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Abstract

Many policy-makers 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 quantitative 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 to one country induces a sharp contraction in that country's economy, whereas the resulting recession in the economy of its trading partner is quantitatively minor. Transmission through goods trade is limited by the calibrated average trade share, which we find insufficient to deliver a sizable recession abroad. The degree of credit-shock transmission depends on the home bias in international trade and the type of goods countries trade with each other. We show that lower home bias dampens the domestic recession following a credit shock, but it amplifies international transmission. Similarly, when traded goods are less substitutable, the domestic recession is less severe, while real consequences abroad are greater. Our model also predicts that credit shocks cause larger declines in international trade than do productivity shocks. These results shed light on the great trade collapse over 2008-09, suggesting that tightened financial constraints may have been a contributing factor.

JEL classification: E22, E32, E44, F41, F44
Bank classification: Business fluctuations and cycles; Economic models; Financial markets; Financial stability; International topics

Résumé

Pour bon nombre d'instances décisionnelles et de chercheurs, les récentes crises financières et économiques qui ont éclaté en Amérique du Nord, en Europe et ailleurs sont un phénomène mondial. D'aucuns estiment que ces récessions prennent toutes leur origine dans la crise financière aux États-Unis. Dans cette étude, nous voulons déterminer l'ampleur des conséquences d'un choc d'offre de crédit sur les partenaires commerciaux d'un pays qui fait face à un tel choc. Nous élaborons à cette fin un modèle d'équilibre général dynamique et stochastique à deux pays dans lequel les producteurs de biens intermédiaires sont soumis à des chocs de productivité idiosyncrasiques persistants et à des contraintes occasionnelles en matière de garanties pour l'obtention de crédits d'investissement.

Il apparaît qu'un choc négatif d'offre de crédit dans un pays provoque un net repli de son économie, mais une légère récession chez son partenaire commercial. La transmission des chocs par le canal des biens échangeables est limitée vu la part moyenne du commerce extérieur dans le PIB. Cette part, qui est étalonnée en fonction de données américaines, est insuffisante pour engendrer une récession sévère à l'étranger. L'intensité des répercussions du choc d'offre de crédit dépend de deux facteurs : la préférence nationale et le type de biens échangés. Nous montrons que lorsque la préférence nationale est moins marquée, la récession déclenchée par un choc d'offre de crédit est moins profonde, mais l'incidence de ce choc est amplifiée à l'international. De même, la récession intérieure est d'autant moins grave et les répercussions sur l'activité réelle à l'étranger sont d'autant plus importantes que le degré de substituabilité entre les biens échangés est moindre. Notre modèle prévoit également que le recul du commerce international est plus prononcé suivant un choc d'offre de crédit qu'après un choc de productivité. Ces résultats mettent en lumière le rôle que l'exacerbation des contraintes financières pourrait avoir joué dans l'effondrement du commerce mondial au cours de la période 2008-2009.

Classification JEL : E22, E32, E44, F41, F44
Classification de la Banque : Cycles et fluctuations économiques; Modèles économiques; Marchés financiers; Stabilité financière; Questions internationales

Non-Technical Summary

Many policy-makers 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. One striking observation from this crisis episode is that the global recession was accompanied by a sharp collapse of international trade, pointing to the possibility that international trade and the resulting exposure of countries to external shocks may have contributed to propagating the global recession.

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). In our model, intermediate-good producers face persistent idiosyncratic productivity shocks and occasionally binding collateral constraints when borrowing to finance investment in physical capital. Countries trade intermediate goods and state-contingent bonds in complete international financial markets.

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. Quantitatively, however, the recession abroad is smaller than it is in the country directly experiencing the shock, so long as our model is calibrated to match the average trade share in the postwar U.S. data. We show that the degree of credit crisis propagation is influenced by a country's openness to international trade and the type of goods countries trade with each other. When countries are more open to trade or the goods they trade are less substitutable, the domestic recession is less severe, whereas international transmission is greater as each country grows more exposed to the health of its trading partner.

We also show that international transmission of credit shocks in our model is nearly double that of aggregate productivity shocks, since credit shocks induce declines in a country's exports and imports significantly larger than those caused by productivity shocks. These results shed light on the linkage between financial constraints and the great trade collapse over 2008-09, suggesting that our framework may be useful in interpreting recent empirical evidence that financial constraints contributed to the collapse in international trade after the start of the U.S. financial crisis.

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 policy-makers and researchers to view the crises as a global phenomenon. At the same time, such an 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 can 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 economic activity since the onset of the 2007 U.S. recession.[1] One striking observation from this crisis episode 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. For example, Lane and Milesi-Ferretti (2011) find that openness to international trade had significant effects on the severity of affected countries' recessions, and that an individual country's GDP movement was affected by the coincident economic performance of its trade partners. These findings suggest cross-country propagation of financial crisis through real channels.

A number of recent studies examining closed-economy business cycle models have found that financial shocks can cause large, persistent recessions.[3] Given the coincident timing of the U.S. financial crisis and the trade collapse of 2008-09, it is natural to consider the extent to which a financial shock in one country is transmitted to its trade partners in an international business

[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.

[3] Examples include Jermann and Quadrini (2012), Arellano, Bai and Kehoe (2012), Khan and Thomas (2013), Buera and Moll (forthcoming), Bassetto, Cagetti and De Nardi (2015).

cycle model developed along similar lines. We examine this question using a two-country model in other respects similar to the closed-economy general equilibrium model of Khan and Thomas (2013).

Intermediate-good producers in our model economy 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 take on one-period loans from domestic households in order to finance their investment in physical capital; however, they face collateralized borrowing constraints that depend on their individual levels of cash on hand. 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 volatility of the investment-to-capital ratio from establishment-level investment data and the aggregate debt-to-asset ratio.

Examining the effects of a credit shock 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 quantitatively small 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, production, and hence the supply of exports. At the heart of this is an endogenous decline in aggregate productivity that arises from cash-poor firms' reduced ability to access the loans they need to finance efficient investment. This depresses production of final goods, which in turn curtails demand for imported intermediate goods. Turning to the country's trading partner, the fall in demand for the foreign country's exports discourages investment and employment there, and, coupled with a fall in imports from the country directly affected by the shock, reduces the production of intermediate goods and hence final goods abroad. Thus, the foreign country experiences a slowdown in real economic activity when its trade partner is hit by a credit shock. Quantitatively, however, the recession abroad is far smaller than it is in the country directly experiencing the shock, so long as our model is calibrated to reproduce the average trade share in the data; if the trade share is counterfactually large, international transmission is far greater.

Alternative calibrations of our model reveal that the degree of credit crisis propagation is influenced by the extent of home bias in international trade and the type of goods countries trade with each other. Lower home bias dampens the domestic recession, but amplifies international transmission of financial shocks. When the weight on imported goods in final-good production is larger, each country is more susceptible to the health of its trade partner and less to shocks in its own economy. For the country directly experiencing a credit shock, the impact of the shock on its domestic production is mitigated, since the reliance on its trade partner is comparatively large. Conversely, for the trade partner, a larger reliance on imports in final-goods production implies greater effects of the shock abroad for its own economy. In sum, the more important is international goods trade, the larger are the effects of a credit shock in one country on the economies of its trade partners. This result is consistent with Lane and Milesi-Ferretti's (2011) empirical finding of a significant positive correlation between countries' pre-crisis levels of openness to international trade and the depth of the recessions they experienced.

Similarly, when traded goods are less substitutable across countries, the domestic recession is less severe following a credit shock, while international transmission is greater. When domestically produced intermediate goods are not easily replaced by imports, the higher reliance on domestic goods mitigates the fall in domestic production of intermediates, dampening the effects of the credit shock for domestic investment and employment. On the other hand, for the trading partner, final-good production falls by more, as do investment and consumption, since the decline in imports from the directly affected country cannot be easily replaced with its own products. This result is consistent with Heathcote and Perri's (2002) finding 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 the decisions of firms with smaller amounts of cash on hand but relatively high productivity, since they are unable to take on sufficient loans to finance their optimal levels of investment. This directly implies an inefficiently low allocation of capital to these firms, distorting the allocation of production, and thus generating an endogenous fall in measured total factor productivity (TFP). Compared with our model economy's responses to those following an exogenous TFP shock of equal magnitude and persistence, we find that a credit shock and the endogenous fall in aggregate productivity it generates induce substantially larger declines in aggregate quantities for both domestic and foreign countries. For instance, the peak-to-trough drop in GDP abroad is twice as deep following a credit shock as it is following an exogenous productivity shock.

Our findings extend to the overall volume of trade. Credit shocks induce large declines in a country's exports and imports, and these declines are larger than those arising following aggregate productivity shocks. This finding is consistent with empirical evidence linking the recent financial crisis and the great trade collapse of 2008-09. Behrens, Corcos and Mion (2013) and Coulibaly, Sapienza and Zlate (2011) report that financial constraints explain some of the decline in exports during the great trade collapse. As shocks to the credit supply constrain production and the export supply, financial constraints can exacerbate the decline in trade during the crisis period.[4]

The remainder of the paper is organized as follows. Section 2 reviews the recent economic performance of the United States and other G7 countries. Section 3 discusses the literature most closely related to our analysis. The model is presented in section 4, and its calibration is described in section 5. Section 6 reports results, and section 7 concludes.

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

We begin with a review of the business cycle experiences in the United States and other G7 countries during and following the U.S. 2007-09 recession, as well as credit conditions in the United States. Perri and Quadrini (2014) provide a more in-depth examination of these data and also analyze other post-war U.S. recession episodes for comparison; the brief summary here is merely to set the stage. Figure 1 shows log-detrended quarterly 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 recession started.

By the second quarter of 2009, real GDP and consumption had fallen 5.3 percent and 4.1 percent, respectively. Investment fell sharply, reaching 14.3 percent below its 2007Q4 level by 2009Q2. Consumption and investment hovered near their trough levels for several quarters before beginning a gradual recovery in 2010. Although its decline was comparatively slow over the first

[4] Bems, Johnson and Yi (2013) survey studies of the collapse in international trade during the recent global recession. Taken as a whole, a series of studies suggest that the dominant force behind the trade collapse was the collapse in aggregate expenditure (Bems, Johnson and Yi (2010, 2011), Eaton et al. (2011), Bussière et al. (2013)). Alessandria et al. (2010, 2011, 2013) emphasize inventory adjustments as an important amplification mechanism.

several quarters of the recession, employment eventually reached 4.6 percent below its 2007Q4 level. The post-2009Q2 recovery from this sharp recession has been sluggish and uneven. As of 2013Q1, no series in Figure 1 had regained its pre-recession level.

A similar pattern of steep economic downturn and sluggish recovery is evident for other advanced economies during this period. In Figure 2, we plot log-detrended real GDP, investment, consumption and employment for G7 countries from 2007Q4 to 2013Q1. As in Figure 1, these series are percentage deviations from their respective 2007Q4 levels. The comovement in GDP and investment across these countries is striking, particularly during the U.S. recession dates. Although less synchronized across countries than GDP and investment, consumption also fell in all the G7 countries until mid-2009 and had exhibited gradual recovery until mid-2010. Relative to other G7 countries, the fall in U.S. employment was distinctively larger. Perri and Quadrini (2014) suggest that this may be due to differences in the structure of the local labor market across these countries. Nonetheless, all G7 countries experienced employment declines and sluggish employment recovery over the following years.

What could cause such a severe global recession? Some have argued that it was triggered by a financial crisis in the United States. Following the collapse in housing markets starting in the mid-2000s, 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 banks started to enforce stricter conditions on their loans in 2007, and the number of domestic banks that tightened their loan standard soared between 2007 and 2008, reaching 80 percent (in net) by the end of 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 bursting of the housing bubble peaking in 2006-07, the growth rate of private sector debt plunged from 8.4 percent to -1.7 percent between 2007 and 2009.

3 Related literature

Our paper contributes to a large literature on the role of financial frictions in propagating business cycle fluctuations.[5] Our particular focus on collateralized borrowing constraints as a

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

source of frictions follows a line that stems from the seminal work of Kiyotaki and Moore (1997).[6] Proposing a model where durable assets serve as collateral for loans, they examine how credit constraints interact with aggregate economic activity over the business cycle, and show that the interdependence of credit limits and the prices of collateralized assets plays an important role in amplifying and propagating shocks affecting firms' net worth.

The model we develop is a two-country extension of the financial frictions model of Khan and Thomas (2013), which introduces an endogenous TFP channel for credit shock propagation. There, as here, firms experience persistent shocks to their individual productivity levels, and they face collateral constraints when borrowing to finance their capital investment. When collateral constraints are tightened by a credit shock, the financing barriers that prevent cash-poor firms with relatively high productivities from investing to their optimal capital levels are increased. As a result, a credit shock disrupts the allocation of capital across firms, inducing an endogenous decline in aggregate productivity that, in turn, delivers a persistent decline in real economic activity.

Our paper also contributes to a large literature on international business cycles starting with Backus, Kehoe and Kydland (1994) and Baxter and Crucini (1993, 1995). Without exogenous cross-country spillovers embedded in the shock processes, standard international business cycle models with trade in goods and bonds routinely fail to translate a recession in one country into a quantitatively significant recession in its trading partner. Given the strong propagation mechanism that collateral constraints and firm heterogeneity have been seen to deliver in closed-economy settings, we explore whether the combination of these elements in a two-country business cycle model might overcome this difficulty. In light of the great trade collapse during the recent financial crisis, we examine whether these new propagating forces can produce strong international transmission of financial shocks.

Our focus on the implications of trade linkages for international comovement is related to the analysis by Kose and Yi (2006), who assess whether the standard international business cycle framework can account for the observed high correlation of business cycles for countries with strong trade ties. While their model does imply that international correlations grow with the extent of international trade, its predicted change in the cross-country GDP correlation for a given change in trade intensity is significantly smaller than that in the data. We do not measure our model-

[6] Jermann and Quadrini (2012), Boz and Mendoza (2014) and Buera and Moll (forthcoming) are closed-economy examples. Mendoza (2010) has a small open economy; Perri and Quadrini (2014) consider two linked countries.

generated elasticity of international comovement with respect to trade linkages; however, we find qualitatively that stronger trade relationships increase international transmission of financial shocks.

Our paper is also related to recent studies examining the relationship between financial integration and international business cycle comovement in quantitative frameworks emphasizing the role of financial frictions in propagating aggregate shocks across countries. Devereux and Yetman (2010) develop a two-country model with international portfolio holdings wherein investors borrow from savers in order to invest in domestic and foreign fixed assets (equity), but their borrowing is limited by the value of their equity. Portfolio diversification by investors implies that asset prices are positively correlated across countries, and hence a negative productivity shock lowering the asset price in one country generates a tightening of borrowing constraints in both countries. This hinders investment in fixed assets used in final-good production in both countries, delivering international comovement in production.

Using a similar framework, Devereux and Sutherland (2011) show that an exogenous tightening of the leverage constraint also generates positive cross-country comovements of macroeconomic variables when equity markets are internationally integrated. More recently, Devereux and Yu (2014) extend the framework to allow for occasionally-binding collateral constraints; they show that moving from financial autarky to financial integration not only increases the probability that collateral constraints bind in one country, but also leads these constraints to bind simultaneously in both countries, thereby increasing cross-country comovements.

Dedola and Lombardo (2012) pursue an alternative approach to our emphasis on collateralized borrowing limits. They develop an endogenous portfolio-choice model exploring the financial accelerator channel of Bernanke, Gertler and Gilchrist (1999), wherein investors' borrowing costs depend on an external finance premium that falls in their net worth. They show that the cross-country equalization of credit spreads due to international financial integration leads to strong comovements in asset prices and real activity regardless of the degree of exposure to foreign assets.

The recent financial integration studies above highlight the presence of international investors with access to foreign assets as an important channel through which country-specific shocks are transmitted across countries. With international financial integration, financial conditions in two countries become directly interdependent, so that country-specific shocks induce strong cross-country comovement. As noted above, we focus instead on international goods trade, exploring the effects of reduced production capacity among financially constrained firms, and how the resulting misallocation and supply shortages affect the economies of a country's trade partners.

Perri and Quadrini (2014) introduce a global self-fulfilling liquidity shortage as an explanation for international comovement during the recent global recession. In addition to a Kiyotaki and Moore style borrowing constraint applying to the finance of working capital requirements, they assume that firms can purchase the capital of liquidated firms at a high price only if their borrowing constraints are not binding. Otherwise, the liquidated capital is sold to households at a low price. In this environment, the price of liquidated capital becomes self-fulfilling, and the economy has multiple equilibria, with the price of capital switching stochastically between low and high states. International financial integration equalizes the prices of liquidated capital across countries and leads the borrowing constraints to bind simultaneously in the two countries, thus generating international comovements in real and financial variables.

In contrast to the setting in Perri and Quadrini (2014), firms in our model are owned by domestic households, so firms' stochastic discount factors are not necessarily equalized across countries. As mentioned above, our firms are heterogeneous in their capital, debt and productivity. The tightness of their borrowing constraints in any given date depends both on aggregate credit conditions within their country and their individual levels of cash on hand, where the latter is jointly determined by the worldwide aggregate state vector and the three individual state variables that distinguish them.

4 Model

We assume two symmetric countries, country 1 and country 2. In each country, there is a continuum of identical infinitely lived households, each with access to state-contingent nominal bonds, and a representative final-good producer that combines domestically produced intermediate goods and imported intermediate goods to produce a final good used for domestic consumption and capital investment. Each country's intermediate good is produced by a unit measure of heterogeneous domestic firms. All markets are perfectly competitive, and all prices are flexible.

Intermediate-good firms sell their output domestically and abroad. They produce with capital and labor, and they face persistent country-specific aggregate total factor productivity shocks and persistent firm-specific productivity shocks. Firms hire labor from domestic households, but maintain their own capital stocks. Each firm buys investment goods from the final-good producer in its country to augment its capital for the next period, and each can access one-period loans to help finance these purchases. A collateralized borrowing constraint in each country limits the debt any firm can take on as a function of its cash. Firms cannot circumvent the constraint by paying negative dividends. We also assume exit and entry at an exogenous rate each period to prevent all firms from effectively outgrowing financial frictions in the long run.

We denote the aggregate state of the world economy by A, where $A \equiv (Z, S)$. The exogenous state vector is Z, where $Z \equiv [z_1, z_2, \theta_1, \theta_2]$. Its first two elements represent aggregate productivity in country c, for $c = 1, 2$. The last two elements represent credit states; each θ_c parameterizes a country-specific collateral constraint limiting firms' debt in proportion to their cash. All exogenous state variables are assumed to follow Markov chains.

Our model generates a time-varying distribution of firms over capital, ($k \in \mathbf{K} \subset \mathbf{R}_+$), debt ($b \in \mathbf{B} \subset \mathbf{R}$) and firm-specific productivity ($\varepsilon \in \mathbf{E}$) in each country. We summarize the distribution of firms at the start of a period in country c using the probability measure μ_c defined on the Borel algebra $\mathcal{S}$ generated by the open subsets of the product space, $\mathbf{S} = \mathbf{K} \times \mathbf{B} \times \mathbf{E}$ for each $c = 1, 2$. The endogenous aggregate state vector in our model is $S \equiv [\mu_1, \mu_2, B_1, B_2]$, where B_1 and B_2 represent the state-contingent bonds held by households in each country at the start of the period. All agents in the economy take as given the laws of motion determining Z' given Z, as well as 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, specifying the country 2 counterparts only where necessary for clarity or in defining notation.

4.1 Households

The representative household in each country is endowed one unit of time in each period, and values its consumption and leisure according to a period utility function $u(C, 1 - N)$. Future utility is discounted by the subjective discount factor $\beta \in (0, 1)$. Household wealth is held in three forms. First, there are one-period shares in domestic firms, which we identify using the measures ζ_c for $c = 1, 2$. Next, there are one-period non-contingent real bonds corresponding to the total debts of all domestic firms, which we denote by ϕ_c for $c = 1, 2$. Finally, as noted above, households have access to a complete set of state-contingent nominal bonds. Those bonds are denominated in units of the country 1 currency, and we use $B_c(A)$ to denote the nominal bonds with which the household in country c enters the period given current aggregate state A.

The household in country 1 chooses its consumption, C_1, the hours of labor it supplies to firms, N_1, its shares in firms to begin the next period, ζ_1', and its real bonds for next period, ϕ_1'. The household also chooses its state-contingent nominal bonds, $B_1(A')$, which each promise delivery of one unit of country 1 currency if the state A' is realized next period. Let $\varrho(A';A)$ be the real price of one such bond, denominated in units of country 1 consumption goods. Next, let the dividend-inclusive values of the household's current firm shares be $\widetilde{\rho}_1(k,b,\varepsilon;A)$, and the ex-dividend prices of new shares be $\rho_1(k',b',\varepsilon';A)$. Let $q_1(A)$ be the country 1 consumption goods the household must forfeit per unit real bond, let $w_1(A)$ be the domestic real wage, and let $P_1(A)$ be the domestic aggregate price level. Finally, let $G(A'|A)$ represent the conditional probability of realizing given state A' next period, which will be determined by $S' = \Gamma(A)$ and the exogenous transition probabilities for the elements of Z. Given this notation, the country 1 household's expected lifetime utility maximization problem can be written as follows:

$$V_1^h(\zeta_1,\phi_1,B_1(A);A) = \max_{C_1,N_1,\zeta_1',\phi_1',B_1(A')} u(C_1,1-N_1) + \beta \int V_1^h(\zeta_1',\phi_1',B_1(A');A')G(dA'|A), \tag{1}$$

subject to

$$\int \widetilde{\rho}_1\left(k,b,\varepsilon;A\right)\zeta_1\left(d\left[k\times b\times\varepsilon\right]\right) + \phi_1 + \frac{B_1(A)}{P_1(A)} + w_1(A)N_1 \geq$$
$$C_1 + \int \rho_1\left(k',b',\varepsilon';A\right)\zeta_1'\left(d\left[k'\times b'\times\varepsilon'\right]\right) + q_1(A)\phi_1' + \int \varrho(A';A)B_1(A')dA'.$$

Let $\lambda_1(A) = D_1u(C_1,1-N_1)$ be the Lagrange multiplier on the budget constraint in the problem above. The household's efficiency conditions with respect to hours worked, firm shares and real bonds immediately imply a series of restrictions on the country 1 real wage, firm share prices and inverse loan price listed in (2) - (4). Its efficiency conditions with respect to state-contingent nominal bonds yield the additional price restrictions in equation (5):

$$w_1(A) = \frac{D_2u(C_1,1-N_1)}{\lambda_1(A)} \tag{2}$$

$$\rho_1\left(k',b',\varepsilon';A\right) = \int \frac{\beta\lambda_1(A')}{\lambda_1(A)}\widetilde{\rho}_1\left(k',b',\varepsilon';A'\right)G(dA'|A) \tag{3}$$

$$q_1(A) = \int \frac{\beta\lambda_1(A')}{\lambda_1(A)}G(dA'|A) \tag{4}$$

$$\varrho(A';A) = \frac{\beta\lambda_1(A')}{\lambda_1(A)}\frac{1}{P_1(A')}G(A'|A). \tag{5}$$

The household in country 2 solves an analogous problem adjusted for the fact that the nominal bonds it holds are denominated in the other country's currency. Let $Q(A)$ represent the current real exchange rate, the price of country 2 final output in units of country 1 final output. Each nominal bond held at the start of the period returns $\frac{1}{P_1(A)}$ units of country 1 output, each worth $Q(A)^{-1}$ units of country 2 consumption goods. Similarly, one nominal bond for a given next-period state A' costs the country 2 household $\varrho(A';A)$ units of country 1 output, each implying the forfeit of $Q(A)^{-1}$ units of country 2 consumption:

$$V_2^h(\zeta_2, \phi_2, B_2(A); A) = \max_{C_2, N_2, \zeta_2', \phi_2', B_2(A')} u(C_2, 1 - N_2) + \beta \int V_2^h(\zeta_2', \phi_2', B_2(A'); A') G(dA'|A), \tag{6}$$

subject to

$$\int \widetilde{\rho}_2 (k, b, \varepsilon; A) \zeta_2 (d [k \times b \times \varepsilon]) + \phi_2 + \frac{B_2(A)}{P_1(A)Q(A)} + w_2(A)N_2 \geq$$
$$C_2 + \int \rho_2 (k', b', \varepsilon'; A) \zeta_2' \left(d \left[k' \times b' \times \varepsilon'\right]\right) + q_2(A)\phi_2' + \int \frac{\varrho(A';A)}{Q(A)} B_2(A') dA'.$$

Let $\lambda_2(A) = D_1 u(C_2, 1 - N_2)$. The country 2 household's efficiency conditions imply restrictions on $w_2(A)$, $\rho_2 (k', b', \varepsilon'; A)$ and $q_2(A)$ mirroring those in equations (2) - (4), and restrict nominal bond prices to satisfy the equations in (7):

$$\varrho(A'|A) = \frac{\beta \lambda_2(A')}{\lambda_2(A)} \frac{Q(A)}{P_1(A')Q(A')} G(A'|A). \tag{7}$$

Comparing (5) and (7), we arrive at a set of equations determining the evolution of the real exchange rate across every date and state: $Q(A') = \frac{\lambda_2(A')}{\lambda_1(A')} \frac{\lambda_1(A)Q(A)}{\lambda_2(A)}$. Assuming an initial date zero in which $\frac{\lambda_1(A^0)Q(A^0)}{\lambda_2(A^0)} = 1$, we can write the real exchange rate in every period as the ratio of marginal utilities of consumption in countries 2 and 1:

$$Q(A) = \frac{\lambda_2(A)}{\lambda_1(A)}. \tag{8}$$

4.2 Final-goods production

The representative final-good producer in country 1 combines domestically produced intermediate goods, y^{D1}, and intermediate-good exports from country 2, y^{X2}, to produce final goods, H_1, through the constant-elasticity-of-substitution production function:

$$H_1 = \left[\omega \left(y^{D1}\right)^{\frac{\rho-1}{\rho}} + (1 - \omega) \left(y^{X2}\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}, \tag{9}$$

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). It sells its output at price $P_1(A)$ to households (for consumption) and to domestic intermediate-good firms (for investment).

The nominal prices associated with intermediate goods from each country are denominated in the currency of the country in which the good is sold. Let $p^{D1}(A)$ be the price of the country 1 intermediate good sold in country 1, and let $p^{X2}(A)$ denote the price of the country 2 intermediate good sold in country 1, with both denominated in the country 1 currency. Taking as given these input prices, the price of its output, $P_1(A)$, and the technology in (9), the final-good producer in country 1 solves the static profit maximization problem in equation (10). Its resulting conditional factor demands are listed in (11) - (12):

$$\max_{y^{D1},y^{X2}} \; P_1(A)H_1 - p^{D1}(A)y^{D1} - p^{X2}(A)y^{X2} \tag{10}$$

$$y^{D1} = \omega^{\rho}\left(\frac{p^{D1}(A)}{P_1(A)}\right)^{-\rho} H_1 \tag{11}$$

$$y^{X2} = (1-\omega)^{\rho}\left(\frac{p^{X2}(A)}{P_1(A)}\right)^{-\rho} H_1. \tag{12}$$

The final-good producer in country 2 solves an analogous problem determining its conditional factor 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 above, we retrieve the aggregate price level (price index) in each country:

$$P_1(A) = \left[\omega^{\rho}\left(p^{D1}(A)\right)^{1-\rho} + (1-\omega)^{\rho}\left(p^{X2}(A)\right)^{1-\rho}\right]^{\frac{1}{1-\rho}} \tag{13}$$

$$P_2(A) = \left[\omega^{\rho}\left(p^{D2}(A)\right)^{1-\rho} + (1-\omega)^{\rho}\left(p^{X1}(A)\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{14}$$

Country 1's exports in units of country 1 final output are $\frac{p^{X1}y^{X1}}{P_2}Q$, and its imports are $\frac{p^{X2}y^{X2}}{P_1}$.

4.3 Intermediate-goods firms

Throughout this section, we restrict attention to intermediate-good firms in country 1. Since there are no trade frictions, each firm is indifferent between selling a unit of its output domestically versus exporting it in equilibrium. From the perspective of a country 1 firm, this means $\frac{p^{X1}}{P_2}Q = \frac{p^{D1}}{P_1}$, so its problem can be described entirely in terms of domestic prices. Thus, the description of the problems facing intermediate-good firms in country 2 mirrors the description here.

Each firm enters a period identified by (k, b, ε), where k and b are the capital and debt levels it selected at the end of last period, and ε is its current idiosyncratic productivity. Positive values of b represent debt; negative values are financial savings. The firm produces using capital and labor in a decreasing-returns-to-scale Cobb-Douglas production function:

$$y_1 = z_1 \varepsilon k^{\alpha} n^{\nu}, \tag{15}$$

where z_1 is the aggregate productivity shock in its country, $\alpha \in (0,1)$, $\nu \in (0,1)$, and $\alpha + \nu < 1$. We assume that firm-specific productivity ε follows a Markov chain with N_ε realizations and transition probabilities $\varphi^{\varepsilon}_{ij} = pr(\varepsilon' = \varepsilon_j \mid \varepsilon = \varepsilon_i)$, and that the aggregate productivity shock z_1 also follows a Markov chain.

Given its capital and productivity, the domestic real wage, $w_1(A)$, and the relative price of its output, $\frac{p^{D1}(A)}{P_1(A)}$, the firm chooses its labor demand to solve the following static problem, subject to the production technology (15):

$$\max_n \left(\frac{p^{D1}(A)}{P_1(A)}\right) y_1 - w_1(A) n. \tag{16}$$

The firm's labor and output decision rules follow immediately, as does its static profit defined as real sales less wage payments. Notice that each of these is independent of the firm's debt position:

$$\begin{aligned}
n_1(k,\varepsilon;A) &= \left[\frac{\nu\left(\frac{p^{D1}(A)}{P_1(A)}\right)\varepsilon z_1 k^{\alpha}}{w_1(A)}\right]^{\frac{1}{1-\nu}} \\
y_1(k,\varepsilon;A) &= z_1 \varepsilon k^{\alpha} n_1(k,\varepsilon;A)^{\nu} \\
\pi_1(k,\varepsilon;A) &= (1-\nu)\left(\frac{p^{D1}(A)}{P_1(A)}\right) y_1(k,\varepsilon;A).
\end{aligned}$$

4.3.1 Cash and debt

Let x represent the (k,b,ε) firm's real cash on hand in units of the domestic final good; we define this variable as its static profit and non-depreciated capital net of outstanding debt:

$$x \equiv \pi_1(k,\varepsilon;A) + (1-\delta)k - b. \tag{17}$$

The firm receives $q_1(A)$ units of domestic final output in the current period for each unit of debt it incurs. Thus, taking on debt with face value b' delivers it a loan of size $q_1(A)b'$. Capital accumulation is one-period time-to-build; $k' = (1-\delta)k + i$, where i is investment. This implies the following budget constraint governing the firm's choice of k', b' and current dividends, D:

$$x + q_1(A)b' \geq D + k'. \tag{18}$$

We assume that the firm cannot issue new equity to finance its expenditures, $D \geq 0$, and that the debt it takes on is limited in proportion to its current cash by the collateral constraint:

$$b' \leq \theta_1 x, \tag{19}$$

where $\theta_1 \geq 0$ is an exogenous state variable reflecting the availability of credit in country 1.

Note that we have assumed no real frictions impeding a firm's capital adjustment. Furthermore, the collateral constraint in (19) implies that its ability to borrow is not in any direct way affected by its capital or debt. As a result, the only relevant endogenous individual state variable from the perspective of the firm is its cash on hand x. We use this observation below to simplify the description of the firm's intertemporal problem.

4.3.2 Intertemporal problem

After production in any period, each firm realizes the outcome of a state-invariant, exogenous exit shock. At that point, fraction $\gamma \in (0,1)$ of firms exit the economy with $k' = b' = 0$. Each exiting firm undertakes negative investment $(1-\delta)k$ and returns its cash as dividends to domestic households as it departs. Exiting firms are replaced at the start of the next period by an equal number of new firms. Each new firm begins with zero debt, a capital stock k_0, and a productivity level drawn from the ergodic distribution of ε; thus the total investment in newly arrived firms in any period is γk_0. We focus the remainder of this section on the intertemporal problem solved by a continuing incumbent firm.

It is convenient to impose state-contingent discount factors consistent with equilibrium in the market for firm shares (section 4.1) directly in stating each firm's intertemporal optimization problem. Here, we assign $\Lambda_1(A)$ as the valuation a firm in country 1 assigns to its dividends, and assume that the firm discounts its future value by the household subjective discount factor β. In equilibrium, $\Lambda_1(A)$ will be the domestic household's marginal utility of consumption, $D_1 u(C_1(A), 1 - N_1(A))$. Thus, our statement of the firm's problem below simply translates its value function from units of output to units of marginal utility.

Let $\widetilde{v}_1$ represent the value of a country 1 firm just prior to the realization of the exit shock:

$$\widetilde{v}_1(x, \varepsilon; A) = \gamma \Lambda_1(A) x + (1-\gamma) v_1(x, \varepsilon; A), \tag{20}$$

where v_1 is the expected discounted value conditional on it continuing to the next period. The dividends paid by a continuing firm are immediate from (18) as a function of its k', b' choice.

Thus, we can write the problem of a continuing firm of type (x, ε_i) as

$$v_1(x, \varepsilon_i; A) = \max_{k',b'} \Big[\Lambda_1(A)[x + q_1(A)b' - k'] + \beta \int \sum_{j=1}^{N_\varepsilon} \varphi_{ij}^{\varepsilon} \widetilde{v}_1(x'_j, \varepsilon_j; A') G(dA'|A) \Big], \tag{21}$$

subject to the collateral constraint in (19) and an equation determining next period's cash as a function of the firm's chosen capital and debt and the realization of ε':

$$x'_j \equiv \pi_1(k', \varepsilon_j; A') + (1 - \delta)k' - b'. \tag{22}$$

The problem above can be simplified further by the following observations. In equilibrium, no continuing firm can increase its value by paying strictly positive dividends in the current period, since it borrows and lends at the same price its owners face, and $\Lambda_1(A) = \lambda_1(A)$. On the other hand, for any firm with insufficient cash to preclude the possibility that the collateral constraint (19) may bind in some future date and state, the per-unit valuation of retained earnings exceeds the domestic household's valuation of dividends; any such firm's value is maximized only when $D = 0$. Combining these observations, we see that $D = 0$ is an optimal dividend policy for any continuing firm. Imposing this policy in the binding budget constraint (18), we see that each firm's choice of capital directly implies its debt, $b' = (k' - x)/q_1(A)$. Thus, (21) - (22) can be collapsed to a simple univariate problem:

$$\begin{aligned} v_1(x, \varepsilon_i; A) &= \max_{k'} \beta \int \sum_{j=1}^{N_\varepsilon} \varphi_{ij}^{\varepsilon} \Big[\gamma \Lambda_1(A') x'_j + (1 - \gamma) v_1(x'_j, \varepsilon_j; A') \Big] G(dA'|A) \qquad (23) \\ \text{subject to } x'_j &= \pi_1(k', \varepsilon_j; A') + (1 - \delta)k' - (k' - x)/q_1(A) \\ \text{and subject to } k' &\leq x[1 + \theta_1 q_1(A)]. \end{aligned}$$

Let $g_1(x, \varepsilon_i; A)$ represent the resulting capital decision rule for a firm in country 1, and let $b'_1(x, \varepsilon_i; A)$ be the associated debt rule.

4.4 Recursive equilibrium

A *recursive competitive equilibrium* is a set of functions: $\varrho, Q, \{w_c, q_c, \rho_c, \widetilde{\rho}_c, p^{Dc}, p^{Xc}, P_c, \Lambda_c\}_{c=1,2}$, $\{V_c^h, C_c, N_c, \zeta'_c, \phi'_c, B'_c, H_c, y^{Dc}, y^{Xc}\}_{c=1,2}$, and $\{v_c, n_c, y_c, g_c, b'_c\}_{c=1,2}$ that solve household and firm problems and clear the markets for assets, labor, intermediate goods and final output in each country, as described by the following conditions.

(i) V_1^h solves (1), V_2^h solves (6), and $(C_c, N_c, \zeta'_c, \phi'_c, B'_c)$ are the associated policy functions for households in each country $c = 1, 2$

(ii) country 1 final-good producer solves (10) given (9) with policy functions (H_1, y^{D1}, y^{X2}); country 2 final-good producer solves analogue problems with policy functions (H_2, y^{D2}, y^{X1})

(iii) country $c = 1, 2$ firms solve (16) given (15), and (n_c, y_c) are the associated policy functions

(iv) v_c solves (23) with associated policy functions (g_c, b'_c), for $c = 1, 2$

(v) $\zeta'_c(k', b', \varepsilon_j, \zeta_c, \phi_c, B_c; A) = \mu'_c(k', b', \varepsilon_j; A)$, for each $(k', b', \varepsilon_j) \in \mathcal{S}$ in country $c = 1, 2$

(vi) $\phi'_c(\zeta_c, \phi_c, B_c; A) = \int_{\mathbf{S}} \left[b'_c(k, b, \varepsilon; A) \right] \mu_c(d[k \times b \times \varepsilon])$, for $c = 1, 2$

(vii) $B'_1(A', \zeta_1, \phi_1, B_1; A) + B'_2(A', \zeta_2, \phi_2, B_2; A) = 0$ for all $(A'; A)$

(viii) $N_c(\zeta_c, \phi_c, B_c; A) = N_c^F(A)$, where $N_c^F(A) = \int_{\mathbf{S}} n_c(k, \varepsilon; A)\mu_c(d[k \times b \times \varepsilon])$, for $c = 1, 2$

(ix) $C_c(\zeta_c, \phi_c, B_c; A) = H_c(A) - I_c(A)$, where $H_c(A) = \left(\omega[y^{Dc}(A)]^{\frac{\rho-1}{\rho}} + (1-\omega)[y^{X\widetilde{c}}(A)]^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}$ (with $\widetilde{c}$ representing the trade partner for country c, that is $\widetilde{c} \neq c$), and where $I_c(A) \equiv \int_{\mathbf{S}} \left[(1-\gamma)[g_c(k, b, \varepsilon; A) - (1-\delta)k] + \gamma[k_0 - (1-\delta)k] \right] \mu_c(d[k \times b \times \varepsilon])$, for $c = 1, 2$

(x) $y^{Dc}(A) + y^{Xc}(A) = Y_c(A)$, where $Y_c(A) \equiv \int_{\mathbf{S}} y_c(k, b, \varepsilon; A)\mu_c(d[k \times b \times \varepsilon])$, for $c = 1, 2$

(xi) $\mu'_c(\mathcal{J}, \varepsilon_j) = (1-\gamma) \int_{\{(k,b,\varepsilon_i) \mid (g_c(k,b,\varepsilon_i;A), b'_c(k,b,\varepsilon_i;A)) \in \mathcal{J}\}} \varphi^{\varepsilon}_{ij} \mu_c(d[k \times b \times \varepsilon_i]) + \gamma\chi(k_0)M(\varepsilon_j)$,

$\forall\ (\mathcal{J}, \varepsilon_j) \in \mathcal{S}$, defines Γ, where $\chi(k_0) = \{1 \text{ if } (k_0, 0) \in \mathcal{J};\ 0 \text{ otherwise}\}$, for $c = 1, 2$

In closing this section, we define each country's GDP as the value of its total production, denominated in units of its own final goods. Given the notation in item (x) above, this can be conveniently expressed as: $GDP_c \equiv \frac{p^{Dc}}{P_c} Y_c$.

5 Calibration

The length of a period in our model corresponds to one year. We assume that the household period utility function takes the form:

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

thus adopting the preferences of Greenwood, Hercowitz and Huffman (1988). Because it eliminates wealth effects on labor supply, this is a commonly used specification in international business cycle models (see, for example, Devereux, Gregory and Smith (1992), Raffo (2008), and Alessandria, Kaboski and Midrigan (2013)). Raffo (2008) shows that its use in a standard two-country real business cycle model can generate the observed countercyclical net flow of goods across countries.

The household discount factor β is chosen to deliver a long-run annual real interest rate of 4 percent consistent with the measurement in Gomme, Ravikumar and Rupert (2011). Our relative risk aversion in the household utility function ϕ is 1, following Schmitt-Grohé and Uribe (2003). The labor exponent in utility η is set to deliver a labor elasticity of 1.7, as in Greenwood, Hercowitz and Huffman (1988). Adopting the estimate by Heathcote and Perri (2002), we set the elasticity of substitution between domestic and imported intermediate goods ρ at 0.9.[7] We follow Cooley and Prescott (1995) in setting labor's share in production υ equal to 0.6. The firm liquidation rate χ is 0.0869, ensuring that our model matches the average exit rate among firms in the Bureau of Labor Statistics' Business Dynamics Statistics database (BDS) over 1979 - 2007.

We set the capital depreciation rate δ to imply a long-run aggregate investment-to-capital ratio consistent with that for the average annual private capital stock between 1954 and 2002 in the U.S. Fixed Assets Tables, controlling for growth. Given that value, we set capital's share α in the intermediate-good production function to reproduce the 2.3 average annual private capital-to-GDP ratio over the same period. The weight on labor in utility κ is selected so that households work one-third of their time in steady state. We chose the weight on domestic intermediate goods in the final-good production ω to imply a steady state imports-to-GDP ratio at 9 percent,

[7] Corsetti et al. (2008) estimate the elasticity of substitution between home and foreign tradables through the lens of a two-country model with tradable and non-tradable goods, using the United States to represent the home country and the trade-weighted aggregate of Canada, Japan and EU-15 as the foreign country; their resulting estimate is 0.85. Given the wide range of estimates of the Armington elasticity in the literature (see Ruhl (2008)), we also report results from a version of our model with $\rho = 1.5$ in section 6.1.3 below.

matching the imports of goods and services for the United States between 1960Q1 and 2006Q4.

The collateral constraint parameter θ_c is 0.95 in steady state for $c = 1, 2$. This implies a steady-state aggregate debt-to-asset ratio of 0.31, near the 0.37 average from non-farm non-financial businesses over 1954 - 2006 in the Flow of Funds. We set the initial capital stock for new firms k_0 to imply that, in steady state, the employment size of a new firm is 0.285 that of a typical firm, reproducing the average relative employment size of a new firm in the BDS data over 1979 - 2007. The persistence and standard deviation of the firm-level productivity process, ρ_ε and σ_ε, are jointly chosen for consistency with two aspects of establishment-level investment rates documented by Cooper and Haltiwanger (2006) using panel data from the Longitudinal Research Database. They report a cross-sectional mean investment-to-capital ratio averaging 0.12, and a standard deviation of investment rates averaging 0.34; examining a sample of firms in our model's steady state selected for consistency with the Cooper and Haltiwanger sample, we obtain an average i/k at 0.14 and a standard deviation of i/k at 0.43. Resulting parameter values are summarized in Table 1.

TABLE 1. Parameter values

β	ϕ	κ	η	ρ	ω	δ
0.962	1.000	1.480	1.588	0.900	0.930	0.067
α	ν	ρ_ε	σ_ε	θ	γ	k_0
0.345	0.600	0.757	0.026	0.950	0.087	0.304

NOTE.– Preference parameters: β (discount factor), ϕ (relative risk aversion), κ (weight on labor), η (curvature on labor), ρ (Armington elasticity), ω (home bias). Production parameters: δ (capital depreciation rate), α (capital share), ν (labor share), ρ_ε and σ_ε (persistence and standard deviation of firm-specific productivity shock). Collateral constraint and other parameters: θ (limit on debt per unit cash), γ (exit rate), ξ_k (relative capital of a new firm).

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 in Figures 4 and 5 is a 70 percent fall in the country 1 borrowing constraint parameter θ_1. We assume that

θ_1 remains at this low value for three periods and thereafter recovers fairly rapidly; persistence of the shock is 0.3, following the calibration exercise in Khan and Thomas (2013).[8] We choose the magnitude of the initial fall in θ_1 such that the total debt of firms in country 1 declines by roughly 45 percent from peak-to-trough. This is consistent with Ivashina and Scharfstein's (2010) finding, using Reuters DealScan data on new lending to large corporations, that loans used to fund investment in equipment and structures fell 48 percent during the 2007-09 financial crisis.

6.1.1 Domestic responses

Figure 4 shows the impulse responses of country 1. The credit shock affects firms' current investment decisions and hence their capital stocks for the next period. Because firms' capital stocks for current production are already in place when the shock hits, the responses in aggregate quantity variables are modest in the first date of the shock ($t = 0$). Nonetheless, given the increased misallocation that will soon arise from cash-poor firms' worsened ability to finance levels of investment consistent with their productivities, households immediately foresee a lower future return on investment. Given their reduced incentives for saving, households begin reducing their hours of work immediately; the labor input falls by 0.2 percent upon the impact of the shock, generating a 0.4 percent fall in GDP. At the same time, and for the same reason, households temporarily increase consumption by about 1 percent.

After the first period, the credit shock begins to have more direct effects on firms' production through their capital stocks. First, the initial decline in aggregate investment implies less capital in the aggregate than usual. Second, and more importantly, that aggregate stock is unusually misallocated. As noted above, tightened collateral constraints have particularly adverse implications for the investments of cash-poor firms with relatively high productivity levels. This explains the fall in measured TFP in the lower right panel of Figure 4, despite the absence of any direct shock to aggregate productivity. As this happens, the declines in aggregate quantities grow more pronounced, particularly during the next three periods when firms' capital stocks are most affected by tight credit conditions. Over these dates, firms sharply curtail their borrowing and investment. Aggregate debt falls by around 45 percent over the first three periods after the

[8] In the sample of advanced economies studied in Reinhart and Rogoff (2009), the average number of banking crises between 1945 and 2008 was 1.4, and the average fraction of years countries spent in crises was 7 percent. These observations imply that the probability that a crisis continues from one year to the next once it has started is 0.3125. We adopt this value for the persistence of our credit shock.

shock, then gradually reverts to its steady state level. Investment falls to 12 percent below average one period after the shock, then gradually recovers. The fall in investment reduces demand for final goods, in turn reducing the demand for domestic and imported intermediate goods. Thus, intermediate-goods production drops off, as is reflected in the GDP panel. GDP falls by 2.9 percent after one period, reaching a trough at 3.2 percent below normal two periods later. As with GDP, the response in total hours worked closely tracks endogenous TFP; at its trough three periods after the shock's impact, the labor input is roughly 2.12 percent below normal. Given these declines, the initial consumption rise is sustained only for one period; it declines thereafter until the GDP trough date, where it is 2.7 percent lower than normal.

As noted above, the credit shock reduces production among the firms supplying domestic intermediate goods. However, because these firms' capital stocks are predetermined by the period preceding the impact of the shock, the initially small drop in labor supply is insufficient to reduce their production to match the fall in domestic demand for their products. The resulting excess domestic supply is thus exported to country 2, so country 1's exports temporarily rise. This outflow of country 1 intermediate goods is short-lived, however, as the reduced investments among intermediate-goods firms begin to be reflected in their capital stocks over subsequent periods. Exports are 2.3 percent below normal four periods after the shock's impact, at which point they begin a very gradual recovery. Reduced demand for final goods directly implies reduced demand for imports of foreign intermediate goods. Imports follow a path similar to that of endogenous TFP, and trough around 3.6 percent below normal.

6.1.2 Responses abroad

Figure 5 displays the impulse responses in country 2 arising from the credit shock taking place in country 1. As mentioned above, country 2 experiences a large influx of intermediate goods from country 1 at the date of the shock. Because the two countries' intermediate goods are complements in the final-good production function, this temporary rise in country 2 imports raises its demand for its own intermediate goods. This stimulates local production, leading to temporary rises in GDP (0.4 percent) and employment (0.2 percent) at the impact date. The resulting increase in the production of final goods also temporarily raises consumption and investment by 0.3 and 2 percent, respectively. Aggregate debt rises for several periods, since the rise in investment encourages more borrowing among intermediate-goods firms; their increased cash holdings accommodate this, as the country 2 limit on debt-to-cash ratios, θ_2, is unchanged.

As country 1's exports begin declining and soon fall below normal, country 2 begins to experience the negative effects of the credit shock in country 1. Note that this has nothing to do with aggregate productivity in country 2. With no change in aggregate borrowing conditions there, the extent of misallocation is unaltered, so measured TFP stays at its normal level.

The reductions in country 1's production and exports to country 2 soon begin to curtail domestic demand for intermediate goods in country 2. Compounded by country 1's low demand for imports from country 2, this reduces equilibrium production of intermediate goods and, in turn, final goods. GDP and employment fall, discouraging consumption. Intermediate-goods firms' reduced demands for investment imply reduced needs for borrowing, so aggregate debt declines; once it falls below its steady state level, it remains there for many periods.

Quantitatively, the overall effects of country 1's credit shock on country 2 are quite small compared to the observed depth of recessions outside of the United States during the recent financial crisis. Because the main sources of international transmission in our model economy are the shortage of export supply and the weak demand for imports in the country directly affected by the shock, the size of international trade calibrated to the U.S. data is insufficient to cause a large recession in its trade partner economy. If the trade share is instead set to a counterfactually high value (0.80), the model predicts that GDP, consumption and hours worked in country 2 immediately fall by 4.34 percent, 1.72 percent and 2.76 percent, respectively, and they remain low for several periods.[9]

6.1.3 Implications of greater trade openness and substitutability

In this subsection, we investigate how the propagation of credit shocks in our model economy is affected by countries' openness to trade and by the degree of substitutability in the goods they trade. In particular, we examine two cases. In the first, we consider what happens when home bias is weakened relative to our baseline calibration, so that the average volume of trade is greater. In the second, we compare our baseline model's results to those obtained when traded goods are more substitutable across countries. Throughout these exercises, we study an AR(1) credit shock reducing country 1's collateral constraint parameter, θ_1, by 70 percent for one period, with gradual recovery thereafter governed by persistence 0.7.

[9] Figures from this exercise are available on request.

In our baseline calibration, imports are 9 percent of GDP in steady state, matching the U.S. average over 1960Q1 to 2006Q4. However, the import share is significantly higher for most other advanced economies; indeed, as of 2006Q4, the U.S. figure was almost 16 percent. We explore a 'high trade' version of our model here by reducing the weight on domestic intermediate goods in final-good production (the home bias parameter ω) from 0.93 to 0.82, holding remaining parameters constant; this raises the steady state import share to 20 percent of GDP.

Figures 6 and 7 show the responses to the country-1 AR(1) credit shock in country 1 and country 2, respectively. In each figure, we compare the responses from the baseline calibration to those in the high-trade case. Figure 6 shows that, when countries trade more with each other, the immediate responses in country 1 upon the impact of the shock are larger, but the responses in all subsequent periods are dampened relative to the baseline. Recall from above that, when the credit shock hits this country, the initial decline in production among domestic firms is comparatively small, given their pre-determined capital stocks. With the far sharper drop in aggregate investment demand, there is excess supply of intermediate goods relative to the needs for domestic final good production, and that extra supply is absorbed by country 2 in equilibrium, temporarily raising country 1 exports. In the high trade version of our model, the initial increase in exports is larger. Given lower home bias, the extent to which the domestic economy can usefully absorb excess production capacity is more limited. Thus, at the shock impact date, more intermediates are sent abroad relative to the baseline case, while domestic firms curtail their employment and investment by more. Given the sharper drop in investment, the demand for final goods falls by more, generating larger declines in GDP and imports relative to the baseline case.

After period 0, the credit shock has more direct effects on the economy, as both the misallocation and the reduced aggregate capital stock arising from the previous period's investment decisions take effect. Over these dates, the declines in GDP, consumption and employment are dampened with higher international trade. For example, three periods after the onset of the shock ($t = 3$), GDP is 1.45 percent below normal in the baseline model; whereas, it is 1.09 percent below normal in the high trade case. The rate of decline in investment between dates 0 and 1 is also reduced when the economy is more engaged in international trade, and its subsequent recovery is faster. Given a smaller weight on domestic intermediate goods in the production of its final goods, the country has greater protection against the effects of a shock disrupting its domestic intermediate-good production. Thus, we see more reliance on imports in the lower right panel relative to the baseline case, which helps to sustain consumption in the upper right panel, and both dampens the declines in employment and investment, and accelerates their recoveries starting in period 1.

Figure 7 considers the implications of high trade for international transmission of country 1's credit shock. At date 0, the initial surge in country 2's aggregate quantities is amplified by a higher trade share, as the larger temporary rise in country 1 exports induces a greater increase in country 2's production. In subsequent periods, however, we see that the greater openness to international trade amplifies the transmission of the recessionary effects of the credit shock from country 1. Three periods after the shock ($t = 3$), country 2's GDP is 0.22 percent below normal, and its investment is down 0.74 percent in the high trade case, versus 0.11 percent and 0.14 percent, respectively, in the baseline model. Since lower home bias implies that a larger share of country 1's intermediate goods is used in country 2's production of final goods, country 2 is more exposed to shocks affecting its trading partner. Once the effects of the initial inflow of country 1 intermediate goods subside, the increased cost of imports from country 1 delivers a larger negative impact on final-good production in country 2, generating larger declines in consumption and investment. As intermediate-good firms in country 2 scale back their investments, they require less external finance, so we see a steady decline in aggregate debt over many periods. With the larger contraction in intermediate-good production, employment falls by more. Finally, because the shock-induced gap between country 1's consumption and that in country 2 is narrowed with greater openness to trade, the appreciation in the real exchange rate is smaller.

We next consider implications of the degree of substitutability between domestic and imported intermediate goods for the responses to the same credit shock as above. In our baseline calibration, the Armington elasticity, ρ, is 0.9, so domestic and imported intermediate goods are complements. An alternative value at 1.5 is often used in international business cycle models.[10] We adopt this elasticity as a 'substitutes' case for comparison with our baseline model's responses in Figures 8 and 9 below, again holding other parameters fixed.

Beginning with the domestic responses in Figure 8, we see that, once the credit shock begins to have direct effects on firms' production through their lower capital stocks one period after the shock, the recessionary effects of the domestic credit shock are marginally greater when traded

[10] See, for example, Backus, Kehoe and Kydland (1994) and Chari, Kehoe and McGrattan (2002).

goods are more substitutable. Three periods after the impact date, country 1's GDP is 1.64 percent below its steady state level when goods are more substitutable ($\rho = 1.5$), versus 1.45 percent in the baseline case. This is largely driven by a greater reduction in the production of intermediate goods for export (lower left panel). Given the misallocative effects of country 1's credit shock on its aggregate productivity, the intermediate goods it produces are more expensive in units of country 2 final goods following the shock. When country 2 can more easily substitute away from these goods, exports fall by more, and the overall level of production in country 1 falls slightly further. This is counterbalanced to an extent by country 1's greater ability to substitute imported goods for its own intermediates and the appreciation of country 1 currency (shown in Figure 9), which mitigate the fall in imports and limits amplification in the consumption and labor responses.

As foreshadowed in our reasoning above, Figure 9 shows that international transmission of country 1's credit shock weakens substantially when the two countries' intermediate goods are more substitutable. At $t = 3$, GDP in country 2 is only 0.01 percent below normal, versus 0.11 percent in the baseline model. In the substitutes case, the initial inflow of goods from country 1 induces a smaller initial increase in country 2's output, as the rise crowds out some of its own intermediate-goods production. As such, the initial jumps in consumption, investment and employment are all muted. Conversely, once country 1's aggregate capital and endogenous productivity begin falling, higher substitutability shields country 2 from the recessionary effects originating in country 1. Final-good production in country 2 declines very little, dampening the movements in investment and consumption. This result is consistent with Heathcote and Perri's (2002) finding that, in a two-country business cycle model driven by country-specific productivity shocks, the cross-country correlation of GDP falls with the elasticity of cross-country substitution under complete international financial markets.

In closing this section of results, it is worth noting that the assumption of complete international financial markets has little implication for the transmission of our credit shock. When we modify the baseline model allowing households access to only risk-free non-contingent bonds issued by each country, results are virtually unchanged. Three periods after the credit shock hits country 1, GDP in country 2 is 0.11 percent below normal under the incomplete market assumption, precisely the value in our baseline model.[11] This is reminiscent of the finding by Heathcote

[11] Figures from this exercise are available on request.

and Perri (2002) that equilibrium allocations in the bond-economy model are very similar to those in the complete-markets model, regardless of the elasticity of substitution between country 1 goods and country 2 goods, the degree of cross-country spillover in productivity shocks, and the persistence of the shocks (assuming they are stationary). Kehoe and Perri (2002) also show that impulse responses following a country-specific productivity shock (without exogenous spillovers) are very similar in an incomplete markets version of the international real business cycle model to those with complete financial markets.

6.2 Productivity shock

How does the propagation of credit shocks in our model economy compare to the dynamic responses following country-specific productivity shocks? Here, we examine the results following an exogenous TFP shock to country 1. To control the comparison, we choose the size and persistence of the productivity shock to emulate the baseline model's impulse response of measured TFP in country 1 following the AR(1) credit shock in Figure 6. This leads us to set the initial drop in country 1's exogenous TFP at 1.4 percent, and to assume the series recovers with persistence 0.6. The results of this exercise at home and abroad are shown in Figures 10 and 11; Tables 2 and 3 compare these outcomes to those following the credit shock discussed above.

In Figure 10, we see that the drop in country 1's exogenous TFP reduces its production of intermediate goods and hence GDP immediately, leading to a fall in employment. The contraction in the supply of domestic intermediate goods leads to lower exports and below-average final-good production. The latter implies reduced demand for imports of country 2 intermediates, alongside a fall in domestic consumption and investment.

Despite our model's financial frictions, a TFP shock has a very even incidence across country-1 firms (unlike a credit shock). Thus, as in the closed-economy setting of Khan and Thomas (2013), the distribution of production is largely unaffected, implying no change in the extent of misallocation and no endogenous unraveling of TFP. For that reason, we see no subsequent declines in domestic quantity variables, in contrast to the results following the credit shock in Figure 6; results here are similar to those in the model of Kehoe and Perri (2002) with complete financial markets.

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. Although the two shocks reduce measured TFP by the same amount, notice that the credit shock generates larger declines in all of the other domestic aggregates. The differences with respect to investment are substantial; those with respect to debt are dramatic.

TABLE 2. Domestic peak-to-trough declines

	TFP	GDP	Cons.	Invest.	Labor	Debt	Exports	Imports
credit shock	1.39	2.77	1.39	9.49	1.75	44.57	1.22	3.07
TFP shock	1.40	2.15	1.26	6.49	1.36	0.91	0.62	2.39

NOTE.– Maximum declines in country 1 series in response to domestic shocks. Credit shock (row 1) is 70 percent decline in country 1 collateral constraint parameter θ_1 with persistence 0.7. TFP shock (row 2) is a 1.4 percent fall in exogenous productivity, with persistence 0.6.

As noted above, a credit shock disproportionately hinders the investment activities of firms with low cash on hand, distorting the allocation of capital further from the efficient one. This shock has a particularly sharp impact on domestic investment, since the households that own firms anticipate low rates of return over coming periods. The fall in investment partly explains the decline in debt. However, it is directly compounded by tight credit, given both the drop in θ_1 and the endogenous reductions in firms' cash that generates. By contrast, a productivity shock affects firms' borrowing ability only through their effects on firms' static profits; there, the decline in debt arises only from a decline in investment demand and is thus minor.

The credit shock also generates much larger adverse effects on exports and imports, relative to the TFP shock. Imports fall 1.28 times as far under the credit shock than happens in response to the TFP shock; the drop in exports almost doubles (1.98) as we look from the TFP shock row to the credit shock row. These results are consistent with empirical findings that financial constraints exacerbated the sharp decline in international trade during the U.S. financial crisis (see, for example, Behrens, Corcos and Mion (2013) and Coulibaly, Sapienza and Zlate (2011)).[12]

Figure 11 displays the impulse responses in country 2 arising from the TFP shock taking place in country 1. With the drop in country 1's demand for imports from country 2, alongside a reduced inflow of intermediate goods from country 1, intermediate-goods firms in country 2 cut back their production and hiring upon the impact of the shock. Given international risk sharing and the absence of trade barriers in our model, investment rises briefly as households in country

[12] Bems, Johnson and Yi (2013) conclude that credit shocks account for about 15-20 percent of the great trade collapse of 2008-09.

1 redirect their savings in response to the rise in country 2's relative productivity. This rise in investment induces a temporary increase in borrowing. Thereafter, as reduced international goods trade continues to discourage production in country 2, its investment falls, reaching below-average levels after two periods, and debt begins to decline correspondingly. Meanwhile, consumption falls gradually.

Finally, Table 3 compares international transmission of credit versus productivity shocks, measuring the peak-to-trough declines in country 2 following each country 1 shock. Given its greater impact effects on exports and imports above in Table 2, we see here that the credit shock delivers far greater transmission than does the productivity shock. Aggregate effects abroad under the credit shock are roughly twice the size arising from the TFP shock.

TABLE 3. Peak-to-trough declines abroad

	GDP	Consump.	Invest.	Labor	Debt
credit shock	0.18	0.14	0.48	0.11	0.14
TFP shock	0.09	0.06	0.21	0.06	0.06

NOTE.– Maximum declines in country 2 series in response to country 1 shocks. Credit shock (row 1) is 70 percent decline in country 1 collateral constraint parameter θ_1 with persistence 0.7. TFP shock (row 2) is a 1.4 percent fall in exogenous productivity, with persistence 0.6.

7 Concluding remarks

Our goal in this paper was to explore quantitatively the extent to which a large credit shock in one country is transmitted to its trade partners. To that end, we developed a two-country equilibrium business cycle model wherein the producers of intermediate goods used in the final-good production at home and abroad face persistent idiosyncratic productivity shocks and collateralized borrowing constraints limiting the sizes of their investment loans. We calibrated our model symmetrically using standard long-run aggregate moments drawn from postwar U.S. data, including the average share of imports in GDP, and we chose the parameters most directly influencing firms' decisions on investment and borrowing to reproduce a series of micro-level moments drawn from the Business Dynamics Database and Longitudinal Research Database, as well as the average aggregate level of indebtedness in the United States.

Our model predicts that a credit shock in one country leads to a sharp contraction in the domestic economy and a delayed but persistent downturn in the economy of its trade partner.

When a country's credit availability suddenly tightens, the domestic allocation of production is distorted by the fact that an increased number of cash-poor firms find it harder to finance investments consistent with their productivity levels. Domestic investment and labor supply are immediately discouraged, since households understand that this misallocation will gradually erode aggregate productivity and thus the returns to aggregate capital. As a result, domestic firms cut investment and production. This in turn curtails demand for imported intermediate goods, since those goods complement domestic intermediates in the production of final goods.

Absent exogenous cross-country spillover of the credit shock, sharp declines in export supply and import demand from the country experiencing the credit shock soon transmit the negative consequences of the shock into the foreign economy. Quantitatively, however, the real economic damage felt abroad is small, so long as we confine ourselves to a model calibration consistent with the magnitude of international goods trade indicated by postwar U.S. data. International transmission of a credit shock is greater when countries are more open to trade and when the goods they trade are less substitutable, as each country grows more exposed to the health of its trading partner. Still, under reasonable parameterizations, it seems that the powerful propagation effects of financial shocks uncovered in closed-economy settings with the rich firm-level heterogeneity we have included here do not in themselves extend across borders in an otherwise standard international business cycle framework.

While international transmission of credit shocks is modest in our model, we show that it is nearly double that of exogenous productivity shocks carefully selected for comparability. This is entirely due to trade volumes. Credit shocks in our model generate reductions in international trade substantially larger than those caused by TFP shocks. As such, our framework may be useful in interpreting recent empirical evidence suggesting that financial constraints contributed to the collapse in international trade after the start of the U.S. financial crisis.

While our model offers a rich framework with financial frictions disparately affecting heterogeneous firms in an international business cycle model, we have abstracted from international financial linkages that had an important role during the recent global recession. As discussed above, a key mechanism propagating the credit crisis in our setting is an endogenous decline in aggregate productivity for the country directly affected by tight credit, which arises from misallocation of capital. A financial linkage simultaneously unraveling endogenous TFP abroad would almost certainly deliver strong comovement in our two-country model. One natural, if cumbersome, extension that might achieve this would be a setting in which firms carry two financial state variables. In particular, if firms borrowed at home and abroad subject to distinct collateral constraints associated with each financial source, this would likely amplify the degree of cross-country spillover of a financial crisis, highlighting the importance of international real-financial linkages.

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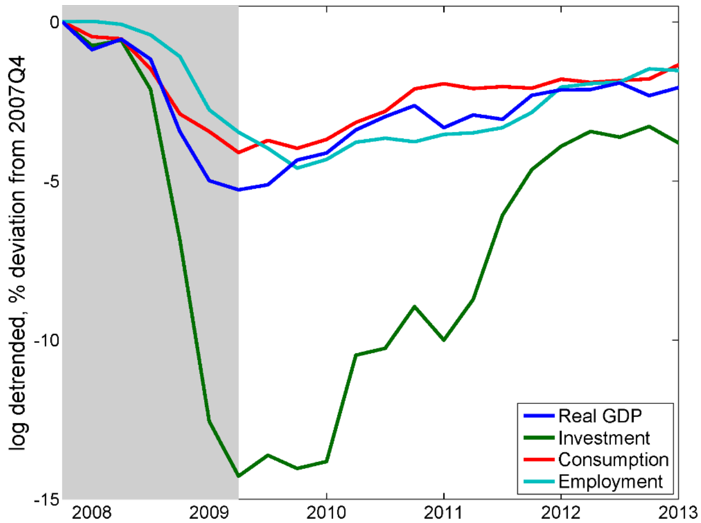
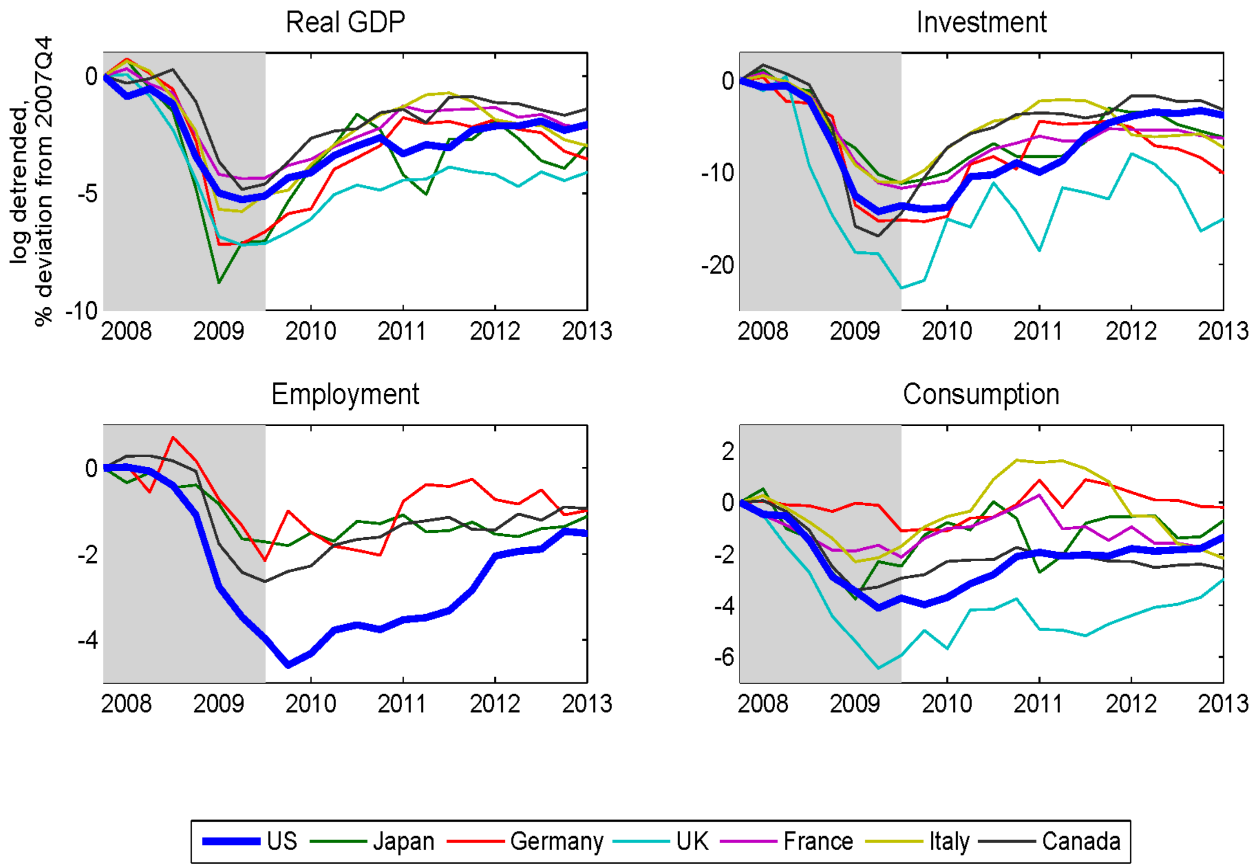
FIGURE 1. U.S. economy and the 2007-09 recession



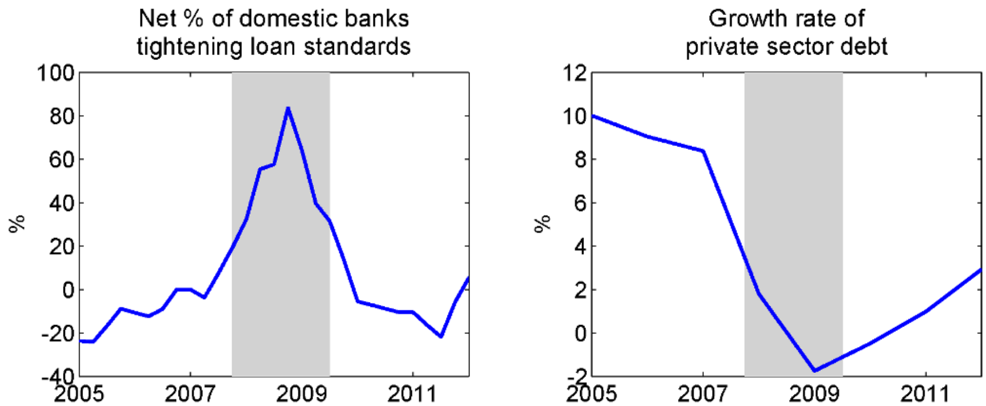
NOTE.– Data from OECD Main Economic Indicators. All series are in logs, detrended using the Hodrick-Prescott filter with weight 1600, and plotted as percent deviations from 2007Q4 values. Shaded gray bar denotes the recession dates defined by the National Bureau of Economic Research Business Cycle Dating Committee.

FIGURE 2. G7 countries and the 2007-09 U.S. recession



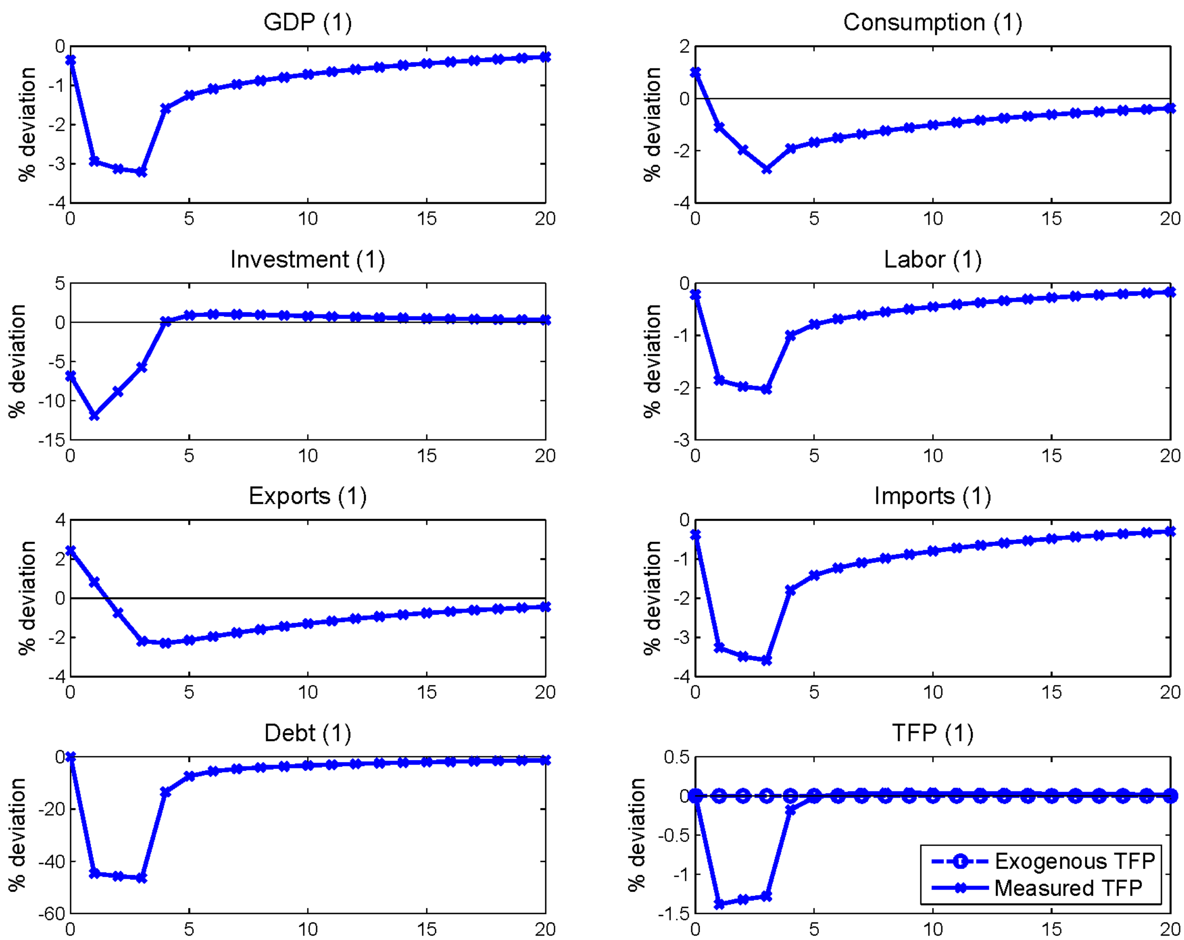
NOTE.– Data from OECD Main Economic Indicators. All series are in logs, detrended using the Hodrick-Prescott filter with weight 1600, and plotted as percent deviations from 2007Q4 values. Shaded gray bar denotes U.S. recession dates defined by NBER dating committee.

FIGURE 3. U.S. financial market



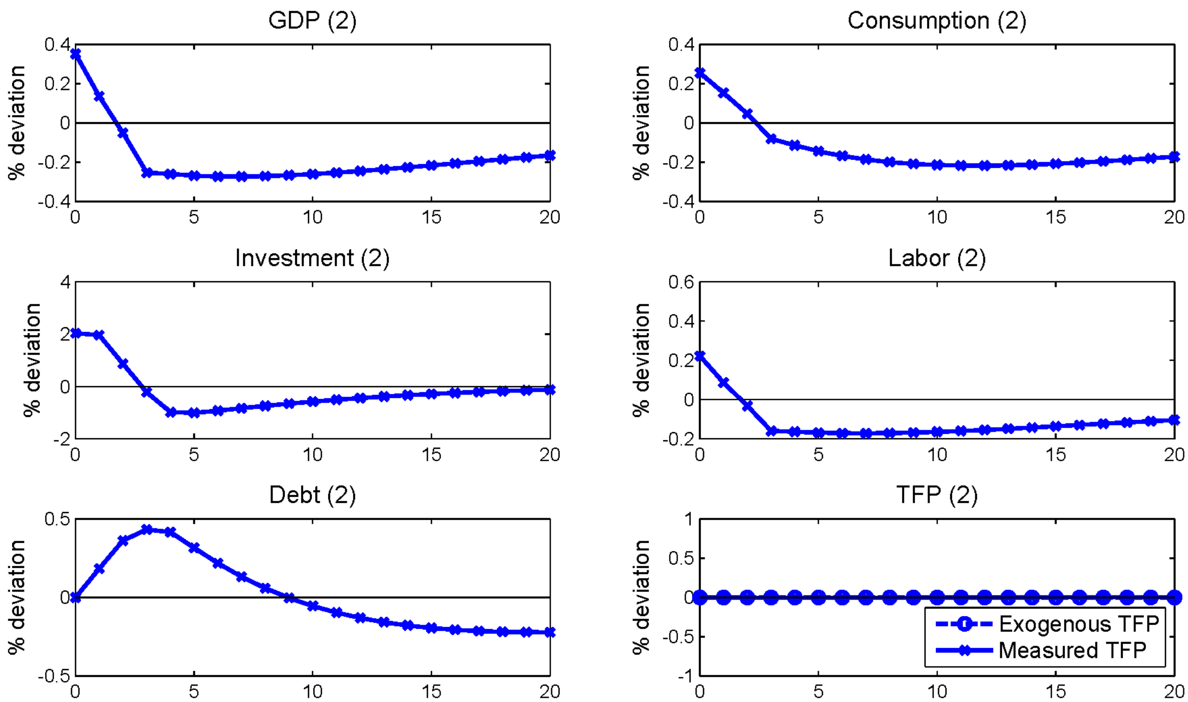
NOTE.– Shaded area reflects 2007 U.S. recession dates defined by NBER dating committee. Data sources: Senior Loan Officer Opinion Survey on Bank Lending Practices, Federal Reserve Board, OECD Main Economic Indicators.

FIGURE 4. Credit shock: domestic responses



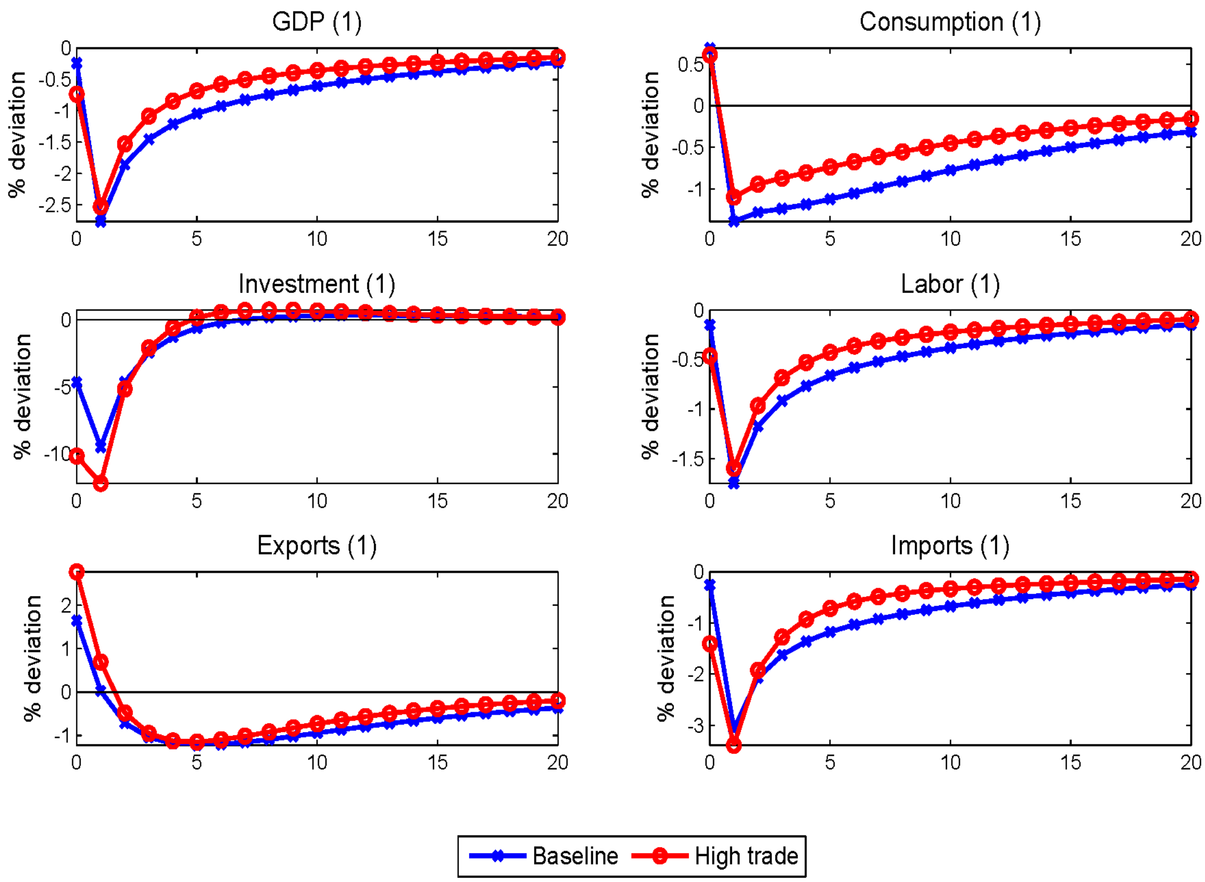
NOTE.– Country 1 impulse responses following exogenous shock to country 1 collateral constraint parameter, θ_1. Shock reduces θ_1 to 70 percent below its ordinary value for three periods; thereafter, θ_1 reverts to normal with persistence 0.3.

FIGURE 5. Credit shock: international transmission



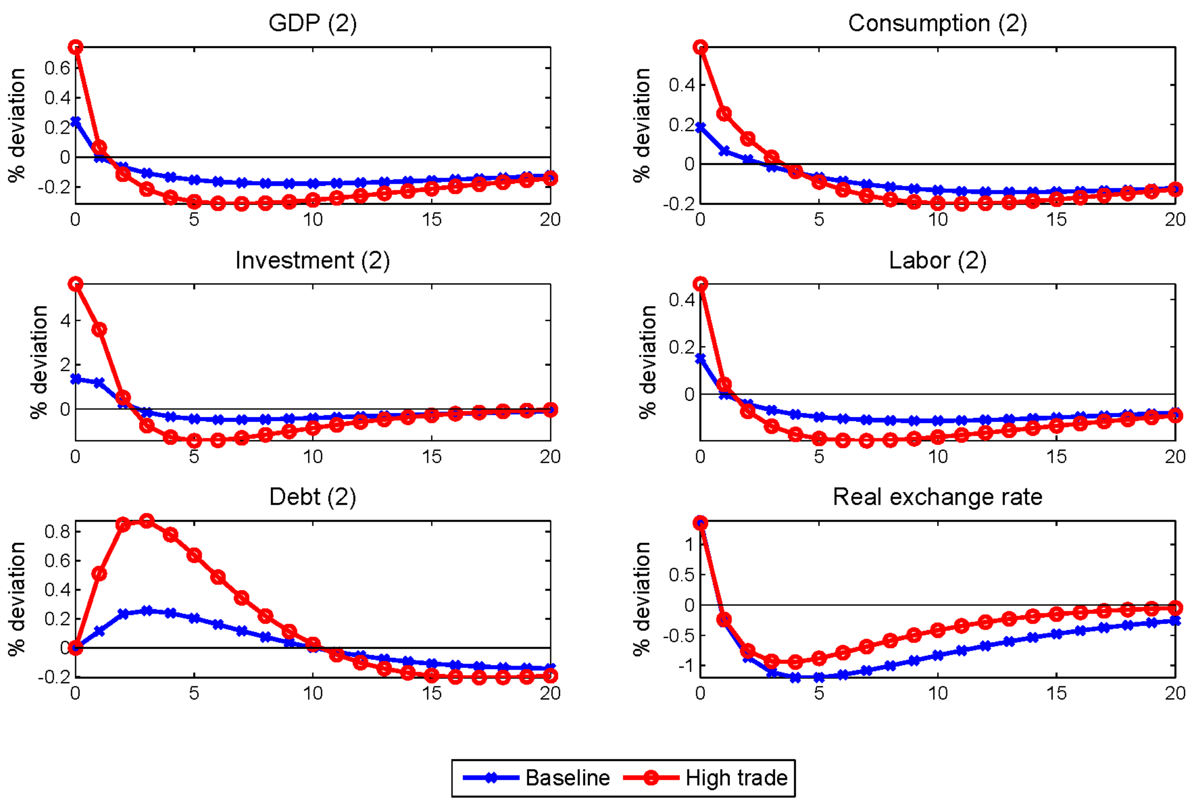
NOTE.– Country 2 impulse responses following exogenous shock to country 1 collateral constraint parameter, θ_1. Shock reduces θ_1 to 70 percent below its ordinary value for three periods; thereafter, θ_1 reverts to normal with persistence 0.3.

FIGURE 6. Trade openness: domestic responses



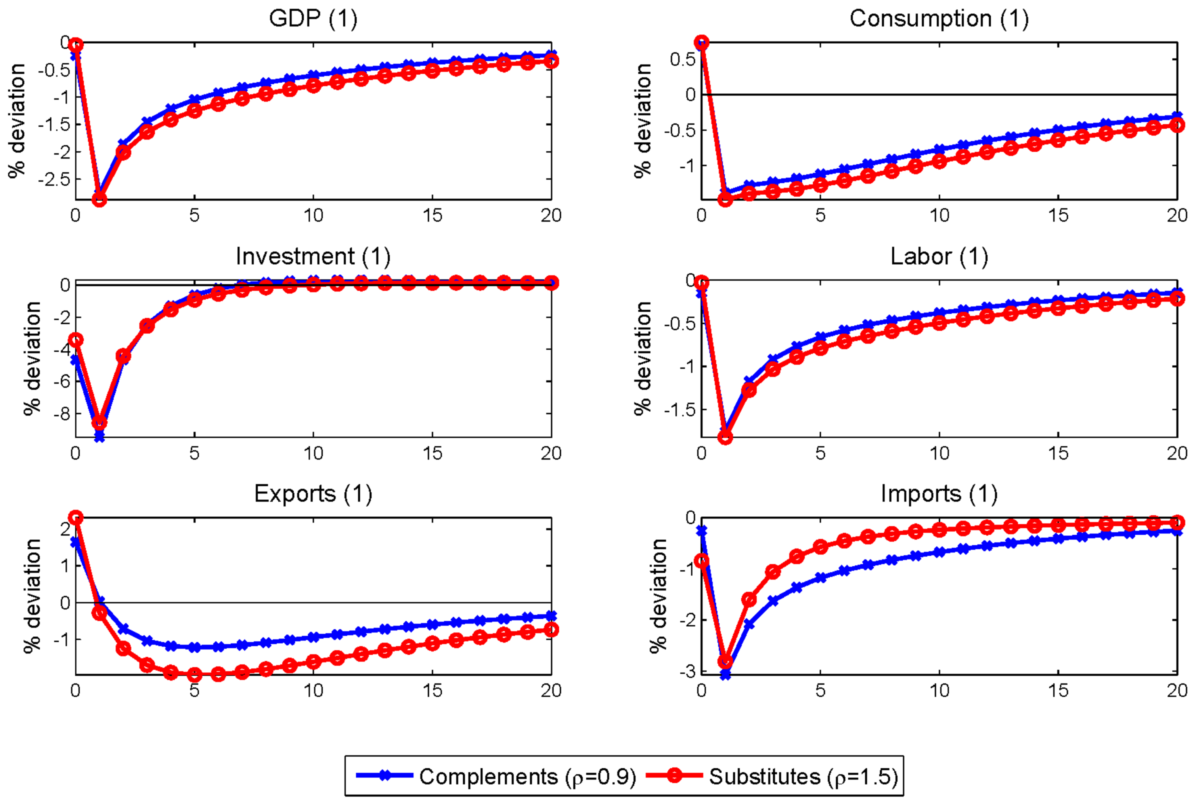
NOTE.– Country 1 impulse responses following exogenous shock to country 1 collateral constraint parameter, θ_1. Shock reduces θ_1 to 70 percent below its ordinary value for one period; thereafter, θ_1 reverts to normal with persistence 0.7. Blue x-curves are responses for the baseline model where $\omega = 0.93$; red o-curves are responses in high-trade model where $\omega = 0.82$.

FIGURE 7. Trade openness: international transmission



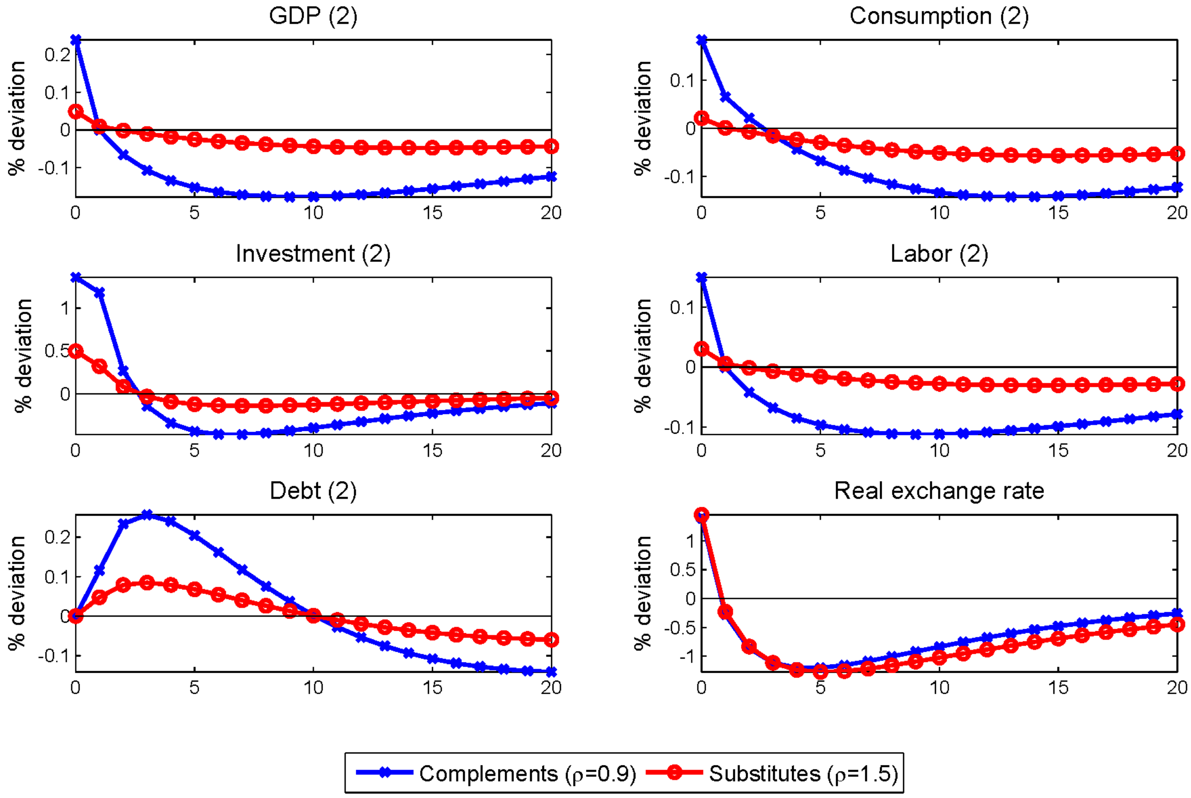
NOTE.– Country 2 impulse responses following exogenous shock to country 1 collateral constraint parameter, θ_1. Shock reduces θ_1 to 70 percent below its ordinary value for one period; thereafter, θ_1 reverts to normal with persistence 0.7. Blue x-curves are responses for the baseline model where $\omega = 0.93$; red o-curves are responses in high-trade model where $\omega = 0.82$.

FIGURE 8. Traded-good type: domestic responses



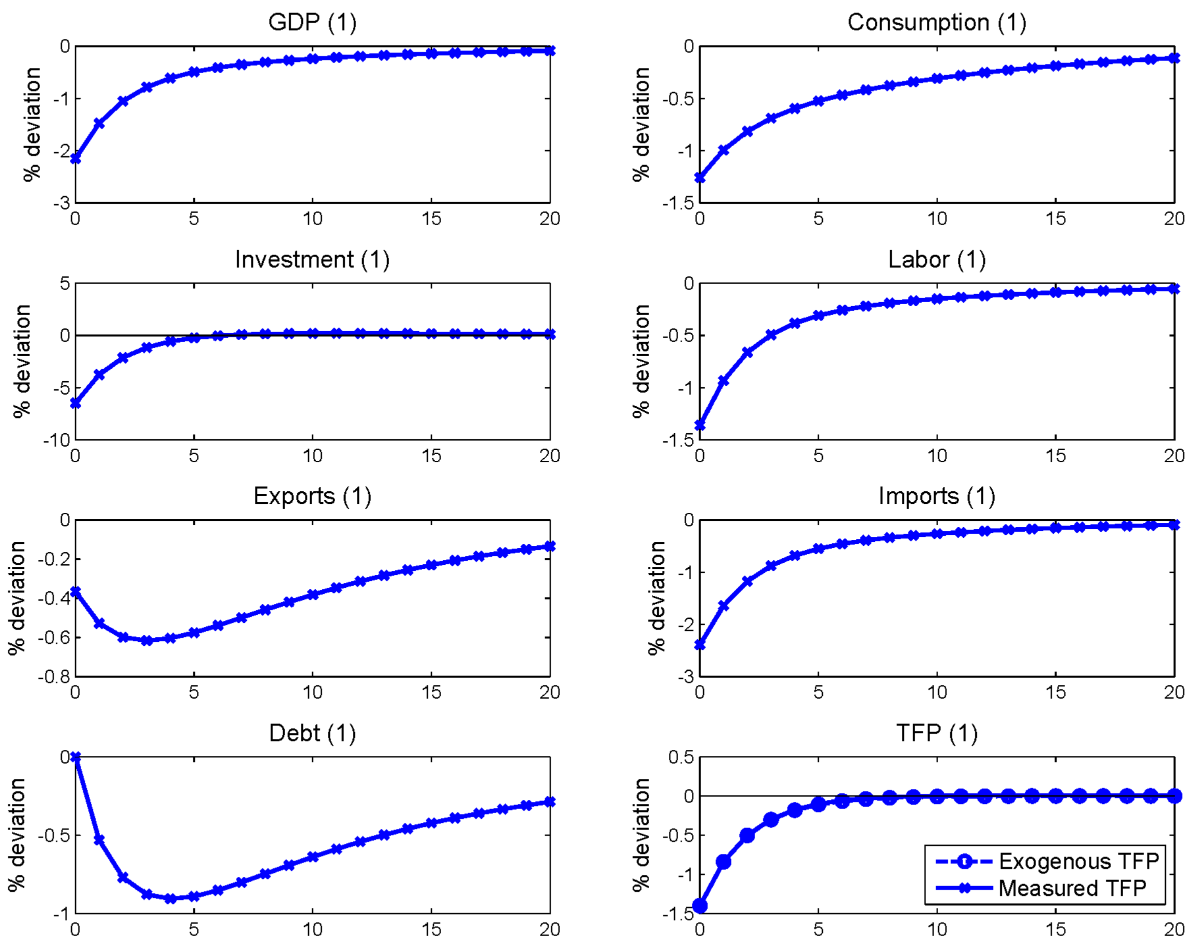
NOTE.– Country 1 impulse responses following exogenous shock to country 1 collateral constraint parameter, θ_1. Shock reduces θ_1 to 70 percent below its ordinary value for one period; thereafter, θ_1 reverts to normal with persistence 0.7. Blue x-curves are responses for the baseline model where $\rho = 0.90$; red o-curves are responses in high substitutability model where $\rho = 1.5$.

FIGURE 9. Traded-good type: international transmission



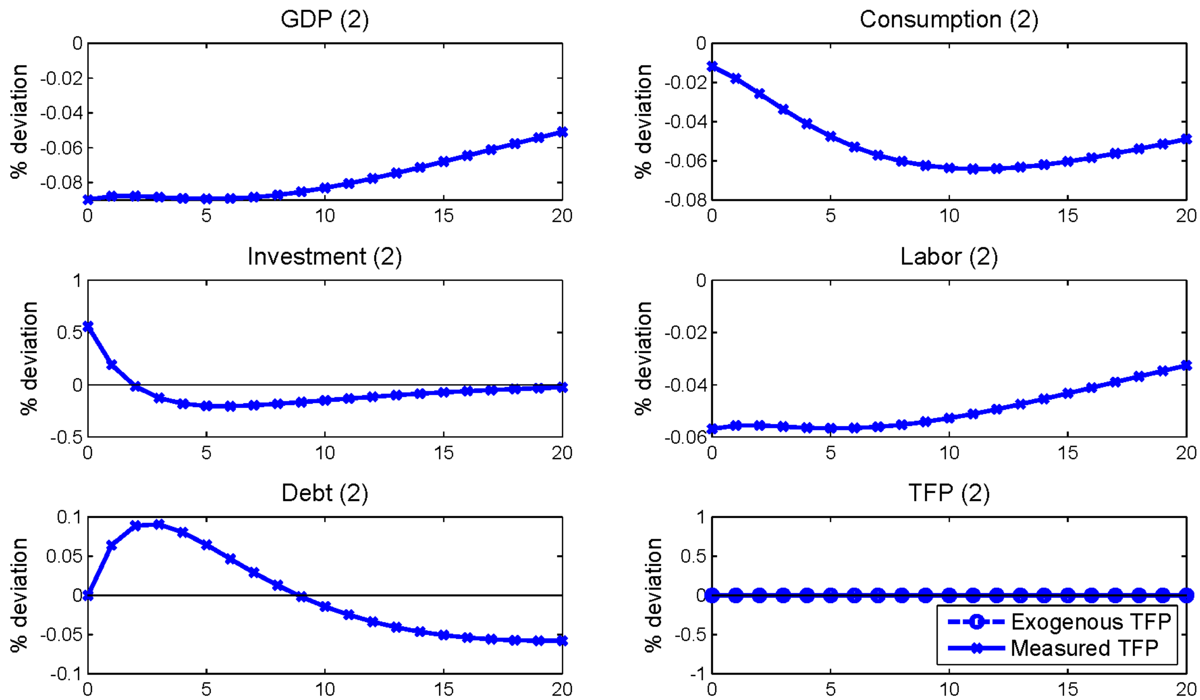
NOTE.– Country 2 impulse responses following exogenous shock to country 1 collateral constraint parameter, θ_1. Shock reduces θ_1 to 70 percent below its ordinary value for one period; thereafter, θ_1 reverts to normal with persistence 0.7. Blue x-curves are responses for the baseline model where $\rho = 0.90$; red o-curves are responses in high substitutability model where $\rho = 1.5$.

FIGURE 10. Productivity shock: domestic responses



NOTE.– Country 1 impulse responses following exogenous TFP shock to country 1. Shock selected to match the (baseline model) path of country 1 measured TFP in exercises above where θ_1 falls by 70 percent for one period and reverts to normal with persistence 0.7. Resulting shock is a 1.4 percent drop in z_1 for one period, followed by steady-state reversion with persistence 0.6.

FIGURE 11. Productivity shock: international transmission



NOTE.– Country 2 impulse responses following exogenous TFP shock to country 1. Shock selected to match the (baseline model) path of country 1 measured TFP in exercises above where θ_1 falls by 70 percent for one period and reverts to normal with persistence 0.7. Resulting shock is a 1.4 percent drop in z_1 for one period, followed by steady-state reversion with persistence 0.6.