Rare Disasters, Risk Sharing and Cross-Country Portfolio Holdings

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Abstract

We quantitatively study the implications of shocks to the disaster (a sharp decline in output) probabilities in a two-country, two-good, and two-bond international macro model. We assume that the global economy is either in the good or the bad state which follows an AR(1) process. In the good state both countries have high levels of endowments and there is no disaster risk. In the bad state they receive low levels of endowments and they face positive probabilities of disasters. From the data we calculate the disaster sizes and probabilities for emerging and developed countries separately and show that there is substantial heterogeneity between them. We use the calculated disaster probabilities and disaster sizes in the calibrated version of the model and show that this framework is consistent with several international data which were proved to be hard to replicate. Some of the key implications of the model are limited risk sharing, highly volatile procyclical real exchange rates and highly volatile countercyclical bond premium.

1 Introduction

In this paper we quantitatively study the implications of shocks to the disaster probabilities in a two-country, two-good, and two-bond international macro model. In each period, the world economy is either in good or bad state which follows an AR(1) process. If the global economy is in the bad state both countries have low endowments and they may experience disasters (a sharp decline in final-output) with some probability. Conditional on experiencing a disaster, counties will partially default on their debt with some probability. One crucial difference between two countries is that the probabilities and the sizes of disasters and the sizes of the default in both countries are different when the global economy is in the bad state. In the good state there is no disaster probability and no default.

We use this model to study the interaction between countries with different disaster sizes and probabilities and different default rate and default probabilities. We show that even small amount of heterogeneity can result in substantially different implications. As a first step, from the data we calculate the disaster sizes and probabilities and the size and the probability of default for emerging and developed countries. Using these sizes and probabilities we study the interaction between the emerging and developed countries. We show that the model is able to match some key features of international macro data such as the level and the volatility of bond premium, risk sharing, real exchange rate volatility and uncovered interest rate parity puzzle. Moreover the cyclical properties of variables implied by this model (that is the signs of correlations with output) are similar to the data. At the second step, we want to focus on the model with two developed countries. For this purpose, we keep the disaster probability and size of developed country fixed at a low level and change the disaster size of the other country from high values to the low levels (high values correspond to the emerging countries). In response, the model is able to match the corresponding statistics of countries between different development levels. Hence, a framework with dynamic rare disaster probabilities offers a unified framework to study the interaction between countries with different development levels.

In the model when the global economy enters into a bad state, consumers observe that there is some probability that countries will experience a disaster and some probability of partial default. As a consequence interest rates that a country can borrow rises. But it rises more in the countries where those probabilities and sizes are larger (i.e. emerging countries). Even though the low endowment in the bad state pushes borrowing higher, higher interest rates and rare disaster risk (things may become even worse) pushes borrowing down. In our calibrations we show that, the second and third effects dominate hence net exports increase for the emerging country during bad times which decreases the output even more. Increased imports during bad times in the developed country imply higher output compared to the emerging country. This mechanism breaks the risk sharing among countries (Backus-Smith puzzle).

As countries cannot insure in the goods markets, countries hold the assets of each other. The size of the gross bond holdings is around 20 percent of the GDP. The existence of the default probability in the model is effective in limiting the size of the gross portfolio holdings. The country with larger disasters holds a net position of around 5 percent. The model with partial default in the larger disaster countries is able to generate a sizeable bond premium. The volatilities and the cyclical properties of the bond premium and gross portfolio holdings (both of them are countercyclical) are similar to the data.

To illustrate the mechanism of the model, we show that if there are only endowment shocks (i.e. we assume there are no rare disaster probability and no default), movements in risk premiums are very limited. Production sharing and international trade in goods between countries provide a very good hedge against the production risk. When there is a positive transitory shock to the emerging country tradable goods, implying an increase in the supply, the price of this good decrease and the terms of trade (TOT) depreciate. Cheaper inputs in the emerging country help the producers in the developed country to increase their production and consequently there is a high level of risk sharing between countries. Another counterfactual implication of the model is the very low volatility of real exchange rates.

2 Data and Related Literature

In Table 1, we present the business cycle properties of real variables for a group of developed and emerging countries. The first panel of the table shows that emerging country business cycles are more volatile and relative volatilities of consumption and net exports are higher in emerging countries.[1] The relative volatility of real exchange rates is around 3 and of the spread is around 1 for both developed and emerging countries. In the second panel, we present the correlations of real variables with domestic output or U.S. output. We see that the correlation between output in the US and in the emerging country is close to zero, and the correlation

[1] Relative with respect to the volatility of output.

between consumption in the US and in the emerging country is negative. Net exports are countercyclical in both country groups. However, there are stark differences in the correlations for real exchange rates and spreads. Real exchange rates are strongly procyclical in emerging countries, i.e. in good times domestic currency appreciates. In contrast, real exchange rates in developed countries are slightly countercyclical. There is a significant difference in the cyclicality of spreads also. Spreads in emerging countries are strongly countercyclical, whereas they are slightly procyclical in developed countries.

Standard open economy models face some difficulties in accounting for several of these properties as explained below. Even though real variables are studied more frequently in the literature, financial variables are not that studied much. In Table 2, we present the international asset positions of the countries that we obtain by using yearly data between 1990 and 2007 from Lane and Milesi-Ferretti (2007). The first panel of the table presents the international asset positions, and the second panel presents the asset positions excluding foreign direct investment and equity flows of the countries during the 1990s and the 2000s.

Multi-country models of the international economy have been commonly used to address the several features of the world economy since the work of Backus, Kehoe and Kydland (1992, 1995). A standard multi-country model implies a high level of risk-sharing among countries and there is not much holding of foreign assets. For example, Cole and Obstfeld (1991) find that the welfare gains from international financial markets are very small if there is specialization in the production of goods among countries. A productivity shock in one country causes a depreciation in its terms of trade (ToT) and real exchange rate (RER). Hence, a positive shock in one country is transmitted to the other through the terms of trade channel, providing a natural hedging against production risk in the other country. As a result, this mechanism generates a high level of risk sharing and gains from international financial markets are very small. However, empirical findings point out a low level of risk sharing[2] among countries and large holdings of international financial assets (in Table 2 we find that both developed and emerging countries hold significant amounts of gross portfolios). In Table 1, we see that the correlation between the output in the US and in the emerging country is close to zero. There have been numerous

[2]Using bilateral data, Fitzgerald (2011) shows that financial market frictions impede optimal consumption risk sharing between developed and emerging countries.

attempts in the literature to address this puzzle. For example, Corsetti et al. (2008) explain this puzzle by highlighting the wealth effects of productivity shocks using a two-country set up with tradable and non-tradable sectors. In their setting, either a combination of low trade elasticity and incomplete asset markets or a combination of high trade elasticity, persistent productivity shocks and complete markets is necessary to induce low risk sharing across countries. In both cases, productivity shocks cause an appreciation in the ToT and the RER, which exacerbates rather than dampens production risk across countries and induce a low level of risk sharing.

In addition to the low level of international risk sharing, another puzzling feature indicated by the economic data is that real exchange rates are highly volatile and very persistent in all country groups. Real exchange rates are on average three times more volatile than output in the data, as shown in Table 1. However, in two-country models, a high level of risk sharing also implies a low level of RER volatility and persistence. There are also attempts in the literature to explain these facts. For example, employing a sticky price assumption, leisure-separable preferences and high risk aversion in an international business cycle model, Chari et al. (2002) are able to generate real exchange rates that are as volatile and persistent as in the data. But they also find that this model still implies a high level of risk sharing across countries.[3]

In the literature, recent studies have analyzed the financial side of open economies in more detail using different solution techniques other than linearization.[4] Some of these papers include Ghironi et al. (2009), Evans and Hnatkovska (2007), Engel and Matsumoto (2006, 2009), Devereux and Sutherland (2006, 2009), Tille and van Wincoop (2010), Pavlova and Rigobon (2007, 2009), Coeurdacier et al. (2009), and Kraay et al. (2005).[5] Also, similar to our study, some papers look at the combination of a developed-emerging country world economy. For example, Devereux and Sutherland (2009) analyze a developed-emerging country model. They compare three financial structures, ranging from no portfolio diversification to a structure close to complete asset markets (two countries trade equities and a non-contingent real bond issued

[3]For other papers on risk sharing and real exchange rates, see Backus and Smith (1993), Baxter and Crucini (1995), Benigno and Thoenissen (2008), Benigno and Küçük (2011), Burstein et al. (2005), Dellas and Stockman (1989), Dotsey and Duarte (2008), Engel and Matsumoto (2009), Heathcote and Perri (2002, 2009), Kehoe and Perri (2002), Kollmann (1995, 1996), Kose et al. (2009), Matsumoto (2007), Palacios-Huerta (2001).

[4]With linearization methods only net positions can be studied.

[5]Pavlova and Rigobon (2010) provide a summary of this so called "international macro-finance" literature.

by the developed country). They find that the structure, where the emerging country issues equities and the developed country issues nominal bonds, enables a high degree of risk-sharing across countries. Similar to the papers mentioned, our paper uses nonlinear methods to study the financial implications of the model in detail. Different from these papers, thanks to the interaction of preference heterogeneity with trend shocks, our model is able to generate a sizeable emerging country bond premium that is highly volatile and countercyclical as in the data. In addition, these papers focus on the financial side and are mostly silent about the implications for the real side of the economy such as real exchange rate dynamics, whereas our model closely matches the data.

A very recent paper by Barro (2005), by extending the Rietz (1988) paper, introduced the notion of disasters to explain high equity premium, row risk-free rate and volatile stock returns. The sharp contractions associated with historical events such as WWI, the Great Depression and WWII are called economic disasters and carry a potential to explain a lot of asset pricing puzzles and low real interest rates in the US during major wars. He constructs a model of the equity premium that maintains a tractable framework of a representative agent, time-additive and iso-elastic preferences, complete markets and i.i.d. shocks to productivity growth. The model is calibrated using the economic disasters of twentieth century. The allowance of economic disasters explains the equity premium puzzle introduced by Rajnish Mehra and Edward Prescott.

In a later paper by Barro and Ursua (2008), they employ the data on real per capita personal consumer expenditure, C, and GDP per capita since 1870. Using the definition of an economic disaster as a peak-to-trough fall in GDP per capita of at least 10 percent, they find that 95 crises for C and 152 for GDP. This means a disaster probability of 3.5 percent, disaster (mean) size of 22 percent and (average) disaster duration of 3.5 years. By simulating a Lucas-tree model with i.i.d. shocks and Epstein-Zin-Weil preferences with a coefficient of relative risk aversion (CRRA) of 3.5, they end up with the observed average equity premium puzzle of around 7 percent on levered equity.

The behavior of economic agents towards risk is measured by the coefficient of relative risk aversion; however, there is no agreement on the best reliable estimate of this parameter. This parameter is the key to understand the risk response and agent's decisions in equity markets.

Therefore, equity premium also depends on this parameter, which can be explained by the probability and size distribution of disasters according to recent disaster literature. Barro and Jin (2011) study various aspects of the probability and size distribution of disasters using long historical data on per capita consumption and per capita GDP.

Nakamura, Steinsson, Barro and Ursua (2010) estimate an empirical model of consumption disasters using a panel data set on consumption for 24 countries. They use a richer model than the one used in Barro (2006) and Barro and Ursua (2008) by improving over the previous works. Their model allows for permanent and transitory effects of consumption disasters that unfold over multiple years, while allowing for correlation in the timing of disasters across countries. For example, there are transitory shocks on growth in normal times. Their estimates imply that the probability of entering a disaster is 1.7% per year and disasters on average last 6.5 years. In the disaster periods used from their data, consumption drops 30% in the short run; however, in the long run this drop becomes 14%. The asset pricing implications of this study depends significantly on how permanent the disaster is. The model produces an unleveraged equity premium of 4.8% with an intertemproral elasticity of substitution (IES) parameter of 2 and CRRA parameter of 6.5. How does the multi-year nature of disasters affect the asset prices? Under the case of single-period disasters the drops in consumption and stock prices are completely coincident while agents save under a multi-period disaster case to smooth the consumption which limits the drop in stock prices.

By using the parameters for U.S. post World War II data on consumption with reasonable CRRA numbers, Lucas (1987) claimed that there are welfare gains from eliminating uncertainty in aggregate consumption. Salyer (2007) shows that embedding low-probability crash state in the model amplifies the welfare costs presented in Lucas (2007). Barro (2007) based on these two papers concludes that changes in consumption uncertainty due to shifts in probability of disasters have significant welfare implications.

The long-term data show that majority (67%) of minor, non-war depressions are accompanied by stock-market crashes, whereas most major, non-war depressions (83%) are accompanied by these crashes. Therefore, in the absence of a crash, the occurrence of a depression is highly unlikely. The paper Barro and Ursua (2009) complements the analysis of Barro and Ursua (2008) by considering the comovement between macroeconomic depressions and stock market crashes. The matched cases of stock market crashes and depressions provide most of the explanatory power for generating a reasonable equity premium with a familiar asset-pricing formula. The required CRRA value is in the range of 3 to 4.

3 Model[6]

In this section, we develop a two-country and two-sector endowment economy model with bond holdings in an incomplete asset market structure. Countries are indexed as $i = H, F$ representing the home country and foreign country blocs respectively. Each country is endowed with two inputs: tradable and non-tradable. Production sharing takes place in tradable inputs, so countries use both home and foreign tradable inputs to produce their respective tradable outputs. Then, they combine this tradable output with non-tradable input to produce their distinctive final goods, which will later be consumed by the households of both countries.

Our model has a structure similar to that of Backus, Kehoe and Kydland (1995), Stockman and Tesar (1995) and Corsetti et al. (2008). Apart from these models, we allow the countries to receive rare disaster probability shocks. Second, we allow each country to issue its own bonds instead of an international bond. These main differences from a standard symmetric two-country model help us to analyze a world economy.

3.1 Firms' problem

We assume that there are perfectly competitive intermediate tradable good producers in each country that combine domestic and foreign tradable endowments to produce intermediate tradable goods. Intermediate tradable good producers use a constant elasticity of substitution production technology:

$$Y_{i,T,t} = \left[v_i^{\frac{1}{\kappa_i}} X_{Fi,T,t}^{1-\frac{1}{\kappa_i}} + (1 - v_i)^{\frac{1}{\kappa_i}} X_{Hi,T,t}^{1-\frac{1}{\kappa_i}} \right]^{\frac{\kappa_i}{\kappa_i - 1}} \qquad i = H, F \tag{1}$$

[6] In this section a theoretical model with shocks to tradable and nontradable endowments in both countries is specified to be general. In the numerical exercises, we give shocks one at a time or we assume a perfect correlation between shocks (either positive or negative) due to computational difficulties.

where κ_i is the elasticity of substitution between the home country's tradable input $X_{Hi,T}$ and the foreign country's tradable input $X_{Fi,T}$, and ν_i is the share of the emerging country's tradable input in country i's intermediate tradable goods production, where $v_E = 1 - v_H$. Taking the foreign country's tradable input price as the numeraire ($P_{E,T} = 1$) and denoting relative prices of home and foreign country endowments of tradable and non-tradable inputs as $P_{H,T}$, $P_{H,N}$ and $P_{F,N}$, we can derive the tradable price index for home and foreign countries as follows:

$$P_{i,Tradable,t} = \left[v_i + (1 - v_i)P_{H,T,t}^{1-\kappa_i}\right]^{\frac{1}{1-\kappa_i}} \qquad i = H, F \tag{2}$$

Once the sharing of tradable endowments takes place and the production of intermediate tradable goods is carried out, competitive final good producers in each country combine their own intermediate tradable output with their own country's non-tradable endowments to produce final goods. Final good producers also use a constant elasticity of substitution production technology:

$$Y_{i,t} = A_{i,t}\left[\theta_i^{\frac{1}{\eta_i}} Y_{i,T,t}^{1-\frac{1}{\eta_i}} + (1-\theta_i)^{\frac{1}{\eta_i}} E_{i,N,t}^{1-\frac{1}{\eta_i}}\right]^{\frac{\eta_i}{\eta_i - 1}} \qquad i = H, F \tag{3}$$

where η_i is the elasticity of substitution between intermediate tradable goods $Y_{i,T}$ and non-tradable endowment $E_{i,N}$, and θ_i is the share of tradable goods in the final goods production. From the optimization problem of the firm, we can derive the final goods price index as follows:

$$P_{i,t} = \left[\theta_i P_{i,Tradable,t}^{1-\eta_i} + (1-\theta_i)P_{i,N,t}^{1-\eta_i}\right]^{\frac{1}{1-\eta_i}} \qquad i = H, F \tag{4}$$

Since, in the model, international trade takes place only in tradable inputs, the final good is consumed totally in each country. This gives us the following resource constraint: $Y_{i,t} = c_{i,t}$ where $c_{i,t}$ is consumption in the country i.

For both countries there are two more relevant prices, i.e., terms of trade and real exchange rates. We define terms of trade, ToT, from the perspective of the foreign market, as the ratio of its export prices to its import prices; and the real exchange rate, ReR, as the ratio of the foreign country's final goods prices to the developed country's final goods prices:

$$ToT_t = \frac{1}{P_{H,T,t}} \quad \text{and} \quad ReR_t = \frac{P_{F,t}}{P_{H,t}} \tag{5}$$

An increase in the ToT means an improvement for the foreign country by making its export prices more expensive or it's import prices less expensive. An increase in ReR means an appreciation for the foreign country and a depreciation for the home.

3.2 Asset markets and budget constraints

Both home and foreign countries issue internationally tradable bonds that pay in units of their own (final) consumption good. Both bonds share similar properties such that they are non-state contingent and have zero net supplies. After the international trade of inputs takes place, the net trade balance is given by $X_{FH,T,t} - P_{H,T,t}X_{HF,T,t}$ for the foreign country and $P_{H,T,t}X_{HF,T,t} - X_{FH,T,t}$ for the home country. Income from the endowments in the foreign country is given by $E_{F,T,t} + P_{F,N,t}E_{F,N,t}$. This income equals final production plus net trade balance: $P_{F,t}Y_{F,t} + (X_{FH,T,t} - P_{H,T,t}X_{HF,T,t})$. Therefore, the foreign country household faces the following budget constraint:

$$P_{F,t}\ c_{F,t} + Q_{F,t}B_{F,t+1} + Q_{H,t}B_{H,t+1} = P_{F,t}Y_{F,t} + (X_{FH,T,t} - P_{H,T,t}X_{HF,T,t}) + P_{F,t}B_{F,t} + P_{H,t}B_{H,t} \tag{6}$$

where $Q_{H,t}$ and $Q_{F,t}$ are the nominal prices of the home and foreign country bonds. As each country issues bonds in units of its final goods, the foreign country's bond, which is issued at an amount of $B_{F,t}$ at time $t-1$ at a price of $Q_{F,t-1}$, is supposed to pay $B_{F,t}$ units of the foreign country's final good at time t. The home country also faces a similar budget constraint. The budget constraint of the home country household is as follows:

$$P_{H,t}c_{H,t} + Q_{H,t}B^*_{H,t+1} + Q_{F,t}B^*_{F,t+1} = P_{H,t}Y_{H,t} + (P_{H,T,t}X_{HF,T,t} - X_{FH,T,t}) + P_{H,t}B^*_{H,t} + P_{F,t}B^*_{F,t} \tag{7}$$

The real price of the home country's bonds in its own units is $\frac{Q_{H,t}}{P_{H,t}}$, the real price of home bonds in the foreign country's units is $\frac{Q_{H,t}}{P_{F,t}}$ and a similar expression follows for foreign country's bonds. We assume that countries cannot short their own bonds; in other words, they need to supply non-negative amounts of own bonds. This implies that $B_{F,t} \leqslant 0$ and $B^*_{H,t} \leqslant 0$. As the market clearing condition for each bond, we have the following expression: $B_{i,t} + B^*_{i,t} = 0$. Then the gross portfolio holdings are defined as $P_{F,t}B^*_{F,t} + P_{H,t}B_{H,t}$. Consequently, the net portfolio holdings of the emerging country are defined as $P_{F,t}B_{F,t} + P_{H,t}B_{H,t}$, where the negative of this expression is the net portfolio position of the developed country.

3.3 An endowment economy with variable rare disaster probabilities

To this standard international macro model, we incorporate rare disasters similar to Barro(2006). In particular, we assume that the world economy has two states, namely good and bad. In good state both economies have high level of tradable endowment and also the probability of being exposed to a disaster is zero. In bad state, both countries have low level of tradable endowment.[7] We model the transition between good and bad state by the two-state Markov-process:

$$\begin{bmatrix} \Omega_{gg} & \Omega_{gb} \\ \Omega_{bg} & \Omega_{bb} \end{bmatrix}$$

where g and b correspond to good and bad states respectively and Ω_{xy} is the probability of transition from state x to y. Note that asset trade takes place after the realization of current state at the beginning of the period.

If the economy is in bad state, each country can experience a disaster which leads to a significant destruction in final output in addition to the low level of tradable input. More formally final output:

$$Y_{i,t} = \left\{ \begin{array}{l} (1-\alpha_i)Y_{i,t} \text{ with probability } p_i \text{ (disaster case)} \\ Y_{i,t} \text{ with probability } 1-p_i \text{ (no disaster case)} \end{array} \right\}.$$

where $Y_{i,t}$ is the final output, α_i corresponds to the proportion of loss and p_i is the disaster probability in country i=H,F. In our setting developed country has lower α_i and lower p_i with respect to emerging country. Also, we assume that the effect of disaster is limited with the current period and the output fully recovers in the following period.

[7] Hign and low levels of output differ between developed and emerging country.

Also by following Barro(2006), we allow emerging country to partially default on its bonds with some probability if a disaster occurs. However, developed country does not default even in disaster times. The differences mentioned above enable us to explore the potential effects of differential sizes of rare disasters on asset prices, real exchange rate and other macroeconomic variables.

3.4 Households' problem

Representative agents in both economies have CRRA preferences over consumption of the final goods:

$$U_{i,t} = \frac{c_{i,t}^{1-\gamma_i}}{1-\gamma_i}$$

where γ_i is the risk aversion parameter for country i. Households choose the levels of the next period's foreign and home country bonds after realizing the state of the economy. Hence, the dynamic programming problem of the foreign country's households is as follows;

$$V_{F,t} = \underset{B_{H,t+1},B_{F,t+1}}{Max} \{E_t u(c_{F,t}) + \beta E_t(V_{F,t+1}(E_{F,T,t+1}, E_{F,N,t+1}, E_{H,T,t+1}, E_{H,N,t+1}, B_{H,t+1}, B_{H,t+1}))\} \tag{8}$$

In the problem, state variables are the four endowment processes and the two bonds. Similar to the emerging country's problem, the developed country's household faces the following dynamic programming problem:

$$V_{H,t} = \underset{B^*_{H,t+1},B^*_{F,t+1}}{Max} \left\{E_t u(c_{H,t}) + \beta E_t(V_{H,t+1}(E_{H,T,t+1}, E_{H,N,t+1}, E_{F,T,t+1}, E_{F,N,t+1}, B^*_{H,t+1}, B^*_{F,t+1}))\right\} \tag{9}$$

Household problem depends on the state of the economy. If the economy is in bad state, households give their saving decision by considering disaster and default However, there are no disasters in good sate. So the expected utility from consumption within the period differs between two states.

3.5 Calibration

Most of the parameter values are standard and chosen from the literature. We mostly follow Corsetti et al. (2008) and Garcia-Cicco et al. (2010) to calibrate our parameters. The parameter that governs the home input share in intermediate tradables production, υ, is chosen to be 0.72, which produces a home bias. The elasticity of substitution between home tradable inputs and imported tradable inputs, κ, is 3/2. The share of intermediate tradables goods in final goods, γ, is 0.55. The elasticity of substitution between tradable intermediate goods and nontradable inputs, η, is 2/5. The discount factor for households, β, is 1/1.04, implying a risk-free interest rate of 4 percent. Risk aversion parameter σ is selected as 2. We calibrate the transition probabilities between good and bad states as to generate a TFP process with AR(1) coefficient of 0.83 which is standard in literature. The level of tradable endowment in developed and emerging countries are 1.02 and 1.03 in good state, and 0.98 and 0.97 in bad states.

To calibrate the disaster shocks, we follow Barro (2006). Barro defined a disaster as a contraction of real per capita GDP over 15%. Then, he uses a data set consisting 35 countries to calculate disaster probability and average disaster size. In the data set, rare disasters happen around 1.7% of the times. The average size of the disaster is around 30% There are two points that are worth mentioning. First, most of the disasters occurred pre-WW2 period. After WW2, among the developed countries there are no events that one can count as disaster[8]. Put differently, all disasters in post-WW2 period are occurred in emerging countries. Second, it is difficult to take the current developed countries as developed for the pre-WW2 period. Probably, they can be better named emerging during pre-WW2 period. Thus, we focus on the post-WW2 period to make a proper distinction between emerging and developed countries.

Considering the points above, we can argue that both probability and size of the disasters are greater in emerging countries than developed countries. So we assume very low disaster probability for developed country $p_F = 0.1\%$ and a small contraction size of $\alpha_F = 5\%$. For the emerging country, the disaster probability is $p_H = 1.7\%$ and the disaster size is $\alpha_H = 15\%$.

We also assume the default probability for emerging country during the disaster is 60% and

[8] If we decrease the threshold for disaster from 15% to 10%, there are only 3 disasters in developed countries after the WW2. However, 25 disasters occured in emerging countries for the same period.

Calibration

Definition	Parameter	Value
Home input share in intermediate tradables production	v	0.72
EIS bw home and foreign tradable inputs	κ	3/2
Intermediate tradable goods share in final goods production	γ	0.55
EIS bw intermediate tradable and nontradable	η	2/5
Risk aversion parameter	σ	2
Discount factor for households	β	1/1.04
AR(1) coefficient for the shock process	ρ	0.83
Disaster probability(%) (Developed and Emerging)	p	0.1 and 1.7
Disaster size(%) (Developed and Emerging)	α	5 and 15

the size of the default is 30%. As mentioned earlier, developed country does not face a default.

4 Results

We present our results in three subsections addressing the three puzzles we are discussed above. We obtain the statistics by simulating the model for 15000 periods.

4.1 Risk Sharing

In data, we observe that consumptions of developed and emerging countries has no correlation (Table 4). However, standard two country models generate a positve correlation stemming from the good trade. The mechanism can be explained as follows. Technology shock to tradable sector of one country has two effects, namely wealth effect and substitution effect. If home country experiences a high level of tradable input, households increase their demand due to welath effect that triggers a price increase.in home tradable good On the other hand, households demand foreign tradable goods since tradable goods are substitutes. Substitution effect dominates the wealth effect for the trade elasticity $\kappa = 3/2$. In turn, foreign country enjoys the relative wealth increase.due to improvement in TOT and demand to its tradable goods. Hence, wealth of both countries improve and this generates a positive correlation in output levels of two countries.

The inclusion of rare disasters in the model breaks the above mentioned mechanism and generates negative correlation.between the output levels of two countries The rare disaster probability jumps the savings in emerging country in bad states to minimize the negative effect of huge decline in final output. To increase its savings, households in emerging country decrease their consumption. However, change in comsuption of developed country is limited since the probability of rare disaster is too small w.r.t. emerging country. This behaviour breaks the tight link and generates negative correlation in consumption.

The correlation between net exports and output is negative for emerging countries in data. The emerging countries increase their demand more than output in good times and this generates trade deficit. However, standard models generates positive correlation since households decrease their consumption in good times to consume more in future periods. Our model with rare disasters able to generate the cyclicality in data by changing the consumption behaviour in bad state. In bad state, households in emerging country decrease their consumption and increase their savings to refrain from destructive effects of disasters.

The model with rare disasters is able to match the correlation of RER and output. In bad state, the sudden decrease in consumption in emerging country declines the price of its own tradable good more than the developed tradable good since there is home bias in intermediate tradable input production. So, both TOT and RER depreciates for emerging country.

The spread, the difference between the return of emerging bond and developed bond, is negatively correlated in data. Also we observe that interest rates increase in emerging countries when they are in recession even though capital becomes less productive. This situation is explained by the increase in risk premia. Our model is able to generate this premium endegenously. However, our model implies low correlation with output. Main reason behind is that households in both countries price the rare disaster risk even in good states and this prevents the spread to depend heavily on tradable good endowment.

Table 4 :Model Moments with and without Disaster-Correlations

	Data	*Model-Disasters*	*Model-No Disasters*
$\rho(Y, Y^{US})$	0.01	-0.44	0.84
$\rho(C, C^{US})$	-0.30	-0.44	0.84
$\rho(NX/Y, Y)$	-0.53	-0.56	0.82
$\rho(ToT, Y)$	0.5	0.48	-0.93
$\rho(ReR, Y)$	0.54	0.57	0.05
$\rho(Spread, Y)$	-0.55	-0.05	-0.12

4.2 Volatilities

The RER volatility is three times greater than the output volatility in data (Table 5). However, standard models generate low level of relative volatility for trade elasticity parameter $\kappa = 3/2$ since for this level of trade elasticity tradable goods prices do not fluctuate too much since goods are substitutes. This limits the volatility in TOT and RER. However, possibility of rare disasters triggers the demand in emerging country and that leads a high level of depreciation in RER. The source of fluctuation in our model can be explained by Balassa-Samuelson effect. Observe that, the source of fluctuation in RER is the price of non-tradable goods since tradable goods are substitutes whereas in stadard model the source of fluctuation in RER is mainly TOT.

Our model can match the volatility in spreads. This can be explained by the level. The level of returns are high in our model relative to standard model (Table 6). So, transition between states changes the level significantly.and cause a significant volatility. However in standard model, levels of returns are small and close to each other in both countries and respond in small amounts to changes in tradable endowment.

Table 5: Model Moments with and without Disaster-Volatilities

	Data	*Model-Disasters*	*Model-No Disasters*
$\sigma(Y)$	4.05	2.53	2.75
$\sigma(C)/\sigma(Y)$	1.15	1.00	1.00
$\sigma(NX/Y)/\sigma(Y)$	0.86	0.56	0.58
$\sigma(\ ToT)/\sigma(Y)$	1.68	0.25	1.45
$\sigma(\ ReR)/\sigma(Y)$	3.00	2.05	0.80
$\sigma(\ Spread)/\sigma(Y)$	0.83	1.32	0.05

4.3 Portfolio Holdings

Our model can generate a significant spread between the return of bonds (Table 6). This spread stems from the default porbability in bad state. Default probability in emerging country produce an endogeneous risk premium. Also, our model matches the home and foreign return. However, standard model fail to match these return statistics. Our model can also generate positive net asset position for emerging country. However, it is not close to data.

Table 6: Model Moments with and without Disaster-Levels

	Data	*Model-Disasters*	*Model-No Disasters*
$Foreign\ Return\ \ \%$	8.4	9.8	4.0
$Home\ Return\ \ \%$	7.1	5.7	4.0
$Spread$	1.3	4.1	0.0
$\frac{Net\ Exports}{Y}$		0.05	0.0
$\frac{NFA\_Debt}{Y}$	17.42	4.4	0.0
$\frac{GFA\_Debt}{Y}$	73.39	16.0	54.0

5 Conclusion

In this paper we develop a two country model with incomplete asset markets. Our model incoporates rare disaster and default possibility into standard international macro models. These innovations help us to match the business cycle statistics of emerging and developed countries.

One contribution of our paper is that high exchange rate volatility and imperfect risk sharing occur together. Actually, the mechanism that generates imperfect risk sharing in the model is the the difference between the rare disaster and default probabilities of developed and emerging countries. Another contribution of our paper is in generating significant spread between home and foreign return as well as matching the level of these returns.

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6 Appendix: Computational Algorithm, Tables, and Figures

We use an algorithm similar to the one first introduced by Lustig (2008) and Chien and Lustig (2010) and developed further by Arslan (2008). In a typical general equilibrium numerical solution algorithm, all endogenous variables in the model are formulated as functions of the state variables. In our model relevant state variables are emerging and developed country bond holdings ($B_{E,t}$, $B_{D,t}$) and exogenous shocks to the endowment, (E_t). In the model's formulation, we can state an endogenous variable, say $Q_{E,t}$, as:

$$Q_{E,t}= f(B_{E,t-1}, B_{D,t-1}, E_t)$$

As $B_{E,t-1}$ and $B_{D,t-1}$ are also endogenous variables, they can be further written as functions of past realizations of state variables and past endowment shocks as well.

$$B_{E,t-1} = f_{B_E}(B_{E,t-2}, B_{D,t-2}, E_{t-1})$$

$$B_{D,t-1}= f_{B_D}(B_{E,t-2}, B_{D,t-2}, E_{t-1})$$

Inserting the functions of $B_{E,t-1}, B_{D,t-1}$ into the first equation yields $Q_{E,t}$ as;

$$Q_{E,t}= f(B_{E,t-2}, B_{D,t-2}, E_{t-1}, E_t)$$

Recursive plugging of functions of past endogenous variables into the equation for the current period home bond price function enables us to obtain price as a function of current and past endowment shock realizations.

$$Q_{E,t} = f(E_0, E_1, ..., E_{t-1}, E_t)$$

Applying the same logic to the other endogenous variables makes it possible to use endowment shocks as the sole argument for the functions defining all endogenous variables.[9] Putting it differently, observing the current and past endowment shocks makes it possible to derive current prices and choice variables without the need for any other state variables. Although it is theoretically possible to derive current period endogenous variables as a function of past history of endowment shocks, it is computationally impossible and inefficient to solve for this whole history. Therefore, we suppose that agents are boundedly rational and they only use the information embedded in the recent history, which can be defined as the current and most recent lags of the technology shocks. Although the addition of further lags is always possible, after some history it increases the time and memory required to come up with a numeric solution while not making much contribution to the solution accuracy.

Economies under consideration experience either high or low technology shocks. Combining this with the nine-period history gives 512 (2^9) possible states to solve for. Using Mathematica, we algebraically find first order conditions and market clearing conditions for all of these possible states. Then we use the sum of the squared errors of these first order conditions and market clearing conditions across all states to define the objective function. Having obtained the objective function, we use both global and local minimization algorithms of Mathematica to solve for prices and allocations that minimize the objective function. Simulation errors of the model for Euler equations of bonds in both countries are presented in Figure 6.

[9] Endogenous variables that we solve for in the model are as follows; $Q_{E,t}$, $Q_{D,t}$, $B_{E,t}$, $B_{D,t}$, $P_{E,t}$, $P_{D,t}$, $P_{E,T,t}$, $P_{D,T,t}$, $P_{E,N,t}$, $P_{D,N,t}$, $X_{E,T,t}$, $X_{D,T,t}$.

Table 1: Business Cycle Properties of Real Variables

	$\sigma(Y)$	$\sigma(C)/\sigma(Y)$	$\sigma(I)/\sigma(Y)$	$\sigma(NX/Y)/\sigma(Y)$	$\sigma(ReR)/\sigma(Y)$	$\sigma(Spread)/\sigma(Y)$
Emerging Countries						
Mean	4.05	1.15	3.32	0.86	3.00	0.83
Median	3.91	1.08	3.35	0.81	2.95	
Developed Countries						
Mean	2.25	0.84	2.89	0.54	2.64	1.21
Median	2.05	0.84	2.68	0.54	3.19	
	$\rho(Y, Y^{US})$	$\rho(C, C^{US})$	$\rho(I, I^{US})$	$\rho(NX/Y, Y)$	$\rho(ReR, Y)$	$\rho(Spread, Y)$
Emerging Countries						
Mean	0.01	-0.30	-0.15	-0.53	0.54	-0.55
Median	0.03	-0.35	-0.16	-0.57	0.59	
Developed Countries						
Mean	0.45	0.29	0.22	-0.42	-0.14	0.20
Median	0.43	0.29	0.16	-0.47	-0.13	

Notes: Y is real GDP. C is real consumption. I is real investment. NX/Y is exports minus imports over GDP. ReR is the real exchange rate. Spread is the risk premium. All series except net exports and spreads are in logs. All series have been Hodrick–Prescott filtered. All statistics are based on yearly data for years between 1970 and 2008. Source is IMF-IFS. Emerging countries are Argentina, Brazil, Chile, Colombia, India, Indonesia, Israel, Korea, Mexico, Malaysia, Paraguay, Peru, Philippines, Turkey, Uruguay, Venezuela and South Africa. Developed countries are Australia, Canada, England, Finland, France, Germany, Japan, New Zealand, Portugal and the U.S. Spread statistics are from Neumeyer and Perri (2005).

Table 2: International Asset Positions of Countries

	$\frac{GFA}{Y}$		$\frac{NFA}{Y}$		$\frac{\Delta NFA}{Y}$	
Emerging Countries	1990s	2000s	1990s	2000s	1990s	2000s
Mean	88.86	129.60	-25.58	-19.85	-0.79	2.78
Median	90.64	112.32	-25.30	-26.70	-0.93	2.77
China	51.77	86.62	-3.14	11.36	0.26	2.79
Developed Countries						
Mean	187.49	377.32	-18.45	-15.85	-0.79	0.83
Median	156.32	355.53	-11.39	-15.70	-1.00	0.40
US	99.39	185.42	-7.46	-18.18	-0.23	-1.06
	$\frac{GFA\_Portfolio}{Y}$		$\frac{NFA\_Portfolio}{Y}$		$\frac{\Delta NFA\_Portfolio}{Y}$	
Emerging Countries	1990s	2000s	1990s	2000s	1990s	2000s
Mean	66.92	82.49	-13.63	1.05	0.60	3.68
Median	68.34	80.07	-16.48	-1.39	0.77	3.70
China	36.38	58.09	6.27	32.99	1.80	4.38
Developed Countries						
Mean	127.29	229.55	-14.99	-19.81	-0.18	-0.81
Median	106.08	200.46	-11.66	-28.68	-0.53	-1.53
US	58.74	99.84	-12.18	-28.32	-0.98	-2.90

Notes: GFA is the gross financial asset position. NFA is the net financial asset position. ΔNFA is the change in NFA. $\_Portfolio$ measures exclude equity and FDI variables from the calculation. All series have been Hodrick–Prescott filtered. All statistics are based on yearly data between 1990 and 2007. Source is Lane and Milesi-Ferretti (2007). Emerging countries are Argentina, Brazil, Chile, China, Colombia, India, Indonesia, Israel, Korea, Mexico, Malaysia, Peru, Philippines, Paraguay, Thailand, Turkey, Uruguay, Venezuela and South Africa. Developed countries are Australia, Canada, Finland, France, Germany, Japan, New Zealand, Portugal, United Kingdom and United States.