses on the responses that are similar across the models while Figure 3 highlights the differences across the models. Figure 4 plots the credit channel mechanism that generates the differences. All figures report values as deviations of the variables from their stochastic steady-state values.

As in Fogli and Perri (2015), on impact the shock increases the standard deviation of TFP innovations $\left(e^{V_t^i} \sigma_\varepsilon\right)$ in country 1 from 1% to 1.5%. Before the shock hits, both countries are in the long-run symmetric equilibrium with a zero net asset position and the same standard deviations of TFP innovations. Figure 2 shows that both the standard IRBC model and the model with the credit channel predict that consumption and the risk-free rate decrease in the country that becomes more volatile (country 1). These results are due to the precautionary savings motive. Higher volatility induces prudent households to consume less and save. Higher demand for the international bonds implies a fall in the risk-free rate. The surge in domestic savings induces a current account surplus in country 1. Interestingly, the reaction of the current account is larger in the model with the credit channel. This is because in this model, higher volatility induces lower investment as Panel b in Figure 3 shows. Thus, two forces push the current account towards surplus when there is a credit channel: higher savings and lower investment. Without the credit channel, the investment response is counterfactual as we discuss next.

Figure 3 plots output, investment, employment and capital. For these variables, the reaction to a volatility shock is very different in the model with a credit channel relative to the model without it. When the labor input can be adjusted freely and investment is reversible, output and investment are convex functions of productivity and thus, by Jensen's inequality, their expected values increase in the volatility of TFP. Thus, the standard IRBC without a credit channel

predicts that higher uncertainty leads to higher investment and output, which contradicts the empirical evidence of Section 2. Adding the credit channel fixes this comovement problem because it makes investment depend on credit (entrepreneurs need to borrow to finance their capital purchases).

Figure 4 plots the reaction of credit markets. Higher uncertainty increases default risk and banks increase their lending spreads as reported in Panel b of Figure 4. Moreover, households are now more exposed to the risk of losing their deposits. Thus, they reduce their credit supply asking for a higher risk premium, which leads to higher funding costs for banks. This general equilibrium effect reinforces the contraction in credit supply that we discussed in Section 4. In equilibrium, credit to entrepreneurs falls, investment, output and the price of capital collapse and trigger a financial accelerator à la Bernanke et al. (1999) in which lower entrepreneurs' net worth makes their cost of external funds even higher. Employment drops as lower capital stock in the next period implies lower returns to labor supply. Thus, the IRBC with the credit channel is consistent with the comovements reported in Section 2.

5.3 Simulations

To quantify the differences between model mechanisms, we simulate the IRBC models with and without the credit channel to generate an artificial world economy with 20 countries and run regressions as in Section 2.⁹ Table 8 contains the results. The first column has the regression coefficients for the simulations of the IRBC with the credit channel. The second column is for the IRBC without the credit channel. The last column displays the regression coefficients reported in Section 2.

Table 8 shows that both qualitatively and quantitatively the model with the credit channel is closer to the data than the model with only precautionary savings. Both models predict the correct sign for the comovement between aggregate volatility and changes in the NFA, but the model with a credit channel is much closer to the data. This is because with a credit channel the current account is driven by both an increase in savings and a collapse of investment. Without the credit channel the IRBC model predicts that investment increases, as it is shown by the positive regression coefficients for investment and output. In the data these signs are negative.

⁹We simulate 21 time series of volatility shocks (V_t^i) each one of 220 periods. We assign one series to country 2 and the remaining 20 series to country 1. We feed these series in the IRBC models with and without credit channel. This way we have all variables of the model for a world economy of 20 countries. Then, we regress the simulated series of NFA-to-output ratio, growth of output, growth of investment, lending spread, and quarter-over-quarter change in credit-to-output ratio on the simulated volatility series. We repeat this procedure 10 times. Thus, the reported model-implied regression coefficients are averages over 10 simulations of the 20-country world economy.

Adding the credit channel allows the model to get the correlation signs correct. However the correlations are weaker than in the data. The model with the credit channel is also consistent with the empirical relationship between credit, spreads and aggregate volatility.

Most of the popularity of the IRBC model is due to its ability to account for the right standard deviations and comovement between business cycle variables. To test if those appealing properties remain when we add the credit channel, we simulate the two models with TFP and volatility shocks for 4000 periods. We then apply Hodrick-Prescott filter, with smoothing parameter equal to 1600, to the simulated data to compute standard deviations, autocorrelations and comovements of the variables of interest. The empirical moments are also computed based on the Hodrick-Prescott filtered data. Table 9 shows that the IRBC model with a credit channel does equally well as the standard IRBC. This happens because both models react very similarly to TFP shocks and these are the dominant shocks when we simulate the models with both TFP and uncertainty shocks.

6 Conclusions

Recent literature has documented the importance of changes in aggregate volatility in understanding current account dynamics. The leading explanation is a precautionary savings channel: when a country faces higher uncertainty, its households save more and the current account moves towards surplus. In this paper we show that countries with higher aggregate volatility also have lower investment, output and credit flows. These facts cannot be explained only by a precautionary savings channel. We show that an IRBC model with a credit channel can simultaneously predict all the comovements. Higher uncertainty increases default risk and credit supply contracts, while spreads rise and investment collapses leading to a current account surplus. For this credit channel to match the data, the financial contract cannot have predetermined lenders' return, as is common in the literature following Bernanke et al. (1999). Lenders need to be exposed to aggregate credit risk. Our results suggest that the link between credit supply and uncertainty is important in understanding recent cross-country dynamics. Our empirical findings hint that credit from domestic banks is less sensitive to volatility than credit from non-banks and foreign lenders. Future research may further study how this matters for international macro models.

Acknowledgements

We thank Chuqiao Bi, Behzad Diba, Martin Evans and Fabrizio Perri for comments. Pedro Gete gratefully acknowledges the financial support of the Spanish Ministry of Economy and Competitiveness Grant No. ECO2014-53022.

References

- Arellano, C., Bai, Y. and Kehoe, P.: 2012, Financial markets and fluctuations in volatility, *Federal Reserve Bank of Minneapolis Research Department Staff Report* **466**.
- Baum, C. F., Caglayan, M. and Ozkan, N.: 2009, The second moments matter: The impact of macroeconomic uncertainty on the allocation of loanable funds, *Economics Letters* **102**(2), 87–89.
- Bernanke, B. S., Gertler, M. and Gilchrist, S.: 1999, The financial accelerator in a quantitative business cycle framework, *Handbook of Macroeconomics* **1**, 1341–1393.
- Bloom, N.: 2009, The impact of uncertainty shocks, *Econometrica* **77**(3), 623–685.
- Bloom, N., Bond, S. and Van Reenen, J.: 2007, Uncertainty and investment dynamics, *The Review of Economic Studies* **74**(2), 391–415.
- Cesa-Bianchi, A., Pesaran, M. and Rebucci, A.: 2014, Uncertainty and economic activity: A global perspective.
- Cho, J.-O., Cooley, T. F. and Kim, H. S. E.: 2015, Business cycle uncertainty and economic welfare, *Review of Economic Dynamics* **18**(2), 185–200.
- Christiano, L. J., Motto, R. and Rostagno, M.: 2014, Risk shocks, *The American Economic Review* **104**(1), 27–65.
- Chugh, S. K.: 2016, Firm risk and leverage-based business cycles, *Review of Economic Dynamics* .
- Fernández-Villaverde, J., Guerrón-Quintana, P., Rubio-Ramírez, J. F. and Uribe, M.: 2011, Risk matters: The real effects of volatility shocks, *American Economic Review* **101**(6), 2530–61.
- Fogli, A. and Perri, F.: 2006, The Great Moderation and the US external imbalance, *Monetary and Economic Studies* pp. 209–225.
- Fogli, A. and Perri, F.: 2015, Macroeconomic volatility and external imbalances, *Journal of Monetary Economics* **69**, 1–15.
- Gilchrist, S., Sim, J. W. and Zakrajšek, E.: 2014, Uncertainty, financial frictions, and investment dynamics.

- Gourio, F., Siemer, M. and Verdelhan, A.: 2013, International risk cycles, *Journal of International Economics* **89**(2), 471–484.
- Gourio, F., Siemer, M. and Verdelhan, A.: 2015, Uncertainty and international capital flows.
- Hoffmann, M., Krause, M. and Tillmann, P.: 2014, International capital flows, external assets and output volatility.
- Jo, S.: 2012, Bank lending and loan securitization under uncertainty.
- Juillard, M. and Kamenik, O.: 2005, Solving SDGE models: approximation about the stochastic steady state.
- Lester, R., Pries, M. and Sims, E.: 2014, Volatility and welfare, *Journal of Economic Dynamics and Control* **38**, 17–36.
- Ramey, G. and Ramey, V.: 1995, Cross-country evidence on the link between volatility and growth, *The American Economic Review* **85**(5), 1138–1151.
- Reinhart, C. M.: 2012, The return of financial repression.
- Santos, T.: 2014, Antes del diluvio: The Spanish banking system in the first decade of the Euro.
- Seoane, H. D.: 2014, Time-varying volatility, default and the sovereign risk premium.
- Zeissler, A. G., Ikeda, D. and Metrick, A.: 2015, Ireland and Iceland in Crisis D: similarities and differences.
- Zeke, D.: 2015, Financial frictions, volatility, and skewness.

Appendix: data sources

Below are the data sources for the series used in the paper. Our sample are the following OECD countries: Australia (AUS), Austria (AUT), Belgium (BEL), Canada (CAN), Denmark (DNK), Finland (FIN), France (FRA), Germany (DEU), Greece (GRC), Italy (ITA), Mexico (MEX), Japan (JAP), South Korea (KOR), Netherlands (NED), Norway (NOR), Spain (ESP), Sweden (SWE), Switzerland (CHE), United Kingdom (GBR) and the United States (USA).

a) Real GDP (1960Q2-2014Q4), investment (1960Q2-2014Q4), consumption (1960Q2-2014Q4), net-exports (1960Q2-2014Q4). Source: OECD Quarterly National Accounts.

b) Net foreign asset position (1970-2012). Source: Fogli and Perri (2015), which extend the data in Lane and Milesi-Ferretti (2007).

c) The spread for each country is the difference between the country's government bond yields and Germany's government bond yields. The data on yields are from IMF International Financial Statistics, line 61. The series are not available with the same length for all countries: AUT (1970Q1-2014Q4), ESP (1978Q2-2014Q4), FIN (1988Q1-2014Q4), GRC (1992Q4-2014Q4), JAP (1966Q4-2014Q4), KOR (1973Q3-2014Q4), MEX (1999Q2-2014Q4) and 1960Q-2014Q4 for the rest of the countries.

d) The credit data comes from the Bank of International Settlements. Total credit comprises financing from all sources, including domestic banks, other domestic financial corporations, non-financial corporations and non-residents. Bank credit includes credit extended by domestic banks to the private non-financial sector. The length of the series varies across the countries: AUS (1960Q2-2014Q4), AUT (1960Q4-2014Q4), BEL (1970Q4-2014Q4), CAN (1960Q1-2014Q4), CHE (1960Q4-2014Q4), DEU (1960Q4-2014Q4), DNK (1966Q4-2014Q4), ESP (1970Q1-2014Q4), FIN (1970Q4-2014Q4), FRA (1969Q4-2014Q4), GBR (1963Q1-2014Q4), GRC (1970Q4-2014Q4), ITA (1960Q4-2014Q4), JAP (1964Q4-2014Q4), KOR (1962Q4-2014Q4), MEX (1980Q4-2014Q4), NED (1961Q1-2014Q4), NOR (1960Q4-2014Q4), SWE (1961Q1-2014Q4), and USA (1960Q1-2014Q4).

A Derivation of equilibrium conditions

We use superscript i to index the country ($i = 1, 2$) and subscript j to refer to an individual entrepreneur.

A.1 Households

The Lagrangian of the household's problem is:

$$\mathcal{L} = \max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[u(C_t^i, H_t^i) + \lambda_t \left(\begin{array}{l} W_t^i H_t^i + R_{f,t-1} B_{t-1}^i + R_{D,t}^i D_{t-1}^i + \Pi_t^i + \Pi_{c,t}^i + \\ -\phi_B (B_t^i - \bar{B})^2 - C_t^i - B_t^i - D_t^i - T_E^i \end{array} \right) \right].$$

Household's stochastic discount factor is $M_{t+1}^i \equiv \beta \frac{u_C(C_{t+1}^i, H_{t+1}^i)}{u_C(C_t^i, H_t^i)}$. The first order conditions are:

$$R_{f,t} \mathbb{E}_t [M_{t+1}^i] = [1 + 2\phi_B (B_t^i - \bar{B})]. \quad (\text{A.1})$$

$$\mathbb{E}_t [M_{t+1}^i R_{D,t+1}^i] = 1. \quad (\text{A.2})$$

$$-\frac{u_H(C_t^i, H_t^i)}{u_C(C_t^i, H_t^i)} = W_t^i. \quad (\text{A.3})$$

A.2 Capital producers

Capital producers solve:

$$\max_{\{I_{g,t}^i, K_t^i\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u_C(C_t^i, H_t^i) [Q_t^i K_t^i - Q_t^i (1 - \delta) K_{t-1}^i - I_{g,t}^i],$$

subject to

$$K_t^i = (1 - \delta) K_{t-1}^i + I_{g,t}^i - \phi_K K_{t-1}^i \left(\frac{I_{g,t}^i}{K_{t-1}^i} - \delta \right)^2.$$

The Lagrangian for this problem is:

$$\mathcal{L} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[u_C(C_t^i, H_t^i) [Q_t^i K_t^i - Q_t^i (1 - \delta) K_{t-1}^i - I_{g,t}^i] + \eta_t^i \left(\begin{array}{l} (1 - \delta) K_{t-1}^i + I_{g,t}^i + \\ -\phi_K K_{t-1}^i \left(\frac{I_{g,t}^i}{K_{t-1}^i} - \delta \right)^2 - K_t^i \end{array} \right) \right].$$

The FOCs with respect to $I_{g,t}^i$ and K_t^i are:

$$u_C(C_t^i, H_t^i) = \eta_t^i \left[1 - 2\phi_K \left(\frac{I_{g,t}^i}{K_{t-1}^i} - \delta \right) \right],$$

$$u_C(C_t^i, H_t^i)Q_t^i - \eta_t^i = \left\{ \begin{array}{l} \beta(1-\delta)\mathbb{E}_t \left([u_C(C_{t+1}^i, H_{t+1}^i)Q_{t+1}^i] - \eta_{t+1}^i \right) + \\ + \beta\phi_K \mathbb{E}_t \left[\eta_{t+1}^i \left(\frac{I_{g,t+1}^i}{K_t^i} - \delta \right)^2 \right] - 2\beta\phi_K \mathbb{E}_t \left[\eta_{t+1}^i \frac{I_{g,t+1}^i}{K_t^i} \left(\frac{I_{g,t+1}^i}{K_t^i} - \delta \right) \right] \end{array} \right\}.$$

A.3 Firms producing goods

Profit maximization implies the following equilibrium conditions:

$$r_t^i = \alpha \frac{Y_t^i}{K_{t-1}^i}, \quad (\text{A.4})$$

$$W_t^i = (1 - \alpha) \frac{Y_t^i}{H_t^i}. \quad (\text{A.5})$$

A.4 Entrepreneurs and the financial contract

As we show in section (3.3), each entrepreneur chooses the same leverage ratio, κ_t^i and default threshold $\widehat{\omega}_{t+1}^i$ regardless of her individual net worth, $N_{j,t}^i$. The loan amount, $L_{j,t}^i$, and capital purchases, $K_{j,t}^i$, vary across entrepreneurs. We use j subscript to denote the entrepreneur j .

Expected next period profits for entrepreneur j are:

$$\mathbb{E}_t \int_{\widehat{\omega}_{t+1}^i}^{\infty} [\omega R_{K,t+1}^i Q_t^i K_{j,t}^i - R_{L,t+1}^i L_{j,t}^i] dF(\omega).$$

Or, using (11) to substitute for $R_{L,t+1}^i L_{j,t}^i$,

$$\mathbb{E}_t \int_{\widehat{\omega}_{t+1}^i}^{\infty} (\omega - \widehat{\omega}_{t+1}^i) R_{K,t+1}^i Q_t^i K_{j,t}^i dF(\omega) = \mathbb{E}_t [(1 - \Gamma(\widehat{\omega}_{t+1}^i)) R_{K,t+1}^i Q_t^i K_{j,t}^i].$$

Dividing and multiplying by $N_{j,t}^i$ and using the definition of leverage from (16), we obtain:

$$N_{j,t}^i \mathbb{E}_t [(1 - \Gamma(\widehat{\omega}_{t+1}^i)) R_{K,t+1}^i \kappa_t^i].$$

Similarly, substituting in (13), we get:

$$R_{D,t+1}^i L_{j,t}^i = \left(\int_{\widehat{\omega}_{t+1}^i}^{\infty} \widehat{\omega}_{t+1}^i dF(\omega) + (1 - \mu) \int_0^{\widehat{\omega}_{t+1}^i} \omega dF(\omega) \right) R_{K,t+1}^i Q_t^i K_{j,t}^i,$$

or,

$$R_{D,t+1}^i L_{j,t}^i = (\Gamma(\widehat{\omega}_{t+1}^i) - \mu G(\widehat{\omega}_{t+1}^i)) R_{K,t+1}^i Q_t^i K_{j,t}^i.$$

By dividing and multiplying both sides by $N_{j,t}^i$ we obtain:

$$R_{D,t+1}^i = \frac{\kappa_t^i}{\kappa_t^i - 1} R_{K,t+1}^i (\Gamma(\widehat{\omega}_{t+1}^i) - \mu G(\widehat{\omega}_{t+1}^i)).$$

The financial contract specifies the leverage ratio κ_t^i and state-contingent default threshold $\widehat{\omega}_{t+1}^i$, that solve:

$$\max_{\{\kappa_t^i, \widehat{\omega}_{t+1}^i\}} \mathbb{E}_t \left[[1 - \Gamma(\widehat{\omega}_{t+1}^i)] R_{K,t+1}^i \kappa_t^i \right], \quad (\text{A.6})$$

subject to

$$R_{D,t+1}^i = \frac{\kappa_t^i}{\kappa_t^i - 1} R_{K,t+1}^i (\Gamma(\widehat{\omega}_{t+1}^i) - \mu G(\widehat{\omega}_{t+1}^i)), \quad (\text{A.7})$$

$$\mathbb{E}_t [M_{t+1}^i R_{D,t+1}^i] = 1. \quad (\text{A.8})$$

Combining the two constraints we reduce the number of constraints to one:

$$\mathbb{E}_t [M_{t+1}^i \kappa_t^i R_{K,t+1}^i (\Gamma(\widehat{\omega}_{t+1}^i) - \mu G(\widehat{\omega}_{t+1}^i))] = \kappa_t^i - 1. \quad (\text{A.9})$$

Let's denote by χ_t^i the Lagrange multiplier on (A.9). Then the Lagrangian function is:

$$\begin{aligned} \mathcal{L}_t = & \mathbb{E}_t \left([1 - \Gamma(\widehat{\omega}_{t+1}^i)] R_{K,t+1}^i \kappa_t^i \right) + \\ & + \chi_t^i \left[\mathbb{E}_t [M_{t+1}^i \kappa_t^i R_{K,t+1}^i (\Gamma(\widehat{\omega}_{t+1}^i) - \mu G(\widehat{\omega}_{t+1}^i))] - (\kappa_t^i - 1) \right]. \end{aligned}$$

The FOC with respect to $\widehat{\omega}_{t+1}^i$ is:

$$-\Gamma'(\widehat{\omega}_{t+1}^i) R_{K,t+1}^i \kappa_t^i + \chi_t^i M_{t+1}^i \kappa_t^i R_{K,t+1}^i (\Gamma'(\widehat{\omega}_{t+1}^i) - \mu G'(\widehat{\omega}_{t+1}^i)) = 0. \quad (\text{A.10})$$

After canceling the similar terms we obtain:

$$\chi_t^i = \frac{\Gamma'(\widehat{\omega}_{t+1}^i)}{M_{t+1}^i [\Gamma'(\widehat{\omega}_{t+1}^i) - \mu G'(\widehat{\omega}_{t+1}^i)]}. \quad (\text{A.11})$$

Since $\widehat{\omega}_{t+1}^i$ is contingent on aggregate state in $t+1$, equation (A.11) does not have an expectation operator, as it holds state-by-state.

The FOC with respect to κ_t^i is:

$$\mathbb{E}_t \left([1 - \Gamma(\widehat{\omega}_{t+1}^i)] R_{K,t+1}^i \right) + \chi_t^i \mathbb{E}_t \left[M_{t+1}^i R_{K,t+1}^i (\Gamma[\widehat{\omega}_{t+1}^i] - \mu G[\widehat{\omega}_{t+1}^i]) \right] = \chi_t^i. \quad (\text{A.12})$$

The FOC with respect to χ_t^i gives (A.9).

A.5 Derivation of country i 's resource constraint

The time t realized return on bank deposits is:

$$R_{D,t}^i D_{t-1}^i = (\Gamma(\widehat{\omega}_t^i) - \mu G(\widehat{\omega}_t^i)) R_{K,t}^i Q_{t-1}^i K_{t-1}^i.$$

Substituting this expression for $R_{D,t}^i D_{t-1}^i$ into the households time t budget constraint we obtain:

$$C_t^i + B_t^i + D_t^i = W_t^i H_t^i + R_{f,t-1} B_{t-1}^i - \phi_B (B_t^i - \overline{B})^2 + \Pi_{c,t}^i - T_E^i + [\Gamma(\widehat{\omega}_t^i) - \mu G(\widehat{\omega}_t^i)] R_{K,t}^i Q_{t-1}^i K_{t-1}^i.$$

Using (23) to substitute for $\Pi_{c,t}^i$ gives:

$$\begin{aligned} C_t^i + I_{g,t}^i + B_t^i + D_t^i + Q_t^i (1 - \delta) K_{t-1}^i &= W_t^i H_t^i + R_{f,t-1} B_{t-1}^i + Q_t^i K_t^i - \phi_B (B_t^i - \overline{B})^2 - T_E^i + \\ &+ [\Gamma(\widehat{\omega}_t^i) - \mu G(\widehat{\omega}_t^i)] R_{K,t}^i Q_{t-1}^i K_{t-1}^i. \end{aligned}$$

We use the firms zero profit condition to substitute for $W_t^i H_t^i$:

$$\begin{aligned} C_t^i + I_{g,t}^i + B_t^i + D_t^i + Q_t^i (1 - \delta) K_{t-1}^i &= Y_t^i - r_t^i K_{t-1}^i + R_{f,t-1} B_{t-1}^i + Q_t^i K_t^i - \phi_B (B_t^i - \overline{B})^2 - T_E^i + \\ &+ [\Gamma(\widehat{\omega}_t^i) - \mu G(\widehat{\omega}_t^i)] R_{K,t}^i Q_{t-1}^i K_{t-1}^i. \end{aligned}$$

Then, using the expression for $R_{K,t}^i$ from (10), we obtain:

$$\begin{aligned} C_t^i + I_{g,t}^i + B_t^i + D_t^i + R_{K,t}^i Q_{t-1}^i K_{t-1}^i &= Y_t^i + R_{f,t-1} B_{t-1}^i + Q_t^i K_t^i - \phi_B (B_t^i - \overline{B})^2 - T_E^i + \\ &+ [\Gamma(\widehat{\omega}_t^i) - \mu G(\widehat{\omega}_t^i)] R_{K,t}^i Q_{t-1}^i K_{t-1}^i. \end{aligned}$$

Further rearranging we get:

$$C_t^i + I_{g,t}^i + B_t^i + D_t^i + (1 - \Gamma(\hat{\omega}_t^i)) R_{K,t}^i Q_{t-1}^i K_{t-1}^i + T_E^i = Y_t^i + R_{f,t-1} B_{t-1}^i + Q_t^i K_t^i - \phi_B (B_t^i - \bar{B})^2 + \mu G(\hat{\omega}_t^i) R_{K,t}^i Q_{t-1}^i K_{t-1}^i.$$

Using (19) we substitute for $(1 - \Gamma(\hat{\omega}_t^i)) R_{K,t}^i Q_{t-1}^i K_{t-1}^i$:

$$\begin{aligned} C_t^i + I_{g,t}^i + B_t^i + D_t^i + C_{E,t}^i + \gamma_E (1 - \Gamma(\hat{\omega}_t^i)) R_{K,t}^i Q_{t-1}^i K_{t-1}^i + T_E^i - Q_t^i K_t^i &= \\ = Y_t^i + R_{f,t-1} B_{t-1}^i - \phi_B (B_t^i - \bar{B})^2 - \mu G(\hat{\omega}_t^i) R_{K,t}^i Q_{t-1}^i K_{t-1}^i. \end{aligned}$$

Then, using the expression for entrepreneurs net worth (20), we obtain:

$$C_t^i + I_{g,t}^i + C_{E,t}^i + B_t^i + D_t^i + (N_t^i - Q_t^i K_t^i) = Y_t^i + R_{f,t-1} B_{t-1}^i - \mu G(\hat{\omega}_t^i) R_{K,t}^i Q_{t-1}^i K_{t-1}^i - \phi_B (B_t^i - \bar{B})^2.$$

Using the entrepreneurs' balance sheet (31) and the domestic credit market clearing condition we obtain how country 1 employs the numeraire goods:

$$Y_t^i + R_{f,t-1} B_{t-1}^i = C_t^i + I_{g,t}^i + C_{E,t}^i + B_t^i + \mu G(\hat{\omega}_t^i) R_{K,t}^i Q_{t-1}^i K_{t-1}^i + \phi_B (B_t^i - \bar{B})^2.$$

Tables and figures

Table 1: Aggregate Volatility and Net Foreign Assets (NFA)

Dependent variable: NFA (% of GDP)			
	(1)	(2)	(3)
Volatility of GDP growth (5 yrs window)	10.1*** (3.0)		
Volatility of GDP growth (10 yrs window)		14.6*** (3.7)	
Volatility of GDP growth (15 yrs window)			19.7*** (4.6)
Number of observations	760	660	560
Adj. R^2	0.74	0.81	0.89

In parentheses, robust standard errors clustered at the country level.

All regressions include country and time fixed effects. *p-value<0.10, **p-value<0.05, ***p-value<0.01

See Appendix for data sources and countries.

Table 2. Aggregate Volatility and Investment

Dependent variable: Growth of real investment (%)			
	(1)	(2)	(3)
Volatility of GDP growth (5 yrs window)	-0.24** (0.1)		
Volatility of GDP growth (10 yrs window)		-0.31*** (0.1)	
Volatility of GDP growth (15 yrs window)			-0.31** (0.13)
Number of observations	3200	2800	2400
Adj. R^2	0.42	0.5	0.6

In parentheses, robust standard errors clustered at the country level.

All regressions include country and time fixed effects. *p-value<0.10, **p-value<0.05, ***p-value<0.01

See Appendix for data sources and countries.

Table 3. Aggregate Volatility and GDP

Dependent variable: Growth of real GDP (%)			
	(1)	(2)	(3)
Volatility of GDP growth (5 yrs window)	-0.1*		
	(0.1)		
Volatility of GDP growth (10 yrs window)		-0.2***	
		(0.1)	
Volatility of GDP growth (15 yrs window)			-0.2***
			(0.1)
Number of observations	3200	2800	2400
Adj. R^2	0.65	0.75	0.83

In parentheses, robust standard errors clustered at the country level.

All regressions include country and time fixed effects. *p-value<0.10, **p-value<0.05, ***p-value<0.01

See Appendix for data sources and countries.

Table 4. Aggregate Volatility and Spreads

Dependent variable: Spread between Domestic and German bonds			
	(1)	(2)	(3)
Volatility of GDP growth (5 yrs window)	2.1**		
	(1.0)		
Volatility of GDP growth (10 yrs window)		2.0**	
		(0.9)	
Volatility of GDP growth (15 yrs window)			1.7**
			(0.8)
Number of observations	2854	2547	2227
Adj. R^2	0.66	0.72	0.79

In parentheses, robust standard errors clustered at the country level.

All regressions include country and time fixed effects. *p-value<0.10, **p-value<0.05, ***p-value<0.01

See Appendix for data sources and countries.

Table 5. Aggregate Volatility and Total Credit to the Private Non-Financial Sector

Dependent variable: Total credit (% of GDP, QoQ change)			
	(1)	(2)	(3)
Volatility of GDP growth (5 yrs window)	-0.23** (0.11)		
Volatility of GDP growth (10 yrs window)		-0.33** (0.13)	
Volatility of GDP growth (15 yrs window)			-0.45*** (0.16)
Number of observations	3176	2796	2400
Adj. R^2	0.29	0.34	0.41

In parentheses, robust standard errors clustered at the country level.

All regressions include country and time fixed effects. *p-value<0.10, **p-value<0.05, ***p-value<0.01

See Appendix for data sources and countries.

Table 6. Aggregate Volatility and Bank Credit to the Private Non-Financial Sector

Dependent variable: Bank credit (% of GDP, QoQ change)			
	(1)	(2)	(3)
Volatility of GDP growth (5 yrs window)	-0.19*		
	(0.1)		
Volatility of GDP growth (10 yrs window)		-0.28**	
		(0.13)	
Volatility of GDP growth (15 yrs window)			-0.36**
			(0.15)
Number of observations	3176	2796	2400
Adj. R^2	0.28	0.35	0.43

In parentheses, robust standard errors clustered at the country level.

All regressions include country and time fixed effects. *p-value<0.10, **p-value<0.05, ***p-value<0.01

See Appendix for data sources and countries.

Table 7: Parameters

<i>Description</i>	<i>Parameters</i>	<i>Value</i>
Discount factor	β	0.99
Depreciation rate	δ	0.025
Capital share in production	α	0.36
Investment adjustment cost	ϕ_K	15.5
Bond adjustment cost	ϕ_B	0.0005
Curvature of utility function	γ	2
Frisch elasticity of labor supply	ξ	0.5
Parameter of labor in utility function	θ	16.4
Bankruptcy cost	μ	0.63
Survival rate of entrepreneurs	γ_E	0.95
Transfers to entrepreneurs	T_E	0.005
Std. dev. of entrepreneurs productivity	σ_ω	0.25
Persistence of TFP	ρ_A	0.9999
Persistence of volatility shock	ρ_V	0.9999
Std. dev. of TFP level	σ_ε	0.01
Std. dev. of volatility shocks	σ_η	0.048
Correlation of TFP shocks	ϑ	0.4

Subsection 5.1 discusses the calibration.

Table 8. Simulations

	IRBC with credit channel	IRBC	Data (5yrs. windows)
<i>Regression coefficients</i>			
NFA	13.9	2.3	10.1
Output	-0.03	0.01	-0.1
Investment	-0.09	0.03	-0.24
Spread	0.99		2.1
Credit	-0.05		-0.23

All regressions include country and time fixed effects. The data coefficients come from Tables 1 to 5.

The model-implied regression coefficients are based on country 1 simulated data.

See Subsection 5.3 for details.

Table 9: Business Cycle Statistics

	IRBC with credit channel	IRBC	Data
<i>Std. dev. relative to output</i>			
Investment	2.95	2.95	2.95
Consumption	0.90	0.96	0.93
Net Exports/Output	0.64	0.57	0.55
<i>Autocorrelation (lag 1)</i>			
Output	0.73	0.73	0.75
Investment	0.62	0.67	0.77
Consumption	0.77	0.72	0.73
Net Exports/Output	0.59	0.66	0.60
<i>Correlation with output</i>			
Investment	0.82	0.85	0.68
Consumption	0.95	0.99	0.73
Net Exports/Output	-0.49	-0.62	-0.21

All statistics are based on Hodrick-Prescott filtered data.

See Subsection 5.3 for details.

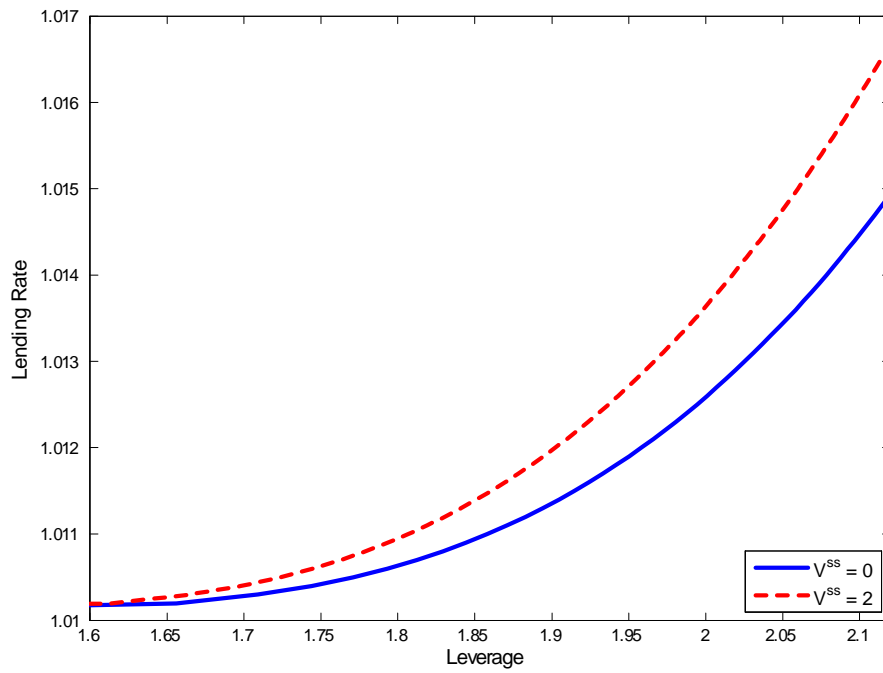


Figure 1. Volatility and Credit Supply. This figure plots the leverage ratio that satisfies the lenders' participation constraint for different values of gross lending rate. One curve is when the volatility parameter V^{ss} is zero, the other curve is the case when it is 2.

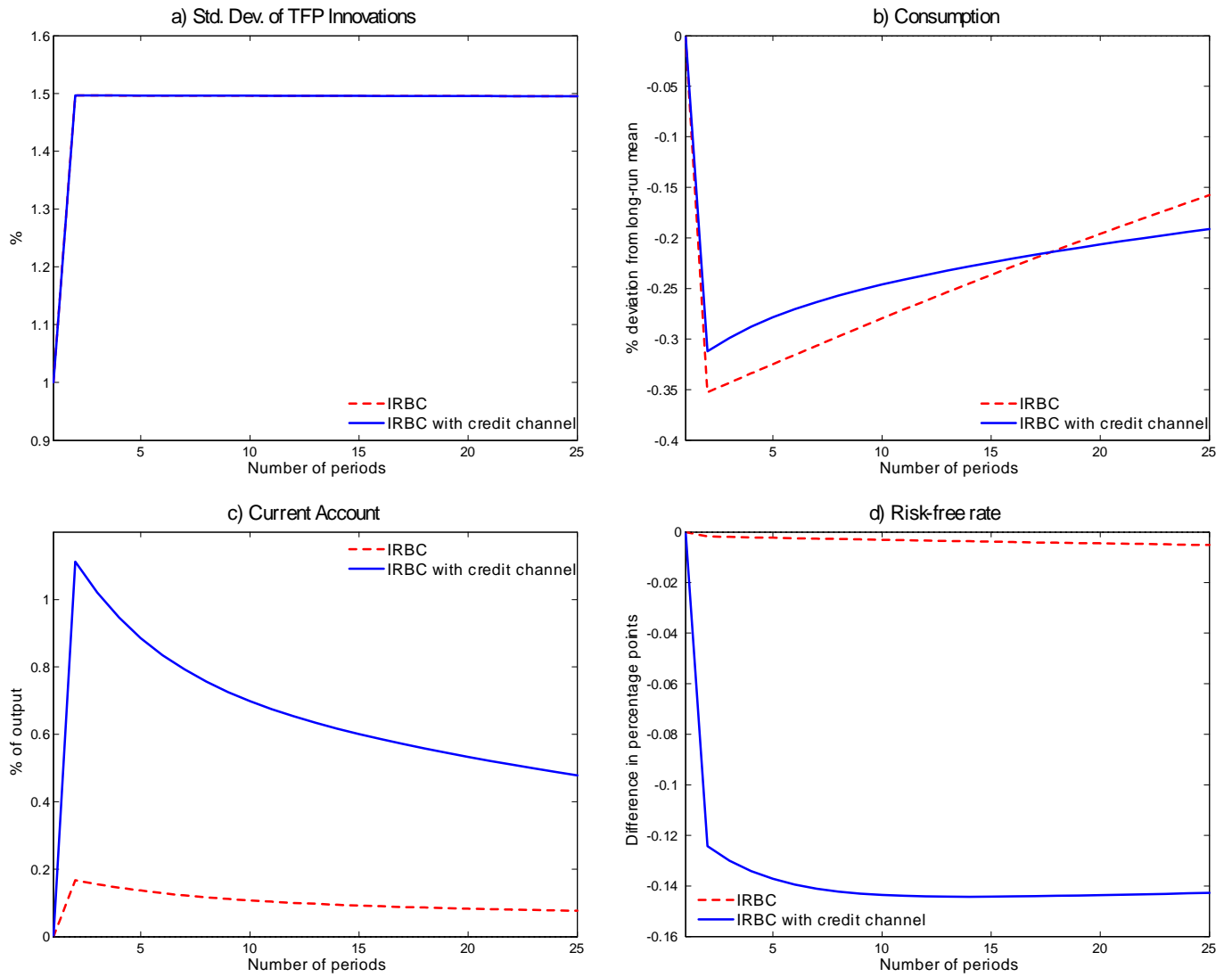


Figure 2. Response to a volatility shock in country 1. This figure compares the responses to a volatility shock in country 1 in the standard IRBC model and in the model augmented with a credit channel.

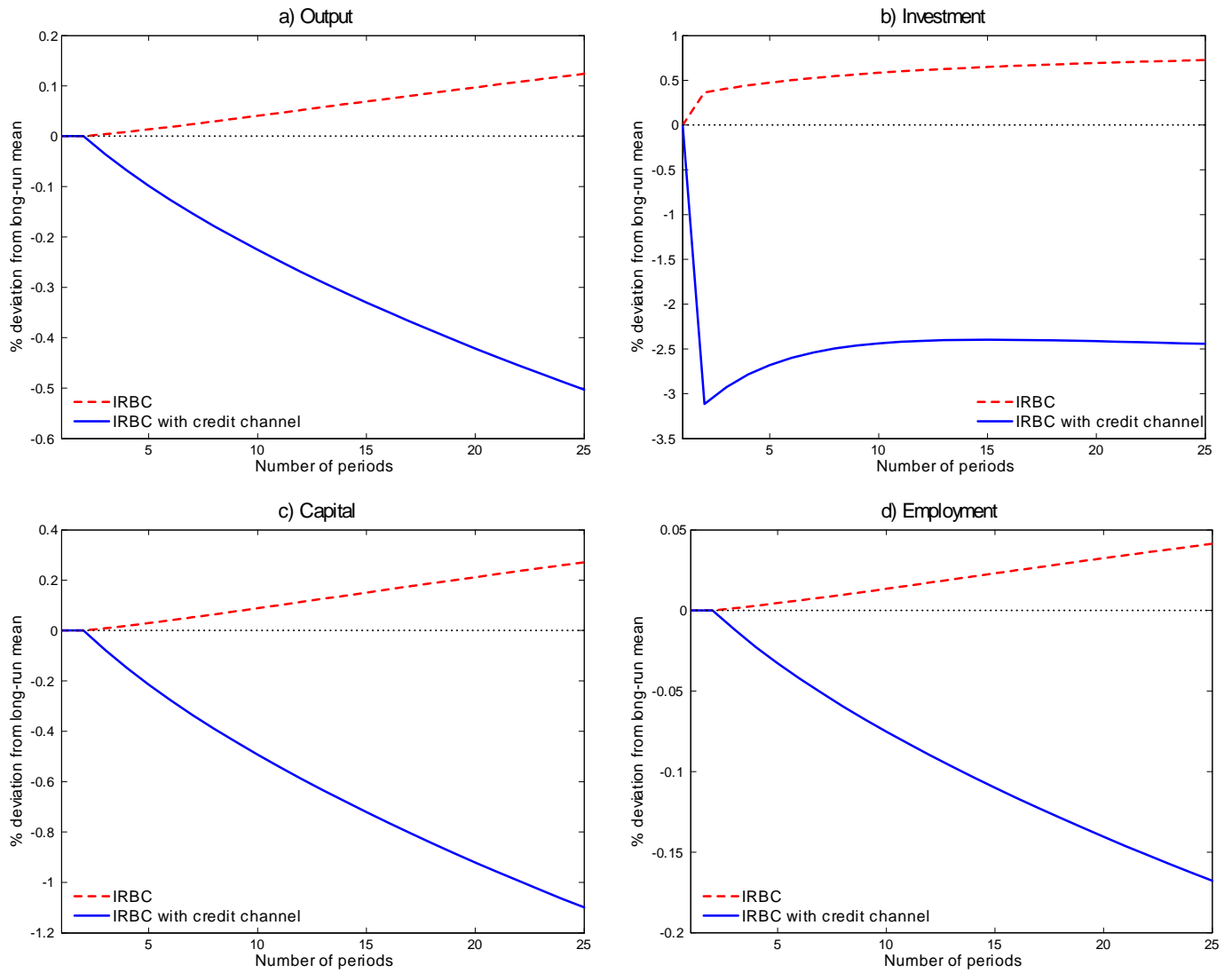


Figure 3. Response to a volatility shock in country 1. This figure compares the responses to a volatility shock in country 1 in the standard IRBC model and in the model augmented with a credit channel.

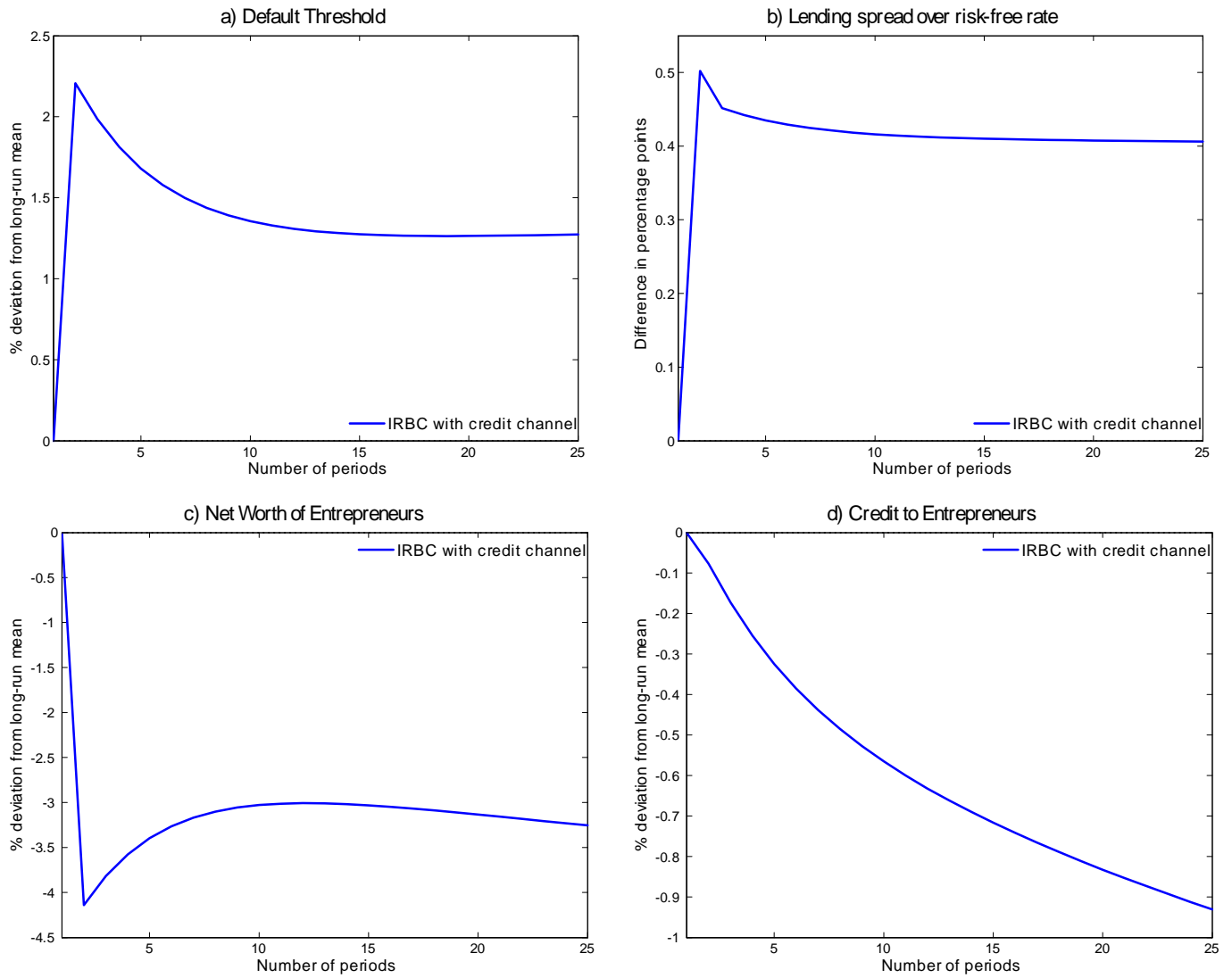


Figure 4. Response to a volatility shock in country 1. This figure analyzes the responses to a volatility shock in country 1 in the model augmented with a credit channel.