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RARE DISASTERS AND RISK SHARING

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Rare Disasters and Risk Sharing

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Abstract

Recent literature shows that incorporating rare disasters in standard model helps to explain many puzzles in macro-finance. In this paper, 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. From the historical data we calculate the disaster sizes and probabilities for emerging and developed countries separately and show that there is substantial heterogeneity between emerging and developed countries. Our model solves many puzzles for emerging markets such as Backus-Smith puzzle, real exchange rate volatility, strong negative correlation between trade balance to output ratio and output, level and volatility of bond premium, and uncovered interest rate parity puzzle.

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1 Introduction

In this study, we develop a two-country, namely developed and emerging, two good, and two bond international macro model. In our setting, developed and emerging countries produce tradable and non-tradable inputs which are used in final good production. Furthermore, both countries issue their internationally tradable bonds and each country is net supplier of its own bond. Economy can be in two states which are associated with the level of tradable input and named as good and bad. Transition between states is determined by Markov process. At the beginning of each period households realize the current state and trade bonds for insurance. In good state, rare disaster, a sizeable destruction in output, cannot occur. However in bad state, there is probability of rare disaster which differs across countries and agents make their bond holdings accordingly. We show that a model with dynamic disaster probabilities is able to match some key features of international macro data such as Backus-Smith puzzle, real exchange rate volatility, strong negative correlation between trade balance to output ratio and output, level and volatility of bond premium, and uncovered interest rate parity puzzle.

One important point in our paper is to differentiate between the rare disaster probabilities of developed and emerging countries using the data set provided by Barro and Ursua .[1] Their data includes GDP per capita for forty two countries and spans more than a century for most countries. Barro and Ursua (2008b) defines a disaster as destruction of output more than 10% in consecutive periods and uses GDP per capita data to derive unique disaster probability. However, Table 1.1 shows that disaster probabilities and sizes are significantly different for emerging and developed countries after World War II. We observe that most of the disasters occurred pre-World War II period. After WW II, the developed countries experienced only two events that one can count as disaster. However, twenty three disasters occurred in emerging countries for the same period. As a result, disaster probability of emerging countries is nearly thirteen times greater than developed countries .

[1] Detailed list of countries can be found in Appendix B. We stick to definition of IMF to identify the developed countries. The link for Barro and Ursua data set: www.economics.harvard.edu/barroursuamacrodata.com

Table 1.1 : Disaster Statistics

	Developed		Emerging	
	pre-WW II	post-WW II	pre-WW II	post-WW II
Number	80	2	82	23
Avg. Size	22%	13%	21%	20%
Disaster Prob.	4.02%	0.15%	7.64%	1.93%

Another important point is that it is hard to distinguish emerging and developed countries before the pre-WW II period. One criteria for identifying developed economies is GDP per capita. Table 1.2 shows that real GDP per capita level of developed economies at 1946 is as low as today's emerging economies.[2] Other criteria is GDP volatility. High volatility is generally associated with emerging markets since they expose to more political and economic uncertainty.[3] Table 1.2 reports average volatilities of GDP growth for developed and emerging economies.[4] Volatility of today's developed economies, 6.42%, for pre-WW II period is close to volatility of emerging economies, 7.76%. However, volatilities are significantly different after WW II. Both criteria indicates that it is impossible to make a strict identification for the pre-WW II period. Thus, we focus on post-WW II period in our analysis.

Table 1.2 : Classification

	Average Volatility		real GDP p.c.	
	pre-WW II	post-WW II	1946	2009
Developed	6.42%	2.66%	8160	38662
Emerging	7.76%	4.37%	1444	7038

* The values are calculated according to 2006 prices. We used BU data set and UN data base.

[2] Korinek and Serven (2011) consider countries with GDP per capita below 6000 dollars at 2005 prices as developing countries for 1950-2009 period.

[3] See Taylor (2005) and Neumeyer and Perri (2005).

[4] Garcia-Cicco et al. (2010) documents that developed countries exhibit significantly more volatile in 1900-1945 period than 1946-2005 period.

Before discussing the mechanism of our model, we first discuss a standard model with only endowment shocks to the tradable sector (no rare disaster probability). In standard model, 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 decreases and the terms of trade 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. Since international trade in goods provides enough of a hedge against production risk, countries do not need international asset markets very much. As a result, we observe low levels of volatility in real exchange rates and spreads. Furthermore, the level of the spread produced by this model is negligible. Also, movement of net trade balance is mild.

The mechanism for Backus-Smith puzzle in our model works as follows. In the bad state, emerging agent demands more bonds to prevent possible losses of a disaster and emerging country household increases its precautionary savings and decreases consumption. In turn, price of emerging tradable goods decrease because of low demand and home bias in production. This results a positive wealth effect for developed country since prices of emerging tradable goods are relatively cheaper. In turn, developed country increases its consumption. So, relative consumption (C^E/C^D) decreases. Moreover, RER of emerging country depreciates because home bias in intermediate good production limits the demand of developed country for emerging country tradable good. This mechanism generates a negative correlation between relative consumption and RER and solves Backus-Smith puzzle.

The RER volatility three times larger than output volatility in data. Our calibration of disaster parameters implies developed countries are less prone to disasters with respect to emerging countries. This distinction between countries leads to significant difference in marginal utility of consumption for emerging and developed households .Together with the home bias in intermediate good production and the existence of non-tradable goods, disaster probability leads to large swings in non-tradable good prices. So, we observe high volatility in RER.

Our model matches the cyclicality and autocorrelation of trade balance to output ratio. In bad state, households in emerging country decrease the level of their consumption and increase their exports to developed country to refrain from destructive effects of disasters. On the other hand, developed country increase their imports since emerging tradable goods are relatively cheaper. The net trade balance of emerging increases. So, we have countercyclical net trade balance to output ratio. Moreover, our model generates an autocorrelation away from unity.

Our model can generate a significant spread between the return and levels of bonds This spread is result of two factors: (i) the differentiation in disaster probability between developed and emerging economies and (ii) the default probability of emerging bonds in disaster times. Because of the differentiation in disaster probability, emerging country's asset demand is much more than developed country. This dampens the return from developed country bonds more than the return of emerging country since both countries are net supplies of its own bonds. Furthermore, default probability in emerging bonds is reflected as risk premia in returns. Also, marginal utility of consumption of emerging household differs significantly between states and this leads to a high volatility in spreads.

Our model also address the UIP puzzle. The possibility of rare disasters increases the precautionary savings of emerging country. In turn, we have a high return premium between emerging and developed economies in bad states. In addition to this, RER of emerging country depreciates due to low demand of emerging country household. On the other hand, in good states RER of emerging country appreciates and recovers the depreciation in bad state. So, developed country can benefit both from excess returns and currency appreciation.

The plan of the paper is as follows. Section 2 to reviews the literature. Section 3 introduces model and calibration. Section 4 discusses the results of the model and Section 5 concludes.

2 Literature Review

The international real business cycle (IRBC) model with complete markets is first introduced by Backus,Kehoe, and Kydland (1992,1995). Their model generates a correlation close to one between relative consumption and RER. However, Backus and Smith (1993) and Kollmann (1995) show that the correlation is negative in data. This anomaly is named as risk-sharing puzzle or Backus-Smith puzzle. Cole and Obstfeld (1991) argue that Backus-Smith puzzle is present even markets are not complete. They emphasize that production sharing through international trade provides a perfect hedging mechanism. Chari, Kehoe and Mcgrattan (2002) shows that Backus-Smith puzzle still exists in a New Keynesian setting with sticky prices and non-contingent bond. Corsetti et al. (2008) is able to break the perfect risk sharing for low and high values of trade elasticity parameters. However, their model generates high correlation for commonly used trade elasticity values in literature.

Another puzzle in IRBC literature is RER volatility puzzle. Even RER is highly volatile, more than three times of output, and persistent in data, models generate poor volatility and relatively low persistency. Chari, Kehoe and Mcgrattan (2002) argues that high RER volatility can be achieved through a model with stick prices and high risk aversion. However, their model implies nearly perfect risk sharing. Our model is able to generate higher RER volatility with low correlation of RER and relative consumption.

There are also puzzles specific to emerging economies that standard models fail to generate. For instance, net export is more counter cyclical compared to developed countries and consumption is more volatile than output. Furthermore, emerging markets exhibit countercyclical risk premia. Aguiar and Gopinath (2007) uses trend shocks and Neumeyer and Perri (2005) uses risk premium shocks to solve these puzzles. Garico-Cicco et al. (2010) show that an RBC model with realistic debt elasticity of risk premium can explain Argentina business cycles Their model also implies that trend shocks explain negligible portion of fluctuations. Our model can address above puzzles by only introducing rare disaster risk in a simple IRBC model.

The concept of rare disaster is first introduced by Rietz (1988). He tries to explain equity premium puzzle introduced by Mehra and Prescott (1985). The novel idea in the Rietz's paper is to include a rare state resulting a huge decrease in return of risky asset. This innovation helps the model to match the observed risk premia between risky asset and riskless bond under reasonable parametrization of isoelastic utility. The premium is obtained since risk averse consumers increase their demand for risk-free asset to prevent high destruction in consumption generating lower returns for risk-free asset. However, Rietz's model is criticized by Mehra and Prescott (1988) because of the lack of empirical support for the size and frequency of rare events. Barro (2006) provides empirical support for rare disasters by using the historical GDP per capita data for twenty OECD countries and fifteen Asian and Latin American countries between for the twentieth century. Barro (2006) defines rare disasters as events resulting 15%

or more destruction in GDP per capita and calculates constant disaster probability 1.7% over periods and average disaster size of 29%. He also allows partial default in risk-free assets at disaster times. His model is able to solve some puzzles such as high equity premium, low risk free rate, and volatile stock returns.[5]

An important contribution that uses rare disaster concept and explains ten puzzles[6] in macro-finance literature is Gabaix (2008). He constructs a simple representative agent model with time additive and isoelastic preferences. He uses time-varying size and probability for disasters instead of constant size and probability as in Barro (2006). These innovations provide time-varying pricing behavior hence implying extra volatility for prices. The findings of Gabaix (2008) are valuable since it shows that one innovation added to simple model solves many puzzles without using sophisticated utility functions or implausible parametrization.

Barro (2006) and Gabaix (2008) assume disasters as permanent which helps them to obtain close form solutions and high premium. This receives criticism from Gourio (2008) since there is strong rebound after disasters in data. He constructs a model with Epstein-Zin preferences which allows distinction between constant relative risk aversion (CRRA) and intertemporal elasticity of substitution (IES). Furthermore, he introduce recoveries after disasters. He finds that the equity premium decreases for high values of IES in presence of recoveries, and if IES is low, the effect is opposite. Our model allows recoveries after disasters as in Gourio (2008) but we use isoelastic utility instead of Epstein-Zin preferences.

Gourio et al. (2013) and Farhi and Gabaix (2011) use rare disasters to solve international macro-finance puzzles. Gourio et al. (2011) develops a two country open economy model with Epstein-Zin preferences and production economy. They group countries as high and low interest rate countries and calibrate probability and size of rare disasters in each group. The only hedge mechanism in the model is capital since there is no good and bond trade. However, our model

[5] Barro and Ursua (2008) and Ursua (2011) extended the data set by including consumption per capita data. They also improved GDP data for some countries.

[6] Gabaix (2008) lists these puzzles as "Equity premium puzzle, risk-free rate puzzle, excess volatility puzzle, predictability of aggregate stock market returns with price-dividend ratios, value premium, often greater explanatory power of characteristics than covariances for asset returns, upward sloping nominal yield curve, a steep yield curve predicts high bond excess returns and a fall in long term rates, corporate bond spread puzzle, high price of deep out-of-the-money puts."

allows both good and bond trade across countries. Their model is able to generate volatile exchange rates and relatively small Backus-Smith correlation but they have inconsistent match between interest rate level and risk level. Consumers in risky countries demand more capital for hedging purposes that leads low interest rates. Farhi and Gabaix (2011) introduce a multi-country model with tradable and non-tradable endowments with time-varying disasters leading a permanent decline in consumption. They make simplifying assumptions such as separable utility and linear technology which converts non-traded goods into traded goods. Their model is able to address UIP puzzle coefficient and exchange rate volatility. To best of our knowledge, our paper is the first study which uses rare disasters in a two country international macro model with bond and good trade.

3 Model

We develop two country model with tradable and non-tradable endowments based on Backus, Kehoe and Kydland (1995), Stockman and Tesar (1995), and Corsetti et al. (2008). Countries are indexed by $i \in \{E, D\}$ corresponding to emerging country and developed country, respectively. We make two important changes in the standard two country models. First, we allow both countries to receive time varying disaster shocks that differ across countries. Second, we allow each country to issue its own bonds instead of an international bond.

3.1 An endowment economy with rare disasters

To this standard international macro model, we incorporate rare disasters In particular, we assume that the world economy has two states, namely good and bad. We model the transition between good and bad state by the two-state Markov-process. In good state both economies have high level of tradable endowment, represented by $E_{i,T}$ for $i \in \{E, D\}$, and also in this state the probability of being exposed to a disaster is zero. In bad state, both countries have low level of tradable endowment. 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 for countries :

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

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

3.2 Firms' problem

There are perfectly competitive intermediate tradable good producer firms that combine domestic and foreign tradable endowments to produce intermediate tradable goods. Firms use a constant elasticity of substitution (CES) production function:[7]

$$Y_i^T = \left[v_i^{\frac{1}{\kappa_i}} X_{Di,T}^{1-\frac{1}{\kappa_i}} + (1-v_i)^{\frac{1}{\kappa_i}} X_{Ei,T}^{1-\frac{1}{\kappa_i}} \right]^{\frac{\kappa_i}{\kappa_i-1}} \qquad i = E, D \tag{2}$$

where Y_i^T is intermediate tradable good, κ_i is the elasticity of substitution between emerging country tradable good $X_{Ei,T}$ and developed country tradable good $X_{Di,T}$, and ν_i is the portion of the emerging country's tradable good in country i's intermediate tradable good production, where $v_D = 1 - v_E$. We take the developed country's tradable input price as the numeraire ($P_{D,T} = 1$) and represent the relative tradable and non-tradable input prices of emerging as $P_{E,T}$, $P_{E,N}$ and non-tradable input price of developed as $P_{D,N}$. The price index P_i^T of intermediate tradable good :

$$P_i^T = \left[v_i + (1-v_i) P_{E,T}^{1-\kappa_i} \right]^{\frac{1}{1-\kappa_i}} \qquad i = E, D \tag{3}$$

Competitive final good producers in each country combine intermediate tradable good with the country's non-tradable endowment to produce consumable final goods. Final good is produced by CES technology:

$$Y_i = \left[\theta_i^{\frac{1}{\eta_i}} (Y_i^T)^{1-\frac{1}{\eta_i}} + (1-\theta_i)^{\frac{1}{\eta_i}} (E_{i,N})^{1-\frac{1}{\eta_i}} \right]^{\frac{\eta_i}{\eta_i-1}} \qquad i = E, D \tag{4}$$

[7] We drop the time indices t for simplicity.

where Y_i is the final good, η_i is the elasticity of substitution between intermediate tradable good Y_i^T and non-tradable endowment $E_{i,N}$, and θ_i is the portion of tradable goods in the final goods production.

The final good price index P_i :

$$P_i = \left[\theta_i (P_i^T)^{1-\eta_i} + (1-\theta_i) P_{i,N}^{1-\eta_i}\right]^{\frac{1}{1-\eta_i}} \qquad i = E, D \tag{5}$$

We define the terms of trade TOT as the ratio of developed export price to its import price, and the real exchange rate RER as the ratio of the developed country's final good prices to the emerging country's final good prices:

$$TOT = \frac{1}{P_{E,T}} \quad \text{and} \quad RER = \frac{P_D}{P_E} \tag{6}$$

An increase in RER means an appreciation for the developed country and a depreciation for the emerging country.

3.3 Budget Constraints and Asset Markets

Final good is consumed totally in each country since we have endowment economy and international trade is possible only for tradable goods. The resulting resource constraint is

$$Y_{i,t} = C_{i,t} \qquad i = E, D \tag{7}$$

where $C_{i,t}$ is the final consumption.

The net trade balance for the for the emerging country is $P_{E,T} X_{ED,T} - X_{DE,T}$ and for the developed country is $X_{DE,T} - P_{D,T} X_{ED,T}$ resulting from exchange of tradable goods. Income from the endowments in the developed country is given by $E_{H,T} + P_{D,N} E_{D,N}$. Emerging and developed countries issue their own internationally tradable non-state contingent bonds, B_E^*, B_E and B_F, B_F^*, that mature next period and pay in units of their own (final) consumption good. Both bonds have zero net supplies. The emerging country household faces the following budget constraint:

$$P_{E,t}C_{E,t} + Q_{E,t}B_{E,t+1} + Q_{D,t}B_{D,t+1} = P_{E,t}Y_{E,t} + (P_{E,T,t}X_{ED,T,t} - X_{DE,T,t}) + P_{E,t}B_{E,t} + P_{D,t}B_{D,t} \tag{8}$$

where $Q_{E,t}$ and $Q_{D,t}$ are the nominal prices of emerging and developed bonds held by emerging country that matures at time t+1 and $B_{E,t+1}$ and $B_{D,t+1}$ are the amount of bonds, respectively..The developed country faces a similar budget constraint:

$$P_{D,t}\ C_{D,t} + Q_{D,t}B^*_{D,t+1} + Q_{F,t}B^*_{F,t+1} = P_{D,t}Y_{D,t} + (X_{DE,T,t} - P_{E,T,t}X_{ED,T,t}) + P_{D,t}B^*_{D,t} + P_{E,t}B^*_{E,t} \tag{9}$$

where $Q_{E,t}$ and $Q_{D,t}$ are the nominal prices of emerging and developed bonds held by developed country that matures at time t+1 and $B^*_{E,t+1}$ and $B^*_{D,t+1}$ are the amount of bonds, respectively.

We assume that countries are net suppliers of their own bonds i.e. $B_{E,t} \leqslant 0$ and $B^*_{D,t} \leqslant 0$ Then, the market clearing condition for each bond implies: $B_{i,t} + B^*_{i,t} = 0$ for $i = E, D$. Then the gross portfolio holding is defined as $P_{E,t}B^*_{E,t} + P_{D,t}B_{D,t}$. The net portfolio holding of the emerging country is defined as $P_{E,t}B_{E,t} + P_{D,t}B_{D,t}$. Net portfolio position of the developed country is $-(P_{E,t}B_{E,t} + P_{D,t}B_{D,t})$.

Furthermore, we allow emerging country to partially default on its bonds with some probability if disaster occurs. However, developed country does not default even in disaster times.

3.4 Households' problem

Representative agents in both economies have isoelastic utility function over consumption of the final goods:

$$U_{i,t} = \frac{c_{i,t}^{1-\gamma_i}}{1-\gamma_i} \quad i = E, D \tag{10}$$

where γ_i is the risk aversion parameter. 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 emerging country household is:

$$V_{E,t} = \underset{B_{E,t+1},B_{D,t+1}}{Max} \{E_t u(c_{E,t}) + \beta E_t(V_{E,t+1}(E_{E,T,t+1}, E_{D,T,t+1}, B_{E,t+1}, B_{D,t+1}))\} \tag{11}$$

In the problem, state variables are the two tradable endowment processes and the two bonds. The developed country household solves:

$$V_{D,t} = \underset{B^*_{E,t+1},B^*_{D,t+1}}{Max} \left\{ E_t u(c_{D,t}) + \beta E_t (V_{D,t+1}(E_{D,T,t+1}, E_{E,T,t+1}, B^*_{E,t+1}, B^*_{D,t+1})) \right\} \tag{12}$$

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 marginal utility of substitution within the period differs between two states.

3.5 Calibration

Most of the parameter values are chosen from the literature. We set the discount factor to 0:96, and depreciation rate to 0:1 for convenience with annual data. We follow Corsetti et al. (2008) for international parameters. The home input share parameter in intermediate tradables production v is 0.72, which implies a home bias in production. The elasticity of substitution parameter 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 parameter between tradable intermediate goods and nontradable inputs η is 2/5 in final good production. Risk aversion parameter σ is selected as 2.

We calculate the transition probabilities between good and bad states by using the data set provided by Barro and Ursua that includes forty two countries.[8] We group the countries into developed and emerging sets.[9] We find good years and bad years for each set of countries by setting the critical level as average GDP growth of developed and emerging countries in Table 1.1 and combine our results to obtain unique numbers for transition probabilities p (from good state to bad) and q (from bad state to good state) .The calculated values are $p = 9.2$ and $q = 26.8$. These values indicate that both good and bad states are persistent. The level of tradable endowment in developed and emerging countries are chosen as 1.02 and 1.03 in good

[8] link: www.economics.harvard.edu/barrorsuamacrodata.com

[9] The classification is provided in Appendix B.

state, and 0.98 and 0.97 in bad state, respectively in order match the relative volatilities of outputs.

To calibrate the disaster shocks, we follow Barro (2006) and Barro and Ursua (2008). Barro and Ursua (2008) define a disaster as a contraction of real per capita GDP over 10% in consecutive periods. We follow the definition of Barro and Ursua (2008) and choose the disaster threshold as 10%.[10] Table B.2 in appendix gives the list of disasters, destruction of output in disaster times and return on bills country by country. We observe only two disasters in the developed countries but emerging countries experienced twenty three disasters after WW-2. Then, average disaster size for developed countries is $\alpha^d = 0.13$ and for the emerging countries is $\alpha^m = 0.20$. Disaster probabilities calculated by the formula $\pi = \frac{\text{disaster years}}{\text{bad years}}$. We have "bad years" in denominator since disasters can only happen in bad states. The resulting disaster probability for developed countries is $\pi^d = 0.98\%$ and for emerging countries is $\pi^e = 4.77\%$.

We also allow default probability for bonds at disaster times. We observe no defaults on developed countries during disasters after WW-2.[11] So, default probability for developed country bonds is zero. Although we have twenty three disasters for emerging economies, we only have bond returns for nine cases. Since we have six negative returns, we set default probability to 67%. Barro (2006) argues that default size should be close to size of disaster. Sturzenegger and Zettlemeyer (2006) estimate haircuts for Russia, Ukraine, Pakistan, Ecuador and Argentina for last three decades and find that haircuts were ranging from 13 to 73 percent and clustered around 25-35 percent. We mildly set size of the default as 30%.

[10] We define contraction as the growth smaller than mean growth of developed and emerging countries after WW-II.

[11] Our data set does not include recent developments in Greece.

Calibration

Definition	Parameter	Value
Home input share in intermediate tradables production	v	0.72
EIS between home and foreign tradable inputs	κ	3/2
Intermediate tradable goods share in final goods production	θ	0.55
EIS between intermediate tradable and nontradable	η	2/5
Risk aversion parameter	σ	2
Discount factor for households	β	1/1.04
Transition probability from good state to bad	p	9.2
Transition probability from bad state to good	q	26.8
Disaster probability(%) (Developed and Emerging)	π	0.98 and 4.77
Disaster size(%) (Developed and Emerging)	α	12 and 20
Default probability (%) (Emerging)	$\pi_{default}$	67
Default size(%) (Emerging)	$\alpha_{default}$	30

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 and HP-filtered required series.[12]

4.1 Risk Sharing and RER Volatility

We observe that consumptions of developed and emerging countries has no correlation (Table C.1). However, standard two country models generate a positive correlation. The mechanism in standard IRBC models can be explained as follows. Technology shock to tradable sector of one country has two effects: wealth effect and substitution effect. If home country experiences a high level of tradable input, home country households increase their demand due to wealth effect that triggers a price increase in home tradable good On the other hand, home country

[12] Business cycle and finacial statistics for emerging and developed countries are summerized in Table A.1 and Table A.2 at appendix.

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, close to one, in consumption levels of two countries.

Studies tried to solve risk sharing or Backus-Smith puzzle introducing taste, expectation shocks or using very low and high values of trade elasticity parameters. Table 4.1. shows that inclusion of rare disasters in the model breaks the above mentioned mechanism and generates Backus-Smith relation for plausible values of trade elasticity. The rare disaster probability increases the precautionary 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 that leads a decrease in prices. Since tradable goods are substitutes and prices are relatively cheaper, developed country increases its consumption even in bad times. In turn, we have negative correlation in consumptions and a decrease in relative consumption C^E/C^D. Furthermore, RER depreciates since home bias in intermediate good production limits the demand of developed country for emerging country tradable good. This mechanism generates a negative correlation -0.58 which accords with data.

Table 4.1 :Correlations

	Data	*Model-Disasters*	*Model-No Defaults*	*Model-No Disasters*
$\rho(Y^E, Y^D)$	0.01	-0.15	-0.17	0.84
$\rho(C^E, C^D)$	-0.30	-0.15	-0.17	0.84
$\rho(C^E/C^D, RER)$	-0.42*	-0.58	-0.60	0.86
$\rho(NX/Y^E, Y^E)$	-0.53	-0.71	-0.74	0.82
$\rho(NX/Y^E)$	0.58**	0.59	0.58	-
$\rho(RER)$	0.54	0.60	0.59	-

*Statistics are from Corsetti et al. (2008)

**Statistics are from Garcia-Cicco (2010)

The RER volatility is three times greater than the output volatility in data (Table C.1). 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. Studies incorporating rare disasters are able to generate high RER volatility. Gourio et al. (2013) produces RER volatility of two in a framework with the rare disaster and households with Epstein-Zin preferences.

Our model provide high RER volatility compared to model without disasters (Table 4.2). Our calibration implies developed countries are less prone to disasters with respect to emerging countries. This difference leads to significant difference in marginal utility of consumption across countries .Together with the home bias in production and the existence of non-tradable goods, disaster probability leads to large variations in non-tradable good prices. In turn, we observe high volatility in RER.

Table 4.2: Relative Volatilities

	Data	*Model-Disasters*	*Model-No Defaults*	*Model-No Disasters*
$\sigma(Y^E)$	4.05	3.97	3.87	3.06
$\sigma(C^E)/\sigma(Y^E)$	1.15	1.00	1.00	1.00
$\sigma(NX/Y^E)/\sigma(Y^E)$	0.86	0.28	0.28	0.38
$\sigma(TOT)/\sigma(Y^E)$	1.68	0.13	0.14	1.17
$\sigma(RER)/\sigma(Y^E)$	3.00	1.31	1.32	0.57
$\sigma(Spread)/\sigma(Y^E)$	0.83	0.59	0.59	0.17

4.2 Net Exports

The correlation between net exports and output is strongly negative for emerging countries in data. However, developed countries have small negative correlation.[13]This means that if income increases, emerging countries respond harshly and increase their imports more with respect to the developed countries. Aguiar and Gopinath (2007) explains this by trend shocks to Solow residuals which implies more persistency in growth compared with the transitory shock. They

[13]Aguiar and Gopinath (2007) finds -0.51 for emerging economies and -0.17 for developed economies by using the quarterly data since 1980Q1.

argue that shocks to trend forms strong wealth effect which leads a strong response in consumption and net exports. Another important feature is autocorrelation of net exports to output ratio Garcia-Cicco et al. (2010) reports that RBC model with trend and transitory shocks generate nearly a random walk trade balance to output ratio NX/Y. However, autocorrelation is significantly less than one in data. They solve this puzzle by introducing financial frictions to the RBC model and finds that country premium explains most of the variance in trade balance to GDP ratio.

Our model with rare disasters matches the cyclicality and autocorrelation of trade balance to output ratio (Table 4.1). In bad state, households in emerging country decrease their consumption and increase its exports to refrain from destructive effects of disasters. On the other hand, developed country increase their imports since emerging tradable goods are relatively cheaper. The net effect on trade balance of emerging country is positive because of home bias and high probability of disaster. So, we have countercyclical net trade balance to output ratio. Furthermore, our model generates an autocorrelation away from unity. The probability of rare disaster leads large swings in saving decisions of emerging country household which directly affects the net exports. In turn, we have mild autocorrelation.

4.3 Portfolio Holdings and Return Premium

There is a significant spread between the bill returns of emerging and developed countries attributed country risk.[14] Our model can generate a significant spread between the return and levels of bonds (Table 5.3). This spread can be attributed to two factors: (i) the differentiation in disaster probability between developed and emerging economies and (ii) the default probability of emerging bonds in disaster times. First, emerging country's asset demand is much more than developed country because of rare disasters. This dampens the developed country bond return more relative to emerging country bond return since both countries are net supplies of its own bonds. Second, default probability in emerging bonds is reflected as risk premia in returns. An alternative calibration may help our model to match the data.

Portfolio choice has started to take attention for last ten years in international macro mod-

[14] See Table C.1. for details.

els However, solving portfolio models with linearization is impossible. Some recent methods are developed by Devreux and Suderland (2006) and Tille and Wincoop (2006). But their methodology is not capable of handling rare disasters and it is also not possible to work with gross positions of portfolios. One advantage of us is our methodology allows us to study gross positions. Our model is able to produce positive net foreign asset position due to rare disaster probability. However, model with no disasters implies zero position in long run since endowment processes of countries are similar.

Another important result is about gross foreign asset positions. Model with disasters produce low gross positions compared to model without disasters. Remember that the gross portfolio holding is defined as $P_{E,t}B^{*}_{E,t}+P_{D,t}B_{D,t}$. So, lower level of gross portfolio can be associated with the low level of $B^{*}_{E,t}$ and $B_{D,t}$. This is reasonable since both countries are reluctant to supply bonds to other country since they first try hedge themselves for a disaster risk.

Table 5.3: Portfolio Results

	Data	*Model-Disasters*	*Model-No Defaults*	*Model-No Disasters*
Emerging Return %	8.4	8.7	8.5	4.0
Developed Return %	7.1	4.9	4.8	4.0
Spread	1.3	3.8	3.7	0.0
$\frac{Net\ Exports}{Y}$		-0.02	-0.02	-0.2
$\frac{NFA}{Y}$	17.42	5.16	4.95	1.7
$\frac{GFA}{Y}$	73.39	6.50	6.32	47.5

4.4 Uncovered Interest Rate Parity

Standard macroeconomic models imply a depreciation in home currency with respect to foreign country if its interest rates exceeds foreign interest rates. However, we observe in data that currency of higher interest rates countries are tend to appreciate. This puzzle is named as uncovered interest rate puzzle.[15] The UIP equation is $\Delta S_t = \alpha + .\beta(R^E_t - R^{US}_t) + \varepsilon_t$ where ΔS_t change in nominal exchange rate, $R^E_t - R^{US}_t$ is return difference. Bansal and Dahlquist (2000)

[15] Since covered interest rate parity (CIP) holds, we use UIP interchangebly with forward premium puzzle (FPP).

use data for twenty eight emerging and developed countries. They find that UIP puzzle is more evident in developed countries but average slope coefficient for emerging economies is still away from unity, it is 0.19.

We run UIP regression using our simulation results. It implies a slope coefficient 0.30 which is consistent with findings of Bansal and Dahlquist (2000). The possibility of rare disasters increases the precautionary savings in emerging country as discussed above. This results a high return premium between emerging and developed economies in bad states since emerging country demands large amount of developed country bonds. Beside this, currency of emerging country depreciates significantly due to low demand of emerging country household. On the other hand, in good states currency of emerging country recovers i.e. appreciates. So, developed country can benefit both from excess returns and currency appreciation. This mechanism produces a coefficient less than unity.

5 Conclusion

In this paper, we develop a standard two country model with isoelastic utility and, tradable and non-tradable sectors to study developed and emerging economies. Then, we augmented the model in two ways. First, we allow emerging and developed countries to issue their own bonds. Second, we incorporate rare disaster risk and default possibility into the model. We calibrate disaster and default parameters by using the data set provided by Barro and Ursua. We show that parameters of emerging countries differ significantly for the post World War II period. These simple innovations help us to solve many puzzles in the international macro literature.

One contribution of our paper is that high exchange rate volatility and imperfect risk sharing, Backus-Smith relation, occur together. Furthermore, our model can address the cyclicality of trade balance to output ratio for emerging country. It generates strong negative correlation between net exports to output ratio and output. It also matches autocorrelation of this ratio. Another contribution is we have significant spread between emerging and home return as well as matching the level of these returns for calibrated disaster and default parameters. Moreover, we have volatile spreads. Another puzzle explained by the model is UIP puzzle. We believe this paper is a good attempt to show a concept that explains many puzzles in macro-finace literature can also account for puzzles international macro literature.

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6 Appendix

6.1 Appendix A: Computational Algorithm

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.[16] 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.

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

6.2 Appendix B: Classification

Table B.1*

Developed	Emerging
Australia	Argentina
Austria	Brazil
Belgium	Chile
Canada	China
Denmark	Colombia
Finland	Egypt
France	India
Germany	Indonesia
Greece	Malaysia
Iceland	Mexico
Italy	Peru
Japan	Philippines
Netherlands	Russia
New Zealand	Singapore
Norway	South Africa
Portugal	South Korea
Spain	Sri Lanka
Sweden	Taiwan
Switzerland	Turkey
United Kingdom	Uruguay
United States	Venezuela

We use the IMF list to identify developed countries. Although, Singapore, South Korea and Taiwan are currently listed as developed, they were named as emerging before 1997.

Table B.2. : Disasters in post WW-2*

Developed Countries	Period	Size	Bill Return
Finland	1989-1993	-0.12	0.092
Iceland	1948-1952	-0.13	NA
Emerging Countries			
Argentina	1979-1985	-0.16	NA
	1986-1990	-0.13	-0.355
	1997-2002	-0.20	0.090
Brazil	1980-1983	-0.12	NA
Chile	1971-1976	-0.23	-0.479
	1981-1983	-0.18	0.296
China	1958-1962	-0.25	NA
	1966-1968	-0.14	NA
Indonesia	1961-1967	-0.11	NA
	1997-1999	-0.16	-0.066
Korea	1949-1951	-0.25	NA
Mexico	1981-1989	-0.11	NA
Peru	1987-1993	-0.31	-0.522
Russia	1988-1998	-0.48	NA
South Africa	1981-2003	-0.11	NA
Singapore	1950-1952	-0.34	NA
	1956-1958	-0.11	NA
Uruguay	1957-1959	-0.12	NA
	1980-1985	-0.22	NA
	1998-2003	-0.17	NA
Venezuela	1957-1963	-0.15	0.007
	1977-1986	-0.28	-0.005
	1997-2003	-0.23	-0.043

*Bill returns are taken from Barro and Ursua (2008b). Our disaster periods do not exactly match with their periods because of difference in contraction definition.

6.3 Appendix C

Table C.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 C.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.