Aggregate Volatility and International Dynamics. The Role of Credit Supply

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This Draft: December 2017

Abstract

Changes in country-specific aggregate volatility are positively correlated with the current account but 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 and lowers investment and output. The current account turns to a surplus because savings increase, but also because investment collapses.

Keywords: Credit Supply; Current Account; Uncertainty; Trade Balance; Precautionary Savings.

JEL Classification: D81; F32; G21.

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1   Introduction

There is increasing evidence that time-varying uncertainty is important for macroeconomic dynamics (see Bloom 2014 for a survey). A new literature studies the international dimensions of uncertainty. For example, Fogli and Perri (2015) and Hoffmann, Krause and Tillmann (2016) document that uncertainty and current account dynamics are positively correlated across countries. 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 1970q1–2014q4 to document four other international facts: when aggregate uncertainty increases in a country, then investment, credit flows and output fall, while the credit spread increases. 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.[1]

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 consistent with the data as higher uncertainty induces an investment collapse and a surge of savings. In the IRBC the counterfactual investment boom pushes the current account towards a deficit.

We study a two-country, incomplete markets IRBC model extended with a costly state verification friction à la Bernanke, Gertler and Gilchrist (1999, BGG) between domestic entrepreneurs and domestic lenders. Households deposit with banks that lend to a continuum of entrepreneurs, who use the funds to buy capital that they then rent to the firms. However, a crucial difference from BGG is that in our model lenders are exposed to both aggregate and idiosyncratic credit risk. That is, the lenders' return is not risk-free. If lenders' return does not vary with the aggregate state of the economy as in BGG, then the model with financial accelerator generates the same counterfactual predictions as the IRBC model.[2]

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[1] Cho, Cooley and Kim, (2015) and Lester, Pries and Sims (2014) analyze how higher uncertainty leads to higher investment in the standard real business cycle model with variable productive inputs.

[2] In the BGG framework, borrowers (entrepreneurs) bear the aggregate risk of the financial contract. Lenders obtain a riskless rate of return. Thus, since depositing with lenders is a risk-free investment, higher aggregate uncertainty makes households more willing to supply loanable funds due to a "flight-to-safety" mechanism. As a consequence, in the BGG framework, higher aggregate uncertainty leads to an expansion of credit supply.

Our mechanism works as follows: higher aggregate uncertainty increases the probability of 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.[3] Moreover, when banks' credit risk increases, the risk of losses on bank deposits also becomes higher and households, who would like to avoid the riskier deposits, require a higher risk premium to finance the banks. 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 and the trade balance react strongly and move towards surpluses since the precautionary savings channel is accompanied by an investment collapse.

Quantitative simulations of the model show that the credit 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 model with a credit channel is supported by the cross-country evidence on credit flows and spreads that we show in Section 3. That is, more volatile countries see a reduction in credit towards the private non-financial sector and an increase in credit spreads.

The credit channel that we analyze in the benchmark economy is mitigated when we study global instead of domestic banks. The reason is that with diversified global banks higher volatility in one country does not alter the ability of the global bank to raise funds. Although, higher uncertainty still contracts credit supply because it increases the likelihood of default and debt contracts imply concave payoffs for the lender. In this regard, the model shows that the retreat of banking globalization after the 2008 financial crisis (Forbes, Reinhart and Wieladek 2017) may amplify the negative effects of higher uncertainty.

The rest of the paper is organized as follows. Section 2 discusses the related literature. Section 3 documents the facts. Section 4 presents the model. Section 5 explains how volatility affects credit supply. Section 6 has the core quantitative exercise. Section 7 studies the case when banks are global instead of domestic. Section 8 compares with the time-varying volatility of interest rates studied by Fernandez-Villaverde et al. (2011). Section 9 concludes. The appendix documents the data sources. An online appendix contains the algebra and the robustness exercises.

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[3]In a debt contract, banks' payoff from holding risky loans is a concave function of the borrowers' stochastic income. Thus, a mean-preserving spread (i.e. higher uncertainty) to the borrowers' income reduces lenders' expected return through Jensen's inequality effect.

2 Related Literature

Our paper contributes to the literature studying uncertainty in open economies, and to the literature studying uncertainty and credit markets. Since these are large areas here we only review the more related papers.

Fogli and Perri (2015) and Hoffmann, Krause and Tillmann (2016) document that countries which become more volatile have current account surpluses. Both papers use models driven by precautionary savings motives. Clarida (1990) and Chang, Kim and Lee (2013) also study the role of precautionary savings in accounting for current account dynamics.

Our paper complements the previous papers in both the empirical and the theoretical dimensions. On the empirical side, we confirm the link between volatility and current account dynamics and expand it to other key macro variables: investment, output and credit variables.[4] We show that the precautionary savings channel alone can account for the correlation between volatility and current account dynamics. However, the precautionary savings channel generates counterfactual predictions concerning the effects of volatility on investment and output. We show how to extend the IRBC model with a credit sector to be consistent with all the empirical correlations. Our model gets the current account dynamics right by getting right both the savings and the investment dynamics. To the best of our knowledge this is the first paper to show this result.

Carrière-Swallow and Cespedes (2013) estimate vector auto-regressions and show that there is substantial heterogeneity in the reaction to uncertainty shocks across countries. They find that in comparison to the U.S. and other developed countries, emerging economies suffer more severe falls in investment and private consumption. Their evidence suggests that differences in credit market depth across countries explain the cross-country heterogeneity. Our theoretical framework rationalizes these facts by showing that financial intermediation and credit market frictions are key for the transmission of uncertainty into investment.

In cross-sectional regression analysis on long-run averages, Hoffmann, Krause and Tillmann (2016) find that investment reacts by less than consumption to long-run volatility of GDP growth. Our results, although focused on the short-run effects of uncertainty shocks on real economic activity, provide further evidence that changes in aggregate uncertainty have strong effects on investment.

Fernandez-Villaverde et al. (2011) show that changes in the volatility of international in-

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[4]We measure uncertainty as the realized stock market returns volatility, which is a standard measure in the literature as discussed in the next section.

terest rates have significant negative effects on small open economies. We complement this paper because we show that shocks to interest rate volatility are isomorphic to shocks to domestic TFP growth volatility. This result suggests that domestic macroeconomic factors, such as uncertainty about productivity shocks or default risk, can cause the time-varying volatility of interest rates.

To our knowledge, we are the first to document the cross-country patterns of uncertainty and credit variables with an international focus. Several recent papers have looked at U.S. data. For example, Gilchrist, Sim and Zakrajsek (2014) document that in the U.S. fluctuations in idiosyncratic uncertainty across-firms (measured from high-frequency stock market data) affect credit spreads. Baum, Caglayan and Ozkan (2009) and Bordo, Duca and Koch (2016), using U.S. bank data, show that aggregate uncertainty is a driver of credit supply. Caldara et al. (2016) show that identified uncertainty shocks have a significant negative effect on real economic activity, and that the effect is larger when these shocks are being accompanied by tightening of financial conditions.

The literature that analyzes credit frictions and volatility fluctuations has focused on closed economies and shocks to the cross-sectional dispersion of firms' productivity. This literature includes, among others, Arellano, Bai and Kehoe (2016), Christiano, Motto and Rostagno (2014), Chugh (2016), Gilchrist, Sim and Zakrajsek (2014), Pesaran and Xu (2016) and Straub and Ulbricht (2015). In this paper we show that aggregate uncertainty shocks with lenders exposed to those shocks generate similar transmission channels.[5] Given the substantial evidence on aggregate uncertainty discussed above there is value in expanding the credit channel to aggregate shocks, which requires to depart from the BGG framework as we show in this paper.

3   Facts

In this section we document that, in OECD countries, larger macroeconomic uncertainty leads to a positive trade balance, lower investment, output and credit growth, and larger credit spreads.[6] We measure uncertainty as the realized volatility of stock market returns, which is the standard measure in the literature (see for example, Bloom 2009, Baker and Bloom 2013, Cesa-Bianchi, Pasaran and Rebucci 2016 or Gilchrist, Sim and Zakrajsek 2014, among others).

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[5]Basu and Bundick (2017) and Born and Pfeifer (2014) show that nominal rigidities can help RBC models produce data-consistent comovement between uncertainty and macro aggregates through countercyclical mark-ups.

[6]Following the IRBC literature, we focus on the trade balance as a measure of a country's external position. However, all the results of the paper hold for the current account. In our panel of OECD countries, the average correlation between the two series is 0.84.

This measure has significant variation at the quarterly frequency and can be compared across OECD countries because these economies have developed stock markets with high frequency data.[7,8] We focus on the *relative* volatility of stock market returns, $\Omega_{i,t}^R$. That is, $\Omega_{i,t}^R$ is the domestic volatility $\Omega_{i,t}$ minus the average volatility $\overline{\Omega}_{-i,t}$ in all other countries in our sample, excluding country i.[9]

Formally, volatility $\Omega_{i,t}$ in quarter t for country i, is the quarterly standard deviation of daily stock market returns,

$$\Omega_{i,t} = 100\sqrt{\frac{1}{d_t}\sum_{d=1}^{d_t}\left(u_{i,t}^d - \overline{u}_{i,t}\right)^2}, \tag{1}$$

where $u_{i,t}^d$ is the daily stock market return, d_t denotes the number of trading days in the quarter, and $\overline{u}_{i,t}$ is the average daily return in quarter t,

$$\overline{u}_{i,t} = \frac{1}{d_t}\sum_{d=1}^{d_t}u_{i,t}^d. \tag{2}$$

The relative volatility $\Omega_{i,t}^R$ in time t for country i is

$$\Omega_{i,t}^R = \Omega_{i,t} - \overline{\Omega}_{-i,t}, \tag{3}$$

where

$$\overline{\Omega}_{-i,t} \equiv \frac{1}{n-1}\sum_{j\neq i}\Omega_{j,t}, \tag{4}$$

and n is the number of countries.

Table 1 and Figure 1 show plain-vanilla country-specific pairwise correlations between relative volatility and the trade balance-to-GDP ratio, real quarterly growth rates of output, investment and bank credit, and credit spread.[10] Aggregate uncertainty positively correlates

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[7]Ex-ante uncertainty measures like the VIX index are not available for most countries in our sample. Figure A1 in the online appendix shows that for the U.S. the volatility of stock market returns is highly correlated with the VIX index and with the measure of uncertainty constructed by Ludvigson, Ma and Ng (2017). The correlation coefficients are 0.93 and 0.75 respectively.

[8]Figure A2 in the online appendix shows that the volatility of stock market returns is strongly correlated with TFP growth volatility. Thus, one can interpret the volatility shocks as capturing changes in uncertainty about economic policy (fiscal, trade, or financial policies), or broadly about future economic conditions.

[9]Cesa-Bianchi, Pasaran and Rebucci (2016) find that there is a global common factor driving some of the variation in domestic country volatilities. The relative volatiliy takes out that global common factor to obtain a country-specific domestic volatility. Table A3 in the online appendix confirms that our facts are robust to using the absolute volatility measure $\Omega_{i,t}$.

[10]Credit spreads are defined as the difference between the domestic corporate lending rate and long-term U.S.

with the trade balance-to-output ratio and with credit spreads. There is a negative correlation of uncertainty with growth rates of output, investment and bank credit. Figure 2 confirms these associations with scatter plots on the entire sample. Each dot groups quarterly observations of volatility and each variable of interest between 1970q1 and 2014q4. For ease of appearance the scatterplots are binned following Jorda, Schularick and Taylor (2016).

Table 2 contains a regressions analysis that we interpret as correlations since we lack an identification mechanism to think on causality.[11] Country and time fixed effects control for country-specific time-invariant characteristics and events common across countries that could drive the correlations. Panel B adds controls for macro variables that proxy for the stance of government policies. We include government consumption growth, CPI inflation, changes in exchange rates, trade openness (measured as imports plus exports to GDP), the Chinn-Ito index of financial openness, and the level of stock market returns. The rationale for including these controls is that government policies could drive macroeconomic volatility and the outcome variables.

The results are robust across panels of Table 2. An increase in relative aggregate volatility is associated with an increase in the trade balance-to-output ratio and credit spreads, with a decrease in output, in investment and in credit growth. As the online appendix shows, we obtain similar results if we use the country's absolute volatility, or alternative measures of a country's external balance, credit supply and interest spreads like, for example, the current account, total credit to the private non-financial sector, and government bond spreads.

The online appendix redoes Table 2 using multi-year rolling windows standard deviation of quarterly GDP growth as the measure of uncertainty. This is the measure of uncertainty used by Fogli and Perri (2015), although it is not common in the literature. The results are broadly consistent with those discussed above. However, this measure has several drawbacks that lead us to prefer stock market volatility. For example, rolling windows volatility has a strong time-varying trend component and does not fluctuate much at quarterly frequency. In addition, Figures A1 and A3 show that rolling windows volatility measure spikes at different dates than the popular indices of uncertainty of Bloom (2014) and Ludvigson, Ma and Ng (2017).

The online appendix contains additional robustness tests. For example, Table A2 shows that the stylized fact on the association between volatility and credit spreads is robust to controlling for exchange rate risk. First, we control for expected exchange rate dynamics and

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government bond yields.

[11]All variables are quarterly, non-filtered and stationary. The appendix describes the dataset. It is an unbalanced panel that uses the maximum available data.

volatility using 1-year forward exchange rates and daily exchange rate changes like Gadanecz, Miyajima and Shu (2014). Second, we use a sample without exchange rate risk by focusing on EU countries starting from 1999q1, the period when the Euro was introduced. We obtain similar results as in the benchmark regressions.

To sum up, the data suggest that countries with larger macroeconomic volatility run trade surpluses, have less investment and output, with credit being more expensive and less available. As we will show next, an IRBC model without a credit sector can generate the positive correlation between volatility and the trade balance, but it fails with the other correlations. Adding credit supply with lenders exposed to aggregate volatility can reconciliate the model with the data. Moreover, this new theory is consistent with the evidence on credit spreads and volume discussed above.

4   Model

We study a two-country model with domestic credit markets subject to costly state verification frictions. The key ingredient is that lenders are exposed to aggregate credit risk. Each country is inhabited by households, entrepreneurs, banks, and firms producing goods and capital. The two countries trade consumption goods and risk-free bonds.

4.1   Households and Banks

In each country $(i = 1, 2)$ there is a continuum of homogeneous households who maximize expected utility over consumption $(C_{i,t})$ and hours worked $(H_{i,t})$. Households can invest in risky domestic deposits $(D_{i,t})$, and in riskless international bonds $(B_{i,t})$. The representative household of country i maximizes

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U\left(C_{i,t}, H_{i,t}\right), \tag{5}$$

subject to a sequence of budget constraints,

$$C_{i,t} + B_{i,t} + D_{i,t} = W_{i,t} H_{i,t} + R_{t-1}^f B_{i,t-1} + R_{i,t}^D D_{i,t-1} - \frac{\phi_B}{2} Z_{i,t} \left(\frac{B_{i,t}}{Z_{i,t}} - \widehat{B}\right)^2 + \Pi_{i,t} + \Pi_{i,t}^c - Z_{i,t} T^E, \tag{6}$$

where $W_{i,t}$ is the wage in country i, $\Pi_{i,t}$ and $\Pi_{i,t}^c$ are the profits of the producers of goods and capital respectively and R_{t-1}^f is the gross return on last period holdings of the international

bond. $Z_{i,t}T^E$ are lump-sum transfers to domestic entrepreneurs to ensure that entrepreneurs' equity is never zero.[12] Like in Rabanal, Rubio-Ramirez and Tuesta (2011), we impose small adjustment costs (ϕ_B) on international bond holdings that depend on the trending variable $Z_{i,t}$ to ensure a balanced growth path. Also for the same reason, the transfers are scaled up by $Z_{i,t}$.

In each country there is a continuum of perfectly competitive banks who collect deposits from the domestic households and lend these funds to the entrepreneurs. Banks are 100% deposit financed and make zero profits. Thus, the return on loans equals the return on deposits. The gross return on bank deposits of country i $\left(R_{i,t}^D\right)$ is risky because banks may suffer credit losses and be unable to repay their borrowings. Therefore, households of country i are exposed to the credit risk of their financial system.

The previous assumption is consistent with the recent experiences of Iceland, Ireland, Portugal and Spain during the 2008 financial crisis. These countries had deposit insurance systems in place, but when their 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.[13] 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 will discuss later.

Denoting by U_H and U_C the marginal utility of leisure and consumption, the households' optimality conditions are:

$$\frac{-U_H\left(C_{i,t}, H_{i,t}\right)}{U_C\left(C_{i,t}, H_{i,t}\right)} = W_{i,t}, \tag{7}$$

$$R_t^f \mathbb{E}_t\left[M_{i,t+1}\right] = 1 + \phi_B\left(\frac{B_{i,t}}{Z_{i,t}} - \widehat{B}\right), \tag{8}$$

and

$$\mathbb{E}_t\left[M_{i,t+1}R_{i,t+1}^D\right] = 1, \tag{9}$$

where

$$M_{i,t+1} \equiv \beta\frac{U_C\left(C_{i,t+1}, H_{i,t+1}\right)}{U_C\left(C_{i,t}, H_{i,t}\right)} \tag{10}$$

is the household's stochastic discount factor.

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[12]All results hold if we use alternative mechanisms, like giving labor income to the entrepreneurs.

[13]Moreover, 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 partial default on depositors.

4.2 Entrepreneurs and Financial Contract

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

$$Q_{i,t}K_{i,j,t} = N_{i,j,t} + L_{i,j,t}. \tag{11}$$

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

$$R_{i,t+1}^K = \frac{r_{i,t+1} + Q_{i,t+1}(1-\delta)}{Q_{i,t}}. \tag{12}$$

The idiosyncratic productivity shocks ω_j are not observable when borrowing happens and ex-post create profitable and unprofitable entrepreneurs. These shocks are i.i.d. across both entrepreneurs and time. In both countries, the shocks are drawn from a log-normal distribution with a cumulative density function $F(\omega)$ with mean one and standard deviation σ_ω.

At time t, the financial contract between a bank and an entrepreneur j specifies a loan amount, $L_{i,j,t}$, and a default threshold for next period $\overline{\omega}_{i,j,t+1}$ such that if the entrepreneur has idiosyncratic productivity below $\overline{\omega}_{i,j,t+1}$, then the entrepreneur defaults and her assets are seized by the bank. Default costs are a share μ of the entrepreneur's assets and paid by the bank. The state-contingent interest rate $R_{i,j,t+1}^L$ is implicitly defined as

$$R_{i,j,t+1}^L L_{i,j,t} = \overline{\omega}_{i,j,t+1} R_{i,t+1}^K Q_{i,t} K_{i,j,t}. \tag{13}$$

The lender's return on deposits is the revenue from those entrepreneurs who repay plus the value of the assets seized from the entrepreneurs who default,

$$R_{i,t}^D L_{i,j,t-1} = \int_{\overline{\omega}_{i,j,t}}^{\infty} R_{i,j,t}^L L_{i,j,t-1} dF(\omega) + \int_0^{\overline{\omega}_{i,j,t}} (1-\mu)\omega R_{i,t}^K Q_{i,t-1} K_{i,j,t-1} dF(\omega). \tag{14}$$

To avoid self-financing, entrepreneurs die at the end of each period with an exogenous

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probability $(1 - \chi)$ and consume their equity, which evolves as

$$N_{i,j,t+1} = \int_{\overline{\omega}_{i,j,t+1}}^{\infty} \left[\omega R_{i,t+1}^{K} Q_{i,t} K_{i,j,t} - R_{i,j,t+1}^{L} L_{i,j,t} \right] dF(\omega). \tag{15}$$

Carlstrom, Fuerst and Paustian (2016) show that with forward looking entrepreneurs the optimal contract maximizes expected discounted terminal equity

$$V_{i,j,t} = (1 - \chi) \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\chi)^s N_{i,j,t+s}, \tag{16}$$

subject to the lenders' participation constraint, which is the household's Euler equation (9) with the return on deposits defined in (14).[14]

Because of constant returns to scale and risk neutrality, the financial contract is linear in entrepreneur's equity.[15] This implies that all entrepreneurs have the same default threshold $\left(\overline{\omega}_{i,j,t+1} = \overline{\omega}_{i,t+1} \right)$, lending rate $\left(R_{i,j,t+1}^{L} = R_{i,t+1}^{L} \right)$ and leverage ratio

$$\kappa_{i,j,t} \equiv \frac{Q_{i,t} K_{i,j,t}}{N_{i,j,t}} = \kappa_{i,t}. \tag{17}$$

Thus, we can drop the entrepreneur's j notation as only the country's aggregate variables matter, not the distribution inside the country.

It is convenient to follow BGG and define the function $\Gamma(\overline{\omega}_{i,t+1})$ to denote the next period's expected gross share of outcome going to the bank,

$$\Gamma(\overline{\omega}_{i,t+1}) \equiv \int_0^{\overline{\omega}_{i,t+1}} \omega dF(\omega) + \overline{\omega}_{i,t+1} \int_{\overline{\omega}_{i,t+1}}^{\infty} dF(\omega), \tag{18}$$

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

$$G(\overline{\omega}_{i,t+1}) \equiv \int_0^{\overline{\omega}_{i,t+1}} \omega dF(\omega). \tag{19}$$

Combining the previous definitions with household's Euler equation (9) and with (14) we obtain lenders' participation constraint,

$$\mathbb{E}_t \left[M_{i,t+1} \kappa_{i,t} R_{i,t+1}^{K} \left[\Gamma\left(\overline{\omega}_{i,t+1}\right) - \mu G\left(\overline{\omega}_{i,t+1}\right) \right] \right] = \kappa_{i,t} - 1, \tag{20}$$

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[14] All the results of the paper hold when entrepreneurs are one period myopic like in BGG.

[15] The online appendix has the detailed derivation of all the results in this section.

which is the credit supply equation. Equation (20) includes households' stochastic discount factor $(M_{i,t+1})$ as banks' ability to raise funds depends on households' willingness to provide them at the risky deposit rate. Thus, (20) captures lenders' exposure to aggregate risk.

4.3 Capital Producers

Capital is non-tradable across countries. In each country there is a representative capital producer owned by the domestic households. It buys goods $(I_{i,t})$ from the firms, and the undepreciated capital $(1-\delta)K_{i,t-1}$ from the entrepreneurs, to produce new net capital investment $I_{i,t}^n$ according to

$$I_{i,t}^n = \left[1 - \frac{\phi_I}{2}\left(\frac{I_{i,t}}{I_{i,t-1}} - g\right)^2\right]I_{i,t}, \tag{21}$$

where $I_{i,t}$ is gross investment. The parameter ϕ_I controls the capital adjustment cost that ensures that the price of capital varies endogenously, affecting entrepreneurs' equity. The parameter g is the growth rate along the balanced-growth path.

The law of motion of the capital stock is

$$K_{i,t} = (1-\delta)K_{i,t-1} + I_{i,t}^n. \tag{22}$$

The capital producer sells the capital to the entrepreneurs at price $Q_{i,t}$ making profits:

$$\Pi_{i,t}^c = Q_{i,t}I_{i,t}^n - I_{i,t}. \tag{23}$$

The capital producer chooses investment to maximize the present discounted value of its profits

$$\max_{I_{i,t}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U_C(C_{i,t}, H_{i,t})\Pi_{i,t}^c, \tag{24}$$

subject to (21).

4.4 Consumption Goods Producers

Firms producing consumption goods $(Y_{i,t})$ use labor $(H_{i,t})$ and capital $(K_{i,t-1})$ according to the production function

$$Y_{i,t} = K_{i,t-1}^\alpha \left(Z_{i,t}H_{i,t}\right)^{1-\alpha}, \tag{25}$$

where $Z_{i,t}$ is a non-stationary TFP shock cointegrated across-countries that we define below.

Consumption goods producers hire labor and rent capital to maximize profits[16]

$$\Pi_{i,t} = Y_{i,t} - W_{i,t}H_{i,t} - r_{i,t}K_{i,t-1}.\tag{26}$$

4.5 Market Clearing

International bonds are in zero net supply across countries,

$$B_{1,t} + B_{2,t} = 0.\tag{27}$$

In each country, households' supply of deposits equals entrepreneurs' borrowings,

$$D_{i,t} = L_{i,t}.\tag{28}$$

From the balance sheet of the entrepreneurs (11), the value of the capital stock of country i equals the sum of debt and equity of the entrepreneurs:

$$Q_{i,t}K_{i,t} = L_{i,t} + N_{i,t}.\tag{29}$$

The current account is the change in the net foreign asset position,

$$\text{Current Account}_{i,t} = B_{i,t} - B_{i,t-1}.\tag{30}$$

The trade balance is the current account adjusted by the net interest payments:

$$\text{Trade Balance}_{i,t} = B_{i,t} - R_{f,t-1}B_{i,t-1}.\tag{31}$$

4.6 Technology

As it is standard in the two-country RBC literature with non-stationary shocks, we assume that the TFP processes of each country have a common unit root and are cointegrated across countries (see for example Rabanal, Rubio-Ramirez and Tuesta 2011, Mandelman et al. 2013, Ireland 2013 and Kollmann 2016, 2017). That is, we assume the following representation for

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[16]Because of the constant returns to scale production function, these profits are zero in equilibrium.

the law of motion of the first differences of log TFP in each country:

$$\Delta \log (Z_{1,t}) = (1 - \rho_z) \log (g) + \rho_z \Delta \log (Z_{1,t-1}) + \varphi \left[\log (Z_{1,t-1}) - \log (Z_{2,t-1}) \right] + e^{\sigma_{1,t}} \varepsilon_{z,1,t}, \quad (32)$$

$$\Delta \log (Z_{2,t}) = (1 - \rho_z) \log (g) + \rho_z \Delta \log (Z_{2,t-1}) - \varphi \left[\log (Z_{1,t-1}) - \log (Z_{2,t-1}) \right] + e^{\sigma_{2,t}} \varepsilon_{z,2,t}. \quad (33)$$

where Δ is the first-difference operator. $\varepsilon_{z,1,t}$ and $\varepsilon_{z,2,t}$ are Gaussian innovations with mean zero, unit variance, and correlation ϑ_z. The parameter g is the long-run growth rate of productivity, which is the same for both countries. The parameter φ governs the rate of convergence between the two countries. It takes a small negative value such that when the cross-country differential $\frac{Z_{1,t-1}}{Z_{2,t-1}}$ is larger than its long-run value, then $\varphi < 0$ guarantees that $\Delta \log (Z_{1,t})$ will fall and $\Delta \log (Z_{2,t})$ will rise, driving the differential back to its long-run value. That is, no country grows so much in relative terms that at some point it becomes the whole world. Then, $\Delta \log (Z_{i,t})$ and $\frac{Z_{1,t}}{Z_{2,t}}$ are stationary and the detrended model has a well-defined deterministic steady state.

The country-specific volatility shock $\sigma_{i,t}$ follows a stationary AR(1) process,

$$\sigma_{i,t} = (1 - \rho_\sigma)\sigma + \rho_\sigma \sigma_{i,t-1} + \sigma_\sigma \varepsilon_{\sigma,i,t}, \quad (34)$$

where $\varepsilon_{\sigma,i,t}$ are Gaussian innovations with mean zero and unit variance. σ is the long-run mean. Like for TFP shocks, we allow a non-zero cross-country correlation (ϑ_σ) between the volatility shocks.[17] The parameter σ_σ, which is the same across countries, controls the size of the volatility shocks. TFP and volatility shocks are uncorrelated within each country.

5 Volatility and Credit Supply

In this section, to build intuition for the key mechanism of the model, we show how credit supply reacts to changes in uncertainty in a partial equilibrium setting.[18] The next section solves the full general equilibrium model and contains the quantitative results.

Figure 3 plots the credit supply equation (20) for two levels of aggregate uncertainty. That is, Figure 3 plots the rates that lenders require to lend at a given leverage level. To construct Figure 3, first we use (13) to rewrite (20) as

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

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[17]Bekaert, Hodrick, and Zhang (2012) document that volatility is highly correlated across countries.

[18]Throughout this section, we drop country subscripts since it is a partial equilibrium analysis.

Using a third-order approximation to (35) we solve for the leverage ratio κ_t in the stochastic steady-state for different lending rates R_{t+1}^L.[19] We set the stochastic discount factor M_{t+1} at its steady state value and assume, in partial equilibrium, that the return on capital R_t^K follows an AR(1) process with time-varying volatility:

$$R_t^K = (1 - \rho_z) R^K + \rho_z R_{t-1}^K + e^{\sigma_t} \varepsilon_t, \tag{36}$$

where σ_t follows (34). The steady state value of volatility, σ, governs the long-run level of aggregate risk. We compare two values of σ.

Figure 3 shows that higher aggregate volatility (higher σ) contracts credit supply. This effect is due to the structure of debt contracts. Higher volatility of a borrower's income increases the area of default and, since in debt contracts lenders' payoffs are concave in the value of borrower's income, it decreases lenders' expected revenue. Thus, for the same leverage ratio, when aggregate volatility is higher, lenders charge more expensive credit to compensate them for bearing higher default risk.

The effect of uncertainty on credit supply is non-linear in entrepreneurs' leverage ratio. Lending rates react more to increases in aggregate volatility when the entrepreneurs have higher leverage. The reason is that for a given negative shock, default is more likely when leverage is higher.

In the next section we will show that the previous results are stronger in general equilibrium because households are risk-averse and their deposits are exposed to credit risk. That is, when higher aggregate volatility makes bank deposits riskier, households require larger risk premiums to supply bank deposits. The higher cost of raising deposits is a general equilibrium factor pushing lenders to raise their lending rates.

6   The Model with and without Credit Channel

In this section, we compare the model with the credit channel presented in Section 4 and another without it. First, we discuss how we parametrize the model, then the impulse responses and simulation results. We solve the stationary version of the model (that is, all trending variables deflated by their trends along the balanced growth path) using a third-order

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[19]We 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.

approximation.[20]

6.1 Parametrization

We set some parameters exogenously following standard values in the literature. Then we estimate the rest of the parameters with a simulated method of moments (SMM).[21] Table 3 contains the exogenous parameters.

We use GHH preferences to avoid wealth effects on labor supply,

$$U(C_{i,t}, H_{i,t}) = \frac{1}{1-\gamma} \left(C_{i,t} - \eta Z_{i,t} \frac{(H_{i,t})^{1+\frac{1}{\xi}}}{1+\frac{1}{\xi}} \right)^{1-\gamma},$$

where ξ is the elasticity of labor supply and γ controls the curvature of the utility function. We include $Z_{i,t}$ in the labor disutility term to ensure that labor supply remains bounded along the balanced growth path (Aguiar and Gopinath 2007).

We choose the value of η so that the long-run mean of hours worked equals $\frac{1}{3}$. We set a period in the model to be one quarter and pick standard values in the literature for the subjective discount factor β, elasticity of labor supply ξ, depreciation rate δ and capital share in production α. For the long-run TFP growth parameter we use the 2% annual rate ($g = 1.005$), which corresponds to the average long-run output growth rate in our sample. The bond adjustment cost parameter ϕ_B must be a positive number for the model to have a unique steady-state growth path (Boileau 2008). Following Fernandez-Villaverde et al. (2011) we set it to a very small positive number so that it does not affect the model dynamics.[22] Similarly, following Kollmann (2016, 2017), we assign a small negative value to the technology convergence parameter φ to ensure a well-defined balanced-growth path.[23] For the survival rate of entrepreneurs (χ) we set a value (0.97) in the range of the values used in the financial frictions literature. For example, BGG set this parameter at 0.973, Christiano, Motto and Rostagno (2014) at 0.982,

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[20]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 by adding higher order terms to the approximations.

[21]Ruge-Murcia (2012) shows that SMM delivers very accurate estimates when applied to non-linear DSGE models.

[22]Figure A6 of the online appendix shows that model dynamics are not affected when we halve the value of this parameter.

[23]This parameter affects the relative persistence of the TFP shocks: the higher the absolute value of the convergence parameter, the lower is the relative persistence of the domestic TFP shock. Figure A5 in the online appendix illustrates this point. We experimented with different values of φ and found that as long as the model is re-estimated to match our empirical targets (which include the persistence of output growth) the results are unaffected.

and Carlstrom, Fuerst and Paustian (2016) use 0.94.

We estimate the following parameters: 1) γ, the inverse of the elasticity of intertemporal substitution (IES); 2) ϕ_I, the investment adjustment cost parameter; 3) μ, the monitoring cost; 4) σ_ω, the cross-sectional standard deviation of entrepreneur's idiosyncratic productivity; 5) ρ_z, the persistence of the first-difference of (log) TFP; 6) ρ_σ, the persistence of the volatility shock; 7) σ, the steady-state value of the volatility shock; 8) σ_σ, the standard deviation of the volatility shock; 9) ϑ_z, the cross-country correlation of productivity shocks; and 10) ϑ_σ, the cross-country correlation of volatility shocks.

We target the following 10 moments from the data analyzed in Section 3: 1-5) standard deviations of output growth, investment growth, consumption growth, trade balance-to-output ratio, and relative stock market returns volatility; 6-7) persistence of output growth and relative stock market returns volatility; 8) the cross-country correlation of output growth rates; 9) the cross-country correlation of stock market returns volatility;[24] and 10) long-run mean of entrepreneurs' leverage ratio, which comes from Gourio (2013).[25]

To estimate the endogenous parameters we minimize the squared percent deviation between the moments of the model simulations and the actual data.[26] To obtain a model counterpart of the volatility measure, we follow Basu and Bundick (2017) and define the model-implied stock returns volatility, $\Omega_{i,t}^{\mathrm{model}}$, as the conditional standard deviation of the returns on entrepreneurs' equity,

$$\Omega_{i,t}^{\mathrm{model}} = 100\sqrt{\mathbb{E}_t[(R_{i,t+1}^K)^2] - [\mathbb{E}_t(R_{i,t+1}^K)]^2}. \tag{37}$$

As in Section 3, we define the relative volatility measure as domestic volatility minus foreign volatility. In the symmetric two-country world model this implies,

$$\Omega_{1,t}^{R,\,\mathrm{model}} = \Omega_{1,t}^{\mathrm{model}} - \Omega_{2,t}^{\mathrm{model}}. \tag{38}$$

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[24] We measure persistence with the AR(1) coefficient. Standard deviations, persistence coefficients, and international correlations are averages across the countries in our sample.

[25] With high-order perturbations, deterministic steady states of stationary endogenous variables are in general different from their long-run means defined as stochastic steady-states (Juillard and Kamenik 2005).

[26] The algorithm is as follows: let $m_j(\mathbf{X})$ be an empirical moment j computed from the data $\mathbf{X}$. Denote by $m_j(\mathbf{X}^{sim}(\theta))$ the model-implied moment from simulating the model using the parameter vector θ. Starting from the stochastic steady state we simulate the stationary model for 180 periods (length of our dataset) with all the shocks. We simulate the model 20 times saving the results of country 1 to generate a world economy of 20 countries. Then, we compute the moments of interest in exactly the same way as in the actual data. We repeat this procedure 50 times such that the model-implied moment $m_j(\mathbf{X}^{sim}(\theta))$ is the average over 50 repetitions of the 20-country world economy. The estimated parameter vector $\widehat{\theta}$ minimizes the squared percent deviation:
$\widehat{\theta} = \arg\min_\theta \sum_j \left[\frac{m_j(\mathbf{X}^{sim}(\theta)) - m_j(\mathbf{X})}{m_j(\mathbf{X})} \right]^2.$

Table 4 reports the results of the estimation. Table 5 shows the model-implied moments and empirical targets. The model is successful at matching the targets and accurately estimates the parameters. The estimated parameters are within the range of the values used in the RBC and financial frictions literature. For example, the estimated curvature parameter γ implies an IES of about 0.30 that is within the range used in the literature.[27] The estimated values for σ_ω and μ are close to the values used in BGG and to those estimated by Christiano, Motto and Rostagno (2014). The persistence ρ_z and steady-state standard deviation e^σ of the productivity growth are in the range used in the RBC literature (see for example, Aguiar and Gopinath 2007, Ireland 2013, or Cicco, Pancrazi and Uribe 2010). Concerning the volatility shocks, the estimated persistence ρ_σ and standard deviation σ_σ are similar to the values used by Fernandez-Villaverde et al. (2011), Born and Pfeifer (2014), and Kollmann (2016).

6.2   Impulse Responses

Figures 4 and 5 compare impulse responses to an unanticipated one standard deviation aggregate volatility shock in country 1.[28] The solid line is the model with the credit channel presented in Section 4, and the dashed line is the same model but with no financial frictions and no entrepreneurs. That is, the dashed line is basically the IRBC model of Fogli and Perri (2015) but with the volatility shocks in the log first-differences of productivity to avoid Fogli and Perri's transitory TFP shocks with nearly unit roots. Figure 4 focuses on the responses that are similar across the models while Figure 5 highlights the differences.

Figure 4 shows that both the model with and the model without 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 a precautionary savings motive and to a flight-to-quality mechanism. Higher volatility induces prudent households to consume less and save more. Higher demand for the international bonds implies a fall in the risk-free rate.

In both models higher volatility induces a surplus in the trade balance of the volatile country. However, the reaction of the trade balance is larger and more persistent in the model with the credit channel. This is because in both models the surge in domestic savings push towards a

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[27]Ogaki and Reinhart (1998) estimate the IES to be around 0.30. Fernandez-Villaverde et al. (2011) use GHH preferences with the IES of 0.20. Basu and Kimball (2002) find an IES of about 0.50.

[28]The impulse responses display the trending variables as percent deviations from their balanced-growth path. Stationary variables are in percentage point differences from their stochastic steady state values. To compute the stochastic steady-state we simulate the detrended model for many periods with zero innovations of exogenous shocks until the economy converges to a point where all the stationary 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.

surplus. Moreover, with a credit channel, higher volatility induces lower investment, as Panel b in Figure 5 shows. Thus, in the model with a credit channel, both the investment collapse and a surge of savings push the trade balance towards surplus. Without the credit channel, investment increases, pushing the trade balance towards a deficit.

Figure 5 shows that for output and investment, the reaction to a volatility shock has opposite signs 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 3.

Adding the credit channel fixes the comovement problem because it makes investment depend on credit (entrepreneurs need to borrow to finance their capital purchases). Panels c and d of Figure 5 plot the reaction of the domestic credit market. Higher uncertainty increases default risk and triggers the contraction of credit supply discussed in Section 5. 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. Credit to entrepreneurs falls, investment, output and the price of capital collapse, triggering a financial accelerator à la BGG in which lower entrepreneurs' equity makes their cost of external funds even higher. Employment drops as lower capital stock in the next period implies lower returns to the labor supply. Thus, the model with the credit channel is consistent with the comovements reported in Section 3.

6.3 Quantitative Assessment of the Credit Channel

To gauge the quantitative importance of the credit mechanism, we investigate how well the estimated model with the credit channel matches the empirical associations between the trade balance, investment, output growth and volatility documented in Section 3. Since the estimation in Section 6.1 does not use this information, the successful performance of the model will strongly support the plausibility of our mechanism.

We simulate the IRBC model with and without the credit channel, and using the simulated data, we redo Table 2 Panel A following the simulation procedure described in Section 6.1. Table 6 contains the results. The first row displays the regression coefficients reported in Table 2 Panel A for the actual data for OECD countries. The second row has the regression coefficients from the artificial data generated by simulating the model with the credit channel. The last

row reports the results for the model without the credit channel.

Table 6 shows that both versions of the model predict a positive correlation between aggregate volatility and the trade balance-to-output ratio, as in the data. Importantly, the model with the credit mechanism is much closer to the data because in that model the trade balance is driven by both an increase in savings and a collapse of investment when volatility rises.

The second and third columns of Table 6 highlight the problem of the model without a credit channel. It predicts a positive correlation between aggregate volatility and investment and output. However, in the data these correlations are negative. Incorporating the credit channel allows us to generate the correlations found in the data. These results provide strong evidence supporting the credit channel.

Figure A4 in the online appendix shows that incorporating the credit channel does not prevent the model from being consistent with other stylized facts. For example, Hoffmann, Krause and Tillmann (2016) provide evidence that the trade balance-to-GDP ratio is less countercyclical when the volatility of output growth is high. We show that the same fact holds in the model with the credit channel. The mechanism is as follows: a positive TFP shock causes the trade balance to deteriorate, but less when uncertainty is high. Consumption reacts less because of precautionary savings. Investment is less responsive because credit reacts less to good TFP news when uncertainty is high.

7   Global versus Domestic Banks

The analysis so far has assumed that domestic entrepreneurs are financed by domestic lenders. In this section we analyze the implications of allowing foreign financing of the domestic entrepreneurs. To keep the analysis tractable, we consider two different small open economy versions of the model of Section 4. First, we study only domestic lenders as in the credit supply equation (20). Second, we assume that domestic entrepreneurs are financed by a global bank which collects funds from international investors and builds a diversified portfolio of loans across-countries that allow the global bank to diversify the individual country shocks. Thus, with a global bank, the credit supply equation (20) is replaced by

$$\mathbb{E}_t \left[M \kappa_t R_{t+1}^K \left[\Gamma \left(\overline{\omega}_{t+1} \right) - \mu G \left(\overline{\omega}_{t+1} \right) \right] \right] = \kappa_t - 1, \qquad (39)$$

where the global bank's stochastic discount factor M is fixed at its steady state value.[29]

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[29]This is equivalent to a risk-neutrality assumption.

Figure 6 compares the reaction of both versions of the model (domestic banks versus global bank) to the same uncertainty shock analyzed in Section 6.2. Qualitatively both models display the same dynamics, although the global bank significantly mitigates the effects of volatility shocks. Since the global bank has a diversified portfolio, higher volatility in one country does not alter the ability of the global bank to raise funds. That is, credit supply contracts only because of the mechanism of Section 5 without the amplification generated by households' aversion to the higher risk of their deposits.

Thus, global banks mitigate the contraction of credit supply and the fall in investment and output, associated with higher volatility. This result is relevant for policymakers. Banking globalization has been in retreat since the 2008 financial crisis (Forbes, Reinhart and Wieladek 2017), while, in many countries, aggregate volatility has increased since that crisis (Baker, Bloom and Davis 2016). Our model suggests that the more domestic the financial system becomes, the larger are the effects of volatility.

8   Interest Rate Volatility

In a seminal paper, Fernandez-Villaverde et al. (2011) show that volatility shocks to interest rates have an important effect in small open economies. In this section we compare the model with TFP volatility and the credit channel of Section 4 with interest rate volatility shocks à la Fernandez-Villaverde et al. (2011). To do so, we study a small open economy version of Section 4 but we now assume that the risk-free rate on international bonds is subject to volatility shocks. That is, we make the households net borrowers in the international bonds market and the international rate follows an AR(1) process with time-varying volatility as in Fernandez-Villaverde et al. (2011),[30]

$$R_t^f = (1 - \rho_R) R^f + \rho_R R_{t-1}^f + e^{\sigma_{R,t}} \varepsilon_{R,t}, \tag{40}$$

$$\sigma_{R,t} = (1 - \rho_{\sigma_R}) \sigma_R + \rho_{\sigma_R} \sigma_{R,t-1} + \sigma_{\sigma_R} \varepsilon_{\sigma_R,t}. \tag{41}$$

Households borrow from international lenders in order to finance their own consumption and to give loans to domestic entrepreneurs. When interest rate volatility increases, households translate this into their lending conditions to the entrepreneurs. Thus, the analysis in this section allows to compare volatility that comes from the borrower side as entrepreneurs' income fluctuates with TFP volatility, and volatility emanating from the lenders' side, with the

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[30]We use the quarterly equivalents of the parameters estimated by Fernandez-Villaverde et al. (2011), $\rho_R = 0.91, \rho_{\sigma_R} = 0.83, \sigma_R = -5.71, \sigma_{\sigma_R} = 0.8$.

fluctuations in the international rate.

Figure 7 compares the impulse responses to volatility shocks to the international rate and to TFP. In both models the size of the shock is one standard deviation. Figure 7 shows that the two shocks are observationally equivalent. That is, higher volatility in borrowers income generates the same dynamics as higher volatility in lenders' cost of funds. Thus, the time-varying volatility of interest rates studied by Fernandez-Villaverde et al. (2011) can be due to volatility on the borrower's income, or to volatility in lenders' cost of funds.

Table 7 presents an additional exercise inspired by Fernandez-Villaverde et al. (2011). It measures the contribution to aggregate fluctuations of each of the shocks. Fernandez-Villaverde et al. (2011) discuss that in this class of models the precautionary savings motive is so strong that following TFP level shocks consumption is less volatile than output. The second column of Table 7 confirms this result. In the data, for most emerging economies, consumption is more volatile than output. Table 7 shows that the key to making consumption more volatile than output is to depart from TFP level shocks. For example, column 5 shows that when the economy borrows from abroad to finance their entrepreneurs, fluctuations in interest rates make consumption much more volatile than output.

9   Conclusions

This paper contributes to the growing literature studying the international dimensions of volatility changes. We show that open-economy models built around the precautionary savings channel can explain the positive correlation between volatility and current account dynamics, but generate counterfactual comovements concerning investment and output in OECD economies.

We show that when the precautionary savings channel is complemented with a credit supply channel, the model can simultaneously be consistent with 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 a predetermined lenders' return, as is common in the BGG literature. 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. Future research may further study how this matters for optimal policy. For example, some authors argue that recent regulations have

encouraged banking deglobalization after the 2008 financial crisis. Our paper shows that this may make economies more vulnerable to increases in uncertainty.

Acknowledgements

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Appendix: Data Sources

Our sample includes Australia (AUS), Austria (AUT), Belgium (BEL), Canada (CAN), Finland (FIN), France (FRA), Germany (DEU), Greece (GRC), Ireland (IRL), Italy (ITA), Mexico (MEX), Japan (JPN), South Korea (KOR), Netherlands (NLD), Norway (NOR), Spain (ESP), Sweden (SWE), Switzerland (CHE), United Kingdom (GBR) and the United States (USA).

These are the data sources for the series used in the paper:

a) GDP, investment, consumption, government expenditure and the trade balance-to-GDP ratio are from the OECD Quarterly National Accounts and cover 1970Q1-2014Q4.

b) Current account-to-GDP ratio is from the OECD's Economic Outlook database. The length of the series varies across the countries: AUS (1970q1-2014q4), AUT (1970q1-2014q4), BEL (1975q1-2014q4), CAN (1970q1-2014q4), CHE (1972q1-2014q4), DEU (1971q1-2014q4), ESP (1975q1-2014q4), FIN (1974q4-2014q4), FRA (1973q1-2014q4), GBR (1970q1-2014q4), GRC (1995q1-2014q4), IRL (1990q1-2014q4), ITA (1970q1-2014q4), JPN (1970q1-2014q4), KOR (1975q1-2014q4), MEX (1993q1-2014q4), NLD (1970q1-2014q4), NOR (1975q1-2014q4), SWE (1975q1-2014q4), and USA (1970q1-2014q4).

c) The volatility and level of stock market returns are computed using MSCI Index daily data from Datastream. The series are available for 1970q1-2014q4 for all countries in our sample, except for FIN (1982q1-2014q4), GRC (1988q1-2014q4), IRL (1988q1-2014q4), KOR (1988q1-2014q4), and MEX (1988q1-2014q4).

d) Credit variables come from the Bank of International Settlements. Bank credit is credit extended by domestic banks to the private non-financial sector. Total credit comprises financing from all sources, including domestic banks, other domestic financial corporations, non-financial corporations and non-residents. The length of the series varies across countries: AUS (1970q1-2014q4), AUT (1970q1-2014q4), BEL (1970q4-2014q4), CAN (1970q1-2014q4), CHE (1970q4-2014q4), DEU (1970q1-2014q4), ESP (1970q1-2014q4), FIN (1974q4-2014q4), FRA (1970q1-2014q4), GBR (1970q1-2014q4), GRC (1970q4-2014q4), IRL (1971q2-2014q4), ITA (1974q4-2014q4), JPN (1970q1-2014q4), KOR (1970q1-2014q4), MEX (1980q4-2014q4), NLD (1970q1-2014q4), NOR (1970q1-2014q4), SWE (1970q1-2014q4), and USA (1970q1-2014q4). Total credit-to-GDP ratio data for each country is available for the same period as the bank credit series, except for FIN (1970q4-2014q4) and ITA (1970q1-2014q4). We deflate nominal credit variables using the consumer price index to obtain the real variables.

e) Corporate lending rates are from Global Financial Data. For all countries we use corporate bond yield data, except for FIN, GRC, NLD, and IRL, in which due to lack of data, we use the interest rate on bank loans to non-financial corporations. The length of the series varies across countries: AUS (1983q2-2011q4), AUT (1970q1-2014q4), BEL (1970q1-2012q3), CAN (1970q1-2014q4), CHE (1982q1-2014q4), DEU (1970q1-2014q4), ESP (1977q1-2013q3), FIN (2003q1-2013q4), FRA (1970q1-2014q4), GBR (1970q1-2014q4), GRC (2003q1-2013q3), IRL (2003q1-2014q4), ITA (1970q1-2014q4), JPN (1970q1-2014q4), KOR (1972q1-2014q4), MEX (1993q2-2014q4), NLD (2003q1-2013q3), NOR (1970q1-2003q4), SWE (1974q1-2011q4), and USA (1970q1-2014q4).

f) Government bond yields are from the IMF's International Financial Statistics (line 61). The series are available for the period 1970q1-2014q4 for all countries in our sample, except for ESP (1978Q2-2014Q4), FIN (1988Q1-2014Q4), GRC (1992Q4-2014Q4), KOR (1973Q3-2014Q4), MEX (1999Q2-2014Q4).

g) CPI inflation (1970Q1-2014Q4) and quarterly spot exchange rates (1970Q1-2014Q4) are from the IMF's International Financial Statistics.

h) The Chinn-Ito index of financial openness is from the updated dataset of Chinn and Ito (2006).

i) Daily exchange rates, both spot and 1-year forward rates, are from Datastream. The length of the series varies across countries. For AUS, CAN, CHE, GBR, JPN, NOR, SWE the data on spot and forward rates are available for the period 1990q2-2014q4. For AUT, BEL, DEU, ESP, FIN, FRA, GRC, IRL, ITA, NLD, and MEX daily spot exchange rates are available for 1994q1-2014q4, and forward rates for 1997q1-2014q4. For KOR spot rates cover 1994q1-2014q and forward rates cover 2002q1-2014q4.
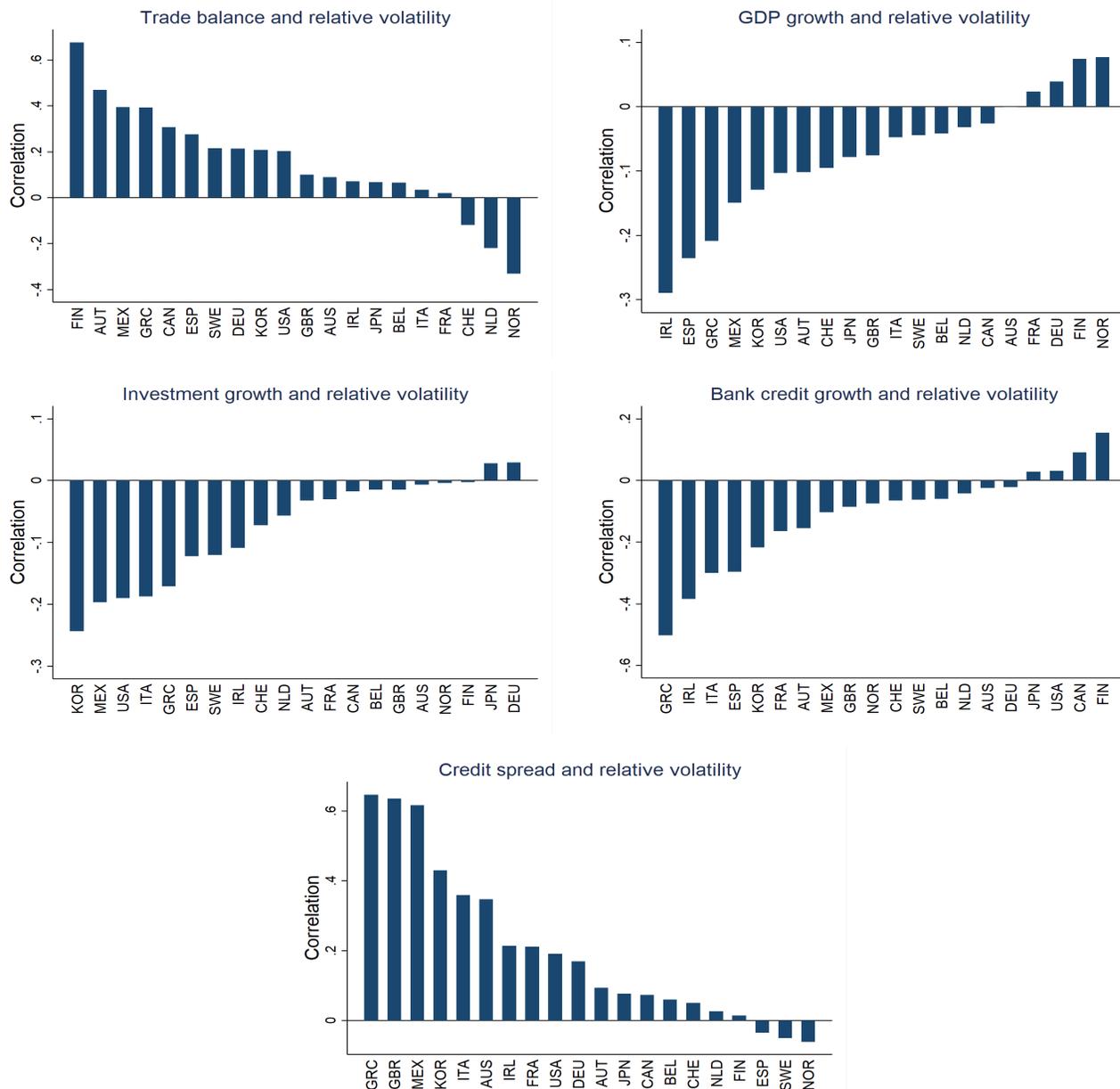
Figures

Figure 1. Within country correlations. Each bar-chart plots the country-specific correlation between the variable of interest (trade balance-to-GDP, real quarterly growth rates of GDP, investment, bank credit, and credit spread) against the relative volatility of stock market returns. Relative volatility is domestic volatility minus average volatility in the rest of the countries. We measure volatility with quarterly standard deviation of daily stock market returns from the MSCI index. The Appendix contains the country names.
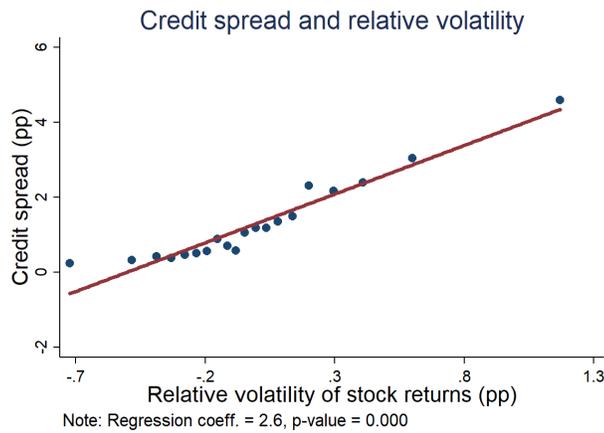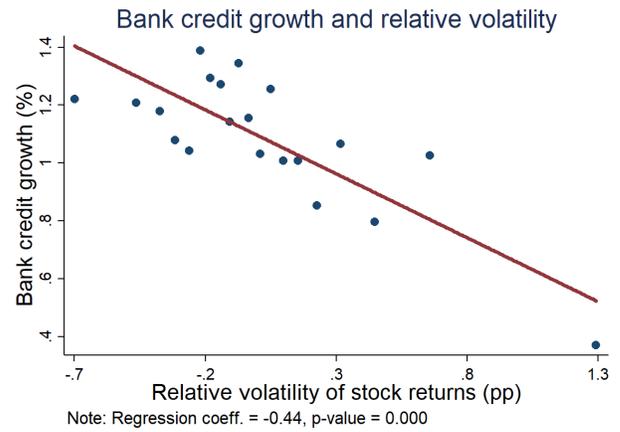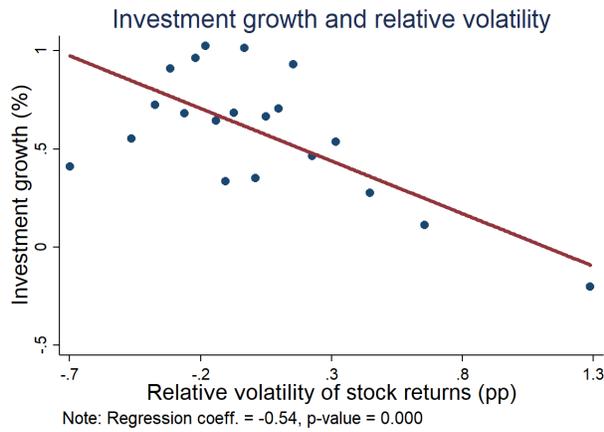
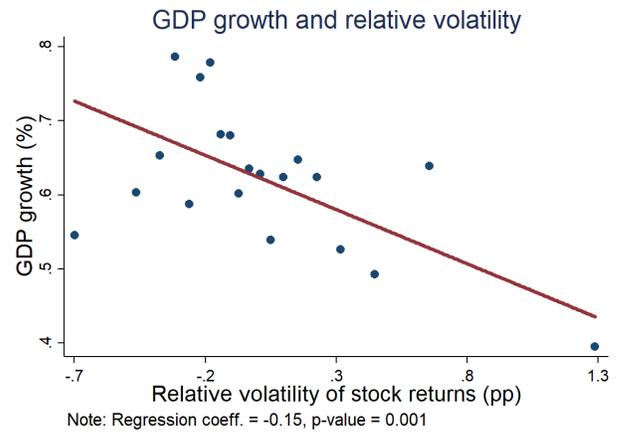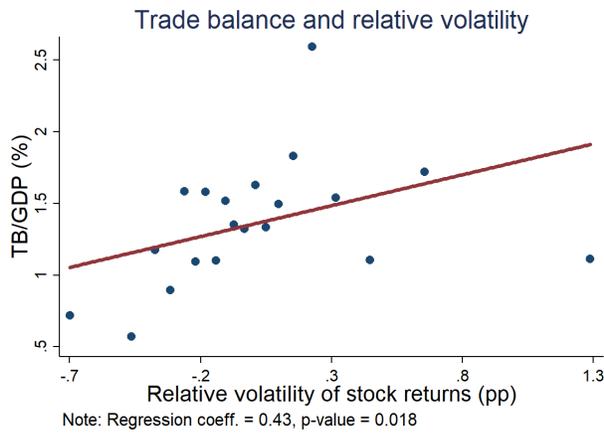**Figure 2. Scatter plots.** Each panel plots a binned scatterplot of the variable of interest (trade balance-to-GDP, real quarterly growth rates of GDP, investment, bank credit, and credit spread) against the relative volatility of stock market returns. The variables are defined as in Figure 1. Each scatterplot has 20 equally sized bins, each with around 166 observations. The fitted line comes from the OLS regression.
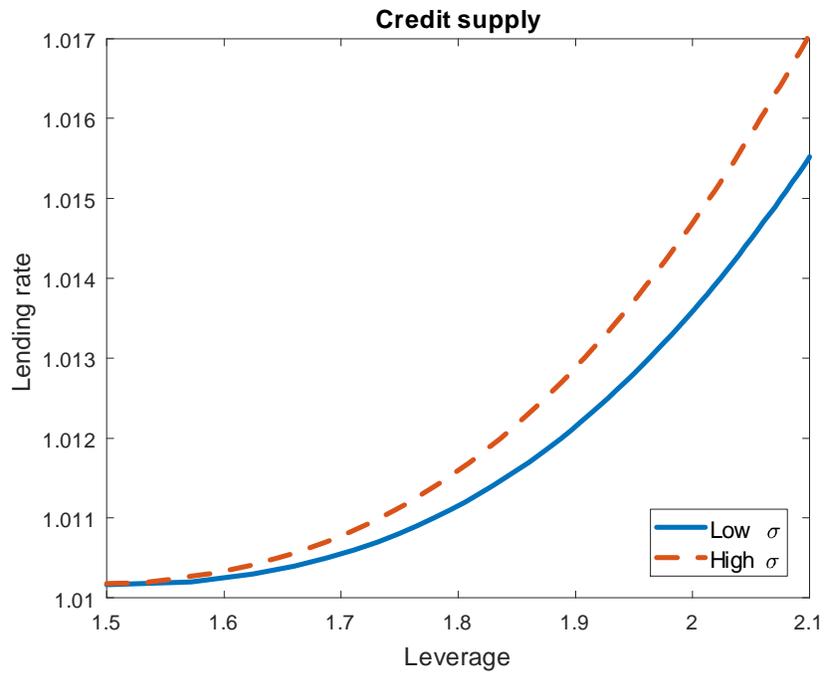
Figure 3. Volatility and credit supply. This figure plots the leverage ratios and gross lending rates that satisfy the lenders' participation constraint (20) for a high (-2.5) and a low (-4.57) value of the steady state volatility parameter σ.
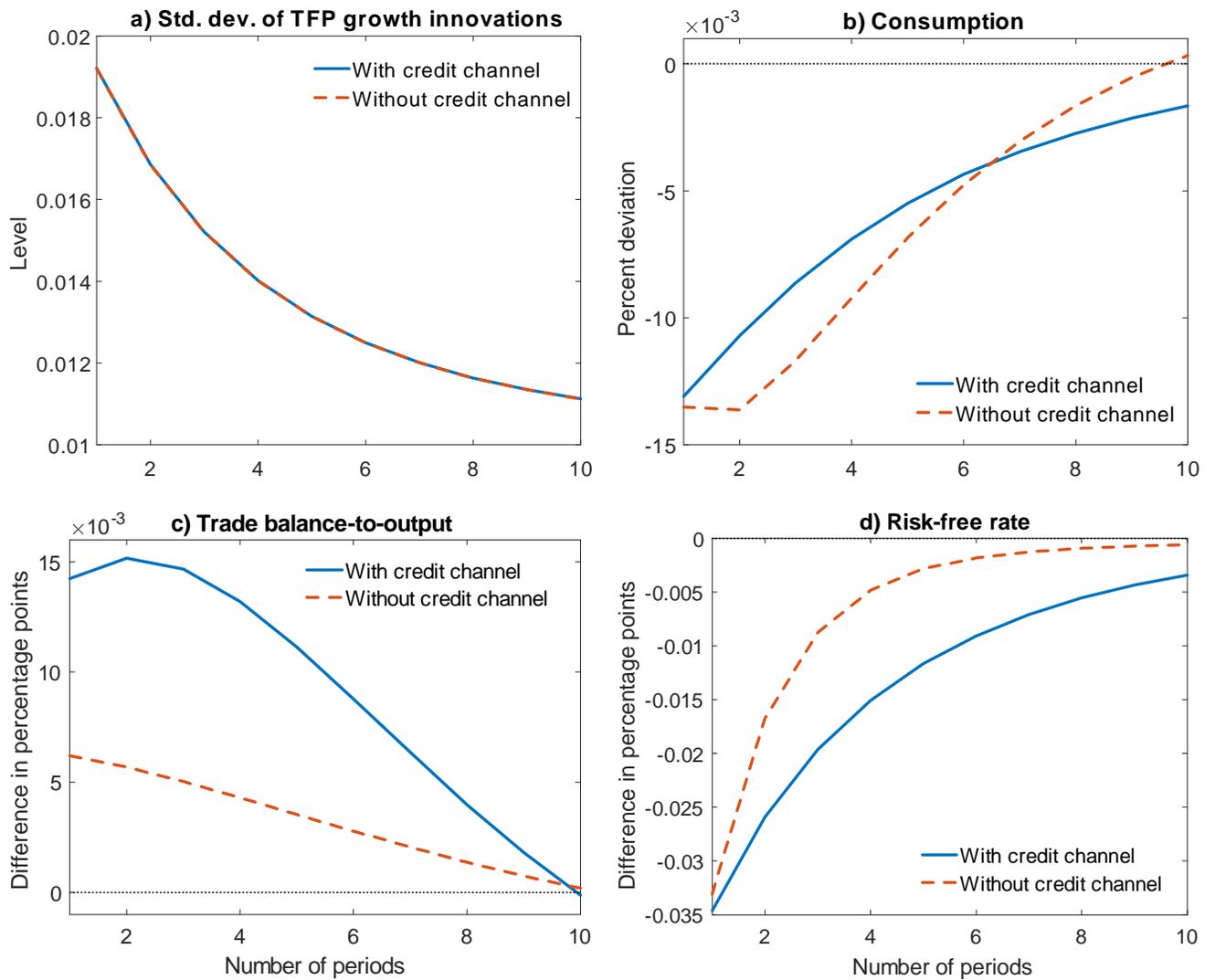
Figure 4. **Common patterns in the models with and without credit channel.**
This figure compares the responses to a one standard deviation volatility shock in country 1 in the models with and without a credit channel.
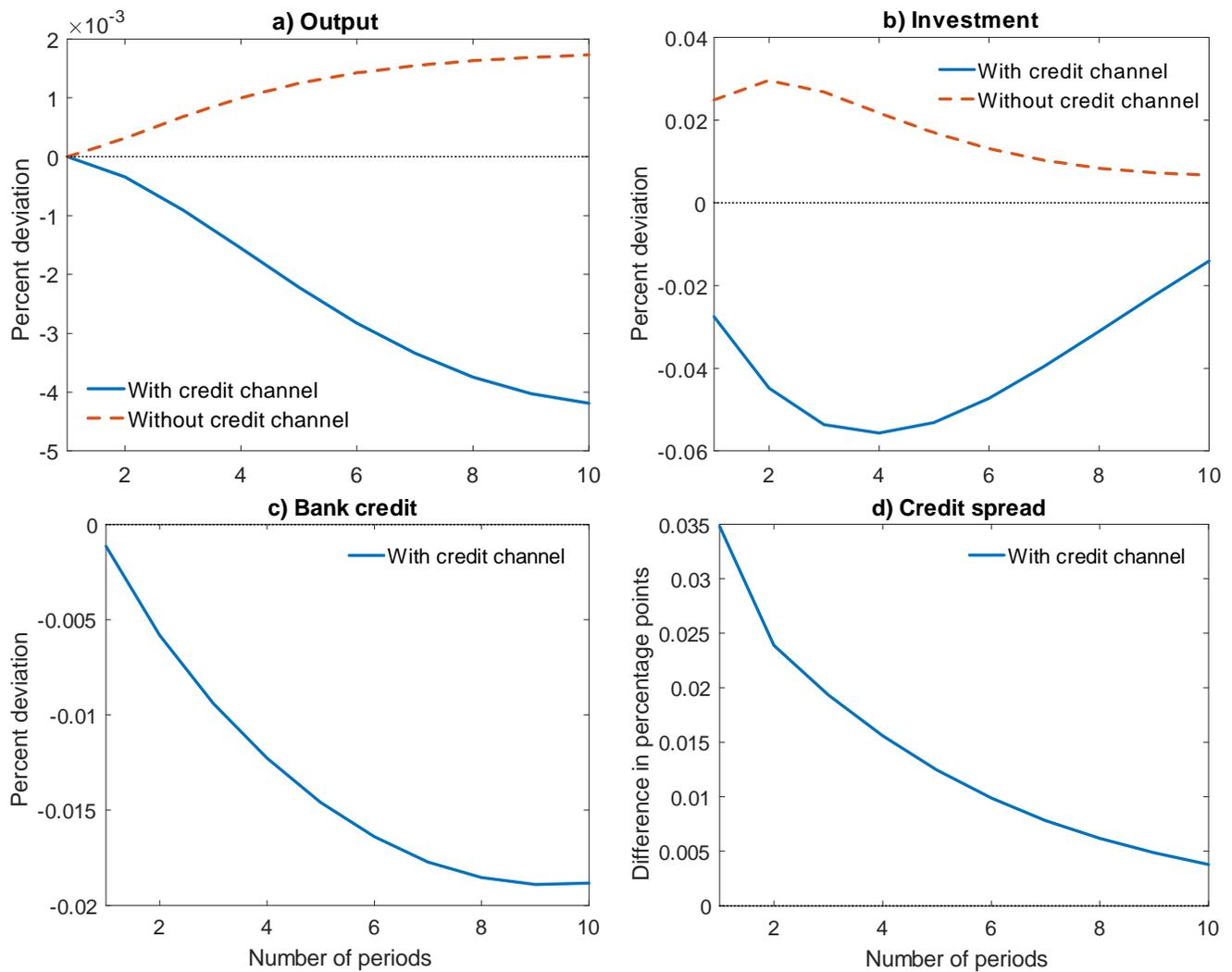
Figure 5. Differences between models with and without credit channel. This figure compares the responses to a one standard deviation volatility shock in country 1 in the models with and without a credit channel.
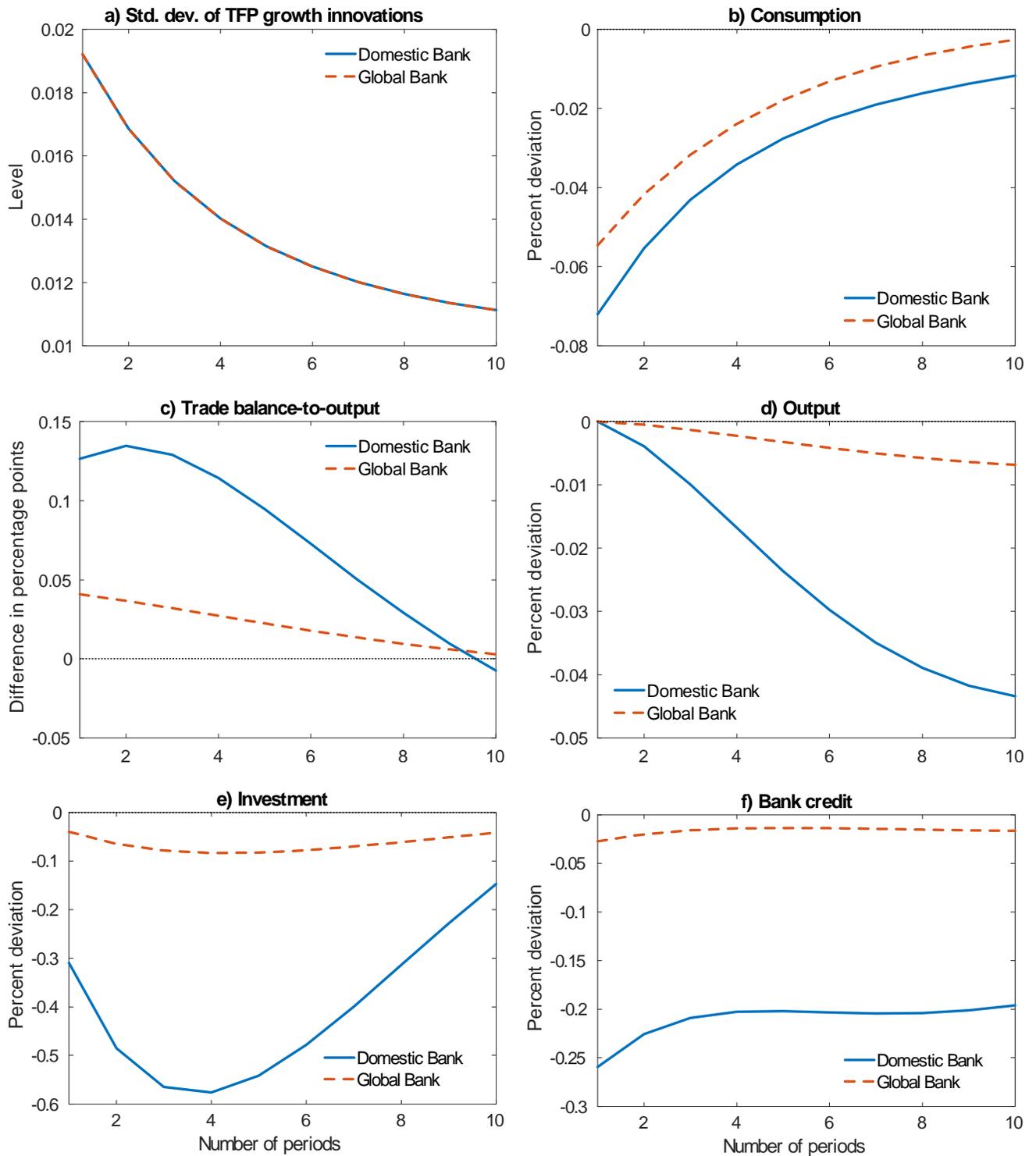
Figure 6. Domestic bank versus global bank. This figure compares the responses to a one standard deviation volatility shock in the model with a domestic bank and in the model with a global bank. See Section 7 for details.
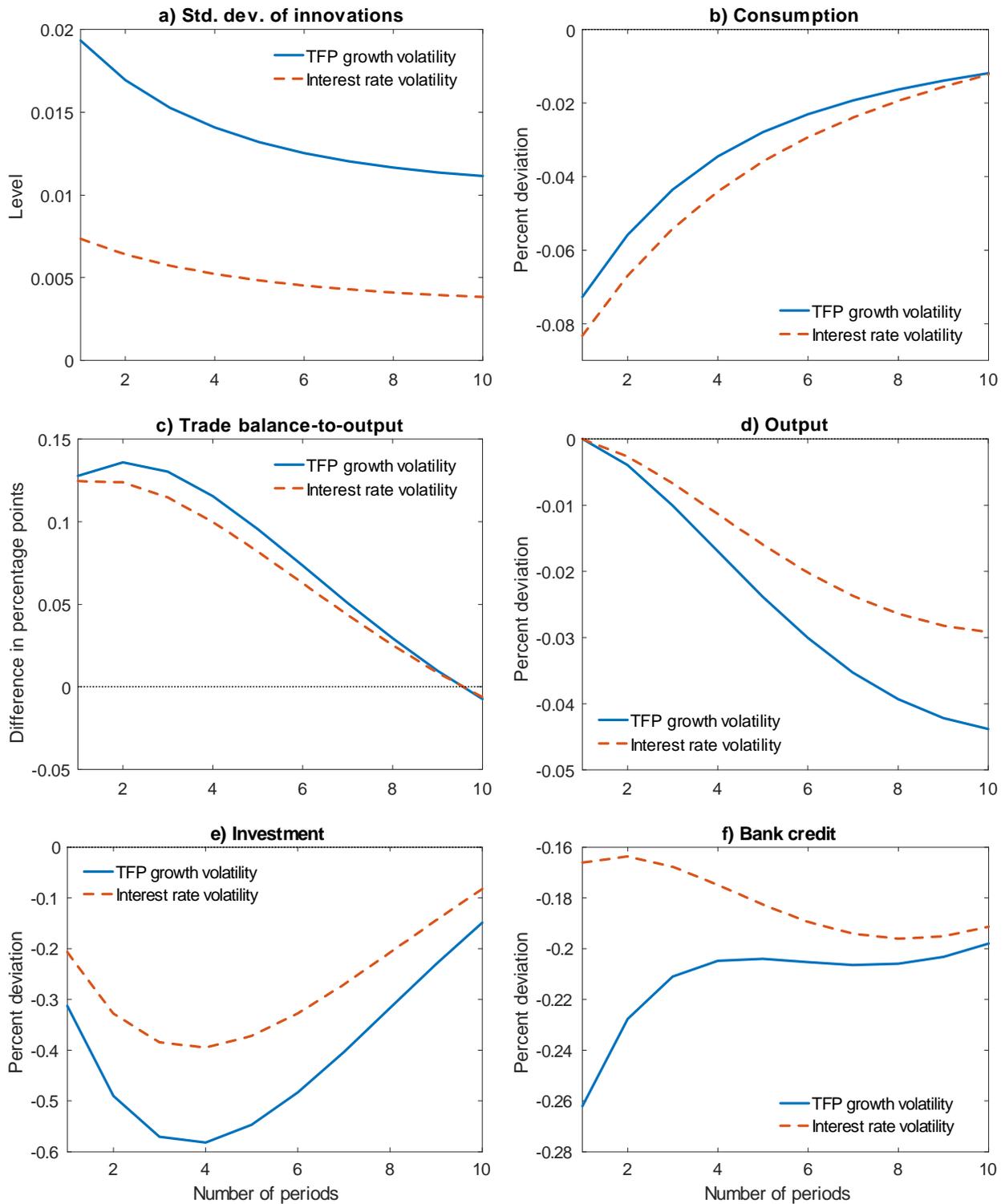
Figure 7. TFP growth volatility versus interest rate volatility. This figure compares the responses to shocks to TFP growth volatility and to shocks to interest rate volatility in a small open economy version of the model with the credit channel. Both shocks are one standard deviation shocks. The solid line is the same as in Figure 6. Section 8 discusses the details.

Tables

Table 1: **Correlations with relative volatility**

|	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log$(Bank credit)	Credit spread
AUS	0.08	0.00	-0.01	-0.02	0.35
AUT	0.45	-0.10	-0.03	-0.15	0.09
BEL	0.01	-0.03	0.00	-0.03	0.06
CAN	0.28	-0.01	-0.01	0.08	0.07
CHE	-0.15	-0.07	-0.05	-0.05	0.05
DEU	0.18	0.06	0.04	-0.01	0.17
ESP	0.30	-0.24	-0.12	-0.32	-0.04
FIN	0.67	0.08	0.00	0.16	0.01
FRA	-0.02	0.04	-0.03	-0.15	0.21
GBR	0.12	-0.07	-0.01	-0.07	0.64
GRC	0.40	-0.21	-0.17	-0.51	0.65
IRL	0.07	-0.29	-0.11	-0.38	0.21
ITA	0.03	-0.03	-0.18	-0.30	0.36
JPN	0.08	-0.06	0.05	0.05	0.08
KOR	0.21	-0.12	-0.24	-0.22	0.43
MEX	0.40	-0.14	-0.19	-0.09	0.62
NLD	-0.24	-0.03	-0.06	-0.04	0.03
NOR	-0.35	0.08	0.00	-0.08	-0.06
SWE	0.18	-0.03	-0.12	-0.06	-0.05
USA	0.23	-0.09	-0.17	0.03	0.19
Mean	0.16	-0.07	-0.08	-0.11	0.20

This table reports correlations, at the individual country level, between relative volatility and each variable of interest. All variables, unless otherwise noted, are expressed in percentages. Volatility is defined as the quarterly standard deviation of daily stock market returns, computed using the MSCI index. Relative volatility is domestic volatility minus average volatility in the other countries of the sample. $\frac{TB}{Y}$ denotes trade balance-to-GDP ratio. $\Delta \log Y$, $\Delta \log I$ and $\Delta \log$(Bank credit) denote quarterly real growth rates of GDP, investment and bank credit. Credit spread is the difference between the domestic lending rate to corporations and the interest rate of long-term US government bonds (in annualized percentage points). The sample period is 1970:q1-2014:q4 (subject to data availability as reported in the appendix).

Table 2: **Aggregate uncertainty and macroeconomic dynamics**

	Panel A				
	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log$(Bank credit)	Credit spread
Relative volatility	1.16**	-0.21**	-0.59**	-0.76***	1.77**
	(0.013)	(0.034)	(0.010)	(0.009)	(0.047)
Controls	No	No	No	No	No
Country & time FE	Yes	Yes	Yes	Yes	Yes
Observations	3264	3264	3264	3239	2640
R^2	0.67	0.29	0.14	0.22	0.53
	Panel B. Adding control variables				
	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log$(Bank credit)	Credit spread
Relative volatility	1.07**	-0.16*	-0.53**	-0.56**	0.92**
	(0.030)	(0.077)	(0.016)	(0.039)	(0.024)
Controls	Yes	Yes	Yes	Yes	Yes
Country & time FE	Yes	Yes	Yes	Yes	Yes
Observations	3098	3098	3098	3073	2584
R^2	0.70	0.34	0.16	0.24	0.74

p-values are in parentheses (*p-value<0.10, **p-value<0.05, ***p-value<0.01). Robust standard errors are clustered at the country level. All variables, unless otherwise noted, are expressed in percentages. Volatility is defined as the quarterly standard deviation of daily stock market returns, computed using the MSCI index. Relative volatility is domestic volatility minus average volatility in the rest of the countries in our sample. $\frac{TB}{Y}$ denotes trade balance-to-GDP ratio. $\Delta \log Y$, $\Delta \log I$ and $\Delta \log$(Bank credit) denote quarterly real growth rates of GDP, investment and bank credit. Credit spread is the difference between the domestic lending rate to corporations and the interest rate of long-term US government bonds (in annualized percentage points). Panel A reports the results from fixed effects regressions. Panel B adds control variables: CPI inflation, change in exchange rate (national currency per USD), trade openness ($\frac{\text{Exports+Imports}}{\text{GDP}}$), Chinn-Ito index of financial openness, growth of real government spending, and stock market returns. The sample period is 1970:q1-2014:q4 (subject to data availability as reported in the appendix).

Table 3: **Exogenous parameters**

Discount factor	β	0.99
Frisch elasticity of labor supply	ξ	0.5
Labor weight in utility function	η	14.26
Depreciation rate	δ	0.025
Capital share in production	α	0.33
Bond adjustment cost	ϕ_B	0.001
Trend growth rate	g	1.005
Convergence parameter	φ	-0.001
Survival rate of entrepreneurs	χ	0.97
Transfers to entrepreneurs	T^E	0.0001

Table 4: **Estimated parameters**

Inverse of IES	γ	3.35
		(0.66)
Investment adjustment cost	ϕ_I	1.94
		(0.39)
Std. dev. of entrepreneurs productivity	σ_ω	0.29
		(0.12)
Bankruptcy cost	μ	0.26
		(0.14)
Persistence of TFP growth	ρ_z	0.19
		(0.01)
Persistence of volatility shock	ρ_σ	0.79
		(0.04)
Steady state value of volatility shock	σ	-4.57
		(0.48)
Std. dev. of volatility shock	σ_σ	0.62
		(0.27)
Correlation of innovations to TFP growth	ϑ_z	0.29
		(0.05)
Correlation of volatility shocks	ϑ_σ	0.56
		(0.12)

Standard errors are in parentheses and computed as in Lee and Wolpin (2010). Section 6.1 describes the estimation exercise.

Table 5: **Model versus empirical targets**

	Model	Target
$\sigma\left(\Delta \log Y\right)$	1.19	1.14
$\sigma\left(\Delta \log I\right)$	3.32	3.33
$\sigma\left(\Delta \log C\right)$	1.06	1.05
$\sigma\left(\frac{TB}{Y}\right)$	2.81	2.81
Std. dev. of relative volatility	0.37	0.38
Persistence of output growth	0.23	0.22
Persistence of relative volatility	0.72	0.73
Cross-country corr. of output growth	0.19	0.19
Cross-country corr. of volatility	0.57	0.60
Mean leverage ratio	1.77	1.80

$\Delta \log Y$, $\Delta \log I$ and $\Delta \log C$ denote quarterly growth rates (in percentages) of output, investment and consumption. $\frac{TB}{Y}$ is the trade balance-to-output (in percent). $\sigma\left(x\right)$ denotes standard deviation of variable x. Section 6.1 discusses the details.

Table 6: **Quantitative assessment of the credit channel**

	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log(\text{Bank credit})$
Data (Table 2, Panel A)	1.16	-0.21	-0.59	-0.76
With credit channel	0.88	-0.20	-0.67	-0.53
Without credit channel	0.15	0.12	0.27	

The first row copies the regression coefficients from Table 2, Panel A. The second row has the regression coefficients estimated with data generated from the model with the credit channel. The third row is like the second row but the data come from the model without credit channel. Both models are simulated with all the shocks. Section 6.3 discusses the details.

Table 7: **Conditional standard deviations**

	(1) All shocks	(2) TFP level	(3) Interest rate level	(4) TFP volat.	(5) Interest rate volat.
$\sigma\left(\Delta \log Y\right)$	1.40	0.73	0.22	0.02	0.01
$\sigma\left(\Delta \log I\right)$	12.88	2.90	4.17	0.43	0.29
$\sigma\left(\Delta \log C\right)$	2.32	0.72	0.61	0.08	0.09

This table reports conditional standard deviations of growth rates (in percentages) of output, investment and consumption, when we feed into the small open economy model of Section 8 different combinations of the shocks. That is, we compare: (1) all shocks; (2) only TFP level shocks; (3) only interest rate level shock; (4) only TFP volatility shock, and (5) only interest rate volatility shock.

Online Appendix: NOT-FOR-PUBLICATION

A   Equilibrium Conditions

First we present the equilibrium conditions for the non-stationary system. Then we discuss how we make the system stationary. We use subscript i to index the country $(i = 1, 2)$ and subscript j to refer to an individual entrepreneur.

A.1   Households

The first order conditions for the household's problem are:

$$\eta Z_{i,t} (H_{i,t})^{\frac{1}{\xi}} = W_{i,t}, \tag{A1}$$

$$R_t^f \mathbb{E}_t [M_{i,t+1}] = \left[1 + \phi_B \left(\frac{B_{i,t}}{Z_{i,t}} - \widehat{B} \right) \right], \tag{A2}$$

$$\mathbb{E}_t \left[M_{i,t+1} R_{i,t+1}^D \right] = 1, \tag{A3}$$

where $M_{i,t+1}$ denotes household's stochastic discount factor:

$$M_{i,t+1} \equiv \beta \frac{\lambda_{i,t+1}}{\lambda_{i,t}} = \beta \frac{\left(C_{i,t+1} - \eta Z_{i,t+1} \frac{(H_{i,t+1})^{1+\frac{1}{\xi}}}{1+\frac{1}{\xi}} \right)^{-\gamma}}{\left(C_{i,t} - \eta Z_{i,t} \frac{(H_{i,t})^{1+\frac{1}{\xi}}}{1+\frac{1}{\xi}} \right)^{-\gamma}}. \tag{A4}$$

A.2   Capital Producers

Capital producers solve:

$$\max_{I_{i,t}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U_C(C_{i,t}, H_{i,t}) \left[Q_{i,t} \left(1 - \frac{\phi_I}{2} \left(\frac{I_{i,t}}{I_{i,t-1}} - g \right)^2 \right) I_{i,t} - I_{i,t} \right]. \tag{A5}$$

The first order condition for this problem is:

$$1 + Q_{i,t} \left(\begin{array}{c} \phi_I \left(\frac{I_{i,t}}{I_{i,t-1}} - g \right) \left(\frac{I_{i,t}}{I_{i,t-1}} \right) + \\ - \left(1 - \frac{\phi_I}{2} \left(\frac{I_{i,t}}{I_{i,t-1}} - g \right)^2 \right) \end{array} \right) = \mathbb{E}_t \left[M_{i,t+1} Q_{i,t+1} \phi_I \left(\frac{I_{i,t+1}}{I_{i,t}} - g \right) \left(\frac{I_{i,t+1}}{I_{i,t}} \right)^2 \right]. \tag{A6}$$

A.3 Firms Producing Goods

Profit maximization implies the following equilibrium conditions:

$$r_{i,t} = \alpha \frac{Y_{i,t}}{K_{i,t-1}}, \tag{A7}$$

$$W_{i,t} = (1 - \alpha) \frac{Y_{i,t}}{H_{i,t}}. \tag{A8}$$

A.4 Entrepreneurs and the Financial Contract

The derivation of the optimal contract follows Carlstrom et al. (2016). The financial contract is a pair of leverage ratio $\kappa_{i,j,t}$ and state-contingent default threshold $\overline{\omega}_{i,j,t+1}$ that maximizes entrepreneur's value function,

$$V_{i,j,t} = (1 - \chi) N_{i,j,t} + \beta \chi \max_{\{\overline{\omega}_{i,j,t+1}, \kappa_{i,j,t}\}} \mathbb{E}_t (V_{i,j,t+1}) \tag{A9}$$

subject to lenders' participation constraint:

$$\mathbb{E}_t \left[M_{i,t+1} \kappa_{i,j,t} R_{i,t+1}^K \left[\Gamma \left(\overline{\omega}_{i,j,t+1} \right) - \mu G \left(\overline{\omega}_{i,j,t+1} \right) \right] \right] = \kappa_{i,j,t} - 1, \tag{A10}$$

where $M_{i,t+1}$ is the household's stochastic discount factor. Equation (A9) is the entrepreneur's Bellman equation and is obtained by recursive formulation of (16).

We will show that the leverage ratio $\kappa_{i,j,t}$ and the default threshold $\overline{\omega}_{i,j,t+1}$ are the same for all the entrepreneurs of country i. Using the functions (18), (19), and the definition of leverage (17), entrepreneur j's equity can be written as:

$$N_{i,j,t+1} = \left[1 - \Gamma \left(\overline{\omega}_{i,j,t+1} \right) \right] R_{i,t+1}^K Q_{i,t} K_{i,j,t} = \left[1 - \Gamma \left(\overline{\omega}_{i,t+1}^j \right) \right] R_{i,t+1}^K \kappa_{i,j,t} N_{i,j,t}. \tag{A11}$$

Because of constant returns to scale and risk neutrality, we guess and verify that the value function is linear in individual equity:

$$V_{i,j,t} = V_{i,t} N_{i,j,t}, \tag{A12}$$

where $V_{i,t}$ is time-varying and common across entrepreneurs. Substituting this guess into the

Bellman equation (A9) and using (A11), we obtain:

$$V_{i,t} = (1 - \chi) + \beta\chi \max_{\{\overline{\omega}_{i,j,t+1}, \kappa_{i,j,t}\}} \mathbb{E}_t \left[V_{i,t+1} \left[1 - \Gamma \left(\overline{\omega}_{i,j,t+1} \right) \right] R_{i,t+1}^K \kappa_{i,j,t} \right]. \tag{A13}$$

The Lagrangian for this problem is:

$$\mathcal{L}_{i,j,t} = \left\{ \begin{array}{c} \beta\chi\mathbb{E}_t \left[V_{i,t+1} \left[1 - \Gamma \left(\overline{\omega}_{i,j,t+1} \right) \right] R_{i,t+1}^K \kappa_{i,j,t} \right] + \\ +\Lambda_{i,j,t} \left[\mathbb{E}_t \left[M_{i,t+1} \kappa_{i,j,t} R_{i,t+1}^K \left[\Gamma \left(\overline{\omega}_{i,j,t+1} \right) - \mu G \left(\overline{\omega}_{i,j,t+1} \right) \right] \right] - \left(\kappa_{i,j,t} - 1 \right) \right] \end{array} \right\}.$$

The first order conditions with respect to $\overline{\omega}_{i,j,t+1}, \kappa_{i,j,t}$ and Lagrange multiplier $\Lambda_{i,j,t}$ are:

$$-\beta\chi V_{i,t+1}\Gamma' \left(\overline{\omega}_{i,j,t+1} \right) + \Lambda_{i,j,t} M_{i,t+1} \left[\Gamma' \left(\overline{\omega}_{i,j,t+1} \right) - \mu G' \left(\overline{\omega}_{i,j,t+1} \right) \right] = 0, \tag{A14}$$

$$\beta\chi\mathbb{E}_t \left[V_{i,t+1} \left[1 - \Gamma \left(\overline{\omega}_{i,j,t+1} \right) \right] R_{i,t+1}^K \right] + \Lambda_{i,j,t} \left[\mathbb{E}_t \left\{ M_{i,t+1} R_{i,t+1}^K \left[\Gamma \left(\overline{\omega}_{i,j,t+1} \right) - \mu G \left(\overline{\omega}_{i,j,t+1} \right) \right] \right\} - 1 \right] = 0, \tag{A15}$$

and

$$\mathbb{E}_t \left\{ M_{i,t+1} \kappa_{i,j,t} R_{i,t+1}^K \left[\Gamma \left(\overline{\omega}_{i,j,t+1} \right) - \mu G \left(\overline{\omega}_{i,j,t+1} \right) \right] \right\} = \kappa_{i,j,t} - 1. \tag{A16}$$

Combining (A14) and (A15), we obtain that the default threshold does not depend on individual equity and is the same for all entrepreneurs, that is,

$$\overline{\omega}_{i,j,t+1} = \overline{\omega}_{i,t+1}.$$

Equation (A16) implies that the leverage ratio is common across entrepreneurs,

$$\kappa_{i,j,t} = \kappa_{i,t}.$$

Combining (A15) and (A16) with (A13) we obtain:

$$V_{i,t} = (1 - \chi) + \Lambda_{i,t}. \tag{A17}$$

This equation shows that $V_{i,t}$ is common across entrepreneurs, thus we do not need the j subscript.

Substituting (A17) into (A14) and (A15), and dropping the j index we obtain the equilibrium conditions:

$$\Lambda_{i,t} M_{i,t+1} \left[\Gamma' \left(\overline{\omega}_{i,t+1} \right) - \mu G' \left(\overline{\omega}_{i,t+1} \right) \right] = \beta\chi\Gamma' \left(\overline{\omega}_{i,t+1} \right) \left[(1 - \chi) + \Lambda_{i,t+1} \right], \tag{A18}$$

$$\left\{ \begin{array}{c} \beta\chi\mathbb{E}_t\left[(1-\chi+\Lambda_{i,t+1})\left[1-\Gamma\left(\overline{\omega}_{i,t+1}\right)\right]R_{i,t+1}^K\right]+ \\ +\Lambda_{i,t}\left[\mathbb{E}_t\left[M_{i,t+1}R_{i,t+1}^K\left[\Gamma\left(\overline{\omega}_{i,t+1}\right)-\mu G\left(\overline{\omega}_{i,t+1}\right)\right]\right]-1\right] \end{array} \right\}=0, \qquad (A19)$$

$$\mathbb{E}_t\left[M_{i,t+1}\kappa_{i,t}R_{i,t+1}^K\left[\Gamma\left(\overline{\omega}_{i,t+1}\right)-\mu G\left(\overline{\omega}_{i,t+1}\right)\right]\right]=\kappa_{i,t}-1. \qquad (A20)$$

Finally, aggregating (A11) over individual entrepreneurs, and adding the transfers from the households, we obtain entrepreneurs' aggregate equity:

$$N_{i,t}=\chi\left[1-\Gamma\left(\overline{\omega}_{i,t}\right)\right]R_{i,t}^KQ_{i,t-1}K_{i,t-1}+Z_{i,t}T^E. \qquad (A21)$$

The aggregate consumption of the entrepreneurs passing away is:

$$C_{i,t}^E=(1-\chi)\left[1-\Gamma\left(\overline{\omega}_{i,t}\right)\right]R_{i,t}^KQ_{i,t-1}K_{i,t-1}. \qquad (A22)$$

A.5 Making the System Stationary

The previous model has stationary and trending variables. The trending variables in the model are: $C_{i,t}, Y_{i,t}, I_{i,t}, I_{i,t}^n, K_{i,t}, N_{i,t}, C_{i,t}^E, L_{i,t}, D_{i,t}, B_{i,t}, W_{i,t}$. For a given variable $x_{i,t}$ with trend $Z_{i,t}$, we define the stationary variable $\widehat{x}_{i,t}\equiv\frac{x_{i,t}}{Z_{i,t}}$.

Additional Figures and Tables

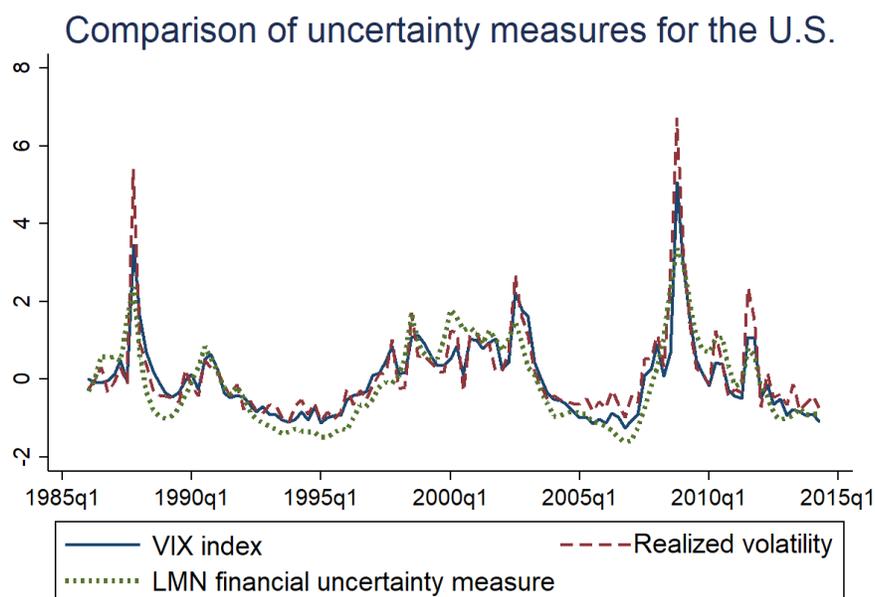Comparison of uncertainty measures for the U.S.

Figure A1. Comparing measures of uncertainty. This figure plots, for the US, the VIX index, the realized stock returns volatility, and Ludvigson, Ma and Ng (2017, LMN) measure of financial uncertainty for the period 1986q1-2014q4. Each variable is expressed in standardized units with the unconditional means normalized to zero. The correlations of realized stock returns volatility with the VIX index and the LMN measure are 0.93 and 0.75, respectively.
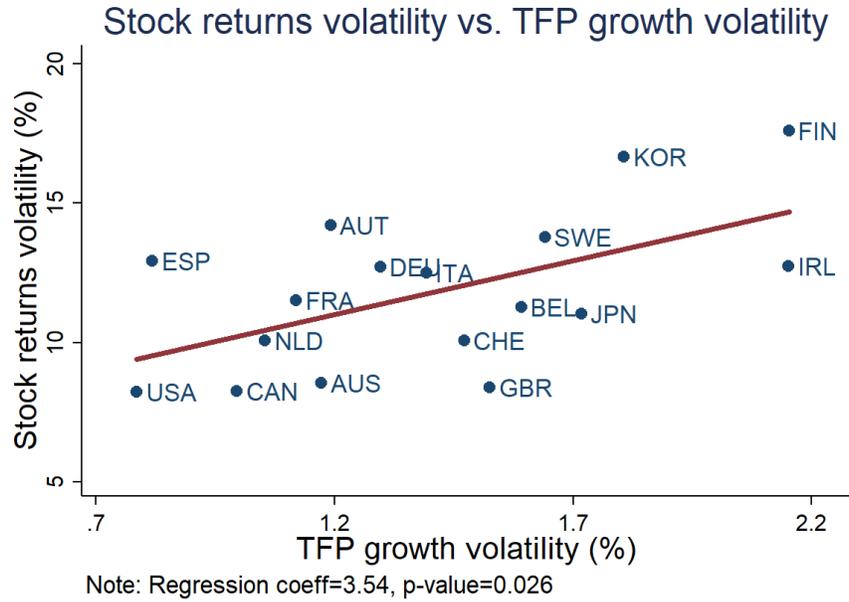
Stock returns volatility vs. TFP growth volatility

Note: Regression coeff=3.54, p-value=0.026

Figure A2. Stock market returns volatility vs. TFP growth volatility. The data for TFP growth is from OECD's Multi-Factor Productivity database which covers 1985-2011. TFP growth volatility is the standard deviation of annual TFP growth rates. Stock returns volatility is the standard deviation of annual stock returns over the same period. The fitted line is the OLS line.
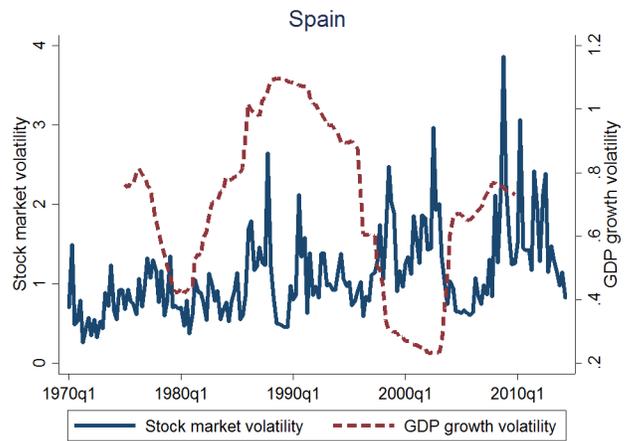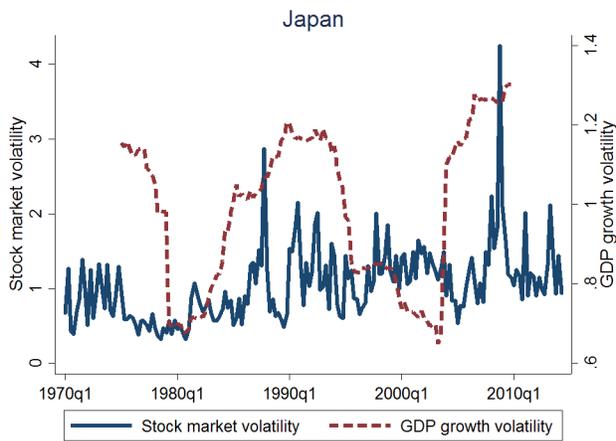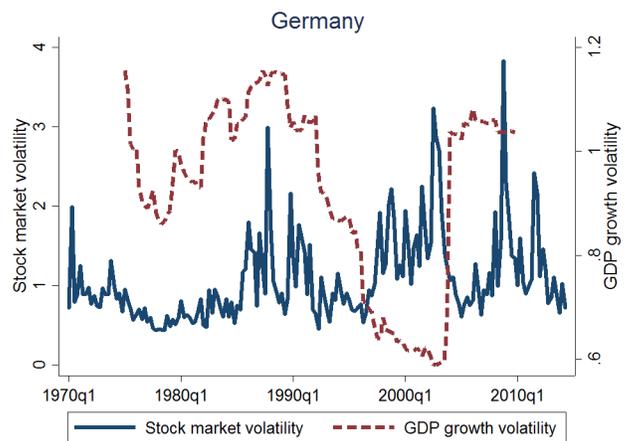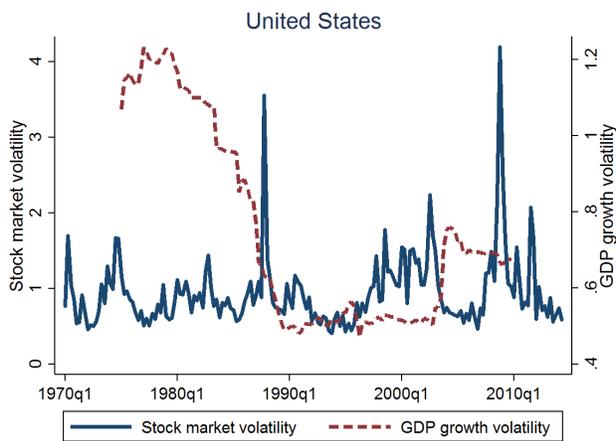
Figure A3. Comparing measures of volatility. This figure plots the quarterly volatility of daily stock market returns and the volatility of quarterly real GDP growth over 10-year rolling windows.

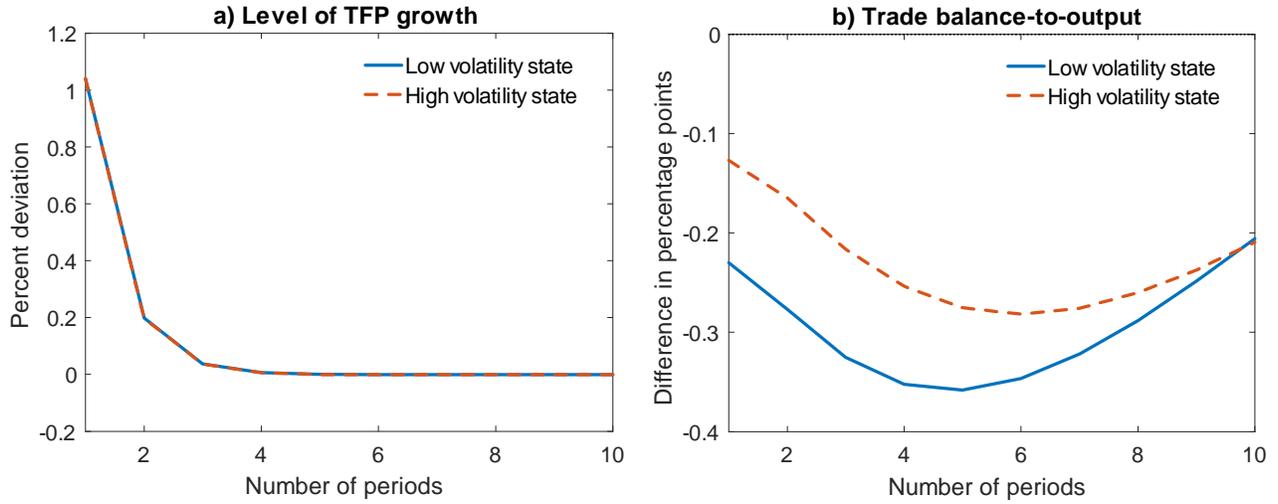**Figure A4 State-dependent responses to a TFP growth shock: high vs. low volatility.** Panel a) reports a shock to the level of TFP growth. Panel b) reports the responses of the trade balance-to-output ratio in the model with credit channel when volatility is high and when it is low. The dashed line has a high parameter of volatility of TFP growth ($\sigma = -2.5$) while in the solid line the volatility is lower ($\sigma = -4.57$).

Figure A5. Robustness to TFP convergence parameter. This figure compares the responses to a one standard deviation volatility shock in country 1 in the model with credit channel for high and low values of the parameter φ. The solid line is the benchmark calibration.
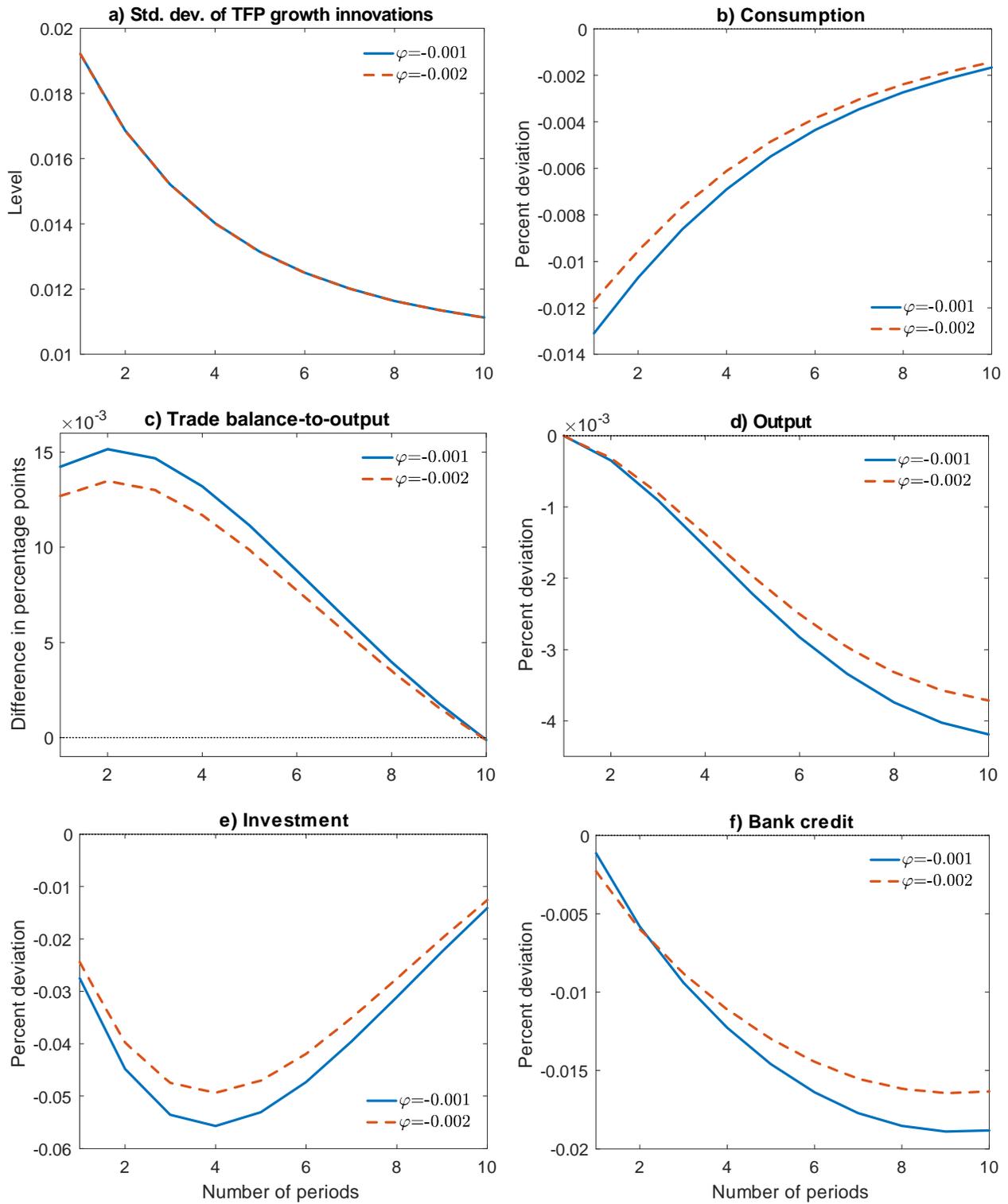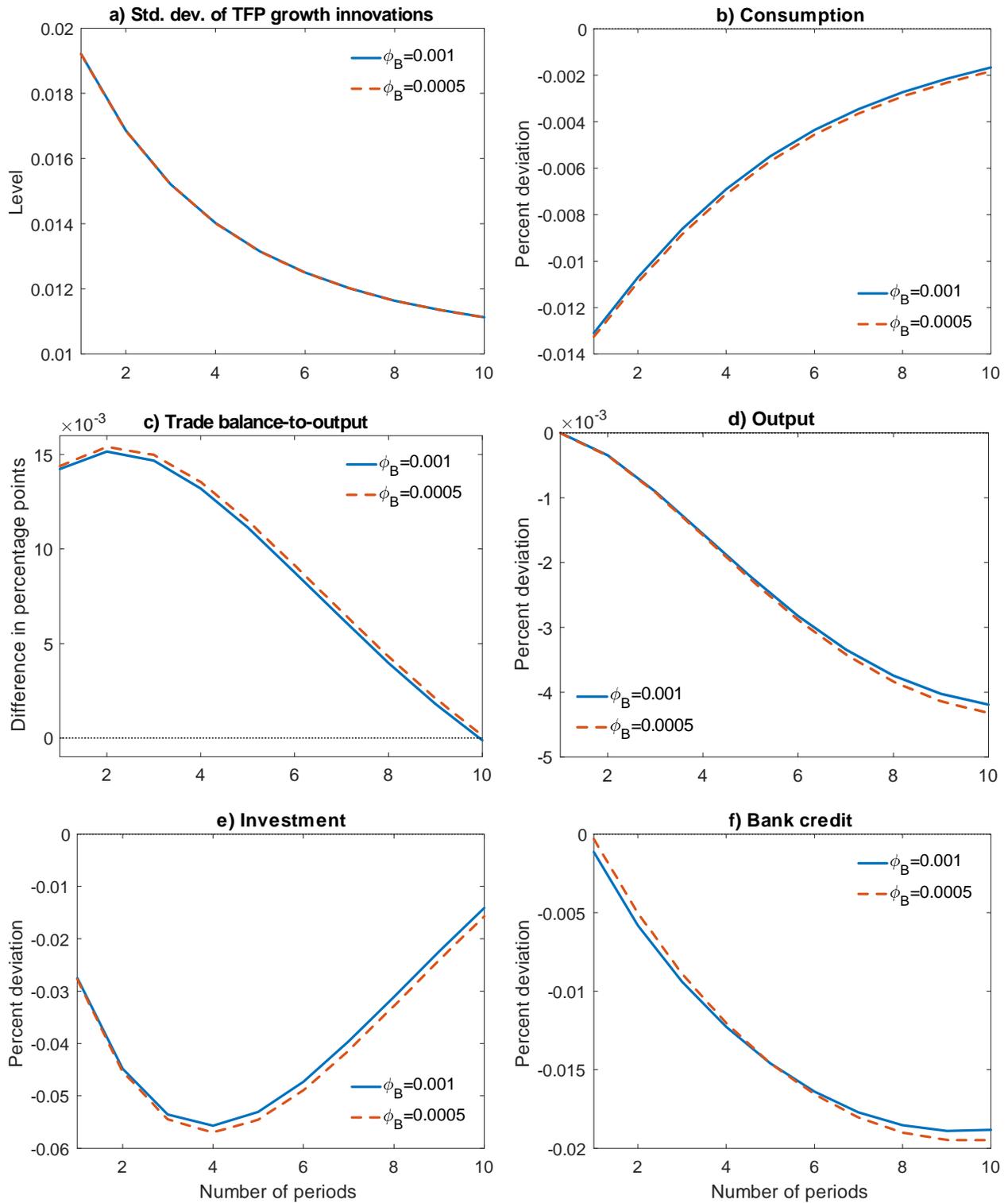
Figure A6. Robustness to bond adjustment cost parameter. This figure compares the responses to a one standard deviation volatility shock in country 1 in the model with credit channel for high and low values of the parameter ϕ_B. The solid line is the benchmark calibration.

Table A1: **Robustness to alternative measures of external position, credit flows and interest rate spreads**

	Panel A		
	$\frac{CA}{Y}$	$\Delta \log$(Total credit)	Gov. spread
Relative volatility	0.95*	-0.79***	0.97**
	(0.076)	(0.000)	(0.032)
Controls	No	No	No
Country & time FE	Yes	Yes	Yes
Observations	3122	3259	3144
R^2	0.54	0.23	0.61
	Panel B. Adding control variables		
	$\frac{CA}{Y}$	$\Delta \log$(Total credit)	Gov. spread
Relative volatility	1.04**	-0.61***	0.77*
	(0.037)	(0.000)	(0.080)
Controls	Yes	Yes	Yes
Country & time FE	Yes	Yes	Yes
Observations	3000	3093	2993
R^2	0.56	0.26	0.65

p-values are in parentheses (*p-value<0.10, **p-value<0.05, ***p-value<0.01). Robust standard errors are clustered at the country level. The measure of volatility and the control variables are the same as in Table 2. $\frac{CA}{Y}$ denotes current account balance as percent of GDP. $\Delta \log$(Total credit) is quarterly real growth rate of total credit. Government spread is defined as the difference between the yields of the long-term domestic government bond and the U.S. government bond (in annualized percentage points). The sample period is 1970:q1-2014:q4 (subject to data availability). The appendix describes the sample and data sources.

Table A2: **Robustness to exchange rate risk**

Panel A. Controlling for Exchange Rate Risk

	Corporate credit spread	
	(1)	(2)
Relative volat. of stock returns	0.40*	0.49**
	(0.056)	(0.018)
Expected change in exch. rate	0.96***	0.84***
	(0.000)	(0.000)
Exchange rate volatility	0.12	0.03
	(0.825)	(0.947)
Controls	No	Yes
Country & time FE	Yes	Yes
Observations	1410	1387
R^2	0.90	0.91

Panel B. Eliminating Exchange Rate Risk

	Corporate credit spread	
	(1)	(2)
Relative volat. of stock returns	0.49	0.41*
	(0.103)	(0.066)
Controls	No	Yes
Country & time FE	Yes	Yes
Observations	522	522
R^2	0.81	0.84

p-values are in parentheses (*p-value<0.10, **p-value<0.05, ***p-value<0.01). Robust standard errors are clustered at the country level. The measure of macroeconomic uncertainty and the controls are the same as in Table 2. In Panel A credit spread is defined as in Table 2. Panel B focuses on the EU countries in the sample starting from 1999q1, when the Euro was introduced. Credit spread is defined relative to long-term German government bond yield.

Table A3: **Robustness to using absolute volatility**

| | Panel A | | | | |
	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log(\text{Bank credit})$	Credit spread
Volatility	1.23**	-0.22**	-0.63**	-0.79***	1.86**
	(0.011)	(0.034)	(0.010)	(0.009)	(0.047)
Controls	No	No	No	No	No
Country & time FE	Yes	Yes	Yes	Yes	Yes
Observations	3264	3264	3264	3239	2640
R^2	0.67	0.29	0.14	0.17	0.53

| | Panel B. Adding control variables | | | | |
	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log(\text{Bank credit})$	Credit spread
Volatility	1.13**	-0.17*	-0.56**	-0.59**	0.97**
	(0.028)	(0.076)	(0.016)	(0.040)	(0.023)
Controls	Yes	Yes	Yes	Yes	Yes
Country & time FE	Yes	Yes	Yes	Yes	Yes
Number Observations	3098	3098	3098	3073	2584
R^2	0.70	0.34	0.16	0.24	0.74

p-values are in parentheses (*p-value<0.10, **p-value<0.05, ***p-value<0.01). Robust standard errors are clustered at the country level. The measure of volatility is stock market returns volatility $\Omega_{i,t}$. The outcome variables and controls are the same as in Table 2. The appendix describes the sample and data sources.

Table A4: **Robustness to volatility measured with GDP growth rolling windows**

	Panel A. 5-year rolling windows				
	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log$(Bank credit)	Credit spread
Relat. volat. GDP growth (5yr)	1.17*	-0.11	-0.35	-0.10	2.00
	(0.084)	(0.123)	(0.124)	(0.118)	(0.104)
Controls	Yes	Yes	Yes	Yes	Yes
Country & time FE	Yes	Yes	Yes	Yes	Yes
Observations	2758	2758	2758	2748	2329
R^2	0.71	0.34	0.16	0.22	0.58

	Panel B. 10-year rolling windows				
	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log$(Bank credit)	Credit spread
Relat. volat. GDP growth(10yr)	1.65*	-0.11	-0.01	-0.36	2.70
	(0.058)	(0.304)	(0.801)	(0.293)	(0.163)
Controls	Yes	Yes	Yes	Yes	Yes
Country & time FE	Yes	Yes	Yes	Yes	Yes
Observations	2418	2418	2418	2418	2049
R^2	0.71	0.34	0.18	0.24	0.60

p-values are in parentheses (*p-value<0.10, **p-value<0.05, ***p-value<0.01). Robust standard errors are clustered at the country level. The measure of volatility is the standard deviation of quarterly real GDP growth rates (in percentage) over 5-year (Panel A) and 10-year (Panel B) rolling windows. The outcome variables and controls are the same as in Table 2. The appendix describes the sample and data sources.

Table A5: **Robustness to all variables measured over rolling windows**

	Panel A. 5-year rolling windows				
	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log$(Bank credit)	Credit spread
Relat. volat. GDP growth (5yr)	1.09*	-0.06*	-0.15	-0.104	1.02**
	(0.094)	(0.093)	(0.145)	(0.794)	(0.079)
Controls	Yes	Yes	Yes	Yes	Yes
Country & time FE	Yes	Yes	Yes	Yes	Yes
Observations	2838	2838	2838	2838	2449
R^2	0.82	0.78	0.42	0.44	0.89

	Panel B. 10-year rolling windows				
	$\frac{TB}{Y}$	$\Delta \log Y$	$\Delta \log I$	$\Delta \log$(Bank credit)	Credit spread
Relat. volat. GDP growth (10yr)	0.81	-0.06*	-0.03	-0.09	1.78
	(0.108)	(0.219)	(0.748)	(0.862)	(0.124)
Controls	Yes	Yes	Yes	Yes	Yes
Country & time FE	Yes	Yes	Yes	Yes	Yes
Observations	2562	2562	2562	2562	2257
R^2	0.87	0.83	0.58	0.51	0.89

p-values are in parentheses (*p-value<0.10, **p-value<0.05, ***p-value<0.01). Robust standard errors are clustered at the country level. This table shows the results from regressions using the same methodology as Fogli and Perri (2015). The measure of volatility is the standard deviation of quarterly real GDP growth rates (in percentage) over 5-year (Panel A) and 10-year (Panel B) rolling windows, as in Table A4, but now the dependent variables, and the controls, are also averages over 5-year and 10-year rolling windows, respectively. The appendix describes the sample and data sources.