Collateralized Borrowing in a Two-Country DSGE Model with Production Heterogeneity

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ABSTRACT

Many policymakers and researchers view the recent financial and real economic crises across North America, Europe and beyond as a global phenomenon. Some have argued that this global recession has a common source: the U.S. financial crisis. This paper investigates the extent to which a credit shock in one country is transmitted to its trade partners. To this end, we develop a two-country dynamic stochastic general equilibrium model wherein intermediate-good producers face persistent idiosyncratic productivity shocks and occasionally binding collateralized borrowing constraints for investment loans.

We find that a negative credit shock in one country induces a sharp contraction of the domestic economy and a delayed, persistent economic downturn in its trade partner economies. Varying the parameterization of the model reveals that the degree of the credit-shock propagation depends on the home bias in international trade and the type of goods countries trade with each other. In particular, a lower home bias dampens the domestic recession but amplifies international transmission of a credit shock. When traded goods are less substitutable, the domestic recession is less severe but international transmission is amplified. Our results shed light on the link between financial crisis and the great trade collapse during the 2007-2009 global recession.

Keywords: Credit crisis, financial frictions, international transmission

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1 Introduction

Beginning in late 2007, advanced economies across North America, Europe and beyond experienced severe and persistent financial and real economic crises. A high degree of business cycle synchronization across these countries in subsequent years has led many policymakers and researchers to view the crises as a global phenomenon. At the same time, such unprecedented global recession triggered a discussion on its cause, and one of the leading explanations is that the recession had a common source: the U.S. financial crisis.

A financial crisis in one country may induce an economic slowdown in other countries through various channels, and a number of empirical studies have examined different factors, both real and financial, that may have contributed to the synchronization of international business cycles during the recent recession.[1] One striking observation from this crisis period is that the global recession was accompanied by a sharp collapse of international trade in goods.[2] While globalization of financial markets may have played a crucial role in accelerating the economic downturn across countries, the international synchronization of trade contractions seems to suggest that international trade and the resulting exposure of countries to external shocks may also have contributed to their macroeconomic responses, and propagated the global recession in an important way. Indeed, Lane and Milesi-Ferretti (2011) find that openness to international trade had significant effects on the severity of a country's recession, and that a country's output change during the crisis period was affected by the economic performance of its trade partners during the same time period. There is also empirical evidence linking financial crisis to the great trade collapse. Bricongne, et al. (2012) and Behrens, Corcos and Mion (2013) find that financial constraints explain some of the decline in exports during the great trade collapse. As shocks to credit supply constrain production and export supply, the resulting fall in international trade can exacerbate a contraction of real economic activity in its trading partners. These findings point to the cross-country

[1] For example, Imbs (2010) finds that the business cycle synchronization among OECD countries is associated with external bank lending, while the trade channel is more important for non-OECD countries. Lane and Milesi-Ferretti (2011) find that the pre-crisis levels of GDP per capita, growth in GDP and private credit, current account deficits, and trade openness are significantly correlated with the intensity of the recent crisis. Rose and Spiegel (2011) find some evidence that current account, credit market regulation and credit growth are significant indicators of the crisis, although their significance depends on the sample of countries and measures of the crisis.

[2] Real world trade fell by about 15 percent between 2008Q1 and 2009Q1. Bems, Johnson and Yi (2012) survey recent studies on the causes of the collapse in international trade during the recent global recession.

propagation of financial crisis through real channels.

This paper investigates the extent to which a credit shock in one country is transmitted to its trade partners. We develop a two-country dynamic stochastic general equilibrium model, building upon the closed-economy financial frictions model of Khan and Thomas (2013). Intermediate-good producers in our model are heterogeneous in capital stock, debt and productivity. In addition to country-specific productivity shocks, firms face persistent idiosyncratic productivity shocks each period. Firms may borrow one-period loans from domestic households in order to finance their investment in physical capital; however, they face collateralized borrowing constrains that depend on individual firms' cash on hand. In our framework, countries are connected with each other through two channels. First, intermediate goods are traded across countries, and imports are combined with domestic intermediate goods to produce final goods used for consumption and investment. Second, households trade state-contingent one-period bonds in complete international financial markets. We calibrate the parameters governing firms' decisions on investment and borrowing to match data on firm-level investment and capital accumulation as well as aggregate indebtedness in the United States. In particular, we target the mean and variance of the investment-to-capital ratio from the firm level data and the debt-to-asset ratio at the aggregate level.

Examining the effects of country-specific credit shocks on the domestic economy and abroad, we find that a credit shock in one country induces an immediate, sharp contraction in the domestic economy and a delayed but persistent downturn in its trade partners. When credit availability suddenly becomes limited in one country, borrowing by domestic intermediate-good producers is reduced, leading them to cut investment and production. This depresses production of final goods, which in turn curtails demand for imported intermediate goods. In the foreign country, a fall in demand for its exports discourages investment and employment, and, coupled with a fall in imports from the shock-hit country, these falls reduce production of intermediate goods and hence final goods abroad. Therefore, the foreign country experiences a slowdown of real economic activity as a result of a credit shock in its trade partner economy.

Alternative calibrations of our model reveal that the degree of credit crisis propagation is influenced by the home bias in international trade and the type of goods countries trade with each other. We show that a lower home bias dampens the domestic recession, but amplifies international transmission of financial shocks. Because a lower home bias increases the weight of

imported goods in the final-good production, countries are more susceptible to the health of its trade partner and less to its own economy. Therefore, for the shock-hit country, a lower home bias mitigates the impact of the shock on its domestic production, as the reliance on its trade partner is relatively larger. On the contrary, for the trade partner economy, a larger weight on imports from the shock-hit economy in its production of final goods increases the effects of the shock from abroad on its own economy. Therefore, with more international trade, a credit shock and the resulting fall in production and exports in one country have larger effects on its trade partners. This result is in line with the empirical finding of Lane and Milesi-Ferretti (2011) mentioned above that the pre-crisis level of openness to international trade is significantly correlated with the intensity of the crisis propagation. This also highlights a linkage between the trade collapse and the propagation of financial crisis, suggesting that the contraction in economic activity in large advanced economies may have been transmitted through a sharp contraction in world trade.

We also find that when traded goods are less substitutable across countries, the domestic recession is less severe but international transmission is amplified. When domestically produced intermediate goods cannot be easily substituted with imports from abroad, the higher reliance on domestic goods mitigates a fall in domestic production of intermediate goods, and the recessionary effects of the credit shock on domestic investment and employment can be dampened. On the other hand, for the foreign country, because a decline in imports from the shock-hit country cannot be easily substituted with its own products, final good production falls by more, thereby resulting in larger falls in their investment and consumption. This result is consistent with the finding of Heathcote and Perri (2002) who show in a two-country business cycle model that the international comovement of output is decreasing in the cross-country elasticity of substitution under complete international financial markets.

As in Khan and Thomas (2013), tighter credit constraints have disproportionately larger effects on firms with smaller cash-on-hand but relatively higher productivity as they are unable to take on sufficient loans to finance their optimal levels of investment. As a result, capital is allocated to less efficient firms, and this leads to an endogenous fall in measured total factor productivity (TFP). Comparing to our model economy's responses to an exogenous TFP shock of the equal magnitude and persistence, we find that a credit shock and the resulting endogenous fall in measured TFP generate significantly larger falls in aggregate variables in both domestic and foreign countries and international trade. For instance, the trough of the fall in GDP in the

foreign country is twice as deep with a credit shock as with an exogenous productivity shock.

The remainder of the paper is organized as follows. In section 2, we examine the business cycles of G7 countries and the U.S. financial crisis during and after the 2007-2009 recession. Section 3 reviews the literature related to our analysis. In section 4, we describe the model economy, and the calibration of the model is explained in section 5. Results are reported in section 6, and section 7 concludes.

2 The U.S. financial crisis and the global recession

In this section, we briefly review the business cycle fluctuations of the United States and other G7 countries during and following the 2007-2009 recession as well as the credit conditions in the United States. Figure 1 shows log-detrended quarterly series of real GDP, investment, consumption and employment for the United States from 2007Q4 to 2013Q1, expressed as percentage deviations from their respective levels in 2007Q4 when the U.S. recession started.

By the second quarter of 2009, real GDP and consumption fell by 5.3 percent and 4.1 percent, respectively. Investment fell drastically, reaching 14.3 percent below the 2007Q4 level in 2009Q2. Consumption and investment remained near their respective trough levels for a few quarters until they started to recover gradually in 2010. Although exhibiting a relatively slow decline for the first several quarters at the onset of the recession, employment eventually reached 4.6 percent below its 2007Q4 level in 2009Q4.

As widely documented, the subsequent recovery of the U.S. economy from this crisis has been sluggish and uneven. Real GDP and consumption had a slow but steady recovery until 2010Q4, but have remained about 2 percent below the 2007Q4 level since then. The recovery of employment has also been sluggish, remaining 1.5 percent below the 2007Q4 level. The recovery of investment has particularly slowed down since the mid 2011. As of 2013Q1, none of these series had reached the pre-crisis levels.

A similar pattern of a steep economic downturn and a sluggish recovery was observed across other advanced economies during the same period. In figure 2, we plot the log detrended series of real GDP, investment, consumption and employment for G7 countries from 2007Q4 to 2013Q1. As in figure 1, these series are shown as percentage deviations from their respective 2007Q4 levels. We see a strong comovement in real GDP and investment across these countries, particularly during the U.S. recession period. Although less synchronized across countries compared to real GDP and

investment, consumption also fell in all the G7 countries until the mid 2009 and exhibited gradual recoveries until the mid 2010. Relative to other G7 countries, the fall in the U.S. employment was distinctively larger. As discussed in Perri and Quadrini (2014), this may be due to differences in the structure of the local labor market across these countries. Nonetheless, other G7 countries experienced falls in employment and its sluggish recovery in the following years as well.

What could potentially be the cause of such severe global recession? Some have argued that it was triggered by a financial crisis in the United States. Following the bursting of the housing bubble in the mid 2000's, it became increasingly evident by 2007 that credit market conditions had begun to deteriorate in the United States. According to the Senior Loan Officer Opinion Survey of the Federal Reserve Board, many more banks started to enforce stricter conditions on their loans in 2007, and the number of domestic banks which tightened their loan standard soared between 2007 and 2008, reaching 80 percent (in net) by the mid 2008, as seen in the left panel of figure 3. The tighter loan standards are reflected in a sharp decline in the growth rate of private sector debt, shown in the right panel of figure 3. With the peak of the housing bubble burst in 2006-2007, the growth rate of private sector debt plummeted from 8.4 percent to -1.7 percent between 2007 and 2009.

3 Related literature

There is a growing line of the literature that examines international transmission of shocks and the cross-country business cycle comovement during the recent recession in quantitative frameworks. In particular, this paper is related to recent studies that focus on frictions in the financial markets and their role in amplifying and propagating aggregate shocks across countries.

Devereux and Yetman (2010) and Devereux and Sutherland (2011) develop a two-country model with international financial markets for bond and equity, and study the financial contagion effect of the equity market integration. In their model, investors hold equity positions in both domestic and foreign assets; however, the amount of debt they can issue is constrained by their net worth. In Devereux and Yetman (2010), they show that, in the presence of binding leverage constrains and the international equity market integration, a negative productivity shock in one country leads to a fall in asset prices of both countries, which in turn tightens the leverage constraints and reduces borrowing in both countries. As borrowing by investors is reduced, the resulting simultaneous reduction in investment in fixed assets across countries lead to interna-

tional comovement. Using a similar framework, Devereux and Sutherland (2011) show that an endogenous tightening of the leverage constraint also generates cross-country comovements of GDP, asset prices and fixed-asset investment.

Dedola and Lombardo (2009) develop an endogenous portfolio-choice model with financial frictions in the spirit of the financial accelerator models of Bernanke, Gertler and Gilchrist (1999). Investors purchase claims to capital stocks that are installed in both the domestic and foreign countries. However, when borrowing to finance their capital investment, investors face an external finance premium which is decreasing in their net worth. When asset prices fall in one country, undercapitalized investors cut borrowing and investment domestically and abroad in order to restore net worth. As financially constrained investors try to deleverage by selling off domestic and foreign risky assets, this worsens the balance sheet of investors abroad, thereby generating strong cross-country comovements.

In these studies, the cross-country exposure of assets in the balance sheet of constrained agents serves as an important channel through which shocks are transmitted across countries, and frictions in the international equity markets amplify such international transmission of shocks. Our paper, in contrast, focuses on collateral constraints and firm heterogeneity as a source of distortions in the efficient allocation of capital within a country, and studies how this distortion in production capacity in one country can be transmitted abroad.

More recently, Perri and Quadrini (2014) develop a two-country model in which firms face borrowing constraints to finance investment and labor as working capital. In their model, firms can purchase capital of liquidated firms, but are subject to a borrowing constraint. They assume that firms borrow from a global bond market at a common interest rate, and there are investors who can purchase shares of firms in both countries. Because of the diversification by the investors, the prices of collateral and hence credit conditions are equalized across countries. They show that, when the liquidation value of capital is binomial, market expectations of low resale prices of the defaulting firms' assets become a self-fulfilling equilibrium, and induce a global shortage of credit and a sharp contraction of real activity across countries. Our model differs from theirs in that while the credit tightness in their model is always equalized across countries due to the presence of investors who can purchase firm shares domestically and abroad, we assume that the price of borrowing is independent across countries. Because firms in our model are heterogeneous in capital, debt and productivity, the tightness of credit constrains in our model varies endogenously

across firms, depending on their current cash on hand and regardless of their location.

This paper also contributes to the literature on the role of financial frictions as a propagation mechanism of business cycle fluctuations.[3] In particular, our focus on collateralized borrowing constraints as a source of frictions relate to a line of studies first advanced by Kiyotaki and Moore (1997).[4] In a seminal paper, Kiyotaki and Moore (1997) introduce a model wherein durable assets serve as collateral for loans, and examine how credit constraints interact with aggregate economic activity over the business cycle. They show that the interdependence of credit limits and the prices of collateralized assets plays an important role in amplifying and transmitting shocks that affect firms' net worth.

The model we develop in this paper is a two-country extension of the financial frictions model of Khan and Thomas (2013) which introduces an endogenous TFP channel of credit shock propagation. In their closed-economy environment, firms experience persistent shocks to firm-level productivity levels, and face collateralized constraints when borrowing to finance investment in physical capital. Firm heterogeneity leads to the level of capital accumulation specific to individual firms, and investment is partially irreversible. They show that this partial irreversibility leads firms to make nonzero investment only if their capital stock falls outside a certain range. When credit constraints are tightened, the limited access to credit prevents smaller firms with relatively higher productivity to invest in their optimal levels of capital stock. As a result, credit shocks disrupt an efficient allocation of capital across firms, and induce an endogenous decline in measured TFP, which in turn generates persistent effects on the aggregate economy.

4 Model

There are two symmetric countries: country 1 and country 2. In each country, there is a unit measure of intermediate-good firms with a decreasing-returns-to-scale technology whose output is sold both domestically and abroad. They hire labor from domestic households, and own their individual capital stocks used for production. In addition to country-specific productivity differences, firms face persistent differences in their individual productivity levels. Each firm borrows in order to finance their investment in physical capital; however, their borrowing may be constrained

[3] See, for example, Bernanke and Gertler (1989), Aiyagari and Gertler (1999), Bernanke, Gertler and Gilchrist (1999), Kocherlakota (2000), and Cooley, Marimon and Quadrini (2004).

[4] See, for example, Boz and Mendoza (2012) and Jermann and Quadrini (2012) in the closed-economy settings, Mendoza (2010) in a small open economy, and Perri and Quadrini (2014) in a two-country economy.

by a collateralized borrowing limit that is determined by the current level of its cash on hand. Domestically produced intermediate goods are combined with imported intermediate goods by a perfectly competitive representative final-good producer to produce final goods. Final goods are used for consumption by households and investment by domestic intermediate-good firms. Each country is inhabited by a continuum of infinitely-lived identical households, each with access to a full set of state-contingent nominal bonds. We assume that prices are perfectly flexible, and all markets are perfectly competitive.

For convenience, we summarize the aggregate state of the economy by $A \equiv (Z, S)$. $Z = (z_1, z_2, \theta_1, \theta_2)$ represents the exogenous state, where z_c is country-specific productivity, and θ_c is a credit shock parameter in country c, for $c = 1, 2$. $S = [\mu_1(k, b, \varepsilon), \mu_2(k, b, \varepsilon), B_1, B_2]$ represents the endogenous state, where $\mu_c(k, b, \varepsilon)$ denotes the start-of-period distribution of intermediate-good firms in country c, for $c = 1, 2$, over capital stock k, outstanding debt b, and firm-level productivity ε, and B_c denotes state-contingent bonds held by households in country c, for $c = 1, 2$, at the beginning of the period. All agents in the economy take as given the evolution of the endogenous state according to an equilibrium mapping $S' = \Gamma(A)$.

We describe the preferences, technologies and optimization problems for country 1 below. Where necessary for clarity or in defining notation, we also specify the country 2 counterparts.

4.1 Households

The representative household in country c is endowed one unit of time in each period, and values consumption and leisure according to a period utility function $u(C_c, 1 - N_c)$. Future utility is discounted by the subjective discount factor β. The household has access to a complete set of state-contingent nominal bonds, B_c, which are denominated in units of country 1 currency. It enters the current period with nominal wealth $B_c(A^t)$, where A^t denotes the full history of the economy up through the current period. It also receives real dividends $d_c(A^t)$ from domestic intermediate-good firms.

Given its wealth and equilibrium prices, the household in country 1 chooses its current consumption, C_1, the level of labor to supply to domestic intermediate-good firms, N_1, the amount of lending to domestic intermediate good firms, and the quantity of bonds to purchase for next period. Let $B_1(A^{t+1})$ denote the amount of bonds purchased in the current date to deliver one unit of country 1 currency if the specific history $A^{t+1} = [A^t, A_{t+1}]$ is realized next period, and

let $\rho(A^{t+1}|A^t)$ be the real price of one such bond denominated in units of country 1 consumption goods.

The household's optimization problem may be expressed as:

$$v^1(B_1(A^t), A^t) = \max_{C_1, N_1, \{B_1(A^{t+1})\}, B_1^F(A^{t+1})} u(C_1, 1 - N_1) + \beta \int_{A^{t+1}} v^1(B_1(A^{t+1}), A^{t+1}) G(dA^{t+1}|A^t)$$

subject to:

$$\frac{B_1(A^t)}{P_1(A^t)} + w_1(A^t)N_1 + d_1(A^t) + B_1^F(A^t) \geq C_1 + \int_{A^{t+1}} \rho(A^{t+1}|A^t) B_1(A^{t+1}) + q_1(A^t) B_1^F(A^{t+1}),$$

where $G(A^{t+1}|A^t)$ represents the conditional probability of history A^{t+1} next period given current history A^t, $w_1(A^t)$ is the current real wage, and $P_1(A^t)$ is the current aggregate price level. Intermediate-good firms in country 1 borrow $q_1(A^t)B_1^F(A^{t+1})$ from the household in the current period, and repay $B_1^F(A^{t+1})$ next period.

The household in country 2 solves a similar problem, but it trades in nominal bonds denominated in units of country 1 currency. Its existing bonds $B_2(A^t)$ return $\frac{1}{P_1(A^t)}$ units of country 1 final output, each of which is worth $\frac{1}{Q(A^t)}$ units of country 2 consumption, where $Q(A^t)$ represents the real exchange rate (the real price of country 2 final output in units of country 1 consumption). Similarly, in order to purchase one country 1 nominal bond for next period state A^{t+1}, the country 2 household must pay $\rho(A^{t+1}|A^t)$ units of country 1 consumption goods, each costing $\frac{1}{Q(A^t)}$ units of country 2 consumption.

The optimization problem of the country 2 household may be expressed as:

$$v^2(B_2(A^t), A^t) = \max_{C_2, N_2, \{B_2(A^{t+1})\}} u(C_2, 1 - N_2) + \beta \int_{A^{t+1}} v^2(B_2(A^{t+1}), A^{t+1}) G(dA^{t+1}|A^t)$$

subject to:

$$\frac{B_2(A^t)}{P_1(A^t)Q(A^t)} + w_2(A^t)N_2 + d_2(A^t) + B_2^F(A^t) \geq C_2 + \int_{A^{t+1}} \frac{\rho(A^{t+1}|A^t)}{Q(A^t)} B_2(A^{t+1}) + q_2(A^t) B_2^F(A^{t+1}).$$

First order conditions with respect to bond holdings in the two countries are

$$\lambda_1(A^t)\rho(A^{t+1}|A^t) = \beta \frac{\lambda_1(A^{t+1})}{P_1(A^{t+1})} G(A^{t+1}|A^t) \tag{1}$$

$$\lambda_2(A^t)\frac{\rho(A^{t+1}|A^t)}{Q(A^t)} = \beta \frac{\lambda_2(A^{t+1})}{P_1(A^{t+1})Q(A^{t+1})} G(A^{t+1}|A^t) \tag{2}$$

where $\lambda_1(A^t)$ is the Lagrange multiplier on the period budget constraint in country 1, and $\lambda_2(A^t)$ is the Lagrange multiplier on the budget constraint in country 2. Since these conditions hold for all periods and states of the economy, we can use equations (1) and (2) to write:

$$\beta \frac{\lambda_1(A^{t+1})}{P_1(A^{t+1})\lambda_1(A^t)} G(A^{t+1}|A^t) = \beta \frac{\lambda_2(A^{t+1})Q(A^t)}{P_1(A^{t+1})Q(A^{t+1})\lambda_2(A^t)} G(A^{t+1}|A^t).$$

This yields an expression for the real exchange rate as a ratio of the country 2 household's marginal utility of consumption relative to that of the country 1 household:[5]

$$Q(A^t) = \frac{\lambda_2(A^t)}{\lambda_1(A^t)}. \tag{3}$$

4.2 Final goods production

The perfectly competitive representative final-good producer in country 1 combines intermediate goods produced in country 1, y^{D1}, and imported intermediates from country 2, y^{X2}, to produce final goods, H_1, through the CES production function:

$$H_1 = \left[\omega \left(y^{D1} \right)^{\frac{\rho-1}{\rho}} + (1-\omega) \left(y^{X2} \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \tag{4}$$

where ρ is the elasticity of substitution between domestic goods and imports (Armington elasticity), and ω is the relative weight on home-produced goods (home bias).

The final good producer in country 1 sells its output to households (for consumption) and domestic intermediate-good firms (for investment) at price $P_1(A)$. The nominal prices associated with intermediate goods from each country are dominated in the currency of the country in which the good is sold.

Let $p^{D1}(A)$ be the price of country 1 intermediate good sold in country 1 (denominated in country 1's currency), and let $p^{X2}(A)$ denote the price of country 2 intermediate goods sold in country 1 (denominated in country 1's currency). Taking as given the price of its output, $P_1(A)$, the prices of its inputs, $p^{D1}(A)$and $p^{X2}(A)$, and the technology given in equation (4), the final-good producer solves the following static profit maximization problem in each period:

$$\max_{y^{D1}, y^{X2}} \; P_1(A)H_1 - p^{D1}(A)y^{D1} - p^{X2}(A)y^{X2}.$$

[5] We assume an initial state for the economy wherein $\frac{\lambda_1(A^0)}{\lambda_2(A^0)} Q(A^0) = 1$.

The resulting conditional factor demands are

$$y^{D2} = \omega^{\rho}\left(\frac{p^{D2}(A)}{P_2(A)}\right)^{-\rho} H_2 \tag{5}$$

$$y^{X1} = (1-\omega)^{\rho}\left(\frac{p^{X1}(A)}{P_2(A)}\right)^{-\rho} H_2. \tag{6}$$

Similarly, the problem of final-good producers in country 2 yields their demand for country 2 intermediate goods, $y^{D2} = \omega^{\rho}\left(\frac{p^{D2}(A)}{P_2(A)}\right)^{-\rho} H_2$, and imports from country 1, $y^{X1} = (1-\omega)^{\rho}\left(\frac{p^{X1}(A)}{P_2(A)}\right)^{-\rho} H_2$.

Given the conditional factor demands obtained above, we can retrieve the price index (or aggregate price level). Using equations (5) and (6), we have the following.

$$P_1(A) = \left[\omega^{\rho}\left(p^{D1}(A)\right)^{1-\rho} + (1-\omega)^{\rho}\left(p^{X2}(A)\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{7}$$

Similarly, the aggregate price index for country 2 is given by

$$P_2(A) = \left[\omega^{\rho}\left(p^{D2}(A)\right)^{1-\rho} + (1-\omega)^{\rho}\left(p^{X1}(A)\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}.$$

4.3 Intermediate goods firms

Each intermediate good firm is identified by (k, b, ε), where k is the capital the firm selected at the end of last period, b is the level of debt it took on last period, and ε is its current idiosyncratic productivity level. Each firm in country c produces its intermediate good through the production function

$$y_c = z_c \varepsilon k_c^{\alpha} n_c^{\nu}, \tag{8}$$

where z_c is the aggregate productivity level in its country, ε is its firm-specific productivity, k is its capital, and n is the domestic labor it hires at real wage $w_c(A)$. We assume that the firm-level productivity ε follows a Markov chain with transition probabilities $\varphi_{ij}^{\varepsilon} = pr(\varepsilon' = \varepsilon_j \mid \varepsilon = \varepsilon_i)$. Any such firm residing in country c chooses n_c to solve:

$$\max_{n_c}\left(\frac{p^{Dc}(A)}{P_c(A)}\right) y_c - w_c(A) n_c,$$

subject to the production technology (8).

4.4 Cash-on-hand and a collateralized borrowing constraint

Define a firm's cash-on-hand, x, as the real value of a firm's static profits and non-depreciated capital net of out-standing debt, denominated in units of the domestic final good:

$$x \equiv \pi + (1-\delta)k - b, \tag{9}$$

where π is the firm's static profit flow which is a solution to the static maximization problem above,

$$\pi_c \equiv \left(\frac{p^{Dc}(A)}{P_c(A)}\right) y_c - w_c(A) n_c.$$

For each unit of debt a firm in country c incurs for next period, it obtains $q_c(A)$ units of domestic final output in the current period. Thus, for a firm in country 1, a debt with face value b' incurred for next period yields $q_1(A)b'$ units of domestic goods now. The firm's total real resources to be divided between dividends, $D \geq 0$, and future capital, k', are:

$$x + q_1(A)b' \geq D + k'. \tag{10}$$

We assume each such firm faces a collateral-based borrowing constraint as a function of its net worth:

$$b' \leq \theta_1 x \tag{11}$$

where $\theta_1 > 0$ is a parameter representing the exogenous tightness of the borrowing constraint.

4.5 Firm's problem

Each period, a fixed fraction $\lambda \in (0,1)$ of the intermediate-good firms are liquidated just after production but prior to investment, and replaced by new entrants. If liquidated, firms neither invest nor borrow, and therefore we have $k' = b' = 0$. Let $\Lambda_1(A)$ be the valuation a firm in country 1 assigns to its current real profit flows given the current aggregate state A.[6]

The value of a country 1 firm at the beginning of the period, prior to the liquidation draw, is given by

$$V_0(x, \varepsilon, A) = \lambda \Lambda_1(A) x + (1-\lambda) V(x, \varepsilon, A), \tag{12}$$

[6] In equilibrium, Λ_1 will be the country 1 household marginal utility of consumption $D_1 u(C_1, 1-N_1))$. Our use of Λ_1 converts the firm value function from being defined in units of country 1 output to instead being defined in units of country 1 marginal utility. In doing this, we can impose equilibrium state-contingent discounting by having the firm discount its future value by the household subjective discount factor β.

while the firm's value conditional on learning it will survive to produce in the next period is

$$V(x,\varepsilon_i,A)=\max_{k',b'}\left[\Lambda_1(A)\Big[x+q_1(A)b'-k'\Big]+\beta\sum_{j=1}^{N_\varepsilon}\varphi_{ij}^{\varepsilon}V_0(x_j',\varepsilon_j,A')\right], \tag{13}$$

subject to:

$$x_j'=\pi_1(k',\varepsilon_j,A')+(1-\delta)k'-b', \text{ and} \tag{14}$$

$$b'\leq\theta_1 x. \tag{15}$$

4.6 Net exports

We define country 1's net exports NX_1 as its exports less imports, denominated in the real value of country 1 final output:

$$NX_1\equiv\frac{p^{X1}y^{X1}}{P_2}Q-\frac{p^{X2}y^{X2}}{P_1}$$

4.7 Recursive equilibrium

A *recursive competitive equilibrium* is a set of functions,

$$\left(w_1,w_2,q_1,q_2,V_0,V_0,N_1,N_2,K_1,K_2,B_1^F,B_2^F,v^1,v^2,C_1,C_2,H_1,H_2,Q\right),$$

that solve firm and household problems and clear the markets for assets, labor and outputs in each country, as described by the following conditions.

(i) The markets for final goods in country 1 and country 2 clear

$$\begin{aligned}H_1(A) &= C_1(A)+I_1(A),\\ H_2(A) &= C_2(A)+I_2(A),\end{aligned}$$

where the total demands for investment goods in country 1 and country 2 are:

$$\begin{aligned}I_1(A) &\equiv \int\Big[g_1(k,b,\varepsilon;A)-(1-\delta)k\Big]\mu_1(d\left[k\times b\times\varepsilon\right]),\\ I_2(A) &\equiv \int\Big[g_2(k,b,\varepsilon;A)-(1-\delta)k\Big]\mu_2(d\left[k\times b\times\varepsilon\right]),\end{aligned}$$

and g_1 and g_2 are the capital policy functions for firms solving the problems in (13)-(15) for each country. H_1 and H_2 are determined by (4) and its country 2 counterpart, alongside the

conditional factor demands in (5), (6), and their respective country 2 counterparts. These two conditions will determine the aggregate price levels, P_1 and P_2.

(ii) Worldwide demand for the country c intermediate must be satisfied by country c firms:

$$y^{Dc}(A) + y^{Xc}(A) = Y_c,$$

for $c = 1, 2$, where the total production of country c intermediates is defined as

$$Y_c \equiv \int y_c(k, b, \varepsilon; A)\mu_c(d\,[k \times b \times \varepsilon]).$$

These conditions are satisfied by an appropriate set of intermediate relative prices $\frac{p^{D1}}{P_1}$, $\frac{p^{X1}}{P_2}$, $\frac{p^{D2}}{P_2}$, and $\frac{p^{X2}}{P_1}$ with the real exchange rate Q from equation (3).

(iii) Equilibrium in the markets for firm shares requires that each firm in each country value its dividends by the marginal utility of the household that owns it.

$$\Lambda_c(A) = \lambda_c(A) = D_1 u\Big(C_c(A), 1 - N_c(A)\Big)$$

for $c = 1, 2$.

(iv) Equilibrium in the labor markets is achieved when total labor demand in each country is exactly satisfied by that country's representative household:

$$N_c(A) = \int n_c(k, b, \varepsilon; A)\mu_c(d\,[k \times b \times \varepsilon])$$

for $c = 1, 2$. These conditions are satisfied by the following equilibrium wages.

$$w_c(A) = \frac{D_2 u\Big(C_c(A), 1 - N_c(A)\Big)}{\Lambda_c(A)},$$

for $c = 1, 2$.

(v) Equilibrium in the debt markets is achieved when the real price a firm in country c pays to borrow one unit in the current period, q_c^{-1}, is equated to the expected gross real interest rate in that country. This implies the following additional price restrictions.

$$q_c(A) = \beta \left[\frac{D_1 u\Big(C_c(A'), 1 - N_c(A')\Big)}{D_1 u\Big(C_c(A), 1 - N_c(A)\Big)} \right],$$

for $c = 1, 2$.

5 Calibration

The model is calibrated to the annual frequency. We assume that the period utility of the representative household takes the form of the GHH preferences (Greenwood, Hercowitz and Huffman, 1988):

$$u(C_i(A), N_i(A)) = \frac{1}{1-\phi}\left[\left(C_i(A) - \frac{\kappa}{\eta}N_i(A)^{\eta}\right)^{1-\phi} - 1\right].$$

The household discount factor β is set equal to 0.9615 to imply an annual interest rate of 4 percent. We set the relative risk aversion in the household utility function ϕ equal to 1 following Schmitt-Grohe and Uribe (2003). The labor exponent in the utility function η is set equal to 1.5882 so that the labor elasticity is 1.7, as used in Greenwood, Hercowitz and Huffman (1988).

The elasticity of substitution between domestic and imported intermediate goods ρ is 0.9, taken from the estimate by Heathcote and Perri (2002). We follow Cooley and Prescott (1995) and set the share of labor in production υ equal to 0.6. The firm liquidation rate χ is 0.0869 which implies that 8.69 percent of firms exit the market each period, consistent with data from the Business Dynamics Statistics of the U.S. Census Bureau.

The remaining set of parameters are calibrated so that the steady state characteristics of our model economy match some important characteristics from data for the United States. We set the weight on labor in the household utility function κ equal to 1.48 so that households work one-third of their time in steady state. The weight on domestic intermediate goods in the final-good production ω is set equal to 0.93 so that the steady state imports-to-GDP ratio is 9 percent.

The share of capital in the intermediate-good production α is 0.33 which implies that the steady state capital-to-GDP ratio is 2.3. We set the capital depreciation rate δ equal to 0.066 so that the steady state aggregate investment-to-capital ratio is 0.066 to be in line with the observed value of 0.067. The borrowing constraint parameter θ_c is 0.95 in steady state for $c = 1, 2$. This implies that the debt-to-asset ratio is 0.31 in steady state, which is close to 0.37 in the data. We set the employment of new firms ξ to be 0.2846 so that the labor of a new firm is 28.6 percent of the employment by an average firm. The persistence and standard deviation of the firm-level productivity process, ρ_{ε} and σ_{ε}, are chosen jointly to match the mean and standard deviation of the firm-level investment-to-capital ratio. Parameter values are summarized in table 1.

6 Results

6.1 Credit Crisis in Country 1

We begin our analysis of credit shock propagation by examining dynamic responses of our model economy to a credit shock in country 1. The credit shock we consider is a 70-percent fall in the country 1 borrowing constraint parameter θ_1, which remains at that level for three periods before recovering gradually. We choose the magnitude of the initial fall in the parameter such that total debt of firms in country 1 declines by about 45 percent at the trough. This is in line with the finding by Ivashina and Scharfstein (2009) that loans used to fund investment in equipment and structures fell by 48 percent during the 2007-2009 financial crisis, using Reuters DealScan data on new lending to large corporations. Persistence of the shock is assumed to be 0.3.

6.1.1 Responses in the domestic economy

Figure 4 shows the impulse responses of country 1. The credit shock affects firms' current investment decisions and hence their capital stock next period. Therefore, the responses of aggregate variables are rather modest on impact of the shock. Nonetheless, households immediately foresee a lower future return on investment, leading them to start reducing labor right away. Labor falls by 0.2 percent on impact of the shock, which in turn is reflected in a fall of GDP by 0.4 percent. Expecting a lower return on saving in the future, households temporarily increase consumption on impact of the shock, generating a transitory 1 percent increase in consumption.

After the first period, as the credit shock begins to have direct effects on firms' production decisions, the economy's responses become more pronounced, particularly during the next three periods when capital accumulation becomes affected by the tight borrowing constraints. The tight borrowing condition leads firms to cut borrowing and investment. Aggregate debt falls by around 45 percent for three periods following the shock, before gradually reverting to its steady state. Investment falls by 12 percent one period after the shock. The fall in investment reduces demand for final goods, which in turn reduces demand for domestic and imported intermediate goods. The fall in production of intermediate goods can be seen as a fall of GDP by 2.9 percent after one period, reaching a trough at 3.2 percent three periods after the shock. The fall in GDP results in contractions in employment and consumption. Employment falls by around 2.0 percent during the tight constraint period. Consumption starts falling after the initial increase, and reaches a trough of -2.7 percent three periods following the shock.

Limited access to credit due to tighter borrowing constraints can severely restrict investment undertaken by firms with small cash on hand but relatively high productivity levels. As a result, capital becomes distributed to less efficient (but larger) firms, and we see an endogenous decline in measured TFP even though there is no exogenous change in TFP here. Measured TFP falls by 1.4 percent one period after the shock, and remains at around this level for the next two periods, before starting to gradually revert to the steady state level.

As discussed above, the credit shock reduces production of domestic intermediate goods. However, because the capital stock held by domestic intermediate-good producers is predetermined from the pre-shock period, the initial small fall in labor supply is not sufficient to reduce production of intermediate goods to match the fall in domestic demand for their products. The resulting excess supply of country 1 intermediate goods is instead exported to country 2. Together with the lower domestic demand for imported intermediate goods, we see an improvement in net exports, generating a surplus of 0.25 percent (of GDP) on impact of the shock and reaching 0.37 percent in the following period. This large outflow of country 1 intermediate goods is, however, short-lasting as firms adjust their investment and hence capital stock in subsequent periods. With the persistent contraction in production, country 1's exports also fall below the steady state level two periods following the shock. After 4 periods, the fall in exports dominates the fall in imports, and net exports turn slightly negative.

6.1.2 Responses abroad

Figure 5 shows the impulse responses of country 2 to the same credit shock in country 1. As discussed above, country 2 experiences a large influx of intermediate goods from country 1 immediately following the shock. Because intermediate goods of the two countries are assumed to be complements for final-good production, this temporary rise in country 2's imports increases demand for intermediate goods of country 2. To absorb this rise in imports, local production of intermediate goods and hence GDP increase temporarily by 0.4 percent, and employment rises by 0.2 percent on impact of the shock. The resulting increase in production of final goods also temporarily increases consumption and investment by 0.3 percent and 2 percent, respectively. As the rise in investment requires more borrowing, and because country 2's borrowing conditions are unchanged, we see that firms take on more debt in the first few periods.

As country 1's exports begin to decline after the initial temporary hike and fall below the

steady state level two periods after the shock, country 2 also begins to experience negative effects of the credit shock in country 1. The declines in country 1's production and exports to country 2 curtail demand for country 2's intermediate goods and production of final goods, which in turn reduce GDP and employment there. The fall in production of final goods is reflected in falls in consumption and investment. With falling investment, total debt of firms in country 2 begins to decline, and persistently remains below the steady state level for an extended period of time.

Contrary to country 1 where measured TFP declines endogenously due to the tightening of credit constraints, measured TFP in country 2 is not affected as its borrowing conditions remain unchanged.

6.2 Alternative parameterization

In this subsection, we investigate how the propagation of credit shocks in our model economy is affected by different parameterization of the model. In particular, we examine two cases where (i) the home bias is lower (i.e., the steady state size of international trade is larger), and (ii) traded goods are more substitutable. We consider a shock which reduces country 1's credit constraint parameter θ_1 by 70 percent for one period and recovers gradually with persistence of 0.7.

6.2.1 Home bias

In our baseline calibration, imports are 9 percent of GDP in steady state. While this is in line with the U.S. data, the import share is significantly higher for the majority of other advanced economies. To examine how trade openness may affect the propagation of credit shocks, we reduced the weight on domestic intermediate goods in final-good production (the home bias parameter) ω from 0.93 to 0.82, while keeping other parameters unchanged. With this value of ω, the imports share is 20 percent of GDP in steady state.

Figures 6 and 7 show the dynamic responses of country 1 and country 2, respectively. In each figure, we compare the responses from the benchmark calibration and the high-trade case. In figure 6, we see that, when a country has a lower home bias in international trade, the effects of a credit shock on the domestic economy are dampened. The declines in GDP, consumption and labor are smaller with higher international trade for all periods. The fall in investment is larger during the first few periods, but the recovery is faster when the economy is more engaged in international trade. With a smaller weight of domestic intermediate goods in production of final

goods, final-good production is less affected by the shock which disrupts domestic intermediate-good production. Therefore, the shock's effects on domestic consumption and investment are dampened, and hence the fall in employment is also mitigated.

We also see that the initial, temporary spike in country 1's exports becomes larger with a larger trade share, but this is followed by a smaller decline in subsequent periods. With a lower bias toward domestic intermediate goods, country 2 relies more on imports from country 1. As a result, the outflow of country 1's excess supply due to the pre-determined capital stock and the declining domestic demand become amplified. In the subsequent periods, however, as firms in country 1 adjust their capital stock, production declines but by less with a lower home bias. The smaller contraction in production, in turn, leads to a smaller decline in country 1's exports after the initial hike has subsided. On the other hand, with more international trade, the decline in country 1's imports is larger immediately following the shock but consistently smaller in subsequent periods. Given the excess production capacity in country 1 on impact of the shock, final good producers try to mitigate the effects of the excess supply of domestic intermediate goods with a reduction in imports from country 2. When the share of imported goods in the final good production is larger, this adjustment of imports is amplified. As the excess production capacity is eliminated in subsequent periods, the smaller contraction in the domestic economy becomes reflected in the smaller reduction in imports, as we see after two periods following the shock.

Figure 7 compares the international transmission of the credit shock in the benchmark calibration and the high-trade case. In contrast to the responses in country 1 where higher trade dampens the effects of the local credit shock, we see that higher international trade amplifies the international transmission of a credit shock. For country 2, a lower home bias means a larger share of country 1's intermediate goods in their production of final goods. Therefore, the effects of country 1's credit shock can be transmitted to country 2 more easily through changes in imports of intermediate goods from country 1 and ultimately the country 2's production of final goods. Once the effects of the initial inflow of country 1 intermediate goods on country 2 subside, the larger fall of final good production in country 2 leads to larger drops in consumption and investment there. The response of investment is in turn reflected in a gradual decline in borrowing. With the amplified effects on intermediate-good production and hence GDP, employment also falls by more in country 2.

6.2.2 Elasticity of substitution between home and foreign goods

Next, we examine how the propagation of credit shocks may be affected by the substitutability of domestic and imported intermediate goods. In the benchmark calibration, the elasticity of substitution between the goods from two countries (the Armington elasticity) ρ is set equal to 0.9, which implies that domestic and imported intermediate goods are complements. We experiment by increasing the elasticity to 1.5 while keeping other parameters unchanged from the benchmark calibration. The value of 1.5 is often used in international business cycle models (see, for example, Backus, Kehoe and Kydland, 1994; Chari, Kehoe and McGrattan, 2002). Figures 8 and 9 show the impulse responses of country 1 and country 2, respectively, to the same credit shock in country 1, each comparing the responses from the two cases.

In figure 8, we see that, when traded goods are less substitutable, the recessionary effects of a domestic credit shock are dampened. Lower substitutability means that domestic intermediate goods cannot be easily substituted with imports from abroad. Therefore, higher reliance on domestic goods mitigates a fall in domestic production of intermediate goods, which dampens declines in employment and investment, and the recessionary effects of the credit shock on domestic investment and employment are dampened. The resulting smaller fall in intermediate-good production mitigates a drop in final good production, which, together with the smaller fall in employment, dampens the reduction in consumption.

In contrast, we see in figure 9 that lower substitutability of domestic and imported goods amplifies international transmission of a credit shock. When intermediate goods are less substitutable (lower ρ), a decline in imports from the shock-hit country (country 1) cannot be easily substituted with its own products. Therefore, with the decline in country 1's production due to the credit shock and the resulting decline in country 2's imports of intermediate goods, final good production declines by more in country 2 than in country 1. This in turn leads to larger falls in investment and consumption there, which reduces production of own intermediate goods and hence GDP and employment. This result is consistent with the finding of Heathcote and Perri (2002) who show in a two-country business cycle model that the international comovement of output is decreasing in the elasticity of cross-country substitution under complete international financial markets.

6.3 Productivity Shock

In this subsection, we examine the propagation of productivity shocks in our model economy, and compare the dynamic responses to those from a credit shock. We chose the magnitude and persistence of the shock so as to mimic the impulse response of measured TFP in country 1 from the above exercises with a credit shock under various parameterizations. Country 1's exogenous TFP falls by 1.4 percent, and recovers with persistence of 0.6. Figures 10 and 11 show the impulse responses of country 1 and country 2, respectively.

In figure 10, we see that a lower level of aggregate productivity reduces production of intermediate goods and hence GDP immediately, leading to a fall in employment. The contraction of intermediate-good production leads to a reduction in production of final goods, which in turn reduces consumption and investment. In addition, with lower final-good production in country 1, imports of country 2 intermediate goods also fall. Although country 1's exports also fall due to the reduced production of intermediate goods, this fall in imports dominates the fall in exports, and we see an improvement in net exports.

In table 2, we compare the depth of the trough of aggregate variables in country 1, as percentage deviation from their respective steady state levels, in response to the credit shock and the productivity shock. We see that the credit shock has consistently larger effects on the aggregate economy compared to the productivity shock, even though the two shocks reduce measured TFP by the same amount. In particular, the productivity shock has significantly smaller effects on debt. As discussed above, credit shocks drastically limit the borrowing ability of firms, and prevent investment undertaken by firms with smaller cash on hand. This leads to a distortion of the efficient allocation of capital stock across firms, thereby resulting in an endogenous fall in measured TFP, and the shocks have large and persistent effects on the aggregate economy. Productivity shocks, on the other hand, only affect firms' borrowing ability through their effects on firms' static profits, since capital and outstanding debt are predetermined. Therefore, the decline in debt in response to the productivity shock reflects a decline in investment demand, unlike in the case of the credit shock.

The adverse effects of the credit shock are also more pronounced on exports and imports, relative to the productivity shock. While the trough of exports with a productivity shock is -0.62 percent, it is -1.22 percent with a credit shock. Similarly, the trough of imports is -3.07 percent with a credit shock, significantly larger than -2.39 percent with a productivity shock. The large

fall in international trade as a result of a financial shock is consistent with the great trade collapse during the 2007-2009 global recession.

Figure 11 shows the international transmission of the negative aggregate productivity shock in country 1. With the decline in country 1's demand for imports from country 2 and a fall in imports of intermediate goods from country 1, total production of intermediate goods falls in country 2 on impact of the shock, resulting in a fall in labor in country 2 as well. Consumption falls gradually, as the intermediate good production in country 2 experiences a contraction. Due to international risk sharing, investment in country 2 increases initially before falling below the steady state level two periods following the shock.

Table 3 compares the extent of international transmission of credit and productivity shocks by measuring the size of the trough in aggregate variables. With the larger falls in exports and imports, we see that the credit shock has much stronger international propagation than the productivity shock, generating the aggregate effects which are about twice as large.

7 Concluding remarks

In this paper, we investigated the extent to which a credit shock in one country is transmitted to its trade partners. Extending the closed-economy financial frictions model of Khan and Thomas (2013), we developed a two-country dynamic stochastic general equilibrium model wherein intermediate-good producers face persistent idiosyncratic productivity shocks and collateralized borrowing constraints for investment loans. We calibrated the parameters governing firms' decisions on investment and borrowing to match data on aggregate indebtedness and firm-level investment and capital accumulation in the United States.

We find that a credit shock in one country leads to an immediate, sharp contraction in the domestic economy and a delayed but persistent downturn in its trade partners. When credit availability in one country becomes limited, domestic firms cut investment and production, which in turn curtails demand for imported intermediate goods. The fall in demand for imports discourages investment and employment abroad, and, together with a fall in exports of the shock-hit country, these falls reduce production abroad. As a result, the foreign country experiences a slowdown of real economic activity from a credit shock to its trade partner. Importantly, a sudden tightening of credit constraints distorts an efficient allocation of capital across firms, generating an endogenous fall in measured TFP. This amplifies the effects of credit shocks, and leads to a

global recession more severe than the one resulting from exogenous TFP shocks.

The degree of credit crisis propagation is shown to depend on a country's openness to international trade and the type of goods traded across countries. Higher trade openness and lower international substitutability of traded goods dampen the domestic recession but amplify the international transmission of financial shocks. In both cases, a country depends more on the health of its trade partner, and hence a domestic financial shock has smaller effects in the local economy, but larger transmission to abroad. This finding highlights a linkage between the trade collapse and the propagation of financial crisis, suggesting that the contraction in economic activity in large advanced economies may have been transmitted through real channels through a sharp contraction in world trade.

While the model and analysis presented in this paper offer a rich framework of financial frictions faced by firms within a country, one intuitive extension would be to introduce international financial linkages through cross-country borrowing by firms. In our current setup, we only allow households to have access to international financial markets, but this can be extended to include firms' borrowing from foreign sources, while maintaining collateral credit constraints for each financial source. Such an extension would highlight the role of international financial interdependence in propagating financial crisis, and allow for an examination of the relative importance of real and financial channels.

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Table 1: Parameter values

Subjective discount factor	β	0.9615
Utility function		
relative risk aversion	ϕ	1
labor exponent	η	1.5882
Armington elasticity	ρ	0.9
Labor share in production	ν	0.6
Firm liquidation rate	χ	0.0869
Weight on labor in utility	κ	1.48
Home bias	ω	0.93
Capital share in production	α	0.33
Capital depreciation rate	δ	0.066
Borrowing constraint	θ	0.95
Employment of new firms	ξ	0.2846
Firm-level productivity		
persistence	ρ_ε	0.757
standard deviation	σ_ε	0.026

Table 2: Trough of aggregate variables: country 1

	TFP	GDP	Consumption	Investment	Labor	Debt	Exports	Imports
Credit shock	-1.39	-2.77	-1.39	-9.49	-1.75	-44.57	-1.22	-3.07
Productivity shock	-1.40	-2.15	-1.26	-6.49	-1.36	-0.91	-0.62	-2.39

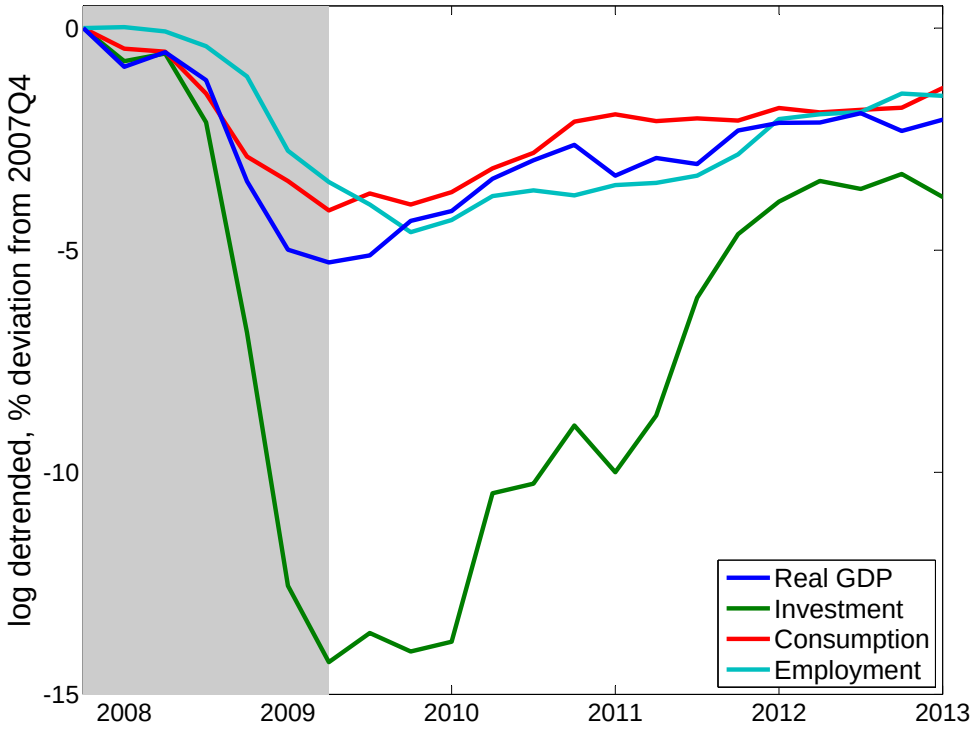
Notes: Maximum declines in aggregate variables in country 1, in response to the respective shock. Row 1 is a 70 percent decline in the borrowing constraint parameter in country 1, θ_1, with a persistence of 0.7. Row 2 is an exogenous productivity decline in country 1 by -1.4 percent, with persistence of 0.6.

Table 3: Trough of aggregate variables: country 2

	GDP	Consumption	Investment	Labor	Debt
Credit shock	-0.18	-0.14	-0.48	-0.11	-0.14
Productivity shock	-0.09	-0.06	-0.21	-0.06	-0.06

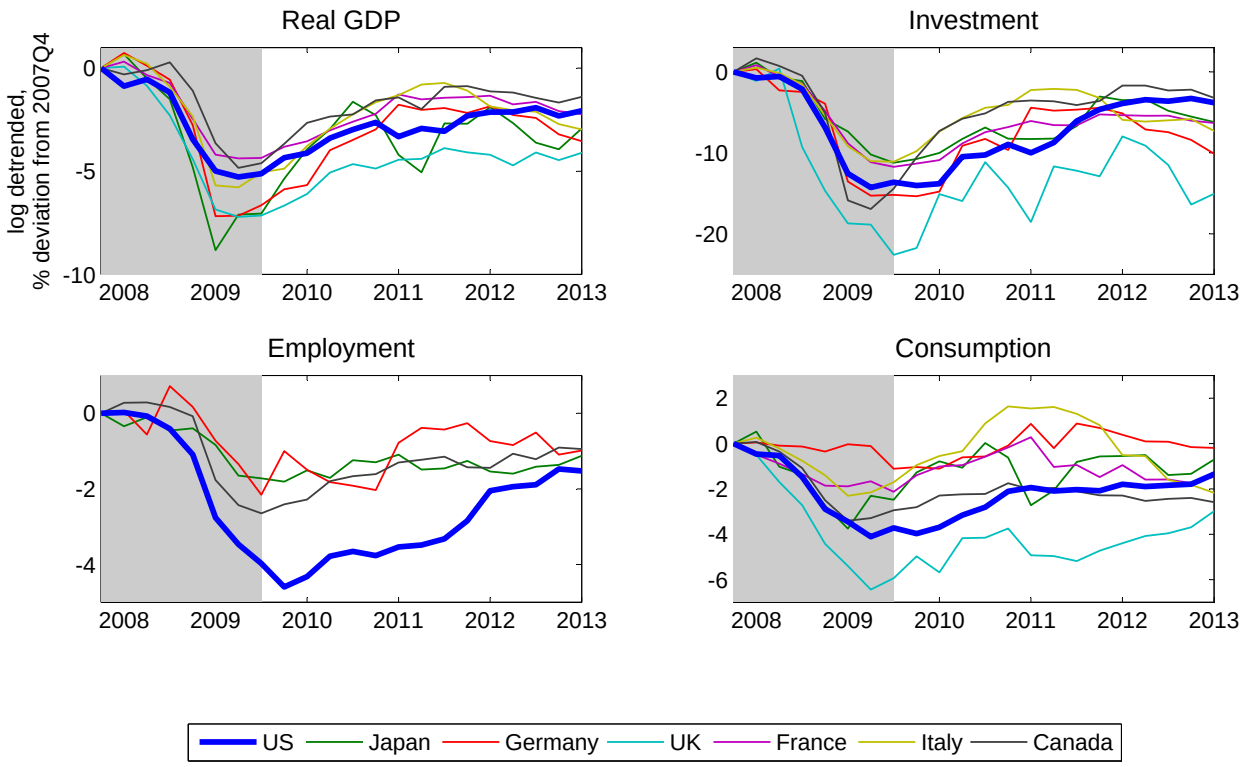
Notes: Maximum declines in aggregate variables in country 2, in response to the respective shock. Row 1 is a 70 percent decline in the borrowing constraint parameter in country 1, θ_1, with a persistence of 0.7. Row 2 is an exogenous productivity decline in country 1 by -1.4 percent, with persistence of 0.6.

Figure 1: U.S. economy and the 2007-2009 recession



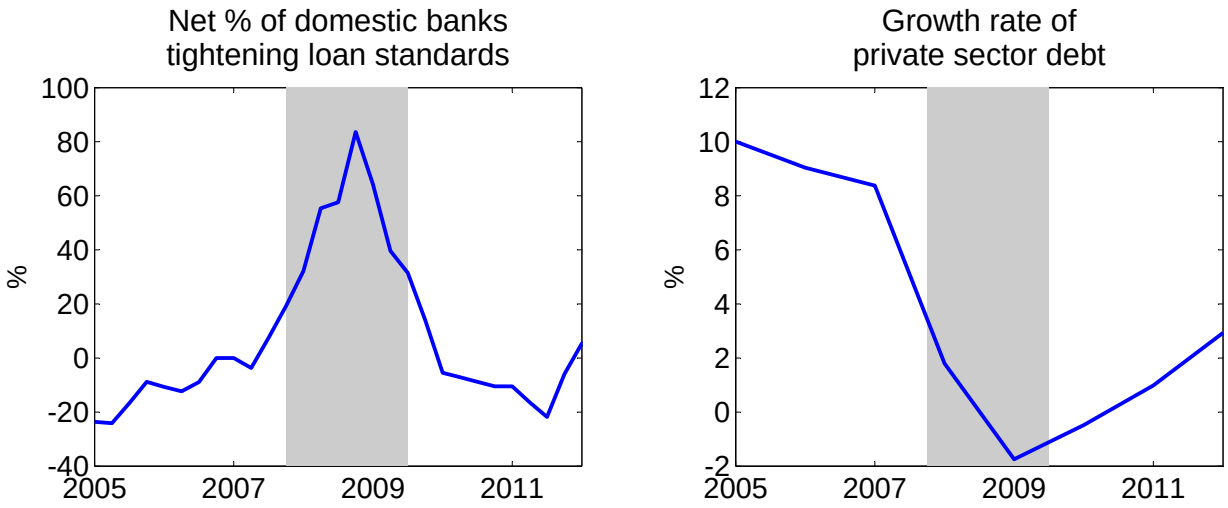
Notes: All series are in logs and detrended using the H-P filter. 2007Q4=0. The shaded area indicates the U.S. recession as defined by the National Bureau of Economic Research. Data are from OECD Main Economic Indicators.

Figure 2: G7 countries and the 2007-2009 U.S. recession



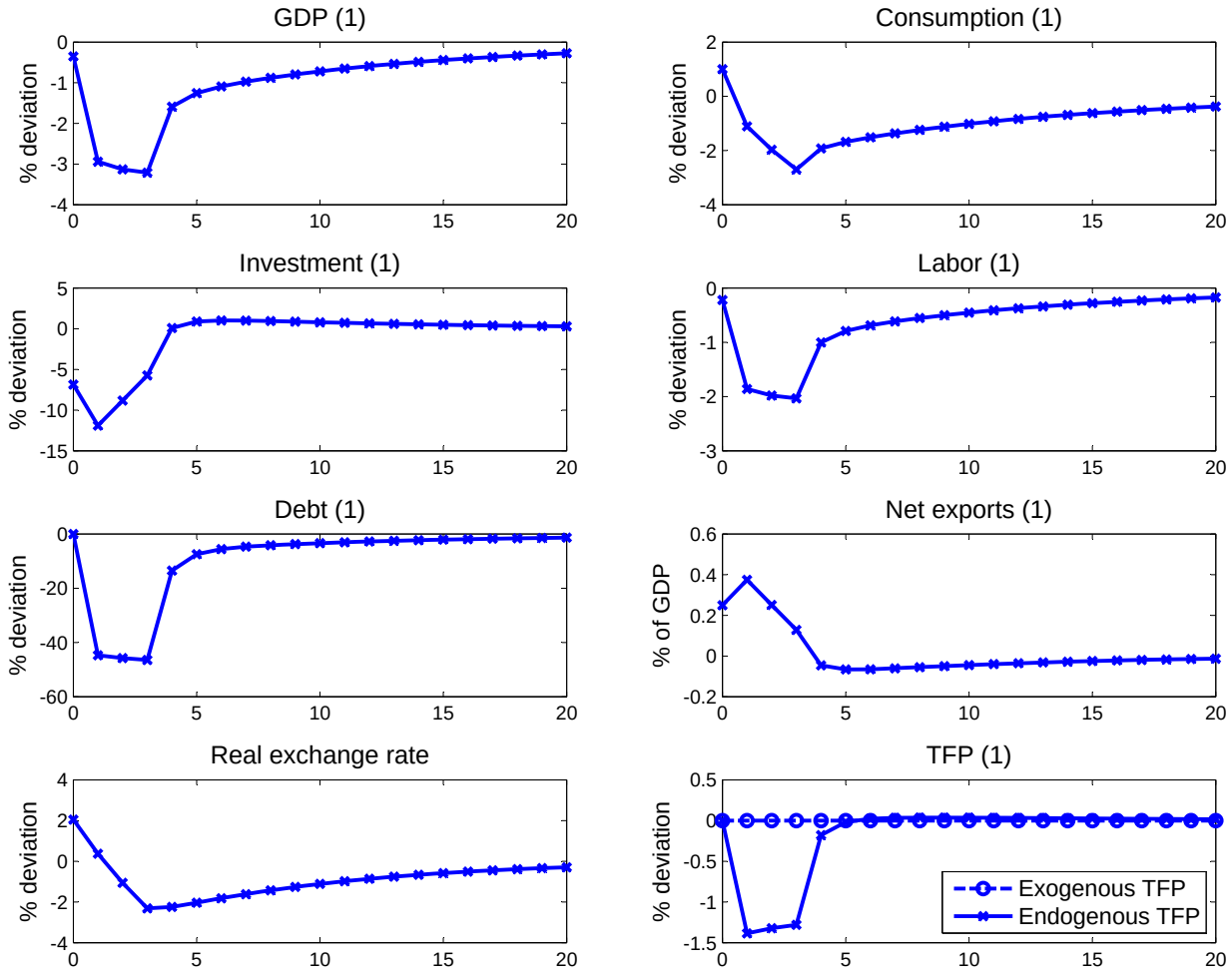
Notes: All series are in logs and detrended using the H-P filter. 2007Q4=0. The shaded area indicates the U.S. recession as defined by the National Bureau of Economic Research. Data are from OECD Main Economic Indicators.

Figure 3: U.S. financial market



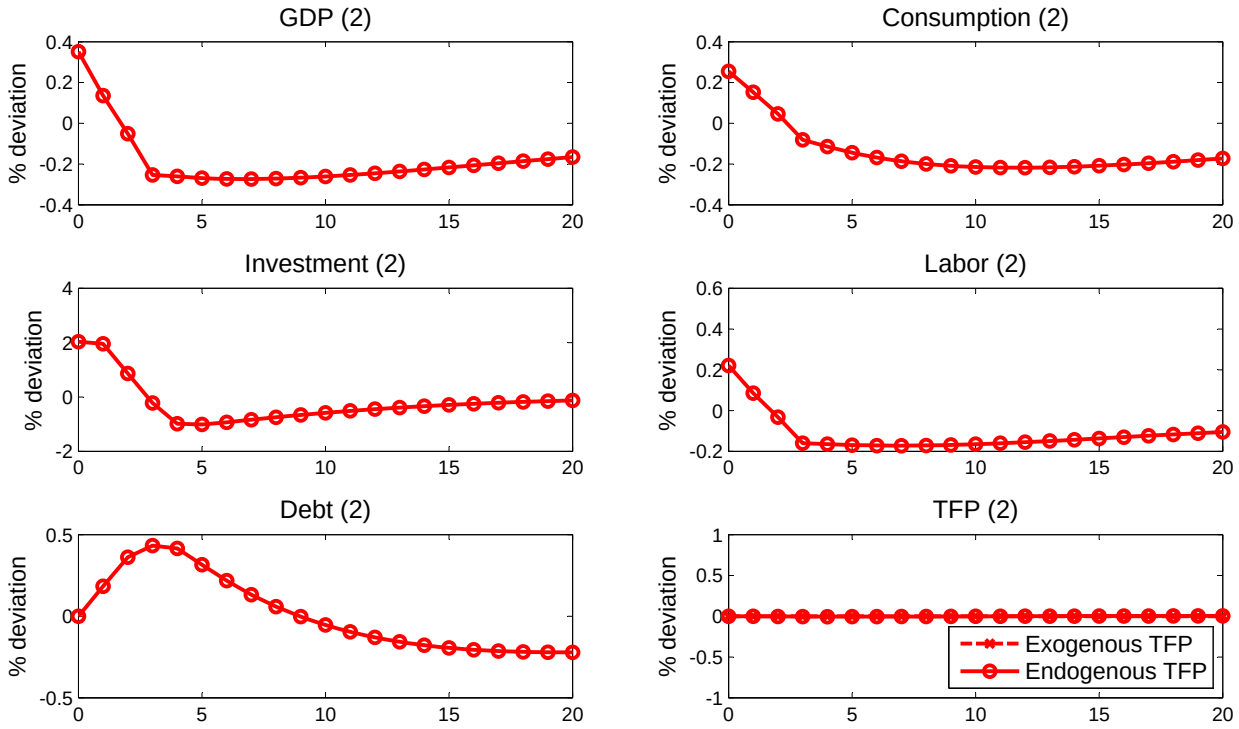
Note: The shaded area indicates the U.S. recession as defined by the National Bureau of Economics Research. *Data sources*: Senior Loan Officer Opinion Survey on Bank Lending Practices, Federal Reserve Board. OECD Main Economic Indicators.

Figure 4: Credit shock: domestic responses



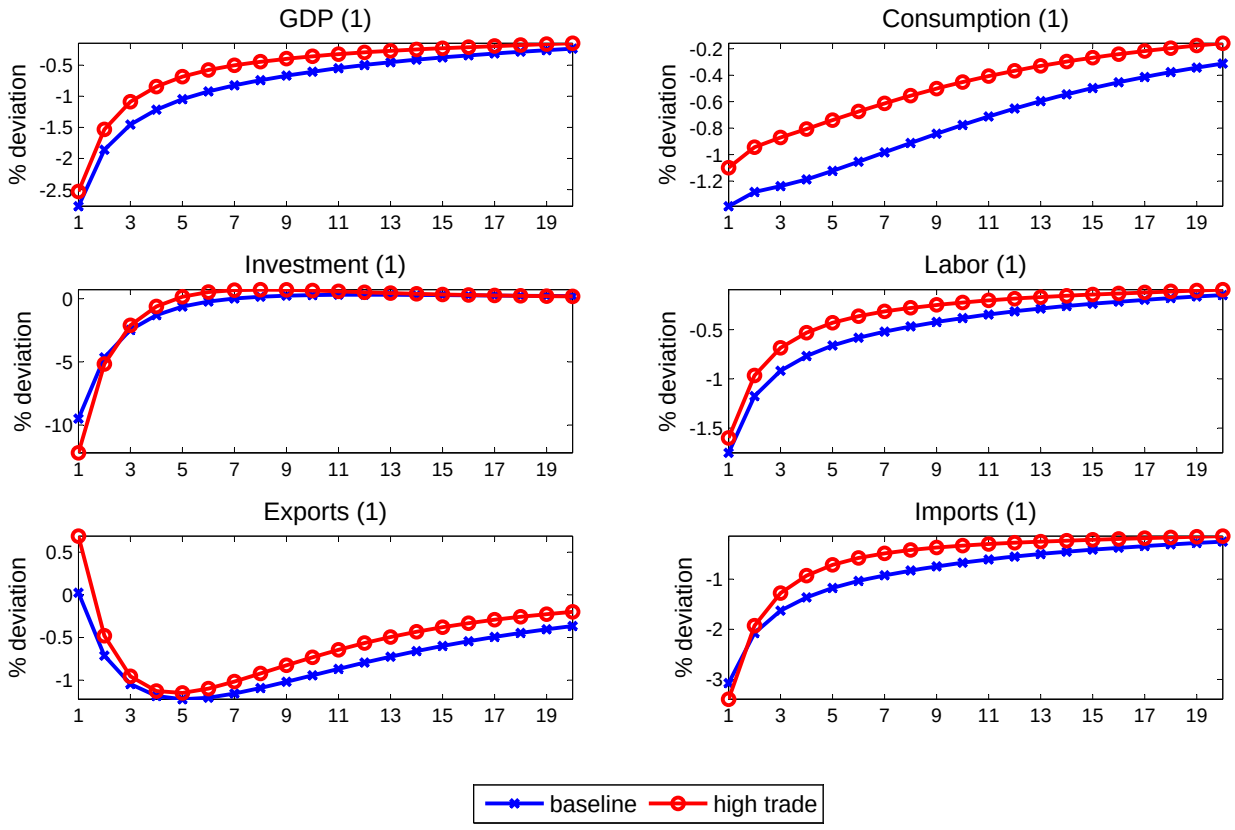
Notes: Impulse responses of country 1 to an exogenous shock to the borrowing constraint parameter in country 1, θ_1. The shock reduces θ_1 by 70% for the first three periods, and reverts to the steady state value with persistence of 0.3.

Figure 5: Credit shock: international propagation



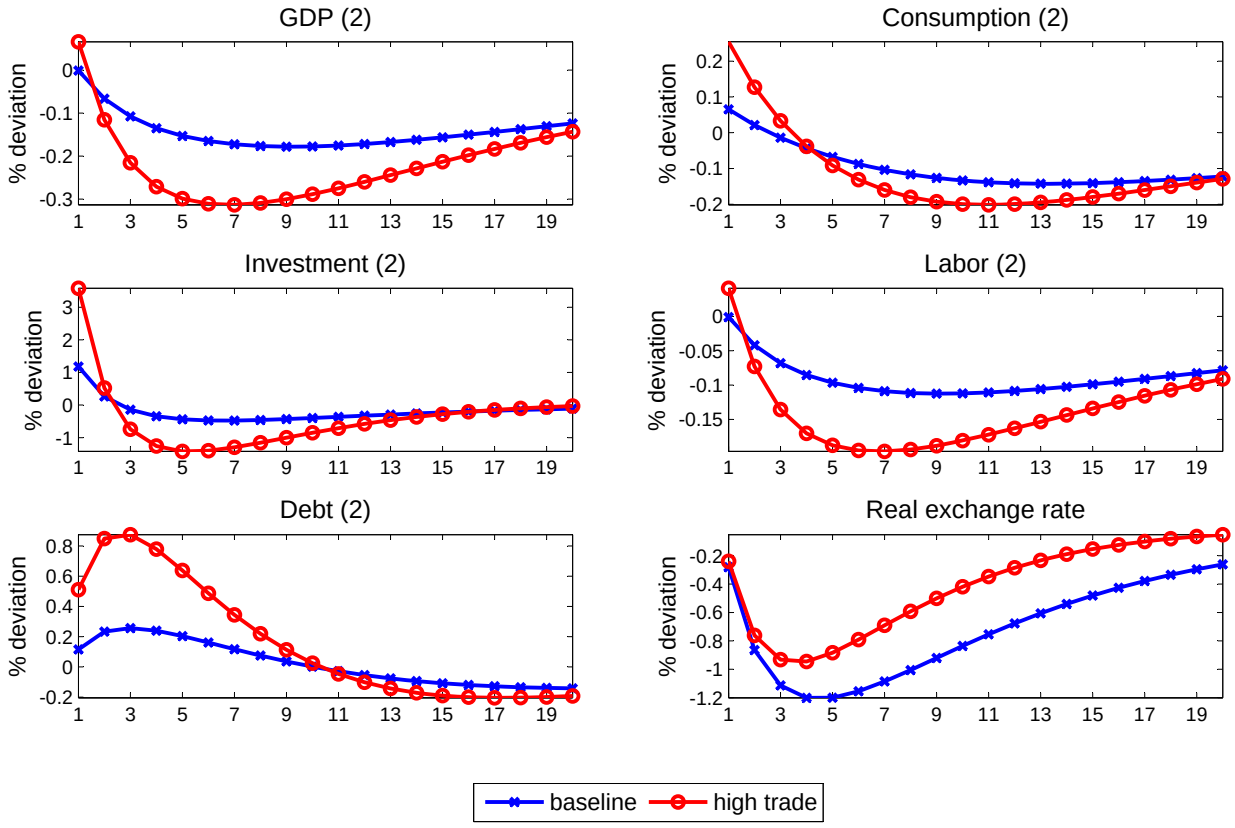
Notes: Impulse responses of country 2 to an exogenous shock to the borrowing constraint parameter in country 1, θ_1. The shock reduces θ_1 by 70% for the first three periods, and reverts to the steady state value with persistence of 0.3.

Figure 6: Trade openness and propagation: domestic responses



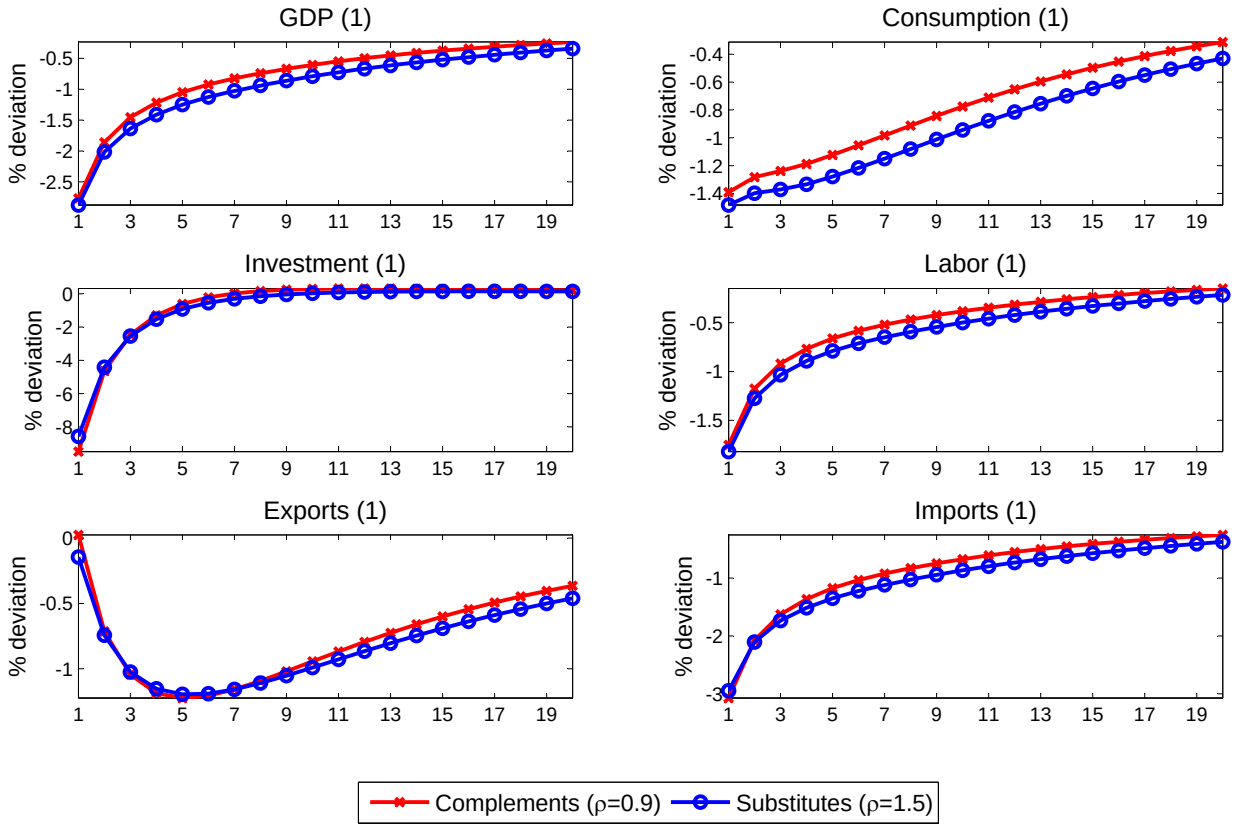
Notes: Impulse responses of country 1 to an exogenous shock to the borrowing constraint parameter in country 1, θ_1. The shock reduces θ_1 by 70% for one period, and reverts to the steady state value with persistence of 0.7. Blue lines indicate the responses from the baseline case (ω=0.93). Red lines indicate the responses from the high-trade case (ω=0.82).

Figure 7: Trade openness and propagation: international transmission



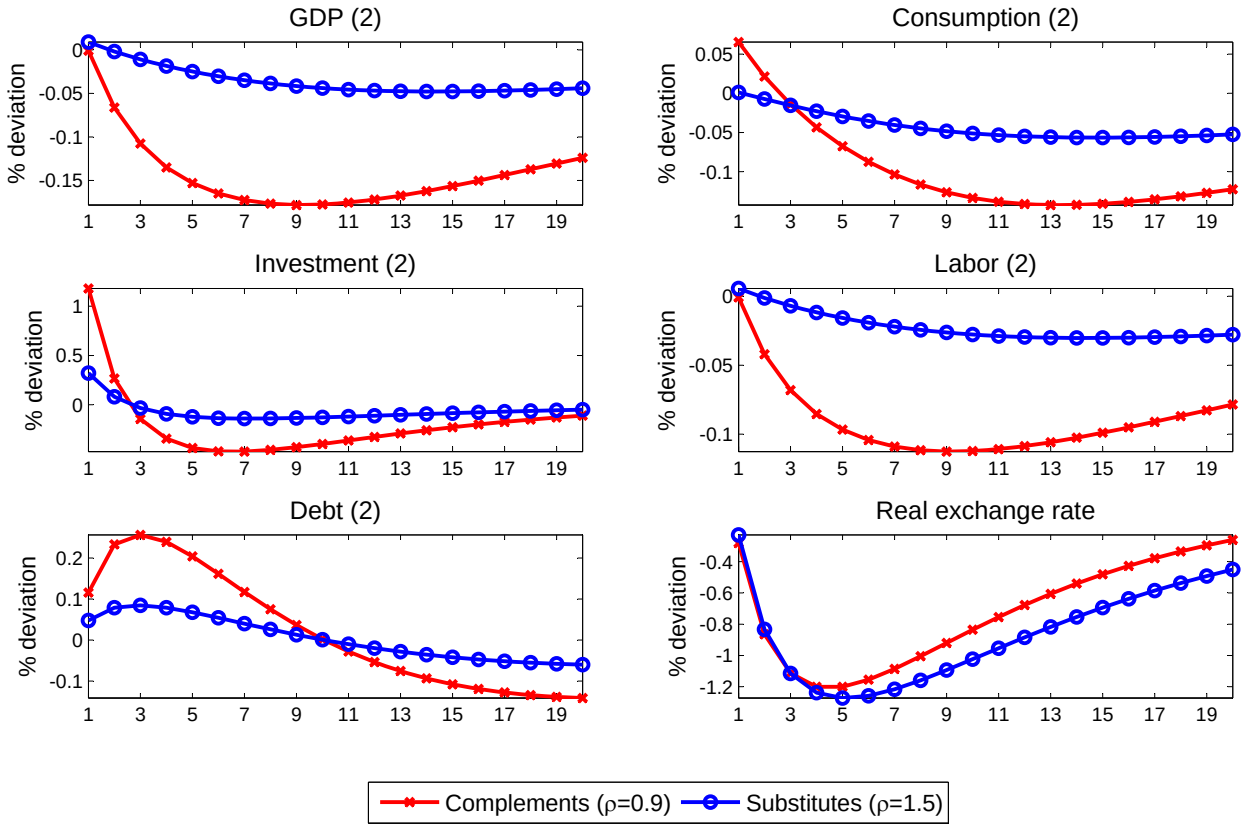
Notes: Impulse responses of country 2 to an exogenous shock to the borrowing constraint parameter in country 1, θ_1. The shock reduces θ_1 by 70% for one period, and reverts to the steady state value with persistence of 0.7. Blue lines indicate the responses from the baseline case (ω=0.93). Red lines indicate the responses from the high-trade case (ω=0.82).

Figure 8: Traded-good type and propagation: domestic responses



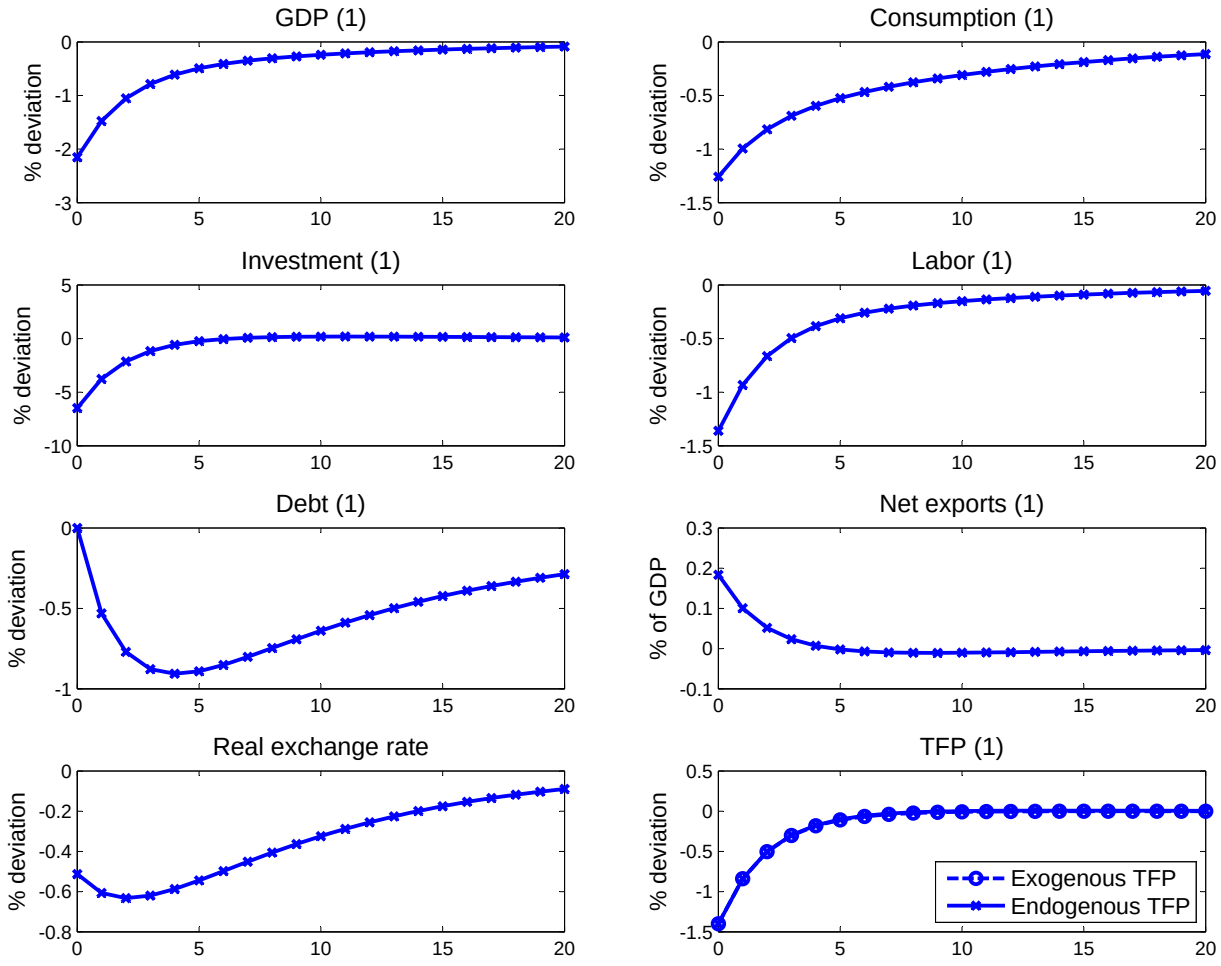
Notes: Impulse responses of country 1 to an exogenous shock to the borrowing constraint parameter in country 1, θ_1. The shock reduces θ_1 by 70% for one period, and reverts to the steady state value with persistence of 0.7. Red lines indicate the responses from the baseline case (ρ=0.9). Blue lines indicate the responses from the case with high substitutability (ρ=1.5).

Figure 9: Traded-good type and propagation: international transmission



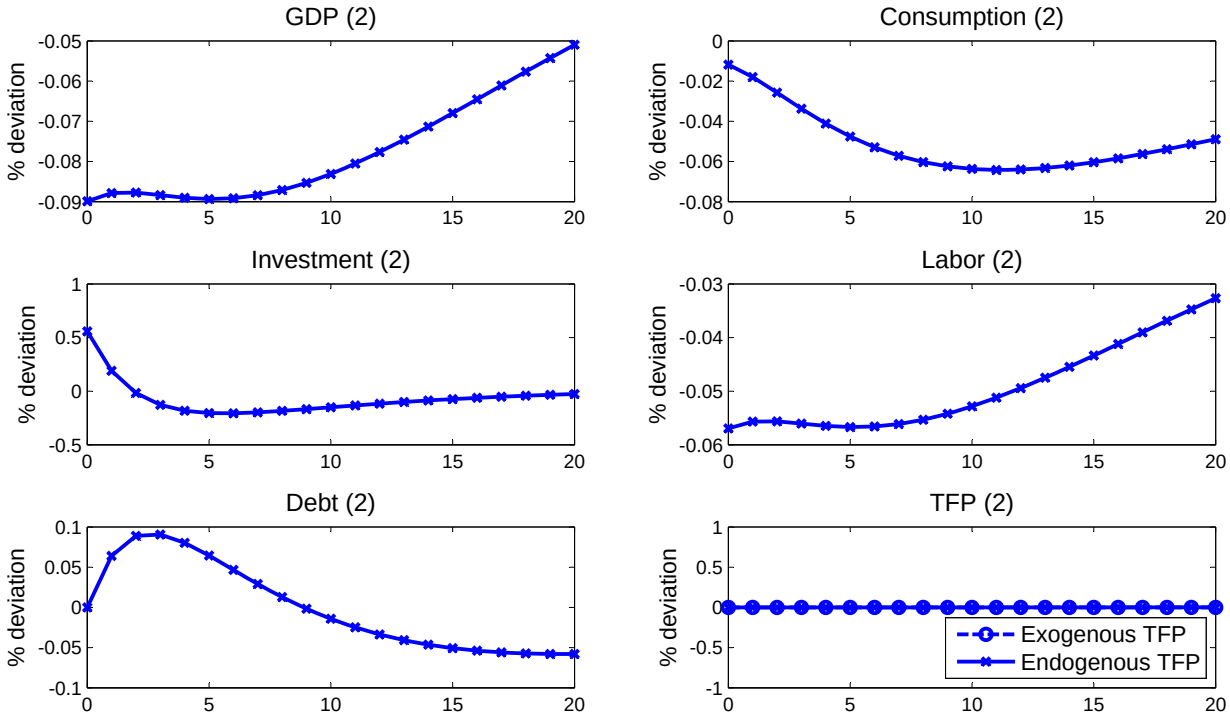
Notes: Impulse responses of country 2 to an exogenous shock to the borrowing constraint parameter in country 1, θ_1. The shock reduces θ_1 by 70% for one period, and reverts to the steady state value with persistence of 0.7. Red lines indicate the responses from the baseline case (ρ=0.9). Blue lines indicate the responses from the case with high substitutability (ρ=1.5).

Figure 10: Productivity shock: domestic responses



Notes: Impulse responses of country 1 to an exogenous negative productivity shock in country 1. The path of the shock is chosen to match the path of measured TFP from the previous exercises. The shock reduces A_1 by 1.4% for one period, and reverts to the steady state value with persistence of 0.6.

Figure 11: Productivity shock: international transmission



Notes: Impulse responses of country 2 to an exogenous negative productivity shock in country 1. The path of the shock is chosen to match the path of measured TFP from the previous exercises. The shock reduces A_1 by 1.4% for one period, and reverts to the steady state value with persistence of 0.6.