Financial Intermediation in a Global Environment*

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I develop a two-country DSGE model with global banks (financial intermediaries in one country lend to banks in the other country). Banks are financially constrained on how much they can borrow from households. The main goal is to obtain a framework that captures the international transmission of a financial crisis through the balance sheet of the global banks as well as to explain the insurance mechanism of the international asset market. A negative shock to the value of capital in one country generates a global financial crisis through the international interbank market. Unconventional credit policies help to mitigate the effects of a financial disruption. The policies help to improve domestic consumers' welfare. The non-cooperative equilibrium yields both central banks intervening.

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1. Introduction

Global banks propagated the financial crisis of 2007–9 internationally. The crisis originated in the U.S. housing sector and spread to a number of economies that had investments in the United States. As a result of the loss of the value of U.S. assets and the large asset position of Swiss banks with U.S. counterparties, the banks in Switzerland were forced to write down several hundred billion U.S. dollars on bad loans. UBS, the largest Swiss bank and one of the largest global banks in the world, wrote off more than $50 billion U.S. dollars related to bad investments. Because UBS was not the only European bank that had a sizable presence and got into difficulty in the United States, the Federal Reserve carried out unconventional policies to help reduce the stress of these banks, such as the Term Auction Facility or relaxing the access of banks at the discount window.

Several papers explain the international transmission of the crisis through banks. Dedola, Karadi, and Lombardo (2013), Kamber and Thoenissen (2013), Kollmann (2013), Kollmann, Enders, and Müller (2011), and Ueda (2012) develop international models with global banks; however, banks do not lend to each other. International lending is done through cross-country lending from households to banks and from banks to firms. Unconventional monetary policy in the United States has been introduced in Gertler and Karadi (2011), Gertler and Kiyotaki (2010), and Gertler, Kiyotaki, and Queralto (2012), among others.

In terms of empirical work, there is a growing literature explaining the role of global banks in the transmission of the financial crisis. Kalemli-Ozcan, Papaioannou, and Perri (2013) analyze cross-border banking flows of the Bank for International Settlements (BIS) and show that the financial crisis generated more business-cycle co-movement among more financially integrated countries. Cetorelli and Goldberg (2011) look at emerging economies and find that the main channel of transmission of the global financial crisis was the reduction in cross-border lending by foreign banks. Helbling et al. (2011) with a VAR highlight that credit market shocks in the United States explain the latest global recession for advanced economies. The research on this paper puts the emphasis on the cross-border interbank lending from global banks as a channel of transmission of the financial crisis.

In this sense, this paper aims to contribute to both the empirical and the theoretical debate on the relation between cross-border banking flows, global banks, and the transmission of the crisis. Moreover, I look at the welfare effects of unconventional monetary policy in the theoretical model.

In terms of empirical contribution, I run a VAR to analyze the international transmission of the crisis from the United States to Switzerland. I am interested in Switzerland, because two of the biggest foreign banks that have an impact on the United States are there: UBS and Credit Suisse. In 2008, the total assets of UBS, $1.2879 trillion U.S. dollars, alone represented 246 percent of Swiss GDP and 8.7 percent of U.S. GDP. As early as 2007, UBS was considered one of the largest firms in the U.S. mortgage market (see Morgenson 2007). I find that the cross-border banking flows from Switzerland to the United States propagated the global financial crisis from the United States to Switzerland. A reduction in U.S. loans prompted a fall in asset prices in both countries; moreover, final domestic demand and how much Swiss banks lend to U.S. banks collapsed.

In terms of theoretical novelty, I build a two-country (home and foreign) model with global banks (banks that interact with other banks across international borders) and financial frictions. I examine the international transmission of a financial crisis through the global interbank market. Home is a relatively small country with a big banking sector, such as Switzerland, while foreign is a big economy with a relatively small banking sector, such as the United States. The model builds on the closed-economy models of Gertler and Karadi (2011) and Gertler and Kiyotaki (2010). There are home and foreign banks. They use their net worth and local deposits to finance domestic non-financial businesses. Banks can also lend to and borrow from each other through the global interbank market. Although banks can finance local businesses by buying their securities without friction, they face a financing constraint in raising deposits from local households because banks are subject to a moral hazard problem. Home banks (Swiss banks) have a longer average lifetime and a larger net worth (relative to the size of the economy) than foreign banks (U.S. banks); as a consequence, home banks lend to foreign banks in the interbank market and effectively participate in risky finance in the U.S. market.

As in the previous literature, Gertler and Karadi (2011), Gertler and Kiyotaki (2010), and Gertler, Kiyotaki, and Queralto (2012), I simulate the model giving a negative shock to the value of capital, the so-called quality-of-capital shock. When there is a reduction in the value of capital and securities in the United States, both U.S. and Swiss banks lose some of their net worth. Because banks are constrained on raising deposits, they have to reduce businesses' financing, which further depresses the value of securities and the banks' net worth. Swiss banks are affected because the asset price of their loans in the United States falls, and so does their net worth. Then, Swiss banks have to reduce the provision of loans to domestic firms because their asset side is shrinking and they are financially constrained. Therefore, the adverse shock in the larger economy leads to a decline in the asset price, investment, and domestic demand in both economies through the global interbank market.

First, I examine how a country-specific quality-of-capital shock is transmitted internationally. By looking at different models, I argue that the model with global banks is the only one that is able to replicate the facts shown in the vector autoregression (VAR). I compare a model without financial frictions with a model with financial frictions but without global banks, à la Gertler and Kiyotaki (2010). Countries in these two models are in financial autarky. In these models there is very little transmission of the financial crisis, which is due to the trade channel. Then, I allow for an international asset, which I will call the international interbank market. When foreign banks are allowed to borrow from home banks, the interbank market insures the foreign economy against the shock. Given that there are no financial frictions involved in borrowing from home banks, there is integration of the domestic asset markets. In comparison to the financial autarky case, integration amplifies the transmission of the shock and prompts a global financial crisis. To a quality-of-capital shock in foreign, the model shows similar characteristics to the VAR evidence: there is asset price co-movement across countries, home banks decrease how much they lend to foreign banks, and the home economy experiences a decrease in the final domestic demand.

Second, I turn to policy analysis during a crisis. It is important to distinguish between unilateral and international cooperative policies. Unilateral policies imply a country-specific authority that carries out a policy in their own jurisdiction, focusing on the benefits

and costs for the domestic households, and taking as given what is done in the other country. Cooperative policies in this paper imply a unique-global welfare, the sum of home and foreign welfare, weighted by the size of their populations. I analyze the effects, benefits, and costs of these two scenarios. I investigate if international cooperative policies imply higher (lower) benefits (costs) for each country than performing unilateral ones. For the range of parameters studied here, the non-cooperative equilibrium implies an active central bank in each country, while the cooperative equilibrium implies that only the foreign central bank should carry out a given policy, while the home central bank should do nothing.

I focus on three interventions: the government can lend directly to non-financial firms, provide credit in the interbank market, or provide direct financing to banks by buying part of their total net worth. I assume that there is no information asymmetry between the government and the banks, as opposed to the households and the banks. Looking at the second-order approximation of the model, in all the policies, there is a higher price of the domestic asset, which relaxes the domestic banks' constraint. Foreign banks borrow more from domestic households and less from home banks. Consumption in foreign increases and labor decreases; foreign households are better off. Because the income from the international asset decreases, the exchange rate depreciates for home. Home banks direct more credit to domestic non-financial firms, but total credit decreases, which reduces domestic deposits. Home households start to work more and consume less, their production is consumed by foreign households, and, consequently, they are worse off.

When both central banks intervene, home consumers are better off in comparison to only the foreign central bank intervening. The asset price at home goes up and home banks lend more abroad. Deposits at home increase, as do income and consumption, while labor decreases. Foreign banks face higher foreign capital and lower demand for domestic deposits because of the increase in loans from home. Foreign consumers are worse off when the home central bank is active. If both central banks intervene with the same parameters, foreign consumers are still better off and home households are worse off in comparison to the no-policy case.

There are two caveats to the results. First, the results are a consequence of the terms-of-trade effect. When the real exchange rate

appreciates (depreciates) for foreign (home), foreign consumers are better off, while home consumers are worse off. Second, the first-order approximation of the model looks at the reaction of an unexpected policy, while the second-order approximation entails an ex ante reaction. When facing a quality-of-capital shock, the agents take into account that the government will intervene.

What is new in this framework is the study of the international transmission mechanism of a financial crisis through the global interbank market with constrained financial intermediaries. The introduction of the global interbank market in the model prompts a high level of co-movement between the foreign and the home economy, with similarities to the VAR shown in section 2. There is international co-movement of asset prices, banks' net worth, and total final demands.

1.1 Related Literature

Three strands of literature are related to my analysis. The first concerns international real business cycles; the second strand is related to the introduction of financial intermediaries in open economies; and the third group refers to the international transmission of financial shocks. Regarding international business-cycle synchronization, Backus, Kehoe, and Kydland (1992) build a standard international real business cycle (IRBC) model. They find that to a technology shock correlated across countries, the model predicts a negative international correlation for investment and output, which does not match the data. It is efficient to allocate the resources in the more productive country, while reducing them in the less productive one. After a country-specific quality-of-capital shock, my model is able to replicate international co-movement of investment and final domestic demands, as seen in the data. Several papers try to improve the results in Backus, Kehoe, and Kydland (1992) by including frictions in the financial markets; Faia (2007) introduces the Bernanke, Gertler, and Gilchrist (1999) model in a two-country framework. This literature does not model banks explicitly.

Financial intermediaries have been added to international models in the last few years. Mendoza and Quadrini (2010) study financial globalization in a two-country model with banks and a country-specific capital shock. However, production is constant. Ueda (2012)

analyzes the international business cycle in a two-country DSGE model with banks. Although he presents a comprehensive model, financial frictions arise because there is an asymmetric information problem between the firms and the financial intermediaries. There is no gap for an international interbank market: global banks have deposits from both countries and lend in either of them. Kollmann, Enders, and Müller (2011) also omit the cross-country intrarelation of banks. In their paper, they look at how far a bank capital requirement affects the international transmission of a shock in a two-country model with global banks. They find that a very large loan loss induces a decline of activity in both countries.

Krugman (2008) points out the relevance of the international transmission of financial shocks to understand how the latest crisis that originated in the U.S. housing sector was transmitted to different countries. Devereux and Yetman (2010) develop a two-country DSGE model to highlight how balance-sheet-constrained agents and portfolio interdependence prompt a large spillover to the other country, given a productivity shock. Devereux and Sutherland (2011) extend the last paper by analyzing how macroeconomic outcomes and welfare behave for different levels of financial integration in the bond and equity markets. They find that bond and equity integration is welfare improving with positive co-movement across countries. In a complementary paper, Dedola and Lombardo (2012) show how equalization of asset prices leads to a higher propagation of an asymmetric shock. In this literature, banks are not modeled explicitly and the authors solve the model using portfolio choice. In my model, I add banks and simplify the portfolio problem by pinning down from the data the fraction of interbank lending from home to foreign banks.

My paper is closely related to the works of Dedola, Karadi, and Lombardo (2013) and Kamber and Thoenissen (2013). Dedola, Karadi, and Lombardo (2013) develop a two-country model with banks à la Gertler and Karadi (2011). Households lend to home and foreign banks; banks make loans to home and foreign firms, i.e., there is full integration. The initial net foreign asset position is zero, the economies are symmetric, and there is only one homogeneous good (there is no role for international relative prices). As opposed to this, in my model there is international interbank lending rather than direct cross-country lending and there is deposit

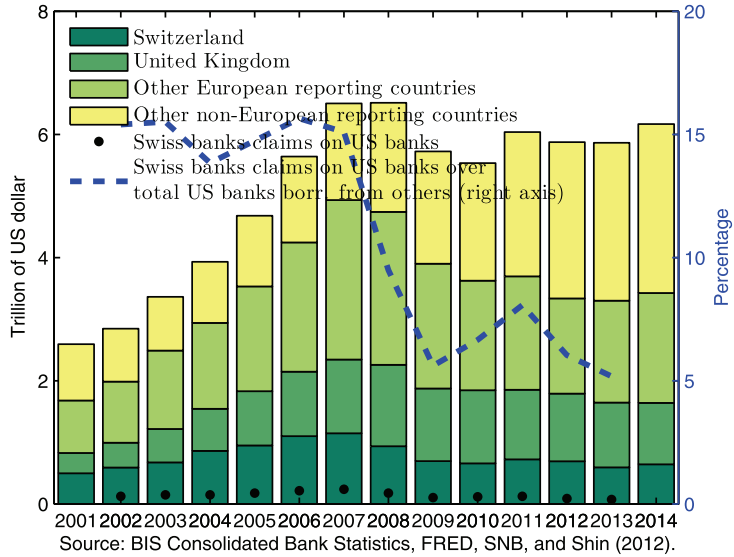
markets segmentation, the economies are asymmetric, and the real exchange rate plays a very important role. These characteristics break the equalization of cross-country interest rate spreads. Moreover, at the deterministic steady state, home banks lend to foreign banks, as seen in the data for Switzerland and the United States. To a country-specific quality-of-capital shock, the different characteristics of the model allow the framework presented in this paper to generate a larger propagation across countries of the financial crisis, while in Dedola, Karadi, and Lombardo (2013) there is very little global transmission after this type of shock. As I will explain later, the international relative prices are key to explaining the differences in the welfare results.[1]

Kamber and Thoenissen (2013) study the relation between the financial exposure of the banking sector and the transmission of foreign banking sector shocks. In their paper, the deposit market is perfectly integrated with the uncovered interest rate parity (UIP) holding every period, which does not hold in the data. They look at a default shock, i.e., a fraction of the stock of capital is destroyed and some loans (held by the small and the big economy) are not repaid. My approach differs from theirs in four ways. First, the deposit interest rate differs across countries and the UIP does not hold. Second, I study a reduction in the quality of the loans in the big economy; the financial friction causes foreign banks to lend less to home banks, prompting a more restricted borrowing constraint for the home banks, without a direct impact of the shock on their balance sheet. Third, the transmission mechanism in the model highlights the asymmetries across countries not only in their size but also in the size of their banking sector. Fourth, I analyze unconventional policy in this setup and possible policy coordination across countries.

The rest of the paper is organized as follows. In the next section, I describe the empirical evidence. In section 3, I present the full model in detail. In section 4, I explain the unconventional credit

[1]Dedola, Karadi, and Lombardo's (2013) model has positive output comovement after a financial shock, rather than a quality-of-capital shock. They relate the two shocks to the beginning of the recent financial crisis. The quality-of-capital shock can be understood as an unexpected realization that the capital installed was of lower quality or productivity than thought, while the financial shock, a shock to the fraction of assets that banks can divert, can be interpreted as a sudden loss of confidence in the financial sector.

Figure 1. Foreign Claims of BIS Reporting Countries on U.S. Counterparties, 2005:Q2–2013:Q4



policy. Section 5 studies the effects of the foreign quality-of-capital shock. I examine the model with and without policy response and I focus on the welfare comparison across the different unconventional policies. I conclude in section 6.

2. Empirical Evidence

The United States is a relatively big economy with a small banking sector. In 2008, the assets of U.S. commercial banks were only 77 percent of the U.S. GDP. The size of the assets of banks outside the United States with U.S. counterparties was 6.5 percent of the total of U.S. commercial banks assets (and 5 percent of U.S. GDP).[2] These loans came mainly from Switzerland. Figure 1 documents this evidence; the left axis shows the cumulative of the BIS reporting countries.

[2]The data correspond to BIS reporting countries. U.S. counterparties include banks and non-bank institutions.

Swiss banks' claims on U.S. banks (the black dots in figure 1), the interbank market channel between Switzerland and the United States, represented 19 percent of total Swiss claims on U.S. counterparties and less than 1 percent of U.S. commercial banks' total assets, in 2008. The right axis documents the ratio of Swiss claims with respect to total claims from banks other than U.S. banks.[3] Borrowing from others was 16.3 percent of total assets in 2008, and Swiss banks' claims on U.S. banks represented 10 percent of borrowing from others. This percentage was around 15 percent during the first half of the 2000s and fell below 8 percent after Lehman Brothers collapsed. This highlights the fall in Swiss banks' financing to U.S. banks after the financial crisis started.

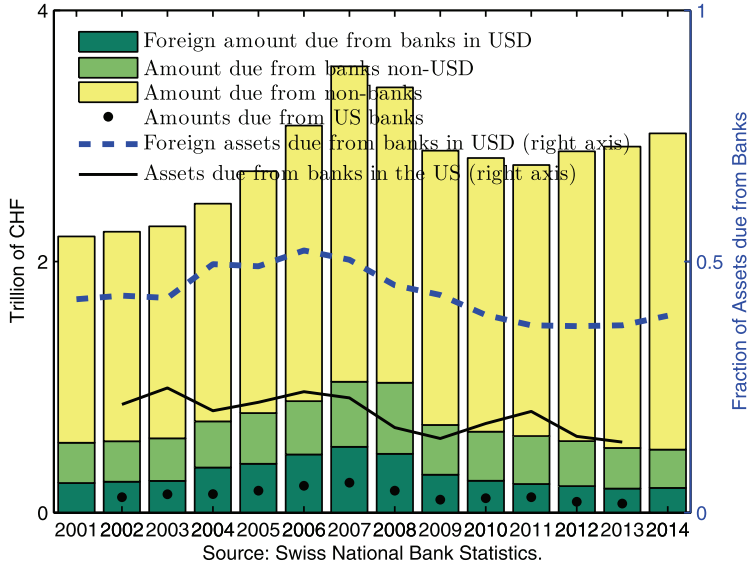
Switzerland is a relatively small economy with a big banking sector. In 2008, the assets of Swiss banks were 542 percent of the Swiss GDP. The Swiss banks' assets with U.S. counterparties were 16 percent of the Swiss banks' total assets.[4] In figure 2, I report the decomposition of Swiss banks' assets. On the left axis are the cumulative of the amounts of assets due from non-banks, due from banks and denominated in currency other than U.S. dollars, and due from banks and denominated in U.S. dollars. I also plot the amount due from U.S. banks (black dots). Assets from U.S. banks (the interbank market channel) represented around 20 percent of assets due from banks (solid black line on the right axis), while assets denominated in U.S. dollars represented around 40 percent. In 2008, UBS and Credit Suisse held 72 percent of the total amount due from foreign banks in foreign currency. Total assets of UBS, $1.2879 trillion U.S. dollars, alone represented 246 percent of Swiss GDP and 8.7 percent of U.S. GDP. As early as 2007, UBS was considered one of the big firms in the U.S. mortgage market (Morgenson 2007). Swiss banks in general and UBS in particular are net lenders to the United States.

To invest in U.S. financial intermediaries, UBS borrowed U.S. dollars. During normal times, UBS could roll over their debts. In 2007, the problems in the U.S. housing sector hit financial

[3]Total claims from others correspond to "Borrowing from others" (than U.S. banks) in the Assets and Liabilities of Commercial Banks in the United States H-8, Federal Reserve Board.

[4]Swiss banks' assets denominated in U.S. dollars were 30 percent of total Swiss banks' assets. This implies that Swiss banks have U.S.-dollar-denominated loans in countries other than the United States.

Figure 2. Foreign Claims of BIS Reporting Countries on U.S. Counterparties, 2005:Q2–2013:Q4



institutions, and many banks found themselves in distress. This, in addition to the failure of Lehman Brothers in September 2008, triggered a severe liquidity crisis in the interbank market. The spread between the interest rates on interbank loans and the U.S. Treasury bills increased by 350 basis points. Assets in the United States started to lose value. Not only did the assets of U.S. commercial banks lose value, but assets in the United States held by global banks did too. To honor its debts and because assets were losing value, UBS started to sell its assets in the United States. From 2008 to 2009, UBS' assets shrank by 28 percent; it reported losses for at least $50 billion U.S. dollars (Craig, Protess, and Saltmarsh 2011). The decrease in the value of UBS' assets in the United States brought about a reduction in the net worth of UBS and other Swiss banks. Because of the large position that UBS held in the United States, and because of the large size of the Swiss banking system, the crisis in the United States spread to the Swiss economy.

As a result of the financial crisis, the Federal Reserve and other central banks introduced a set of so-called unconventional monetary

policies. In particular, the Federal Reserve started to intervene directly in the credit market, lending to non-financial institutions and reducing the restrictions to access the discount window, among other policies.

All the unconventional policies that the Federal Reserve carried out as lender of last resort totaled $29,616.4 billion U.S. dollars, almost twice the U.S. GDP in 2008. Excluding the liquidity swap agreements with other central banks, 83.9 percent ($16.41 trillion U.S. dollars) of all assistance was provided to only fourteen institutions. Among them I find the two big Swiss banks: UBS and Credit Suisse, receiving 2.2 percent and 4 percent of the assistance, respectively (Felkerson 2011).

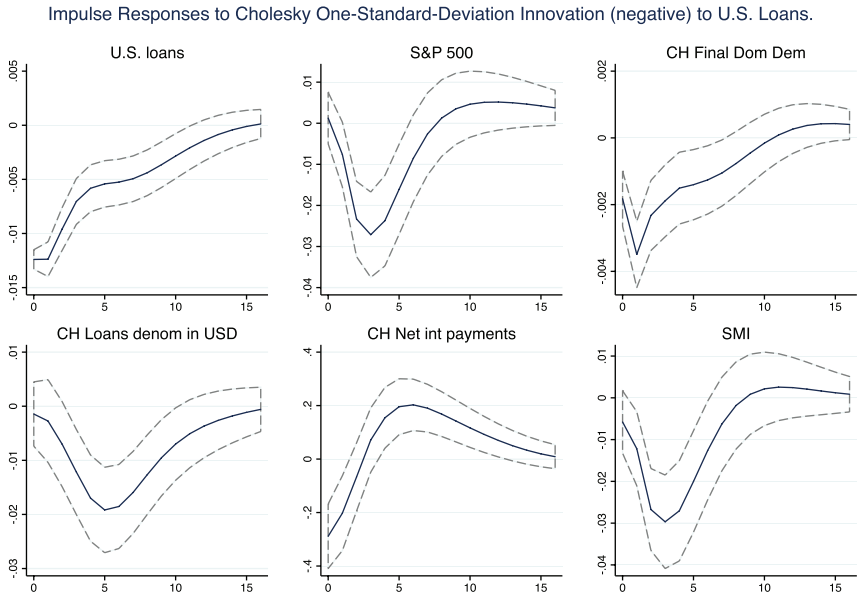
To understand better the transmission of the financial crisis from the United States to Switzerland, I estimate a VAR. Figure 3 shows the orthogonalized impulse response functions from a VAR with two lags with U.S. and Swiss data. The core VAR consists of six variables: real loans of U.S. banks, the S&P500 index, real Swiss domestic demand, real Swiss U.S.-dollar-denominated loans, real Swiss net interest payments, and the Swiss market index (SMI) from 1988:Q2 to 2012:Q2.[5] The starting point corresponds to the availability of the Swiss data. All data are in log (except the net interest payments that are demeaned) and detrended using the Hodrick-Prescott (HP) filter. The Cholesky ordering corresponds to the order of the listed variables.[6]

In choosing the structure of the VAR, I am making several assumptions. First, I do not include an exogeneity block, because

[5]See online appendix 1 (on the *IJCB* website, http://www.ijcb.org) for the definition and the sources of the data. I use the Swiss banks' U.S.-dollar-denominated loans and not the Swiss banks' loans with U.S. counterparties because data on the first are given quarterly and start in 1980, while data regarding the second are provided annually and start in 2002. The magnitudes between the two are different but they highly co-move.

[6]The Akaike information criterion (AIC) suggests the use of two lags. Given the comments of Kilian (2011), I performed different robustness checks. Changing the order for the Cholesky decomposition of the Swiss variables does not alter the behavior of the impulse response functions. Including the Swiss real interest rate and the consumer price index does not alter the results either. A smaller specification of the VAR also suggests that the lag order equals 2 and the general behavior is similar. I have estimated a VAR with the Wilshire 5000 index instead of the S&P500 index and the results do not change.

Figure 3. VAR Evidence



Notes: VAR estimated for 1988:Q2 to 2012:Q2. The dashed lines indicate the 67 percent confidence intervals. The Cholesky ordering is U.S. loans, S&P500, Swiss final domestic demand, Swiss loans denominated in U.S. dollars, Swiss net interest payments, and SMI. The vertical axis shows the percent deviation from the baseline. VAR estimated with two standard deviations confidence intervals are available on request. The results are robust to this specification.

I want the VAR to be as close as possible to my model, which is a two-country one. Second, the ordering of the country variables implies that Swiss series do not influence U.S. ones contemporaneously, and only with one lag; nevertheless, the estimated parameters of U.S. data to changes in Swiss data are smaller than the reaction of Swiss variables to domestic ones. In the same sense, a variable ordered before another has an impact on the latter on the same period. In particular, I first put the data that has the shock; then, I order the rest of the U.S. series. After that, the first Swiss variable is total domestic demand, because it is not affected in that period by other Swiss series. The loans of Swiss banks in U.S. dollars follow, then the net interest payments, and finally the stock exchange index.

The VAR exposes the response to a one-standard-deviation (negative) innovation to the loans and leases in bank credit for all U.S. commercial banks. The shock captures one of the initial characteristics of the financial crisis: the decrease in the value of the U.S. banks' loans. The shock suggests a decrease in the S&P 500 index. Then, the crisis is transmitted to Switzerland, where final domestic demand, the loans denominated in U.S. dollars that Swiss banks make, net interest payments, and the stock market index fall. Swiss domestic demand and net interest payments react on impact. The return that Swiss banks get from the loans in U.S. dollars shrinks and drives the initial reduction in the net interest payments. After four periods, there is less volume of loans denominated in U.S. dollars, and the total net interest payment bounces. The VAR highlights a significant and negative reaction of the Swiss (real and financial) economy to a decrease in the U.S. banks' loans and leases. Furthermore, the co-movement of the stock indexes suggests a strong cross-country relation of the asset prices. While U.S. loans go down because of the shock, the Swiss banks' loans denominated in U.S. dollars shrink, emphasizing the co-movement across countries. In this paper, I build a dynamic stochastic general equilibrium (DSGE) model that explains these interactions. I describe the model in the next section.

3. The Model

The model builds on the work of Gertler and Kiyotaki (2010). My focus, however, is on the international transmission of a simulated financial crisis. In particular, I introduce an international interbank market channel which contributes to the international spillover of the crisis.

I keep the framework as simple as possible to analyze the effects of global financial intermediation. In line with the previous literature, I focus on a real economy, abstracting from nominal frictions. First, I present the physical setup, a two-country real business-cycle model with trade in goods. Second, I add financial frictions. I introduce banks that intermediate funds between households and non-financial firms. Financial frictions constrain the flow of funds from households to banks. A new feature of this model is that home banks can invest in the foreign economy by lending to foreign

banks. This is the international interbank market channel. Moreover, I assume that foreign banks are not constrained on how much they can borrow from home banks. Households and non-financial firms are standard and I describe them briefly, while I explain in more detail the financial firms. In what follows, I describe the home economy; otherwise specified, the foreign economy is symmetric. Foreign variables are expressed with an asterisk. The complete model is presented in online appendix 2 (on the *IJCB* website, http://www.ijcb.org). I describe a model in which foreign banks also lend to home banks in online appendix 5.

3.1 Physical Setup

There are two countries in the world: home and foreign. Each country has a continuum of infinitely lived households. In the global economy, there is also a continuum of firms of mass unity. A fraction m corresponds to home, while a fraction $1-m$ corresponds to foreign. Using an identical Cobb-Douglas production function, each of the firms produces output with domestic capital and labor. Aggregate home capital, K_t, and aggregate home labor hours, L_t, are combined to produce an intermediate good X_t in the following way:

$$X_t = A_t K_t^{\alpha} L_t^{1-\alpha}, \qquad \text{with} \quad 0 < \alpha < 1, \tag{1}$$

where A_t is the productivity shock. This is the domestic production of the home economy.

With K_t as the capital stock at the end of period t and S_t as the aggregate capital stock "in process" for period $t+1$, I define

$$S_t = I_t + (1-\delta)K_t \tag{2}$$

as the sum of investment, I_t, and the undepreciated capital, $(1-\delta)K_t$. Capital in process, S_t, is transformed into final capital, K_{t+1}, after taking into account the quality-of-capital shock, Ψ_{t+1},[7]

[7]Note that I do not include adjustment costs in investment in this equation because this comes from the problem of Gertler and Kiyotaki (2010); in their setup, $K_{t+1} = \Psi_t[I_t + \pi(1-\delta)K_t] + \Psi_t(1-\pi)(1-\delta)K_t$, where π is the probability of having an investment opportunity in that island, and Ψ_t is the quality-of-capital shock. I include the adjustment costs in the resource constraint and the problem becomes standard.

$$K_{t+1} = S_t \Psi_{t+1}. \tag{3}$$

Following the previous literature, the quality-of-capital shock introduces an exogenous variation in the value of capital. The shock affects asset price dynamics, because the latter are endogenous. The disruption refers to economic obsolescence, in contrast with physical depreciation. The shocks Ψ_t and Ψ_t^* are mutually independent and i.i.d. The foreign quality-of-capital shock serves as a trigger for the financial crisis.

As in Heathcote and Perri (2002), there are local perfectly competitive distributor firms that combine domestic and imported goods to produce final goods. These are used for consumption and investment, and are produced using a constant elasticity of substitution technology

$$Y_t = \left[\nu^{\frac{1}{\eta}} X_t^{H\,\frac{\eta-1}{\eta}} + (1-\nu)^{\frac{1}{\eta}} X_t^{F\,\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{4}$$

where η is the elasticity of substitution between domestic and imported goods. There is home bias in production. The parameter ν is a function of the size of the economy and the degree of openness, λ: $\nu = 1 - (1-m)\lambda$ (Sutherland 2005).

Non-financial firms acquire new capital from capital goods producers, who operate at a national level. As in Christiano, Eichenbaum, and Evans (2005), there are convex adjustment costs in the gross rate of investment for capital goods producers. Then, the final domestic output equals the domestic households' consumption, C_t, domestic investment, I_t, and government consumption, G_t,

$$Y_t = C_t + I_t \left[1 + f\left(\frac{I_t}{I_{t-1}} \right) \right] + G_t. \tag{5}$$

Turning to preferences, households maximize their expected discounted utility

$$U(C_t, L_t) = E_t \sum_{t=0}^{\infty} \beta^t \left[\ln C_t - \frac{\chi}{1+\gamma} L_t^{1+\gamma} \right], \tag{6}$$

where E_t is the expectation operator conditional on information available on date t, and γ is the inverse of Frisch elasticity. I abstract

from many features in the conventional DSGE models, such as habits in consumption, nominal prices, wage rigidity, etc.

In online appendix 3, I define the competitive equilibrium of the frictionless economy which is the benchmark when comparing the different models with financial frictions. It is a standard international real business-cycle model in financial autarky with trade in goods. Next, I add financial frictions.

3.2 Households

There is a representative household for each country. The household is composed of a continuum of members. A fraction, f, are bankers, while the rest are workers. Workers supply labor to non-financial firms and return their wages to the households. Each of the bankers manages a financial intermediary and transfers non-negative profits back to its household subject to its flow-of-funds constraint. Within the family, there is perfect consumption insurance.

Households deposit funds in a bank; I assume that they cannot hold capital directly. Deposits are riskless one-period securities, and they pay a return R_t, determined in period $t-1$.

Households choose consumption, deposits, and labor (C_t, D_t^h, and L_t, respectively) by maximizing expected discounted utility, equation (6), subject to the flow-of-funds constraint,

$$C_t + D_{t+1}^h = W_t L_t + R_t D_t^h + \Pi_t - T_t, \tag{7}$$

where W_t is the wage rate, Π_t are the profits from ownership of banks and non-financial firms, and T_t are lump-sum taxes. The first-order conditions for the problem of the households are standard and are defined in online appendix 2.

3.3 Non-Financial Firms

3.3.1 Goods Producers

Intermediate competitive goods producers operate at a local level with constant-returns-to-scale technology with capital and labor as

inputs, given by equation (1). The gross profits per unit of capital Z_t are

$$Z_t = \alpha P_t^H L_t^{1-\alpha} {K_t}^{\alpha-1} \quad \text{with} \quad P_t^H = \nu^{\frac{1}{\eta}} Y_t^{-1} \left(X_t^H\right)^{-\frac{1}{\eta}}. \tag{8}$$

The price of the final home good is equalized to 1.

To simplify, I assume that non-financial firms do not face any financial frictions when obtaining funds from intermediaries and they can commit to pay all future gross profits to the creditor bank. A goods producer will issue new securities at price Q_t to obtain funds for buying new capital. Each unit of security is a state-contingent claim to the future returns from one unit of investment, because there is no financial friction. By perfect competition, the price of new capital equals the price of the security, and goods producers earn zero profits state by state.

The production of these competitive goods is used locally and abroad,

$$X_t = X_t^H + \frac{1-m}{m} X_t^{H*}, \tag{9}$$

to produce the final good Y_t following the constant elasticity of substitution (CES) technology shown in equation (4). The law of one price holds for intermediate goods: $P_t^{H*} NER_t = P_t^H$, where NER_t is the nominal exchange rate; however, due to home bias, the law of one price does not hold in the aggregate level, and I define the real exchange rate as $\varepsilon_t = \frac{P_t^* NER_t}{P_t}$.

3.3.2 Capital Producers

Capital producers use final output, Y_t, to make new capital subject to adjustment costs. They sell new capital to goods producers at price Q_t. The objective of non-financial firms is to maximize their expected discounted profits, choosing I_t

$$\max_{I_t} E_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left\{ Q_\tau I_\tau - \left[1 + f\left(\frac{I_\tau}{I_{\tau-1}}\right)\right] I_\tau \right\}.$$

The first-order condition yields the price of capital goods, which equals the marginal cost of investment:

$$Q_t = 1 + f\left(\frac{I_t}{I_{t-1}}\right) + \frac{I_t}{I_{t-1}} f'\left(\frac{I_t}{I_{t-1}}\right) - E_t \Lambda_{t,t+1} \left[\frac{I_{t+1}}{I_t}\right]^2 f'\left(\frac{I_{t+1}}{I_t}\right). \tag{10}$$

Profits, which arise only out of the steady state, are redistributed lump sum to households.

3.4 Banks

To finance their lending, banks get funds from domestic households and use retained earnings from previous periods. Banks are constrained on how much they can borrow from households. In order to limit the banker's ability to save to overcome being financially constrained, inside the household I allow for turnovers between bankers and workers. I assume that with i.i.d. probability σ a banker continues being a banker in the next period, while with probability $1-\sigma$ it exits the banking business. If it exits, it transfers retained earnings back to its household and becomes a worker. To keep the number of workers and bankers fixed, in each period a fraction of workers becomes bankers. A bank needs positive funds to operate; therefore, every new banker receives a startup constant fraction ξ of total assets of the bank.

To motivate the global interbank market, I assume that the survival rate of home banks σ is higher than that of foreign banks σ^*. Remember that the home economy is the relatively small open economy with a big financial sector. Then, home banks can accumulate more net worth to operate. In equilibrium, home banks lend to foreign banks. This interaction between home and foreign banks is what I call the global interbank market. Home banks fund their activity through a retail market (deposits from households) and foreign banks fund their lending through a retail and a wholesale market (where home banks lend to foreign banks).

At the beginning of each period, a bank raises funds from households, deposits d_t, and with retained earnings from the previous periods, net worth n_t, it decides how much to lend to non-financial firms s_t. Home banks also choose how much to lend to foreign banks b_t.

Banks are constrained on how much they can borrow from households. In this sense, financial frictions affect the real economy. By assumption, there is no friction when transferring resources to non-financial firms. Firms offer banks a perfect state-contingent security, s_t. The price of the security (or loan) is Q_t, which is also the price of the assets of the bank. In other words, Q_t is the market price of the bank's claim on the future returns from one unit of present capital of non-financial firm at the end of period t, which is in process for period $t+1$.

Next, I describe the characteristics of home and foreign banks.

3.4.1 Home Banks

For an individual home bank, the balance sheet implies that the value of the loans funded in that period, $Q_t s_t$ plus $Q_{bt} b_t$, where Q_{bt} is the price of loans made to foreign banks, has to equal the sum of the bank's net worth, n_t, and home deposits, d_t,

$$Q_t s_t + Q_{bt} b_t = n_t + d_t.$$

Let R_{bt} be the global asset rate of return from period $t-1$ to period t. The net worth of an individual home bank at period t is the payoff from assets funded at $t-1$, net borrowing costs:

$$n_t = [Z_t + (1-\delta)Q_t]s_{t-1}\Psi_t + R_{b,t}Q_{bt-1}b_{t-1} - R_t d_{t-1},$$

where Z_t is the dividend payment at t on loans funded in $t-1$, and is defined in equation (8).

At the end of period t, the bank maximizes the present value of future dividends, taking into account the probability of continuing being a banker in the next periods; the value of the bank is defined by

$$V_t = E_t \sum_{i=1}^{\infty} (1-\sigma)\sigma^{i-1}\Lambda_{t,t+i} n_{t+i}.$$

Following the previous literature, I introduce a simple agency problem to motivate the ability of the bank to obtain funds. After the bank obtains funds, it may transfer a fraction θ of assets back to its own household. Households limit the funds lent to banks.

If a bank diverts assets, it defaults on its debt and shuts down. Its creditors can reclaim the remaining $1 - \theta$ fraction of assets. Let $V_t(s_t, b_t, d_t)$ be the maximized value of V_t, given an asset and liability configuration at the end of period t. The following incentive constraint must hold for each bank individually to ensure that the bank does not divert funds:

$$V_t(s_t, b_t, d_t) \geq \theta(Q_t s_t + Q_{bt} b_t). \tag{11}$$

The borrowing constraint establishes that for households to be willing to supply funds to a bank, the value of the bank must be at least as large as the benefits from diverting funds.

At the end of period $t - 1$, the value of the bank satisfies the following Bellman equation:

$$\begin{aligned} &V(s_{t-1}, b_{t-1}, d_{t-1}) \\ &\quad = E_{t-1}\Lambda_{t-1,t}\left\{(1-\sigma)n_t + \sigma\left[\max_{s_t, b_t, d_t} V(s_t, b_t, d_t)\right]\right\}. \end{aligned} \tag{12}$$

The problem of the bank is to maximize equation (12) subject to the borrowing constraint, equation (11).

I guess and verify that the form of the value function of the Bellman equation is linear in assets and liabilities,

$$V(s_t, b_t, d_t) = \nu_{st} s_t + \nu_{bt} b_t - \nu_t d_t, \tag{13}$$

where ν_{st} is the marginal value of assets at the end of period t, ν_{bt} is the marginal value of global lending, and ν_t is the marginal cost of deposits.

I maximize the objective function (12) subject to (11) and rewrite the first-order conditions that I show in online appendix 2 to define the excess value of a unit of assets relative to deposits:

$$\mu_t = \frac{\nu_{st}}{Q_t} - \nu_t.$$

Also, I define the leverage ratio net of international borrowing by rewriting the incentive compatibility constraint,

$$\phi_t = \frac{\nu_t}{\theta - \mu_t}. \tag{14}$$

Therefore, the balance sheet of the individual bank is

$$Q_t s_t + Q_{bt} b_t = \phi_t n_t. \tag{15}$$

The last equation establishes how tightly the constraint is binding. The leverage has negative co-movement with the fraction that banks can divert, θ, and positive with the excess value of bank assets, μ_t.

I verify the conjecture regarding the form of the value function using the Bellman equation (12) and the guess (13). For the conjecture to be correct, the cost of deposits and the excess value of bank assets have to satisfy

$$\nu_t = E_t \Lambda_{t,t+1} \Omega_{t+1} R_{t+1} \tag{16}$$

$$\mu_t = E_t \Lambda_{t,t+1} \Omega_{t+1} \left[R_{kt+1} - R_{t+1} \right], \tag{17}$$

where the stochastic discount factor of the households is $\Lambda_{t,t+1}$ and the shadow value of net worth at $t+1$ is

$$\Omega_{t+1} = (1-\sigma) + \sigma(\nu_{t+1} + \phi_{t+1}\mu_{t+1}) \tag{18}$$

and holds state by state. The gross rate of return on bank assets is

$$R_{kt+1} = \Psi_{t+1} \frac{Z_{t+1} + Q_{t+1}(1-\delta)}{Q_t}. \tag{19}$$

Regarding the shadow value of net worth, equation (18), the first term corresponds to the probability of exiting the banking business; the second term represents the marginal value of an extra unit of net worth given the probability of survival. For a continuing banker, the marginal value of net worth corresponds to the sum of the benefits of an extra unit of deposits, ν_{t+1}, and the payoff of holding assets, the leverage ratio times the excess value of loans, $\phi_{t+1}\mu_{t+1}$. Because the leverage ratio and the excess return vary countercyclically, the shadow value of net worth varies countercyclically, too. In other words, because the banks' incentive constraint is more binding during recessions, an extra unit of net worth is more valuable in bad times than in good times.

Then, from equation (16), the marginal value of deposits is equal to the expected augmented stochastic discount factor (the household discount factor times the shadow value of net worth) times the risk-free interest rate, R_{t+1}. According to equation (17), the excess value

of a unit of assets relative to deposits is the expected value of the product of the augmented stochastic discount factor and the difference between the risky and the risk-free rate of return, $R_{kt+1} - R_{t+1}$. The spread is also countercyclical.

Home banks lend to domestic non-financial firms and to foreign banks through the international interbank market; therefore, from the first-order conditions of the bank,

$$\frac{\nu_{st}}{Q_t} = \frac{\nu_{bt}}{Q_{bt}},$$

which implies that the discounted rate of return on home assets has to be equal to the discounted rate of return on global loans:

$$E_t \Lambda_{t,t+1} \Omega_{t+1} R_{kt+1} = E_t \Lambda_{t,t+1} \Omega_{t+1} R_{bt+1}. \tag{20}$$

Banks are indifferent between providing funds to non-financial home firms and to foreign banks because the expected return on both assets is equalized. R_{bt} is defined in the next section and is related to the return on non-financial foreign firms expressed in home final goods. Next, I turn to the foreign banks' problem.

3.4.2 Foreign Banks

The problem of the foreign banks is similar to the one of the home banks, except that now the interbank market assets, b_t^*, are loans from home banks and they are on the liability side:

$$Q_t^* s_t^* = n_t^* + d_t^* + Q_{bt}^* b_t^*.$$

The net worth of the bank can also be thought of in terms of payoffs; then, the total net worth is the payoff from assets funded at $t-1$, net of borrowing costs which include the international loans,

$$n_t^* = [Z_t^* + (1-\delta) Q_t^*] s_{t-1}^* \Psi_t^* - R_t^* d_{t-1}^* - R_{bt}^* Q_{bt-1}^* b_{t-1}^*.$$

The framework can be thought of as one with asset market integration because banks cannot divert funds financed by other banks. In particular, home banks can perfectly recover the interbank market loans. Foreign banks are only constrained on obtaining funds from foreign households. Then, from the optimization problem of the

foreign banks, the shadow value of global borrowing and domestic assets are equalized,

$$\frac{\nu_{st}^*}{Q_t^*} = \frac{\nu_{bt}^*}{Q_{bt}^*}; \tag{21}$$

or in terms of returns,

$$E_t \Lambda_{t,t+1}^* \Omega_{t+1}^* R_{kt+1}^* = E_t \Lambda_{t,t+1}^* \Omega_{t+1}^* R_{bt+1}^*. \tag{22}$$

The expected discounted rate of return on global interbank loans is equal to the expected discounted rate of return on loans to non-financial foreign firms. Given a shock, the return on the global interbank asset is as volatile as the return on the domestic asset, emphasizing the transmission mechanism from one country to the other. Furthermore, the expected discounted rate of return on the global asset equalizes to the one on loans to non-financial home firms; see equation (20). Then, the home loan market and the foreign loan market co-move. This is the integration of the asset markets.

With Ω_{t+1}^* as the shadow value of net worth at date $t+1$, and R_{kt+1}^* as the gross rate of return on bank assets, after verifying the conjecture of the value function, I define the marginal value of deposits and the excess return on assets as

$$\begin{aligned} \nu_t^* &= E_t \Lambda_{t,t+1}^* \Omega_{t+1}^* R_{t+1}^* \\ \mu_t^* &= E_t \Lambda_{t,t+1}^* \Omega_{t+1}^* \left[R_{kt+1}^* - R_{t+1}^* \right] \end{aligned}$$

with

$$\begin{aligned} \Omega_{t+1}^* &= 1 - \sigma^* + \sigma^* \left(\nu_{t+1}^* + \phi_{t+1}^* \mu_{t+1}^* \right) \\ R_{kt+1}^* &= \Psi_{t+1}^* \frac{Z_{t+1}^* + Q_{t+1}^* (1-\delta)}{Q_t^*}. \end{aligned} \tag{23}$$

3.4.3 Aggregate Bank Net Worth

Finally, aggregating across home banks, from equation (15),

$$Q_t S_t + Q_{bt} B_t = \phi_t N_t. \tag{24}$$

Capital letters indicate aggregate variables. From the previous equation, I define the households' deposits:

$$D_t = N_t(1 - \phi_t). \tag{25}$$

Furthermore,

$$N_t = (R_{k,t}Q_{t-1}S_{t-1} + R_{b,t}Q_{b,t-1}B_{t-1})(\sigma + \xi) - R_t D_{t-1}\sigma. \tag{26}$$

The last equation specifies the law of motion of the home banking system's net worth. The first term in the parentheses represents the return on loans made in the last period. The second term in the parentheses is the return on funds that the household invested in the foreign economy. Both loans are scaled by the old bankers (that survived from the last period) plus the startup fraction of loans that young bankers receive. The last term in the equation is the total return on households' deposits that banks need to pay back.

For foreign banks, the aggregation yields

$$N_t^* = R_{k,t}^* Q_{t-1}^* S_{t-1}^* (\sigma^* + \xi^*) - R_t^* D_{t-1}^* \sigma^* - R_{bt}^* Q_{bt-1}^* B_{t-1}^* \sigma^*, \tag{27}$$

where R_{bt}^* equals R_{kt}^*, from equation (22). The balance sheet of the aggregate foreign banking system can be written as

$$Q_t^* S_t^* - Q_{bt}^* B_t^* = \phi_t^* N_t^*. \tag{28}$$

3.4.4 Global Interbank Market

At the steady state, home banks invest in the foreign economy because the survival rate of home banks is higher than the survival rate of foreign banks; therefore, home banks lend to foreign banks. An international interbank market arises. Foreign banks have an incentive to borrow from home banks because foreign banks are more constrained than home banks.[8] Another way of thinking about the global interbank market is to assume that the deposits foreign

[8]Note that because banks face a borrowing constraint, the difference in the survival rate of banks, which implies different augmented discount factors, does not prompt that the small economy owns all the wealth of the world, as in an unconstrained open capital markets model.

banks get from foreign households are not enough to cover the capital that foreign firms demand. In the foreign country (the bigger economy), capital is higher than national savings. Since at home deposits are higher than capital, there is a gap for an international transaction.

Regarding the interest rate, the return on loans to foreign banks made by home banks is $E_t(R_{bt+1}) = E_t(R^*_{bt+1}\frac{\varepsilon_{t+1}}{\varepsilon_t})$. The rate on global loans is equalized to the return on loans to home firms, R_{kt}, in expected terms in equation (20); home banks are indifferent between lending to home firms or to foreign banks. For foreign banks, equation (22) equalizes the rate of return on global loans to the rate of return on foreign loans. The double equalization drives the asset market integration. In addition, the rate of return on the global asset market is related to the gross return on capital in the foreign country in the following way:

$$R^*_{b,t+1} = \Psi^*_{t+1}\frac{Z^*_{t+1} + Q^*_{b,t+1}(1-\delta)}{Q^*_{bt}}, \tag{29}$$

which equalizes the returns on the international asset and the foreign lending.

3.5 Equilibrium

To close the model, the different markets need to be in equilibrium. The equilibria in the final goods market, the intermediate competitive goods market, and the labor market for home and for foreign are standard and are described in online appendix 2. The market for securities is in equilibrium when

$$S_t = I_t + (1-\delta)K_t = \frac{K_{t+1}}{\Psi_{t+1}}.$$

If the economies are in financial autarky, the net exports for home are zero in every period; the current account results in

$$CA_t = 0 = \frac{1-m}{m}X^{H*}_t - \tau_t X^F_t, \tag{30}$$

with τ_t as the terms of trade, defined by the price of imports relative to exports for the home economy.

On the other hand, if there are global banks in the economy, the current account is

$$CA_t = Q_{b,t}B_t - R_{bt}Q_{b,t-1}B_{t-1} = X_t^{*H}\frac{1-m}{m}\frac{P_t^H}{P_t} - X_t^F\tau_t\frac{P_t^H}{P_t}. \tag{31}$$

The global asset is in zero net supply, as a result:

$$B_t = B_t^*\frac{1-m}{m}. \tag{32}$$

To close the model, the last condition corresponds to the riskless debt. Total household savings equal total deposits plus government debt. Government debt is a perfect substitute of deposits to banks,

$$D_t^h = D_t + \mathcal{D}_{gt}. \tag{33}$$

I formally define the equilibrium of the banking model in online appendix 3.

4. Unconventional Policy

In 2008, the interest rate was almost zero percentage points, and to stabilize the financial system and mitigate the effects of an even deeper recession, the Federal Reserve started to intervene in different markets as lender of last resort to increase credit flows in the economy. From among the policies that the Federal Reserve carried out, I focus on two types: direct lending in credit markets and equity injections in the banking system. For the former, the Federal Reserve extended credit particularly to partnerships and corporations. The Commercial Paper Funding Facility (CPFF), Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility (AMLF), Money Market Investor Funding Facility (MMIFF), and the Term Asset-Backed Securities Loan Facility (TALF) are programs that have these characteristics. Regarding equity injections, the Treasury provided capital facilities to Bear Stearns, JP Morgan Chase, Maiden Lane LLC, American International Group (AIG), Bank of America, and Citigroup. The facilities were under the Troubled Assets Relief Program (TARP) and started after the collapse of Lehman Brothers in September 2008.

There were also coordinated actions between the Federal Reserve and other central banks because of global banks. Specifically, the Federal Reserve provided U.S. dollars to other central banks, such as the Swiss National Bank (SNB), the European Central Bank, and the Bank of England. Afterwards, these central banks provided liquidity to the banks in their jurisdiction, so that banks located in these jurisdictions would continue lending to U.S. institutions. These arrangements, called liquidity swaps, were expected to improve liquidity in the U.S. financial markets.

All the unconventional policies that the Federal Reserve carried out as lender of last resort totaled $29,616.4 billion U.S. dollars—almost twice the U.S. GDP in 2008. Excluding the liquidity swap agreements with other central banks, 83.9 percent ($16.41 trillion U.S. dollars) of all assistance was provided to only fourteen institutions. Among them there were two big Swiss banks: UBS and Credit Suisse received 2.2 percent and 4 percent of the assistance, respectively (Felkerson 2011).

UBS and Credit Suisse were exposed to illiquid securitized loans in the United States. They received assistance from the Federal Reserve by the Term Securities Lending Facility (TSLF), CPFF, mortgage-backed securities, and the term repurchase transactions (ST OMO, or single-tranche open-market operations), and from the SNB. As a policy action, the SNB created the "StabFund" fund to purchase toxic assets from UBS. In October 16, 2008, the SNB announced the creation of a special vehicle to acquire up to $60 billion U.S. dollars of sub-prime and other compromised assets from UBS. The arrangement also included the purchase by the Swiss federal government of $6 billion U.S. dollars in mandatory convertible notes issued by UBS. This last measure helped to strengthen UBS' liability side. StabFund bought $38.7 billion U.S. dollars from UBS' compromised assets; the SNB provided $25.8 billion U.S. dollars in cash (about 5 percent of Swiss GDP). In November 2013, UBS signed a purchase agreement to acquire the StabFund from the SNB (Swiss National Bank 2013).

In this section, I introduce three interventions carried out by the central banks. The first two policies, direct intervention in the loan market and direct intervention in the interbank market, are inspired by the policies that the Federal Reserve carried out to extend credit in specific markets. The third policy provides capital directly to

banks and corresponds to equity injections; this policy can be related to the TARP program that the Treasury put in action, but also to the "StabFund" that the SNB created. I build the modeling of these policies on Dedola, Karadi, and Lombardo (2013), Gertler and Karadi (2011), Gertler and Kiyotaki (2010), and Gertler, Kiyotaki, and Queralto (2012).

The extent to which the central bank intervenes is determined endogenously. The level of intervention follows the difference between the spread of the expected return on capital and the deposit rate, and their stochastic steady-state level under no policy:

$$\varphi_t^* = \nu_g^* \tau_{gt}^* \left[E_t(R_{k,t+1}^* - R_{t+1}^*) - \left(R_k^{*SSS} - R^{*SSS} \right) \right], \qquad (34)$$

where ν_g^* is a policy instrument, and τ_{gt}^* follows an AR(1) process when there is a quality-of-capital shock in foreign; otherwise, it equals zero. This specification contrasts with the policy proposed in the previous literature in two dimensions. First, I target the stochastic steady-state premium instead of the deterministic one. The spread is where banks accumulate earnings; by targeting the deterministic steady state, the net worth takes longer to return to its steady-state value. In this sense, Kiyotaki (2013) suggests targeting the mean of the ergodic distribution of the variables taking into account the distribution of the shocks. Second, the policy is only active when there is a quality-of-capital shock in foreign, while in the other papers the policy is active when the premium is different from its deterministic steady state, even if it is coming from a productivity shock. I assume that $\tau_{gt}^* = \rho_{\tau_g^*} \tau_{gt-1}^* + \varepsilon_{\Psi^*,t}$, where $\varepsilon_{\Psi^*,t}$ is the same exogenous variable that drives the foreign quality-of-capital shock.

According to the specification, the policies are carried out only by the policymaker of the country directly hit by the shock (foreign) or by both policymakers. Next, I describe the three policies separately.

4.1 Loan Market Intervention

The central bank can lend directly to local non-financial firms in order to mitigate the effects of the crisis. The policymaker endogenously determines the fraction of private credit. The level

of intermediation follows equation (34). The total assets of a firm are

$$Q_t^* S_t^* = Q_t^*(S_{pt}^* + \mathcal{S}_{gt}^*),$$

where S_{pt}^* are the loans made by financial intermediaries, and $\mathcal{S}_{gt}^*$ are the ones made by the government. Assuming that $\mathcal{S}_{gt}^*$ is a fraction of total credit, I can rewrite equation (28) as

$$Q_t^*(\underbrace{S_t^* - \varphi_t^* S_t^*}_{S_{pt}^*}) - Q_{bt}^* B_t^* = \phi_t^* N_t^*$$

$$Q_t^* S_t^*(1 - \varphi_t^*) - Q_{bt}^* B_t^* = \phi_t^* N_t^*. \tag{35}$$

Furthermore, the equations of the foreign banking system become

$$Q_t^* S_t^*(1 - \varphi_t^*) = N_t^* + D_t^* + Q_{bt}^* B_t^*$$

$$N_t^* = (\sigma^* + \xi^*)[Z_t^* + (1 - \delta)Q_t^*]S_{t-1}^* \Psi_t^*(1 - \varphi_{t-1}^*) - \sigma^* R_t^* D_{t-1}^* - \sigma^* R_{bt}^* Q_{b,t-1}^* B_{t-1}^*.$$

4.2 Interbank Market Intervention

The second policy is the provision of funds to banks through the interbank market. To what extent the policymaker intervenes is determined endogenously by equation (34). By providing funds in the interbank market, the government increases the total quantity available in the market as such. There are public and private funds in the interbank market,

$$B_t^* = \mathcal{B}_{gt}^* + \tfrac{m}{1-m} B_t, \tag{36}$$

with $\mathcal{B}_{gt}^* = \varphi_t^* Q_t^* S_t^*$. Foreign banks receive higher funding under policy than under no policy. The net worth of foreign banks does not change in structure; the only difference is that B_t^* follows equation (36). The interest rate that the banks pay on government loans is the same as the one paid to home banks.

4.3 Equity Injection

The third policy is equity injections. Under this policy, the central bank gives funds to domestic banks and the banks then decide how

to allocate these extra resources optimally. Again, the quantity of funds that the government provides is a fraction of the total assets of the foreign banks, $\mathcal{N}^*_{gt} = \varphi^*_t Q^*_t S^*_t$. The net worth of the foreign banking system is set to be

$$N^*_t = (\sigma^* + \xi^*)\left[Z^*_t + (1-\delta)Q^*_t\right]K^*_t - \sigma^* R^*_t D^*_{t-1} - \sigma^* R^*_{bt} Q^*_{bt-1} B^*_{t-1} - \sigma^* R^*_{gt} \mathcal{N}^*_{g,t-1}.$$

Redefining equation (28) yields

$$Q^*_t S^*_t = \phi^*_t N^*_t + \mathcal{N}^*_{gt} + Q^*_{bt} B^*_t. \tag{37}$$

The interest rate paid to the government is equal to the interest rate on capital.

4.4 Government

Consolidating monetary and fiscal policy, total government expenditure is the sum of consumption, G^*_t, loans to firms (or total intervention), $\mathcal{S}^*_{gt}$, and debt issued in the last period, $R^*_t \mathcal{D}^*_{gt-1}$. Government resources are lump-sum taxes, T^*_t, new debt issued, $\mathcal{D}^*_{gt}$, and the return on the intervention that the government made in the last period. The consolidated budget constraint of the government is

$$G^*_t + Q^*_t \mathcal{S}^*_{gt} + R^*_t \mathcal{D}^*_{gt-1} = T^*_t + \mathcal{D}^*_{gt} + \left[Z^*_t + (1-\delta)Q^*_t\right]\Psi^*_t \mathcal{S}^*_{gt-1},$$

where I present the equation with total loans to firms, but it should be defined according to the policy.

The debt that government issues is a perfect substitute of the deposits to banks; therefore, the rate that they pay is the same and households are indifferent between lending to banks and to the government. Government expenditure includes a constant fraction of total output and a cost for each unit of intervention issued,

$$G^*_t = \tau^*_{1S} Q^*_t S^*_{gt} + \tau^*_{2S}\left(Q^*_t S^*_{gt}\right)^2 + \bar{g^*} Y^*.$$

The efficiency costs are quadratic on the intervention of the central bank, as in Gertler, Kiyotaki, and Queralto (2012).

5. Crisis Experiment

In this section, I present numerical experiments to show how the model captures key aspects of the international transmission of a financial crisis because of the global interbank market. First, I present the calibration. Second, I analyze a crisis experiment without response from the government and I highlight the role of the global asset market in the transmission of the crisis and how it works as an insurance for the economy that is hit by a shock. Third, I evaluate how well the model explains the financial crisis data. Fourth, I study how credit market interventions by the foreign and the home central bank can mitigate the effects of the crisis. Fifth, I evaluate the welfare of the consumers under the different policies, and, finally, I study non-cooperative versus cooperative policies. In online appendix 5, I relax the assumption that foreign banks cannot lend to home banks and I perform the same exercises as in the baseline model.

5.1 Calibration

The calibration is specified in table 1. The parameters that correspond to the non-financial part of the model, i.e., households and non-financial firms, follow the literature. The discount factor, β, is set to 0.99, resulting in a risk-free interest rate of 1.01 percent at the steady state. The inverse of the Frisch elasticity of labor supply, γ, and the relative weight of labor in the utility faction, χ, are equal to 0.1 and 5.584, respectively. The capital share in the production of the intermediate good, α, is 0.33 and the parameter in the adjustment cost in investment, κ, equals 1. The quarterly depreciation rate of capital is 2.5 percent.

The parameters that enter into the CES aggregator, η and ν, follow the calibrated values for Switzerland in Cuche-Curti, Dellas, and Natal (2009). The elasticity of substitution between home and foreign goods in the production of the final good, η, is set to be greater than 1. This implies substitutability between domestic and foreign goods. The home bias, ν, is defined by the size of the home economy and the degree of openness. I calibrate the size of the countries to match the ratio between Swiss and U.S. GDP as an average between 2002 and 2008.

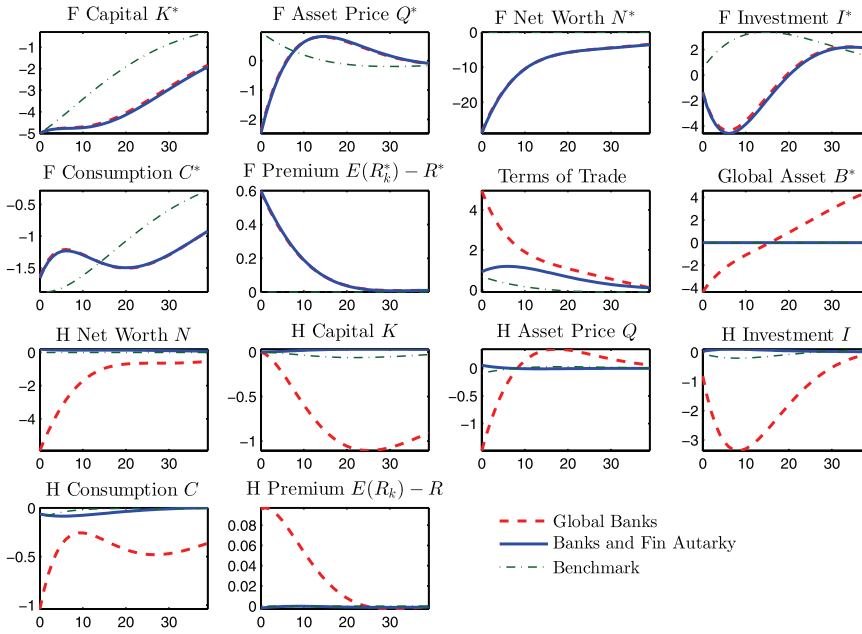
Table 1. Calibration

		Home	Foreign
β	Discount Factor	0.9900	0.9900
γ	Inverse Elasticity of Labor Supply	0.1000	0.1000
χ	Relative Utility Weight of Labor	5.5840	5.5840
α	Effective Capital Share	0.3330	0.3330
κ	Adj. Cost Parameter	1.0000	1.0000
δ	Depreciation	0.0250	0.0250
ν	Home Bias	0.8500	0.9625
η	Elasticity of Substitution	1.1111	1.1111
m	Size of the Countries	0.0400	0.9600
ξ	Startup	0.0018	0.0018
θ	Fraction of Div. Assets	0.4067	0.4074
σ	Survival Rate	0.9740	0.9720
$\bar{g}$	Steady-State Gov. Expenditure	0.1240	0.2000
τ^*_{1S}	Cost of Issuing Loans		0.00125
τ^*_{2S}	Cost of Issuing Loans		0.0120

The parameters of the banking sector are such that the average credit spread is 110 basis points per year; the credit spreads are equal for both economies at the steady state. This is a rough approximation of the different spreads for the pre-2007 period. In particular, how tightly the constraint is binding, explained by the parameter θ, matches that target. The startup fraction that the new banks receive, ξ, is 0.18 percent of the last period's assets, which corresponds to the value used by Gertler and Kiyotaki (2010). The global interbank market exists because the survival rate is different across countries, 0.974 for home and 0.972 for foreign banks. On average, home banks survive nine years, while foreign banks survive around eight years.[9] At the steady state, the holding of global assets represents 16 percent of the total assets of the home banks, which

[9]Data from the SNB, for Switzerland, and from the FDIC, for the United States, on the number of financial institutions show that, over the past thirteen years, the number of Swiss institutions has been more stable and less decreasing than the number of U.S. institutions.

Figure 4. Impulse Responses to a 5 Percent Decrease in Ψ_t^*, Model Comparison



matches the data for total lending by Swiss banks to U.S. counterparties from the year 2002 until 2008, and constitutes 17 percent of Swiss banks' total assets. In online appendix 4, I evaluate the deterministic steady state of the home economy that results from this calibration and I compare it with Swiss data from 2002 until 2008. I assume a negative i.i.d. shock that occurs in foreign.

5.2 No Policy Response

Figure 4 shows the impulse responses to a decline in the foreign quality of capital of 5 percent in period t comparing three models. The first model is one without financial frictions and in financial autarky, and is the thin dashed-dotted line. The second model has financial frictions à la Gertler and Kiyotaki (2010) but no trade in assets, and is the solid line. The third model is one with financial frictions and a global interbank market (financial openness); it is the

thick dashed line. The comparison of these models shows how the transmission mechanism across countries changes given the different assumptions. In the first two models, there is only international spillover due to the trade of intermediate goods. In the third model, I add the international financial mechanism. The comparison helps one understand the insurance and the transmission role of the interbank market. The size of the shock triggers a 30 percent decrease in the net worth of foreign banks and 7 percent of the net worth of home banks, i.e., roughly the rates seen during the latest financial crisis. In online appendix 8, figure A6 shows a larger set of impulse response functions.

When there is a decrease in the foreign quality of capital, and there are no financial frictions (i.e., no banks) in the economy, all the resources are channeled to recover from the initial shock. Investment and asset price go up. On impact, households cut down on consumption because of lower labor income. Final domestic demand and production in foreign fall because of the negative shock. The foreign economy cuts back not only on the demand for local goods, X_t^{*F}, but also on imports, X_t^{*H}. There are fewer foreign goods in the economy because of the shock. As a result, every unit of foreign good is more expensive and the terms of trade slightly improve (deteriorate) for foreign (home). The trade balance is defined by equation (30) and equals zero in every period because there is no international borrowing/lending.

Foreign demand of home goods decreases, but the home economy starts demanding more domestic products because they are relatively cheaper. Home increases its production, X_t, while substituting foreign with domestic goods. Nevertheless, consumption and investment decrease because the interest rate is higher. In the model without financial frictions and in financial autarky, there is no international co-movement either in asset prices or in production. However, there is co-movement in total demand and consumption, while the terms of trade deteriorate for the home economy.

Adding financial frictions but no global banks to the model results in a model similar to Gertler and Kiyotaki (2010). There are banks and they are financially constrained; when their asset (capital) goes down, banks face a decrease in their net worth. Because banks are more constrained on how much they can borrow, there is a fire sale of assets that prompts the asset price, Q_t^*, to go down.

The spread between the foreign rate of return on capital and the risk-free rate, $E(R_k^*) - R^*$, widens. The behavior of the spread is a characteristic of the crisis period. The expected rate of return on capital increases because of the fall in capital.

Foreign production and consumption shrink. There are fewer foreign goods and they are relatively more expensive; similarly to the model without financial frictions, the terms of trade slightly improve for foreign. Home goods are cheaper, the production of home goods increases, and investment increases as well. Home businesses increase their demand for loans, banks are less constrained, and their net worth goes up. Consumption falls because of the reduction in total wages. Similarly to the previous model, asset prices and production do not co-move across countries. Although there is a larger spillover to the home economy with financial frictions than without them, home banks get an increase on their net worth after a negative quality-of-capital shock in foreign.

When I allow for a global asset, home banks lend to foreign banks. In the global interbank market, foreign banks borrow internationally; they diversify their liabilities and pool a country-specific shock. These asset market characteristics have been discussed by Cole and Obstfeld (1991) and Cole (1993).

The decrease in the value of assets and securities in foreign prompts foreign banks to be more financially constrained. The reaction is similar to the model without global banks and is shown by the solid and the thick dashed lines in figure 4. The mechanism that takes place for foreign variables is the same in both models with financial frictions. However, final domestic demand is less affected by the shock when there are global banks because foreign partially pools the country-specific shock.

There is asset market integration: the asset price in foreign falls, and so does the asset price of the global asset. Home banks face a reduction in their net worth because of a country-specific shock in foreign. Home financial intermediaries are more financially constrained and reduce lending to domestic businesses. Investment and the price of capital shrink. The global interbank market transmits the crisis from foreign to home.

Two types of spillovers disturb the home economy: the demand and the global asset effects. The demand effect prompts an increase in production because the home exchange rate is depreciating. The

global asset effect generates a tightening of the home borrowing constraint because there is a decrease in the value of international lending. The global asset effect predominates and the net worth of home banks falls and households cut down on consumption. Global banks imply financial openness; the current account is now defined in equation (31).

In a model with global banks and financial frictions, home and foreign consumption, asset price, and total demand co-move, while production does not. The asset markets across countries are integrated because of the equalization of returns of the asset market at home and abroad.

The results are different from the work of Dedola, Karadi, and Lombardo (2013). In their model, in response to a country-specific quality-of-capital shock with integration in the capital market, but not in the deposit market, assets and net worth of home and foreign move in different directions. To a negative quality-of-capital shock in foreign, foreign loans to home decrease and home loans (assets) to domestic firms increase to compensate for the former reduction. Then, home banks' net worth increase. The leverage and the spread are equalized across countries. This would imply UBS increasing loans in the United States after a quality-of-capital shock in the United States, which is exactly the opposite of what happened during the latest financial crisis. Moreover, the reaction of the home real variables is almost negligible. The equalization of the spreads across countries is a key element to understand their results; however, this does not go in line with the data.[10]

The qualitative behavior of the model matches the VAR evidence shown in figure 3. In the data, a decrease in the U.S. loans prompts a decrease in the domestic asset price that is then transmitted to the Swiss economy. Total final demand, foreign U.S.-dollar-denominated loans, net interest payments, and asset prices fall.

Home has a larger co-movement with the foreign economy in a framework with financial openness than without it. The home economy experiences a crisis because of the quality-of-capital shock

[10]For comparison with Dedola, Karadi, and Lombardo (2013), in figure A12 in online appendix 8, I compare a financial shock with a quality-of-capital shock. In my model, the quality-of-capital shock resembles the VAR better than the financial shock.

abroad, as shown by the VAR evidence and the model. Moreover, through the global interbank market, the foreign economy manages to partially insure itself against the shock.

5.2.1 Case Study: The Great Recession

I evaluate how well the model simulates the effects of the Great Recession in Switzerland. I use data for the United States and Switzerland from 2008:Q1 until 2013:Q1. The data has been HP filtered after taking the log of the real per capita values. Credit in the United States is from the BIS data set, credit by domestic banks to the private non-financial sector; Swiss loans to U.S. banks data come from the SNB; the consumption in Switzerland is OECD data. The data are normalized for 2007:Q4.

I fit in the credit data in the United States as loans to non-financial firms in the model, and I back up the behavior of the quality-of-capital shock in foreign that matches the domestic capital. Then, I simulate the model with financial frictions but in financial autarky (solid line) and the model with global banks (dotted line). The data are the dashed-dotted line. The results are in figure 5.

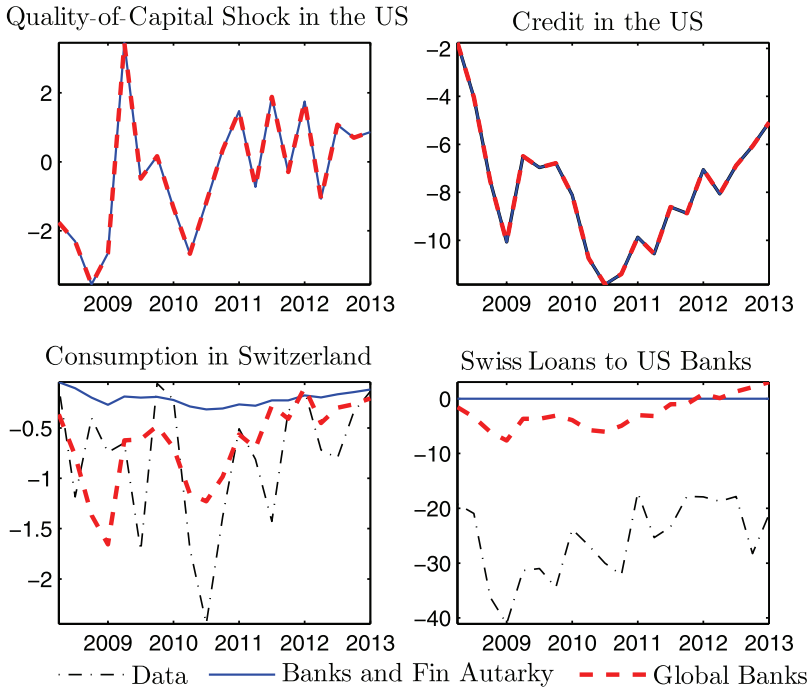
The simulation of the crisis shows that the model with global banks performs well at replicating the financial crisis in Switzerland. The model with global banks follows the movement of the Swiss consumption, while the model without global banks prompts very little reaction. This comes from the channel that I analyze in this paper: cross-border banking flows. In the model with global banks, I allow for lending from Swiss banks to U.S. banks, which falls during the financial crisis and prompts, through financial friction, the reaction of real variables in Switzerland.

This exercise implies that the global interbank market helps explain the behavior of Swiss variables during this period, in comparison to a model without this feature. This highlights the necessity of incorporating this channel for the Swiss economy, given that it is a relatively small economy with a big financial sector.

5.3 Policy Response

One of the reasons that motivated the Federal Reserve to act was the abnormal credit spread in several markets. In this sense, the central

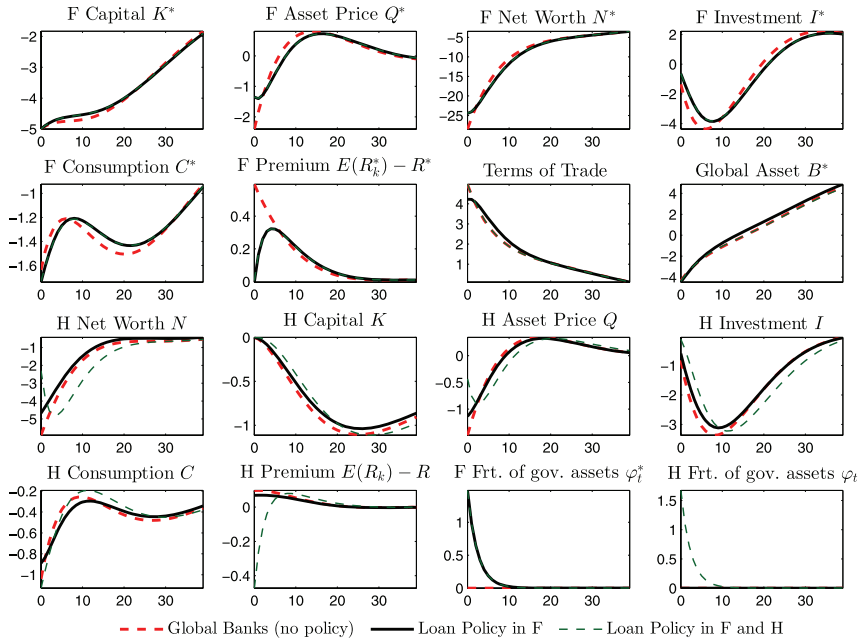
Figure 5. Case Study: The Great Recession: United States and Switzerland



bank determines the fraction of private credit to intermediate by following the difference between the risky and the risk-free interest rate and its stochastic steady-state value, as in equation (34).

Figure 6 shows a small set of variables with the results; figure A9 in online appendix 8 shows more variables. The thick dashed line is the model with financial frictions and financial openness without policy, the same as in the previous figures. The thick solid line is the model with direct intervention in the loan market carried out by the foreign central bank, and the thin dashed line corresponds to loan market intervention by both central banks. The policy parameter ν_g^* is set to be 2,000 and $\rho_{\tau_g^*} = 0.66$. The costs of issuing government loans follow Gertler, Kiyotaki, and Queralto (2012), and the fraction of government expenditure at the steady state matches the data for the United States and Switzerland.

Figure 6. Impulse Responses to a 5 Percent Decrease in Ψ_t^*, Unconventional Policies by Foreign (F) and Home (H) Central Bank



The foreign central bank intervention prompts a higher price of the domestic asset than under no intervention. The initial intervention is around 1.5 percent of total foreign assets. Higher asset price implies that foreign banks are less financially constrained. The foreign banks' net worth falls 5 percent less than under no policy. The asset price is also the price of investment; therefore, investment contraction is lower with the policy. Consumers pay the cost of the policy.

Because of asset market integration, the price of the global asset also falls less. Home banks are less financially constrained than under no policy, and the net worth of home banks drops only 4 percent on impact. Banks lend more to domestic firms; as a result, the home asset price decreases less with the foreign policy and the fall in investment is smoothed.

Therefore, with direct intervention in the foreign loan market, the foreign and the home economy get a smoother impact of the crisis. Although home banks do not have direct access to the policy, home profits through the higher prices in the interbank market. Home consumption and home total demand drop less than under no policy.

When I allow the home central bank also to intervene in the domestic loan market, the price of the domestic asset falls less, which prompts a lower impact on investment and the net worth of banks. However, the foreign economy variables do not change with respect to the intervention only by the foreign central bank because the home economy is relatively small. The fraction of assets that the authority puts on the market is the same as for the foreign central bank.

In conclusion, when only the foreign central bank intervenes, the foreign and home economies get a smoother impact of the crisis—even though the home economy does not have direct access to the policy. When I allow both authorities to intervene, the home economy presents a smoother reaction to the foreign shock, but the foreign economy's behavior does not change; this is a consequence of the relatively small open economy assumption and the fact that I do not allow foreign banks' lending to home banks. The interbank market transmits the financial crisis internationally but also the effects of the policies.

The full set of policies carried out by the foreign central bank are in figures A7 and A8. The three policies, up to a first-order approximation, show a similar effect on smoothing the initial shock. The results of equity injections evaluated in both countries are in figures A10 and A11, and they present a similar reaction to the loan policy carried out by both central banks.

The first-order approximation of the model is useful when studying the impact of an unexpected policy; however, it is not an adequate setup to study welfare. In the next subsection I evaluate the welfare implications of these policies by looking at the second-order approximation of the model.

5.4 Welfare Comparison

I introduce consumers' welfare to rank the policies presented above. The welfare criterion considered here is the one used by Gertler and

Karadi (2011) and developed by Faia and Monacelli (2007). The households' welfare function is given by

$$Welf_t = U(C_t, L_t) + \beta E_t Welf_{t+1}, \tag{38}$$

where the utility function is defined in equation (6). Welfare is defined as the lifetime utility of the consumers. I compare the different policies using the consumption equivalent, i.e., the fraction of household consumption that would be needed to equate the welfare under no policy to the welfare under policy intervention.

The stochastic steady state is defined as the mean of the second-order approximation of the model to a Monte Carlo simulation of the quality-of-capital shock.[11] The shock follows a Poisson process. The advantages of having a Poisson-distributed instead of a normal-distributed shock are twofold. First, I only study negative shocks, which is the nature of the quality-of-capital shock. According to equation (34), the government intervention is positive only with negative shocks; with positive shocks, the intervention would be negative because the spread would be negative. Positive quality-of-capital shocks would correspond to a transfer from the banking sector to the government. Second, the quality-of-capital shock does not occur in every period; instead, I set up the parameters to have a relatively "big" quality-of-capital shock every twenty-eight years. The occurrence of the shock matches Reinhart and Rogoff's (2008) estimate for banking crises in advanced economies; they report 7.2 banking crises between 1800 and 2008, as a world GDP-weighted average. The size of the shock is 0.015 and corresponds to a decrease in output, at the first order, of the economy directly hit by the shock of 1.2 percent from the steady-state level; this corresponds approximately to the drop in output from the peak of all banking crises noted by Boissay, Collard, and Smets (2013). This is an anticipated policy: there is no surprise regarding the intervention of the government; the agents know that every time there is a quality-of-capital shock in foreign, the policymaker intervenes.

Table 2 presents the results of the deterministic and the stochastic steady states of the model with and without policies. The first

[11]I simulate the model for 500 periods, 5,000 times, and drop the first fifty observations. I end up with 450 periods that equal 112 years.

Table 2. Deterministic and Stochastic Steady States Comparison with Policy in Foreign and in Home for Different Shocks

	Determ.	No Policy		Loan Market		Interbank Market		Equity Injection	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
UMP by the Foreign Central Bank: Stochastic Steady-State Ψ Shocks*									
C	0.4697	0.4714	0.0036	0.4695	0.0012	0.4696	0.0012	0.4696	0.0012
L	0.2295	0.2286	0.0031	0.2290	0.0009	0.2290	0.0009	0.2290	0.0009
C^*	0.4430	0.4420	0.0022	0.4421	0.0022	0.4421	0.0022	0.4421	0.0022
L^*	0.2627	0.2628	0.0012	0.2628	0.0013	0.2628	0.0013	0.2628	0.0013
TOT	0.8274	0.8139	0.0149	0.8223	0.0057	0.8223	0.0056	0.8223	0.0057
CE				−0.8695		−0.8700		−0.8696	
CE^*				0.0170		0.0138		0.0132	
UMP by the Foreign Central Bank: Stochastic Steady-State Ψ, Ψ, A, A*, G, and G* Shocks*									
C	0.4697	0.4691	0.0110	0.4672	0.0112	0.4673	0.0112	0.4673	0.0112
L	0.2295	0.2293	0.0138	0.2297	0.0139	0.2297	0.0139	0.2297	0.0139
C^*	0.4430	0.4418	0.0144	0.4418	0.0145	0.4419	0.0144	0.4419	0.0144
L^*	0.2627	0.2627	0.0205	0.2627	0.0204	0.2627	0.0205	0.2627	0.0205
TOT	0.8274	0.8240	0.0314	0.8324	0.0320	0.8325	0.0319	0.8325	0.0319
CE				−0.8802		−0.8802		−0.8801	
CE^*				0.0116		0.0141		0.0140	

(*continued*)

Table 2. (Continued)

	Determ.	No Policy		Loan Market		Interbank Market		Equity Injection	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
UMP by the Foreign and Home Central Banks: Stochastic Steady-State Ψ^* Shocks									
C	0.4697	0.4714	0.0036	0.4698	0.0015	0.4698	0.0015	0.4698	0.0015
L	0.2295	0.2286	0.0031	0.2289	0.0012	0.2289	0.0012	0.2289	0.0012
C^*	0.4430	0.4420	0.0022	0.4421	0.0022	0.4421	0.0022	0.4421	0.0022
L^*	0.2627	0.2628	0.0012	0.2628	0.0013	0.2628	0.0013	0.2628	0.0013
TOT	0.8274	0.8139	0.0149	0.8210	0.0068	0.8209	0.0069	0.8209	0.0069
CE				−0.7433		−0.7409		−0.7402	
CE^*				0.0120		0.0071		0.0065	

Notes: All the variables are in levels except for the consumption equivalents, which are in percentages. For the foreign central bank, $v_g^* = 100$ and for the home central bank, $v_g = 100$.

part of the table considers only quality-of-capital shocks in foreign and policies carried out by the foreign central bank. The second part of the table looks at the unconventional monetary policy by the foreign central bank with other shocks. The third part of the table presents only quality-of-capital shocks in the foreign economy with unconventional monetary policy carried out by both central banks. The second column shows the deterministic steady state, while the rest of the table presents the stochastic steady-state values. The policy parameters are $\nu_g^* = 100$ and $\rho_{\tau_g^*} = 0.66$, and similarly for home. The complete set of results are in online appendix 7, tables A4, A5, and A6, respectively.

Columns 3 and 4 are the mean and the standard deviation of the model without policy. In the stochastic steady state, quality-of-capital shocks in foreign prompt a lower stock of foreign capital with a decrease in its price. Foreign banks are more financially constrained. The lower price of the international asset and their lower value allow foreign banks to increase borrowing from home banks and to decrease deposits. Foreign households have a lower financial income, so they start to work more even though they face lower salaries. They cut down on consumption. The exchange rate depreciates for foreign because there is a higher flow of interbank market borrowing; when banks pay the return on the loans, the demand for foreign currency falls in comparison to the demand for the home currency.

Foreign real exchange rate depreciates; home real exchange rate appreciates. The net interest payments for home go up. In comparison to the deterministic steady state, home households consume more and work less, and consequently home consumers are better off. Households increase bank deposits; this funds the new loans that are made to foreign banks. Home banks substitute domestic capital with interbank market loans.

Columns 5–10 of table 2 show the mean and the standard deviation for the three different policies presented above. The three policies have similar welfare gains. The consumption equivalent gains (last two rows) show improvement in the case of any of these policies for foreign households but worsening for home ones. Three characteristics are important. First, by targeting the interest rate spread, the interventions increase the price of the assets. A higher price prompts a higher value of foreign banks than without policy. Banks

increase domestic deposits and reduce borrowing from home banks; the borrowing constraint is less binding. The net interest payments received by home go down. The terms of trade improve foreign welfare. Second, the policies reduce the volatility of the variables with respect to the no-policy case, as in Dedola, Karadi, and Lombardo (2013). Third, the level of policy intervention is almost zero at the stochastic steady state.

The most effective domestic policy for foreign is loan market intervention; it presents the highest consumption equivalent for foreign households. This policy prompts the highest price of capital which helps relax the financing constraint of the banks. By injecting credit directly into the market in troubled times, the foreign central bank helps the domestic economy, while it hurts home households.

For robustness, I examine the model taking into account quality-of-capital, technology, and government expenditure shocks in both countries. This is shown in the second panel of table 2. The distribution of technology and government shocks follows Schmitt-Grohé and Uribe (2005). Technology shocks have an autoregressive coefficient of 0.8556 and a standard deviation of 0.0064; the autoregressive coefficient of government expenditure shocks and its standard deviation are 0.87 and 0.016, respectively. I assume that all the shocks except for the quality-of-capital shocks follow a normal process. Under this scenario, the results of intervening are very similar to the previous case. The policies carried out by the foreign central bank are effective in improving domestic consumers' welfare, but the gains for foreign households are smaller than in the case where there are only foreign quality-of-capital shocks.

The last part of table 2 shows the results when both countries intervene given the quality-of-capital shock in foreign. The policies are the same as before and to simplify, I assume that the policies carried out by the different policymakers are of the same type.

Comparing the results of both central banks intervening with the no-policy case, foreign consumers are better off, while home consumers are worse off; the result is similar to the one in which only the foreign central bank carries out a policy. The intervention of the home policymaker is still very small and is not able to reverse the sign of the consumption equivalent loss of their domestic households. However, home policy manages to reduce the loss of home consumers

at the cost of decreasing the gain of the foreign households. The policies reduce the volatility of the variables, and the mean of the level of intervention is very low. The order of the policies from the foreign households remains the same: the largest gain comes from loan intervention, while the lowest comes from equity injections.

When the home central bank intervenes, the price of the asset goes up, in comparison to the case in which only foreign intervenes. The value of home banks is higher, so banks take more domestic deposits. The home banking system has more resources and the interest rate on the global asset is higher (because of the lower level of capital in foreign), so home banks increase how much they lend to foreign banks in the interbank market. The real exchange rate appreciates for home in comparison to only foreign intervening. Home consumers are better off with the policy at home and in foreign than with only the policy in foreign; foreign consumers are worse off.

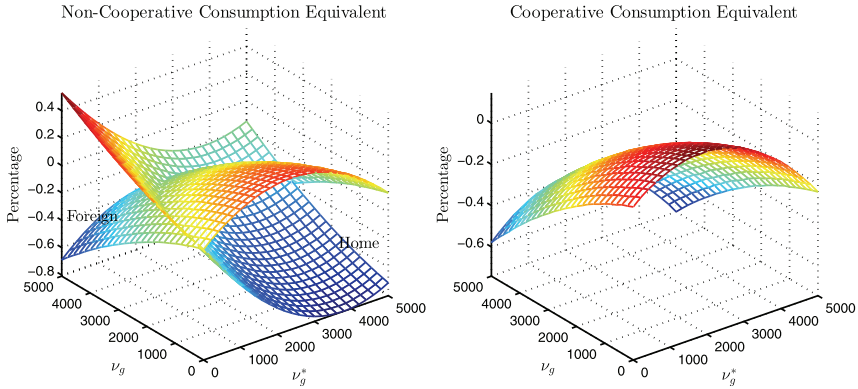
For a robustness check, in online appendix 6, I present the results for the unconditional welfare. The results are similar to the ones presented in this section.

The case of both countries intervening does not result in a Pareto improvement with respect to the baseline model; next, I study the non-cooperative outcome and if a coordinated policy that maximizes the weighted sum of the welfare of both countries can improve the outcome. In online appendix 5, I relax the assumption that foreign banks do not lend to home banks, and find that foreign policy also hurts home consumers but benefits foreign households. However, when both policymakers intervene, home and foreign consumers are better off in comparison to only foreign intervening, because both households benefit from the home intervention.

5.5 Non-Cooperative vs. Cooperative Policies

The left-side plot in figure 7 presents the home and foreign consumption equivalents as the percentage ratio of consumption when both central banks intervene with different policy parameters ν_g and ν_g^*. The range is between 0 and 5,000. The welfare level reported for each combination of ν_g and ν_g^* is the mean of 500 simulations of the model given the quality-of-capital shocks in foreign, Poisson

Figure 7. Non-Cooperative and Cooperative Consumption Equivalents under Quality-of-Capital Shocks in Foreign



distributed.[12] The best reaction of the home policymaker, given what the foreign central bank does, is always to intervene, and to do it to the greatest extent possible. For the range shown in the graph, the best response of home to the different values of ν_g^* is to set $\nu_g = 5{,}000$.

Taking as given what the home policymaker does, the foreign country experiences the highest welfare when $\nu_g^* = 2{,}200$. This is the optimal reaction for any value of ν_g. For the range shown in the graph, the non-cooperative equilibrium corresponds to $\nu_g^* = 2{,}200$ and $\nu_g = 5{,}000$. The consumption equivalents of this combination of parameters for home and for foreign households with respect to no policy are 0.0613 and 0.4036, respectively.

I define the cooperative policy as

$$Welf_t^{\text{coop}} = Welf_t m + Welf_t^*(1-m),$$

where m is the size of the home economy, while $Welf_t$ and $Welf_t^*$ are defined in equation (38).

The Nash outcome from the previous analysis says that both countries have incentives to intervene. When the policymaker of a country carries out a certain policy, that country is better off,

[12]Figure A5 in online appendix 6 presents a similar exercise with the unconditional utility. The results are robust.

while the other is worse off. As opposed to this, when it comes to cooperative welfare (the right-side plot in figure 7), the maximum level of welfare is achieved when the foreign policymaker intervenes ($\nu_g^* = 2{,}200$) and the home policymaker is inactive ($\nu_g = 0$). The consumption equivalents for home and for foreign for this combination are –0.4892 and 0.1939, respectively. The results are driven by the weight (based on the population) that I give to each country and by the range of the parameters; changing the size of the populations changes the implications.

It must be noted that the costs that I assume are very low. There are no microfoundations in the literature for these costs, and I employ the values used by Gertler, Kiyotaki, and Queralto (2012) in order to follow the previous literature. Raising the costs of issuing the policy implies a lower level of welfare; however, foreign consumers are still better off with the policy than without it.

The welfare implications are different from Dedola, Karadi, and Lombardo (2013). There are two main reasons. The first one is that since they assume that there is perfect integration across countries in the deposit and the loan markets, the interest rate spreads across countries are the same. When one country intervenes and cushions the interest rate spread, the other country's spread moves in exactly the same manner. This implies direct positive spillovers across countries from domestic policies. The second reason is that they abstract from real exchange rate effects. When one country's currency appreciates, their consumers are better off; the other country faces a depreciation and their households are worse off. The Nash equilibrium in their paper reflects the free-riding problem: intervention in one country reduces the incentives to intervene in the other country. In the model that I develop in this paper, there is no equalization of the spreads, which is a valid assumption for crisis periods; the purchases of private assets by a government generate negative spillovers in the other country. Moreover, in Dedola, Karadi, and Lombardo (2013) the cooperative welfare results in both countries intervening, while in my model, only the foreign central bank intervenes; this is a consequence of assuming that foreign banks cannot lend to home banks. As I explain in online appendix 5, relaxing this assumption prompts a cooperative equilibrium in which both central banks are active; the main difference is that when foreign banks lend to home banks, home intervention also benefits foreign consumers.

The Nash equilibrium in that model implies both central banks intervening.

6. Conclusion

I have presented a two-country DSGE model with financial intermediaries that captures the international transmission mechanism of the latest financial crisis. Banks in both countries are borrowing constrained on obtaining funds from households. Home can invest in the foreign economy through banks using a global asset (the global interbank market). The return of the international asset is equal to the return on capital of the foreign economy because there are no financial frictions in the international interbank market.

Comparing a model with financial frictions and in financial autarky with one with a global interbank market suggests that the latter generates a higher co-movement of the crisis that matches qualitatively the behavior seen in the data, as shown in the VAR analysis. When a quality-of-capital shock hits the foreign economy, foreign and home economies experience a crisis both in real and financial variables. The global interbank market prompts the international transmission. The net worth of home banks drops because the price of the international asset falls. Home banks face a reduction in their balance sheets, and they are more constrained on lending to domestic non-financial firms. The price of home asset drops, prompting a fall in investment, consumption, and total demand. The key aspect of the transmission mechanism is the equalization of returns across countries; this implies co-movement in asset prices and spreads between the risky and the risk-free interest rate.

I study the introduction of unconventional policies—in particular, direct lending of the foreign central bank to non-financial firms, direct lending in the interbank market, and equity injections into banks. I look at two cases. In the first case, only the foreign central bank carries out the policy. In the second, home and foreign central banks intervene using the same type of policy. Up to the first-order approximation, the policies are effective in mitigating the effects of the crisis not only in the domestic country but also abroad. When the home central bank intervenes, foreign variables are hardly affected, but the net worth of home banks falls less. Because of the equalization of loan returns across countries, when the foreign central bank

intervenes to reduce the abnormal excess return, the price of foreign and global assets falls less than under no policy. As a result, home banks are less financially constrained. On impact, there is crowding out of consumption in the country that carries out the policy because of the costs of issuing the intervention.

I also evaluate the second-order approximation of the model. The quality-of-capital shock follows a Poisson distribution. When only the foreign central bank intervenes, foreign consumers have a welfare improvement as a result of the policies, whereas home consumers are worse off. If the home central bank also intervenes and is aggressive enough, it can improve home welfare and worsen the foreign one. However, if both policymakers behave along the same parameters, home consumers are worse off and foreign consumers are better off in comparison to the no-policy case. As opposed to this, when comparing the results with only the foreign central bank intervening, one can see that home consumers are better off, and foreign consumers are worse off.

The non-cooperative equilibrium implies an active central bank in each country, and the cooperative equilibrium implies that only the foreign central should carry out the policy, while the home central bank should do nothing. These results are subject to the assumption that foreign banks do not lend to home banks.

The paper focuses on one aspect of the unconventional policies that policymakers have carried out over the last few years. Banks that intermediate funds across borders and in different currencies encounter relevant challenges in terms of policy and regulation. In future research, I am planning to study different features of the unconventional policies. In particular, the Federal Reserve had coordinated actions with other central banks because of global banks. The Federal Reserve provided U.S. dollars to other central banks, such as the Swiss National Bank and the Bank of England. Then, these central banks provided liquidity to the banks in their jurisdiction to continue lending to U.S. institutions, thereby improving liquidity conditions in the United States. These arrangements are called foreign liquidity swaps.

In the model, home can only invest in foreign through the banks, and I only look at the net foreign asset position. In reality, the foreign exchange swaps and the interbank market, among other derivatives, make the relations across banking systems much more complicated.

I believe that this simple but relevant relationship between global banks helps us to understand some aspects of the international transmission of the crisis. Future research includes an extension of this model to include non-financial firms' international debt.

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