ON THE ECONOMICS AND PRICING OF NEWLY EMERGING BOND VARIETIES: MICRO AND MACRO EFFECTS OF FOREIGN AND CATASTROPHE BONDS

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ON THE ECONOMICS AND PRICING OF NEWLY EMERGING BOND VARIETIES: MICRO AND MACRO EFFECTS OF FOREIGN AND CATASTROPHE BONDS

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This dissertation studies two newly emerging bond varieties - the foreign bond and the CAT bond. Concerning the foreign bond, we focus on its micro-level impact on the equity value of the issuing firm. We derive a theoretical model to explain why the issuance of foreign bonds impacts firm value through the channel of foreign exchange risk. Then, we empirically test the stock price reaction to the launch of two foreign bonds - dim sum bonds and Eurodollar bonds. We further show that the cross-sectional differences among stock reactions result from foreign exchange volatility rather than from other bond characteristics. Concerning the CAT bond, we focus on its macro-level impacts on the economic development, risk financing and sovereign debt sustainability of least-developed countries. We examine the roles of the CAT bond as both an *ex ante* risk financing strategy and an *ex post* economic development tool. We discuss how the issuance of a government sponsored CAT bond improves the sovereign debt sustainability in an static social wealth maximization framework. In the end, we illustrate how to simulate the price of a drought linked CAT bond through the well-defined closed form solution and show that our simulation technique is adaptive and robust to different settings.

BIOGRAPHICAL SKETCH

Lin Sun was born on November 3, 1985 in Tianjin, China to Shouping Sun and Jiakang Sun. He is the only son of the family.

He resided in Tianjin for 15 years and then moved to Beijing in 2001. He graduated from Peking University Affiliated High School in 2004. Lin firstly matriculated into Tsinghua University, Beijing in 2004, majoring in Economics. One year later, Lin was transferred into the University of Hong Kong, majoring in Economic and Finance.

Lin has been exchanged to Seifu High School, Osaka, Japan in 2003. Lin has also been exchanged out to University of Edinburgh, UK in 2007. Lin accumulated working experience from internships in the Boston Consulting Group, ING Bank and J.P. Morgan Chase Securities. He has visited many countries and has taken part in broader varieties of extracurricular activities.

Lin began his studies at Cornell University in the pursuit of a MSc. degree since the fall of 2008. After successful receiving the MSc. degree, he continued to study towards a Ph.D. degree from the fall of 2010. The Cornell University will confer his doctoral degree in January 2015.

I dedicate my dissertation work to my wife, my parents and many friends at Cornell University. I will always appreciate their encouragement, supports and mentoring throughout the process.

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CHAPTER 1

INTRODUCTION

This dissertation was inspired by my long-term interest in bond products. Bonds are classic financing tools with several hundred years of tradition. They have funded numerous investments, projects, and even wars on behalf of corporations, institutions, municipalities, and sovereigns over the past few centuries. We can trace the footprints of modern bonds in many memorable historical moments, including the Napoleonic Wars, the American Railroad Era, and World War II. The historical existence of bonds has never been challenged or doubted. However, their variety and characteristics have continuously evolved, from bearer bonds to custodial bonds, from sovereign bonds to corporate bonds, from investment-grade bonds to high-yield bonds, from straight bonds to convertible bonds, and so on. I believe this evolutionary process is the most spectacular aspect of modern financial liberalization and innovation.

Whenever a new bond variety is innovated and introduced, I wish to study it. This desire is motivated not only by my curiosity but also by the changes a new bond variety produces. These changes can happen either on a micro level, such as the impact on the value of a firm and stockholder return, or on a macro level, such as the impact on the welfare of a society or the completeness of a financial market. This dissertation studies two newly emerging bond varieties - the foreign bond and the catastrophe (CAT) bond. Concerning the foreign bond, we focus on its micro-level impact on the equity value of the issuing firm. Concerning the CAT bond, we focus on its macro-level impact on the economic development, risk financing and sovereign debt sustainability of less-developed countries. Although foreign and CAT bonds differ in terms of their inherent risks, this dissertation seeks to study and document their changes and impacts.

Chapter 2, “Foreign Bond Issuance and Firm Value,” addresses how firm value changes in response to changes in capital structure. This question has been studied extensively in the contexts of traditional straight bonds and convertible bonds but has received less attention in the context of foreign bonds. This chapter studies the foreign bonds, including Eurodollar bonds and dim sum bonds. We first outline their backgrounds and their differences. Then, we derive a theoretical model to explain why the issuance of foreign bonds impacts firm value through the channel of foreign exchange risk. Later, we empirically test the stock price reaction to the launch of two foreign bonds - dim sum and Eurodollar bonds. The results reveal that the launch of Eurodollar bonds would increase firm value while that of dim sum bonds would decrease it. We further show that the cross-sectional differences among stock reactions result from foreign exchange volatility rather than from other bond characteristics. These empirical findings on foreign bonds tend to support our theoretical model.

Chapter 3, “Economic Development and Risk Financing Topics of Catastrophe Bonds,” firstly examines the significant covariant risks posed by catastrophes in small and least-developed countries (LDCs). We find that not only catastrophes induce poverty traps for the victims in LDCs, but also the lack of financial or insurance markets amplifies the severity of catastrophe-induced poverty traps. We investigate the features of the CAT bond and compare them with those of other risk financing strategies. We show that CAT bonds, as an economic development tool, could help increase the flexibility of post-crisis project selection and provide higher insurance penetration for catastrophe risks. We also show that CAT bonds, as a risk financing strategy, could help solve the low insurability problem of catastrophe risks caused by adverse selection, moral hazard, and basis risk. Therefore, we believe that the CAT bond is an advantageous *ex ante* risk financing strategy and an effective *ex post* economic development tool that could help alleviate the damage of natural disasters and foster post-catastrophe development.

Chapter 4, "Catastrophe Bonds and Sovereign Debt Sustainability", addresses how the issuance of CAT bond enhances the sustainability of LDCs' sovereign debt. We often observe that catastrophes create a short-term budget squeeze and hence trigger the sovereign debt default for LDCs. To help LDCs avoid such painful default, we examine the relationship of CAT bond and sovereign debt in a static wealth maximization framework. Our model results predict that the issuance of CAT bond will crowd out the issuance of sovereign debt, reduce the default incentive on sovereign debt and improve the social welfare for LDCs, if certain opt-in condition has been met. We also reveal that the social welfare improvement is coming from CAT bond's ability to smooth the consumption in disaster state.

Chapter 5, "Pricing and Simulation of Catastrophe Bonds for a Small and Least-developed Country,” explores the pricing methodology of the CAT bond and finds that the closed form solution for CAT bond pricing is the ideal candidate for LDCs because of its robustness to different term structures, computational ease and utilization of historical data. We apply the closed form solution to drought risk in Kenya and simulate the price of a drought-linked CAT bond. We collect monthly rainfall data for Northern Kenya’s Moyale region and run a simulation that generates the intensity of drought occurrence. We then input drought intensity data and the zero coupon Libor curve into the closed form solution to derive the CAT bond price. We also test the sensitivity of the CAT bond price to trigger levels, time, recovery rates, coupon spreads, and the drifts of the zero coupon Libor curve. The result indicates that our simulation method is robust and consistent across different parameter settings.

CHAPTER 2

FOREIGN BOND ISSUANCE AND FIRM VALUE

2.1. Motivation

Whether the issuance of bonds can increase firm value has been long debated in capital structure studies. Amid the extensive literature on this topic, the answer is becoming increasingly clear, at least for mainstream domestic bonds. However, if we redirect our focus to the special bond category of foreign bonds, the answer is less clear and backed by fewer theories and less evidences. The slow development of foreign bond research is mainly attributable to three causes. First, foreign bonds are a relatively rare and small asset class, and hence we have not paid much attention to it. Second, foreign bonds share many standard features with domestic bonds, and we may have overlooked their uniqueness. Third, foreign bonds exhibit cyclical and national characteristics that may complicate their quantitative examination.

Our theory tries to explain foreign bonds' impact on firm value from a new perspective. Our intuition stems from the real-world observation that investors of foreign bonds are exposed to certain amounts of foreign exchange risk. Through sound assumptions and analyses, we show that this foreign exchange risk would not only make the value of the foreign bonds more volatile but also make the value of the assets more volatile. Using Merton's model on equity value, we show that an increase in the volatility of the assets would increase its equity value if we treat equity value as a call option on the assets of the firm.

This study also empirically tests the stock price reaction to the launch of two foreign bonds—dim sum bonds and Eurodollar bonds. Dim sum bonds are a new class of foreign bonds that have emerged in Hong Kong. Their unique foreign exchange risk features make them an appropriate controlled sample for use with Eurodollar bonds. Our results indicate that the launch of Eurodollar bonds would increase firm value, as other researchers have shown, while the launch of dim sum bonds would decrease firm value. Further analyzing the cross-sectional difference in abnormal returns, we found that implied foreign exchange volatility, rather than financial bargains, helps explain such difference. We believe that this result supports our theory, as it links the theory's origin with its symptom.

This chapter is structured as follows. Section 2.2 will introduce the new dim sum bond in terms of its features and development in depth. Then we will cover the same aspects of the Eurodollar bond (briefly, as this product is well known and its market is well established). Section 2.3 will cover the relevant literature in the fields of capital structure and bond issuance to prepare our analyses. In Section 2.3, we will derive a theoretical model to explain why the issuance of foreign bonds impacts firm value through the channel of foreign exchange risk. In Section 2.4, we will empirically detect the announcement day stock price reaction to dim sum and Eurodollar bond issuance. Section 2.5 will summarizes this study and discuss possible avenues for future research.

2.2. Dim Sum Bonds and Eurodollar Bonds

2.2.1. Offshore Chinese Yuan

The term “dim sum” is the generic expression for the offshore renminbi (RMB) bond issued in Hong Kong. Before we further investigate the concept and development of the dim sum bond, we must first learn what the offshore RMB is. Offshore RMB is the same RMB cash used in Mainland China but circulated and traded in Hong Kong. Hong Kong was allowed to accumulate RMB from Chinese residents’ purchases in 2004. In June 2009, the People’s Bank of China (PBOC) and Hong Kong Monetary Authority (HKMA) signed a memorandum of cooperation for RMB cross-border trade settlement. In July 2010, the RMB became officially deliverable in Hong Kong with a joint announcement between the PBOC and the HKMA. The onshore and offshore RMB differ in many ways. First, the onshore RMB uses currency code CNY while offshore RMB uses currency code CNH. Second, CNY and CNH are traded in different jurisdictions of Mainland China and Hong Kong. For example, the CNY exchange rate can be influenced by the PBOC’s daily guidance price. The CNH exchange rate is instead affected by various market factors such as liquidity and risk appetite, beyond its reference to the CNY exchange rate. Third, Mainland China has capital control that limits cross-border capital flows to FDI, QFII, and QDII, and some informal channels. Therefore, the routes and scales of arbitrage activities for CNY and CNH are still marginal in eliminating the gap between CNY and CNH rates. Figure 1 illustrates how onshore and offshore markets differ and interact.

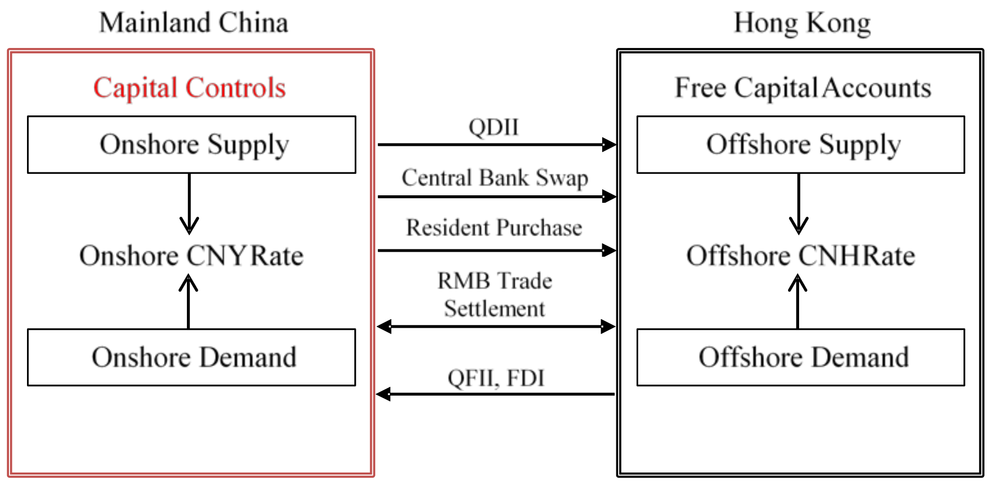

Figure 1 *Mechanism of CNY and CNH Markets*

The RMB, wherever it trades, is still one currency. However, owing to regulatory design and various supply/demand dynamics, the RMB spot rates trade differently in different markets. The CNH spot rate is correlated with the CNY spot rate with a high beta, and the CNY spot rate works as a soft anchor for the CNH rate. However, divergence still occurs. For example, the offshore CNH rate has been traded at a premium to the onshore CNY rate since August 2010, as international investors gained a risk appetite for emerging countries' currencies and fueled the demand of CNH. This divergence slowly disappeared after three months, after international hot money found detours into Mainland China and bought CNY assets. In August 2011, the CNH was traded at a discount against the CNY because the European debt crisis hit investors' risk appetites and their retreat from risky assets was quickly reflected by the weakening USD/CNH rates. Figure 2 illustrates how these two spot rates converged during calm times and diverged during turbulent times.

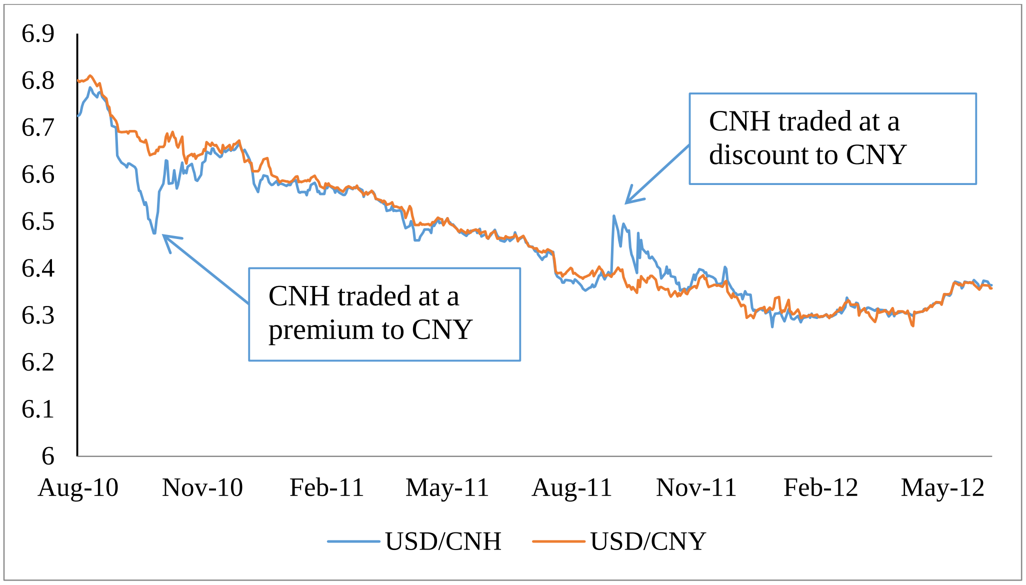

Figure 2 *CNH and CNY Spot Exchange Rates*[1]

The forward curves for CNY and CNH are also different. This is partly due to the higher offshore RMB interest rate that ensures enough RMB liquidity to lend higher-margin RMB loans to offshore corporates. Such higher offshore RMB interest rate could transmit into the CNH forward rate through Covered Interest Rate Parity (CIP) and make the CNH forward curve steeper. Figure 3 illustrates the relationship between CNY and CNH forward curves.

[1] Source: Bloomberg

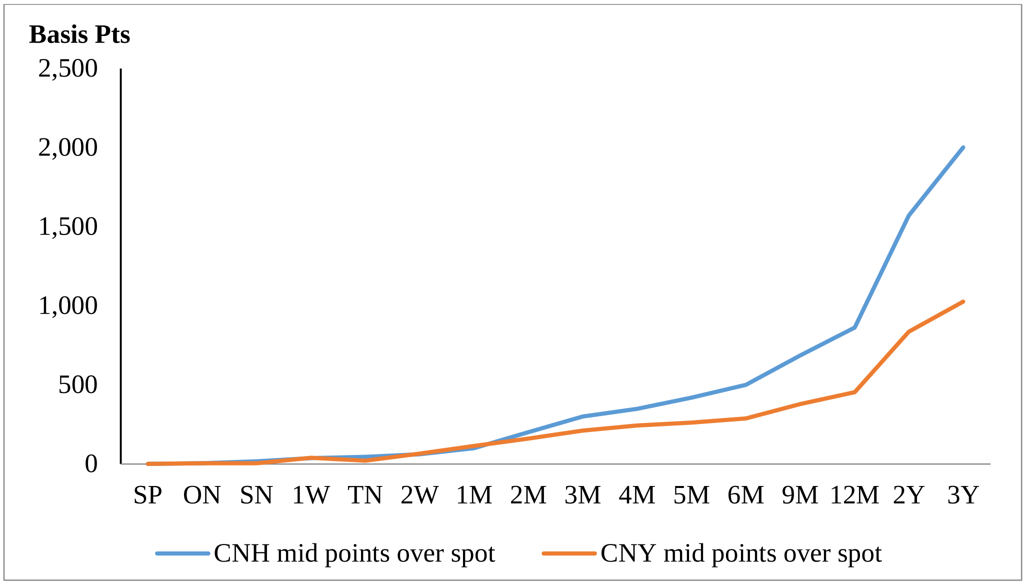

Figure 3 *CNH and CNY Forward Curves*[2]

2.2.2. Characteristics of Dim Sum Bonds

The emergence of dim sum bonds is the immediate result of RMB internationalization. Without RMB held offshore, no dim sum bonds would be issued or subscribed. A dim sum bond is a foreign bond in the sense that it is issued in Hong Kong but not denominated in Hong Kong's local currency, the Hong Kong dollar. On the contrary, a dim sum bond is denominated in RMB, a non-local currency. The Eurodollar bond, another kind of foreign bond, shares many similarities with dim sum bonds. Both of these are issued mainly by foreign issuers, denominated by foreign currencies and mostly subscribed by local investors. Many people mistakenly categorize Australian Kangaroo bonds and Japanese Samurai bonds as foreign bonds and fail to distinguish them from the dim sum and Eurodollar bonds. Actually, Kangaroo and Samurai bonds are denominated by their local currencies, Australian dollar and Japanese yen,

[2] Source: Bloomberg

respectively. For this reason, they cannot be labeled as foreign bonds and will not be included in our study.

The regulatory approval of dim sum bond issuance needs our special attention, as not all Chinese corporations enjoy free access to this market. The Chinese government still processes dim sum bond issuance on a case-by-case basis, as the repatriation of offshore RMB funds involve cross-border capital flows that are strictly monitored and controlled. Currently, Chinese banks and sovereign/quasi-sovereign entities enjoy the most freedom in issuing dim sum bonds. Some manufacturing firms with promising investment plans are also allowed to enter. However, the issuance amount for small and medium corporations is still constrained to RMB1 billion. Finally, domestic property developers are strictly prohibited to enter the CNH market in an effort to cool down the bubbling property market in Mainland China. The trading volume for dim sum bonds is still thin. For this reason, dim sum bonds are traded on the over-the-counter (OTC) market via dealers. The settlement of dim sum bond requires an account with the Central Monetary Unit (CMU) operated by the HKMA.

2.2.3. Development of the Dim Sum Bond Market

The offshore RMB bond market was established in 2007 after the PBOC and National Development and Reform Commission (NDRC) jointly issued *The Interim Measures for the Administration of the Issuance of RMB Bonds in Hong Kong S.A.R. by Financial Institutions within the Territory of China*. In July 2007, the China Development Bank became the first issuer of CNH-denominated bonds. On December

8, 2008, the General Office of the State Council issued *Several Opinions on Providing Financial Support for Economic Development*, allowing corporations and financial institutions with substantial business in China to issue dim sum bonds in Hong Kong.

The dim sum bond market has risen at a dramatic pace. As shown in Figure 4, new issuance grew from RMB10 billion in 2007 to RMB108 billion in 2011, growing more than 10 times in five years. Although the global debt market was hit by the European debt crisis again in late 2011, new issuance in the first four months of 2012 still amounted to RMB38 billion, more than the entire 2010 issuance.

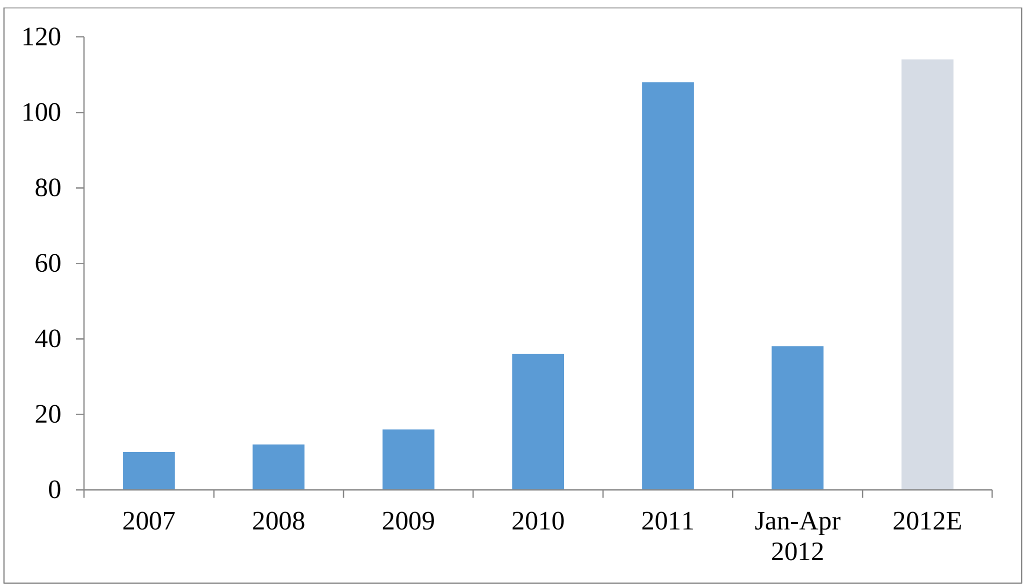

Figure 4 *New Issuance of Offshore RMB Bond*[3]

Three important factors, including RMB internationalization, monetary policy tightening in Mainland China, and RMB appreciation, significantly contribute to the

[3] Source: HKMA

burgeoning development of the dim sum bond market. The liberalization measure of the offshore RMB in Hong Kong is the most notable factor. Since 2010, offshore RMB in Hong Kong cannot only be held in saving accounts but also be invested in various financial products, including the dim sum bond. The requirement for opening an offshore RMB account has also been largely eased. Moreover, the implementation of RMB cross-border trade settlement in 2010 helped supplying RMB from onshore importers/exporters to offshore importers/exporters. Through this channel, the onshore RMB saturated Hong Kong and became offshore RMB. As shown in Figure 5, the amount of trade settlement increased from RMB10 billion in July 2010 to RMB241 billion in June 2012. Benefiting from these liberalization measures, the offshore RMB deposits increased sharply from RMB64 billion in January 2010 to RMB558 billion in June 2012, nine-fold in 30 months. In the meantime, the number of authorized institutions engaged in offshore RMB business more than doubled from 65 to 133. This changing dynamics is clearly demonstrated in Figure 6.

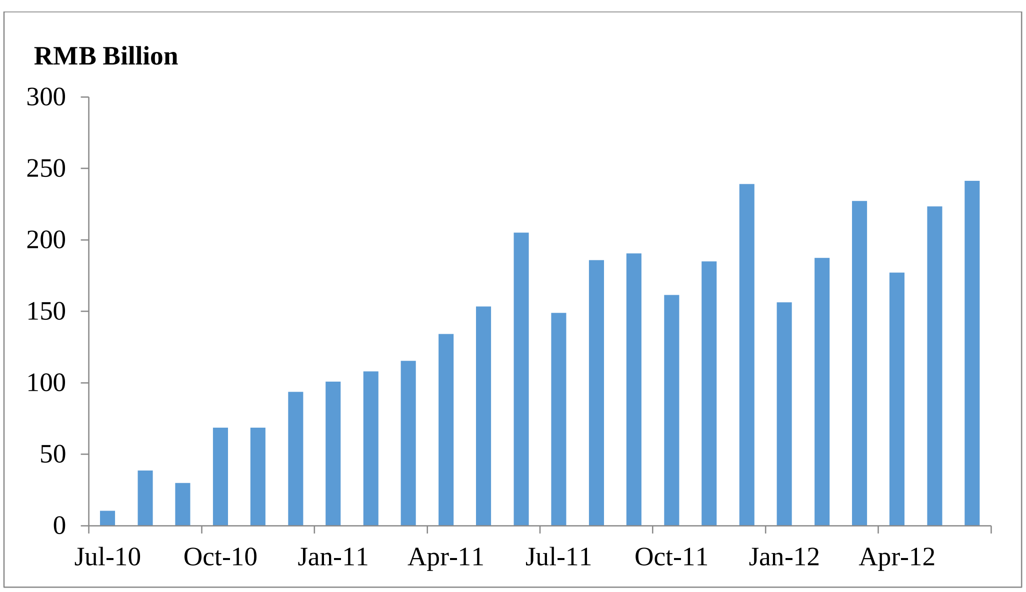

Figure 5 *RMB Cross-Border Trade Settlement*[4]

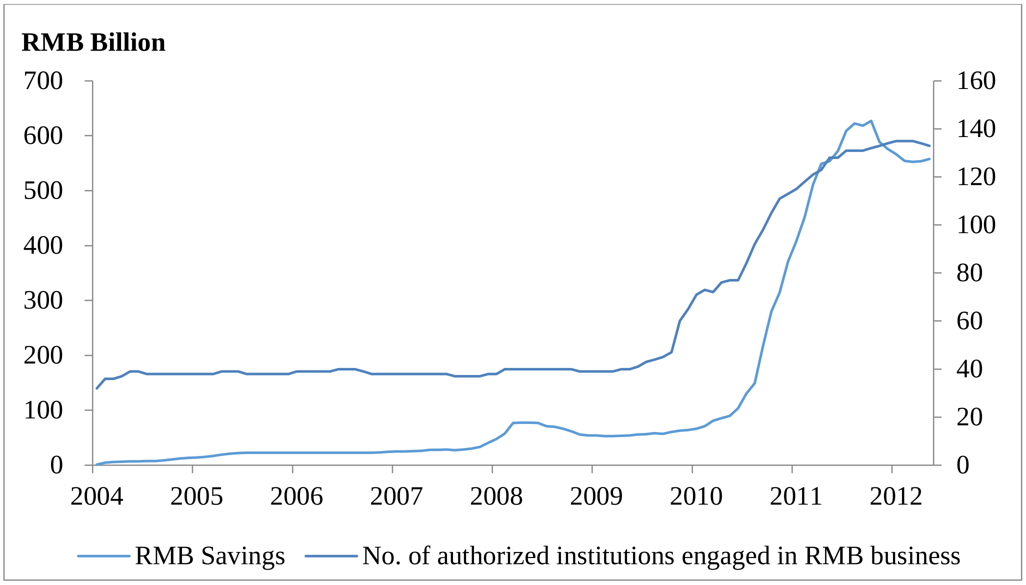

Figure 6 *RMB Savings Deposits in Hong Kong and Number of Institutions Engaged in RMB Business*[5]

The gradual policy tightening in Mainland China starting in 2010 and the resulting corporate funding gap also contributed to the rapid growth of the dim sum bond market. The onshore policy tightening was triggered by an excessive monetary base and associated high inflation after a RMB 4 trillion stimulus plan in early 2009. To address the excessive monetary base, the Chinese government reduced the release of new loans and leveled up the bank reserve ratios. These measures largely reduced the banks' ability and willingness to lend and caused severe funding difficulties for onshore corporations. The changing dynamics of onshore credit market can be seen in Figure 7.

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[4] Source: HKMA

[5] Source: HKMA

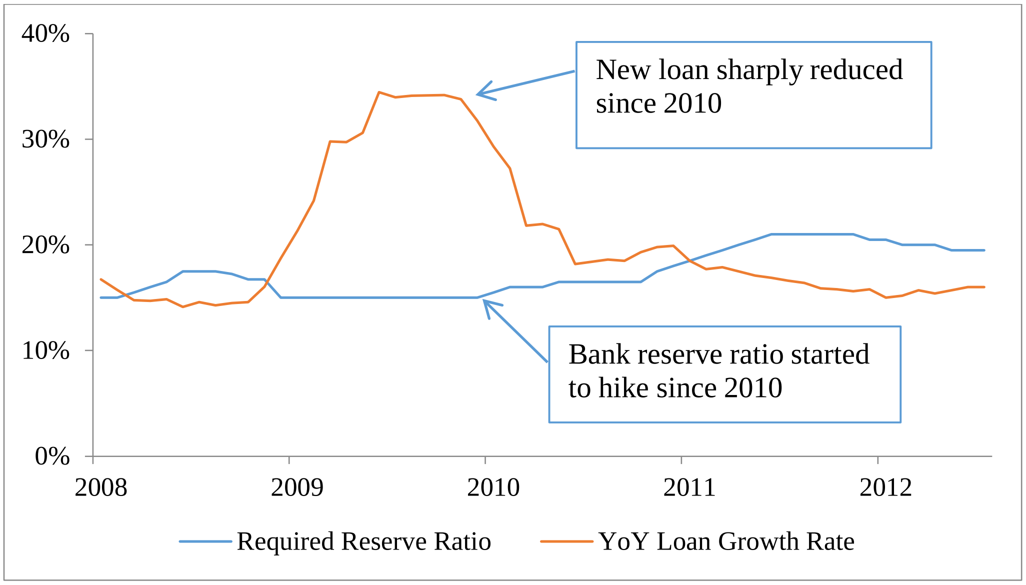


Figure 7 *Loan Deceleration and Bank Reserve Ratio Hike*[6]

Finally, the RMB's appreciation trend also helped boost the dim sum bond market. Due to its large current account surplus, Mainland China suffered huge pressure from its trade partners such as the USA to re-evaluate the value of the RMB. For this reason, the RMB is constantly appreciating against the USD at an annual rate of roughly 5%. International investors are drawn to RMB assets to enjoy the returns brought by RMB appreciation. The dim sum bond is the best product by which to gain RMB exposure without actually investing in Mainland China, where regulatory and legal hurdles still persist for international investors. To have an idea of RMB appreciation, please refer to Figure 2 for the USD/CNH and USD/CNY rates, both showing clear appreciating trend lines.

[6] Source: CEIC database

2.2.4. Issuance Landscape of the Dim Sum Bond Market

The dim sum bond market is emerging, not mature. Several key statistics shown in Figure 8 will illustrate this point. First, the main issuers of CNH bonds are still financial institutions, representing a 78.7% share in current outstanding issues. Banks have a higher share than corporations do because they prefer to tender smaller sized deals multiple times and thus tailor themselves to investors' diversified tastes. Multiple small deals do not incur extra transaction costs for banks, since banks could underwrite for themselves. On the contrary, corporations tend to offer larger deals all at once to reduce the transaction costs. A typical dim sum bond carries a short tenor of less than three years. Around 66.1% of dim sum bonds have tenors of one year or less. This implies that the issuers use dim sum bond mainly to finance their operating cash flows, but rarely use this product to finance their long-term projects. The consequence of short tenor is the lower coupon rate. There is no high yield bond in the dim sum bond market due to its stringent entrance criteria. Around 76.7% of the bonds carry a coupon rate of below 3%. In the dim sum bond market, mega deals are rather rare. About 83.6% of the deals involve less than RMB1 billion, which indicates that the market is still not mature enough and that its liquidity is still thin. Figure 8 illustrate the unique issuance landscape of the dim sum bond market.

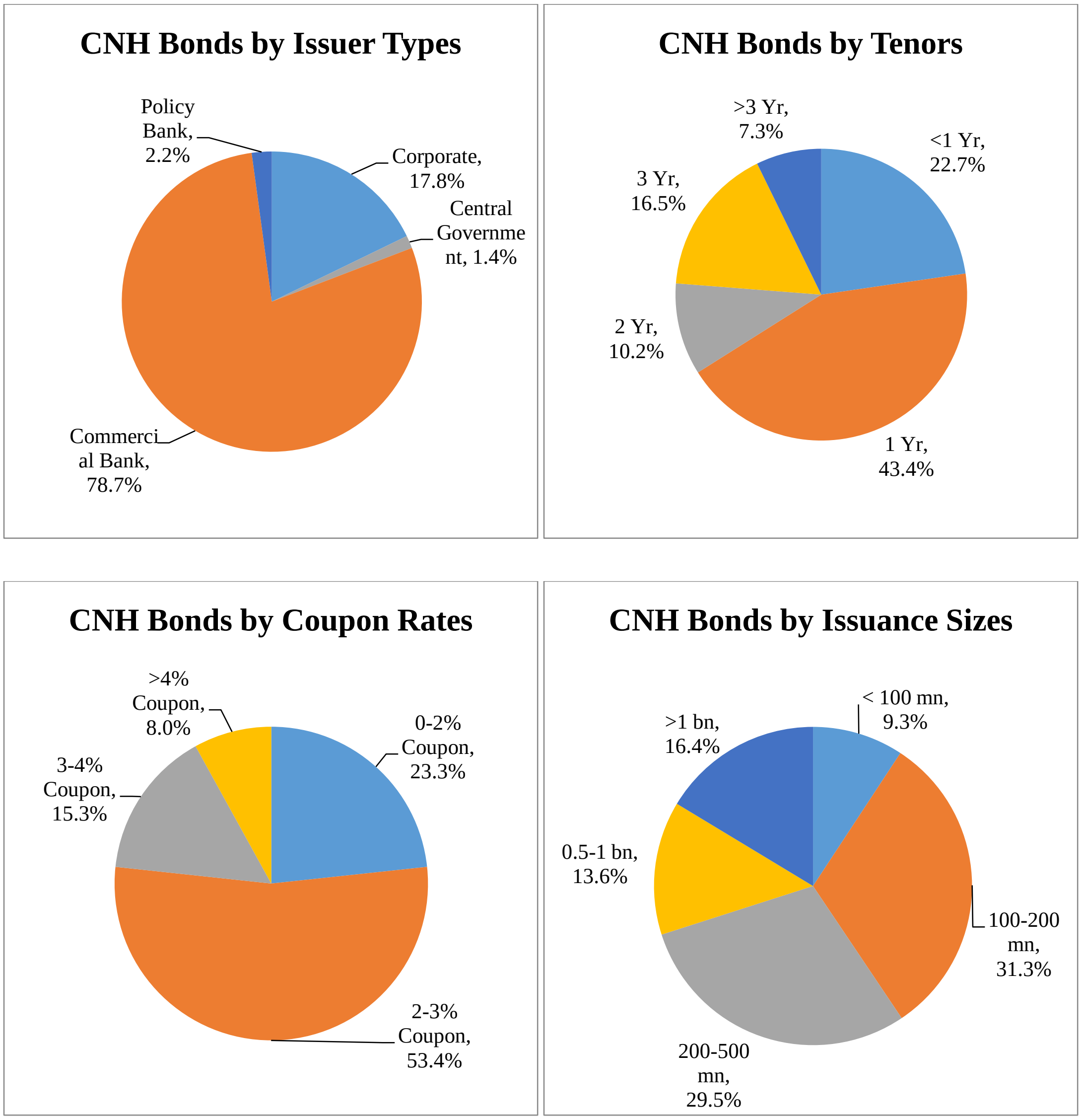


Figure 8 *Unique Features of Dim Sum Bond Issuance*[7]

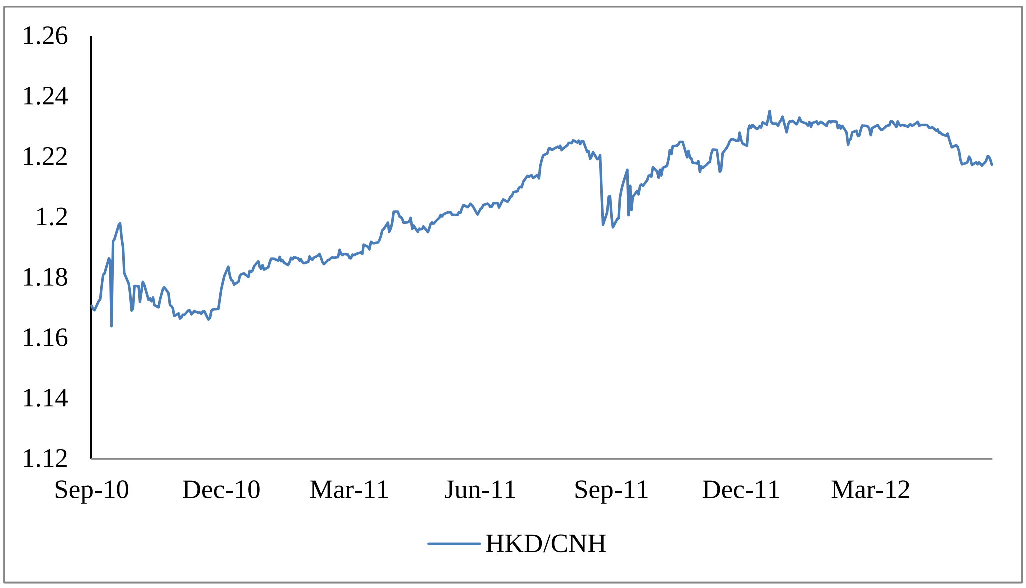
2.2.5. Introduction to Eurodollar Bonds

Eurodollar bonds have a long tradition, with the first Eurodollar bond issued in 1963. According to Rauli Susmel (2012), the emergence of the Eurodollar was mainly due to the measures that the US government took to control international capital outflow: (1) the US government started an Interest Equalization Tax on foreign securities held by

[7] Source: HKMA; based on outstanding CNH bonds as of June 20, 2012

US investors in 1963; (2) under the Foreign Credit Restraint Program imposed in 1965, the amount of credit that the US banks could extend to foreign borrowers (including foreign subsidiaries of the US multinationals) was limited; and (3) under the Foreign Investment Program imposed in 1968, the amount of domestic USD that a US multinational could use to finance its foreign investment was limited. Thus, the Eurodollar bond market emerged 50 years ago to overcome these regulations and frictions.

Eurodollar bond shares many similarities with dim sum bonds, since both of them belong to the category of foreign bond. First and foremost, the denomination rule of the Eurodollar bond and the dim sum bond are exactly the same because both of them are denominated with offshore currencies (i.e., USD in Europe and RMB in Hong Kong). Second, both of them receive less restrictive regulations from domestic monitoring institutions such as SEC in the US and PBOC in Mainland China. Third, most dim sum bond and Eurodollar bond investors do not receive their home currencies as their investment return. Therefore, those investors are taking foreign exchange risks when they invest in such foreign bonds. However, there exists one major difference between dim sum bond and Eurodollar bond: they have different degrees of foreign exchange risks embedded. We know that the RMB is not a floating currency and is pegged to a basket of currencies but mainly to the USD, while the HKD is semi-officially pegged to the USD. Given the high correlation between the RMB and HKD, it is not difficult to understand that the foreign exchange risk is minimal between RMB and HKD. Also, the RMB was generally appreciating against the HKD in the past decade; such a long-term trend would further stabilize the foreign exchange risks between the RMB and HKD. On the other hand, the USD and EUR are both floating currencies, and hence the foreign exchange risk between them contains more randomness and hence is not negligible. Therefore, the foreign exchange risk of the USD/EUR pair would be much higher than that of the RMB/HKD pair; real-world data tends to support our belief as Figure 9 shows below. The foreign exchange rate between CNH and HKD is supported by a clear trend line. In comparison, the foreign exchange rate between EUR and USD exhibits more random walk natures.



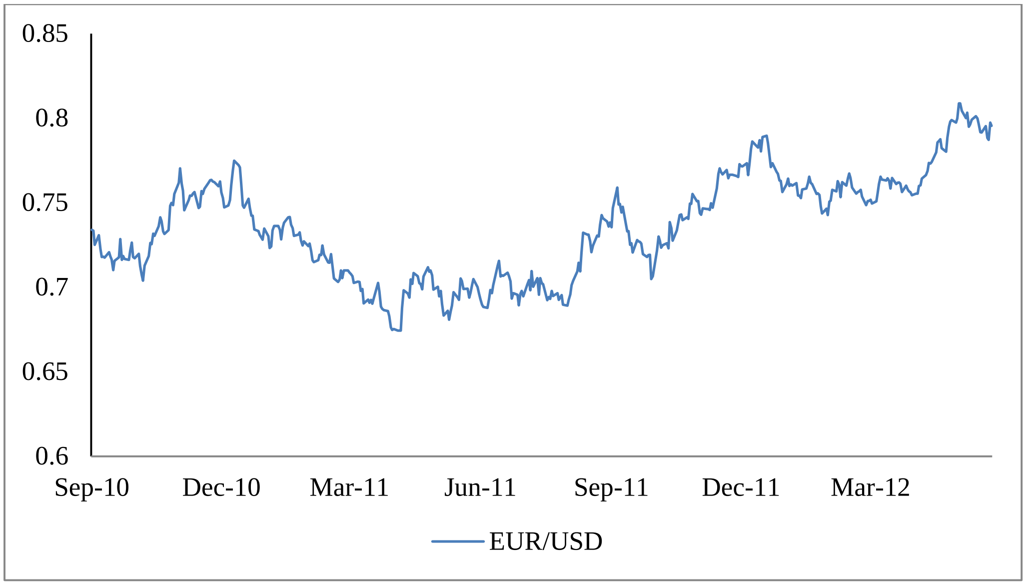


Figure 9 *Foreign Exchange Rates of CNH/HKD and EUR/USD Pairs*[8]

2.3. Literature Review

2.3.1. Capital Irrelevance Theories

Since our question is how foreign debt issuance can increase firm value, it makes sense to start by asking how firm value changes in response to a change in capital structure. In a perfect world, we learn that the answer is "no," according to Modigliani and Miller (1958). They proposed that, when there are no taxes or transactions costs and when lending and borrowing rates are the same, the market value of any firm is independent of its capital structure. In general, they believe it is essentially the assets on the left-hand side of a balance sheet that represent the production and investment plans and hence determine firm value. They also claim that the weighted average cost of a firm's capital is constant and does not co-vary with the firm's debt-to-equity ratio. Stiglitz (1969) shows that the Modigliani and Miller theory holds even under more

[8] Source: Bloomberg

stringent conditions where individual borrowing is unlimited and bankruptcy is possible in the context of a general equilibrium state preference model. Fama and Miller (1972) further proved the irrelevance of capital structure under the added assumption of complete protective covenants, also called “me first” rules. Although the theory is self-fulfilling in its original setting, the Modigliani and Miller theory still leaves many gaps for later studies to close. First, the theory only depicts an equilibrium state in which the benefit of any financial innovation to capital structure is offset by its cost. Thus, a dynamic type of model may need to be considered to complement the equilibrium nature of the existing theory. Second, as the theory was developed under a perfect market assumption, it is worth discussing the capital structure irrelevance under different market frictions. Third, many corporations adhere to an optimal debt ratio, which could not occur if the capital structure is truly irrelevant.

The first market friction that emerged in the study of capital structure is tax, as the interest of debts is a tax-deductible item in the income statement. Modigliani and Miller (1963) noted that debt financing could potentially impact firm value, because of the tax shield on debt. To account for the potential impact of the tax shield, Miller (1977) refines the existing Modigliani and Miller theory by incorporating the higher personal tax rate on interest income and stating that it could offset the tax shield created by the corporate debt. In his proposition, the personal tax disadvantage would be driven to the same level of the corporate tax shield by marginal investors in an equilibrium market. Therefore, the capital irrelevance theory would still hold true, even under the existence of the tax shield.

2.3.2. Tradeoff Theories

Many researchers believe that it may not be high personal tax rates but some other hidden costs on debt, such as financial distress or agency costs, that discourage the over-borrowing behavior. Kraus and Litzenberger (1973) propose a single period general equilibrium model and find that the optimal leverage of a firm is to yield the highest firm value by maximizing tax-saving attributes and minimizing the bankruptcy costs across various states. Jensen and Meckling (1976) argue that the existence of debt reduces the amount of equity, enables higher levels of insider ownership and then mitigates the agency cost for the firm. Based on their argument, the benefit and cost of debt are purely managerial and not tax related. The benefit of debt comes from the mitigation of agency cost. The cost of debt stems from asset substitution effect, implying that management has an increased incentive to undertake risky projects as the debt ratio increases. Myers (1977) believes that opportunity costs occur when firms load up more risky debt, because firms may pass up valuable investment opportunities. Thus, the suboptimal investment policy tradeoffs with the tax saving feature of debt and an optimal debt ratio will be decided by the balancing of those two tradeoffs. DeAngelo and Masulis (1980) prove that available investments related to corporate tax codes (such as depreciation deductions and investment tax credits) will decrease as leverage increases, representing a tradeoff against the tax saving benefits of debt. Myers (1984) generalized this way of thinking as a static tradeoff framework, in which the firm sets a target debt-to-value ratio and gradually moves toward it.

In the static tradeoff theory, no matter what are the benefits and costs assumed in the model, it usually proposes that firm value will become optimal at an inflection point where the marginal benefits equal the marginal costs. Generally, the tradeoff framework predicts an increase in firm value during the course of new debt issuance. The rationale is simple: if the manager decides to issue more debt, then this action would imply that the firm has not yet approached the optimal debt level and that the benefits of debt still outweigh the costs. Hence, the net benefits along with the debt issuance will increase firm value.

Brennan and Schwartz (1984) and Kane et al. (1984) extend the static tradeoff into a dynamic one by introducing multiple time periods and the contingent claim framework into the model. The settings of dynamic tradeoff models differ in many ways such as in their endogenous factors, financial decisions, and investment decisions. For example, Brennan and Schwartz (1984), Mello and Parsons (1992), Mauer and Triantis (1994), Hennessy and Whited (2005), and Titman and Tsyplakov (2007) assume that firms' investment decisions are not exogenous in their model, but are dependent on their financial decisions, while many others such as Kane et al. (1984), Fischer et al. (1989), Goldstein et al. (2001), and Strebulaev (2007) still treat investment decisions as fixed, as the Modigliani and Miller theory did. Although differing in model assumptions and features, many dynamic models in the arena tend to explain similar stylish facts of the capital structure puzzle. Fischer et al. (1989) introduced the transaction cost of debt into the analysis and made financial structuring costly in the model. The transaction cost discourages the company from optimizing its capital structure in a single period. Instead, the firm will not adjust its leverage ratio until the accumulation of debt benefits outweighs the debt costs. Consistent with the findings of Fischer et al. (1989), we also observe that real world debt ratios do not rebalance very often but drift to a target level over a relatively long period of time. Hennessy and Whited (2005) endogenize the choice of leverage, equity payoffs, and real investment, as well as incorporate features such as tax, financial distress cost, and equity floatation costs. They find that there is no target leverage ratio, firms can be savers or heavily leveraged, optimal leverage is path dependent, and profitable firms tend to be less highly levered. Titman and Tsyplakov (2007) endogenize investment decisions and firm value in a continuous time model that was originally designed for derivative pricing, wherein features such as agency cost, financial distress cost and transaction cost are also included. Their model confirms that firms in general move slowly to the target ratio. It also suggests that firms suffering financial distress costs and firms without conflict of interest between debt holders and equity holders will adjust quicker towards their target leverage ratios.

In dynamic tradeoff theories, no matter if the firms are rebalancing actively or are drifting after several lagged periods, the objective of the manager is still to maximize firm value or equity value. Therefore, the manager's decision to issue more debt depends on the net benefits of the extra debt being positive. Hence, we believe that the dynamic tradeoff theory will point to an increase in firm value, should a rational firm decide to issue new debts.

2.3.3. Pecking Order Theories

Another market imperfection worth studying is asymmetric information. Donaldson (1961) inspired this series of studies by stating that firms prefer internal to external funding except when they urgently need funds. Myers and Majluf (1984) assume asymmetric information exists in a perfect capital market that managers know the true value of assets and investors believe that managers have inside information. Normally, issuing equity signals positive NPV growth opportunity and should be deemed as good news. However, Myers and Majluf (1984) argue that the true objective of managers is to maximize existing shareholder wealth; thus they may refuse to issue under-valued new shares to transfer wealth from old investor to new investors. Given that external investors know the managers' true objective, they may view equity offerings as bad news, as only over-valued stocks will be issued. The pooling equilibrium in their model reveals, when stock is issued to finance investment, stock prices will fall if the value of the assets in place is quite high relative to the positive NPV of the project. This objective of maximizing existing shareholders' wealth will motivate managers to pass by positive NPV opportunities to avoid the fall in stock price. Therefore, they argue that optimistic managers should use internal and safe funding first to mitigate the potential losses caused by missing growth opportunities. In short, Myers and Majluf (1984) conclude that firms prefer internal to external financing under the condition of asymmetric information and will choose safer security first (i.e. debt over equity) to fulfill the capital required for growth opportunities.

Later, Myers (1984) offers a modified version of the pecking order theory that further explains why firms will prefer debt to equity. When the manager has favorable information, he claims, the undervaluation of new equity will exceed the undervaluation of new debt, and such undervaluation is caused by asymmetric information. For this reason, it is better to issue debt than equity, if the investment opportunity requires external financing. When the manager has unfavorable information, it seems firms should issue equity first as it is overpriced. However, Myers (1984) argues that investors will anticipate the overpricing of equity under this scenario and will buy equity only when the firm exhausts all of its debt capacity. This way, the investors would effectively force the firm to follow a pecking order. The follow-up studies on pecking order theory are mainly based on empirical studies, including Baskin (1989), Shyam-Sunder and Myers (1999), Frank and Goyal (2003), Fama and French (2005), and Leary and Roberts (2010).

We believe that the pecking order theory also predicts an increase in firm value in the event of debt issuance in some circumstances. The rationale is that, if debt issuance is generally viewed as a signal to fund a positive NPV project (as the pecking order theory implies), then firm value should increase in response to this good news. However, at what percentage a debt issuance could be linked to a positive NPV project is still uncertain, for debt could be issued to replenish working capital, roll over old debts, or pay down some non-production expenses. Therefore, the overall effect of debt issuance on firm value is less clear in the pecking order theory than in the tradeoff theories.

2.3.4. Valuation Effect of Bond Offerings

The valuation effect of bond offering studies the stock price reaction to the announcement of debt issuance. Many researchers have empirically examined this effect for many varieties of debt. In general, the valuation effect of straight bonds is non-positive and the valuation effect of convertible bonds is negative, although this conclusion varies to some extent under different methodologies, samples, and time periods.

In early days, most market practitioners believed that equity should respond positively to leverage increases and respond negatively to leverage decreases. However, this argument has not been quantitatively examined nor is scenario-specific. Masulis (1980) finds that common stockholders could on average earn a 9.79% abnormal return over a two-day announcement period if a firm offers to exchange debts for common stocks. Mikkelson (1981) reports that the announcement of the call for convertible bonds will cause a statistically significant negative return of -2.13% for stockholders, as well as a negative impact on aggregate firm value. Dann and Mikkelson (1984) provide evidence on the valuation effect of the issuance of convertible debt by finding that the convertible debt issued from 1970 to 1979 is associated with statistically significant negative average returns of -2.31%. They also find that the stock price reaction to the issuance of convertible bonds cannot be explained by leverage change, unfavorable information conveyed by the issuing, or the potential underpricing of the convertible offerings. In the same study, Dann and

Mikkelson (1984) also report a marginally significant average return of -0.37% with a T-value of -1.76 for 150 straight debt issues in their sample. Eckbo (1986) provides milestone evidence on the valuation effect of bond offerings by examining 700 additional corporate debt offerings. In summary, he finds that straight bond offering has a non-positive impact on the share price of the issuing firms with an average two-day abnormal return of -0.06% and a Z-value of -0.44. He also confirms the finding of Dann and Mikkelson (1984) that convertible bond offering has a negative impact on the share price of the issuing firms with an average two-day abnormal return of -1.25% and a Z-value of -4.60. More importantly, Eckbo (1986) finds that there is no detectable statistical relationship between the valuation effect of debt offering and (1) the size of the offering, (2) the increase in the debt-related tax shield, (3) the rating of the bonds, (4) the abnormal change in the following earning release, and (5) the offering method. Mikkelson and Partch (1986) examine the valuation effects of several types of security offerings and investigate the nature of the information inferred by investors from offering announcements. Mikkelson and Partch (1986) confirm a negative and statistically significant valuation effect of the announcement of common stock and convertible debt offerings. For straight debt, their results are mixed: the stock price effect is insignificant at the 0.10 level but is negative and significant at the 0.05 level for the subset of completed offerings (excluding incomplete straight bond offerings). Mikkelson and Parth (1986) also conduct a cross-sectional analysis on the relationship between stock price reaction and the information conveyed along with the offerings such as the (1) net amount of new financing, (2) size of the offering, (3) the quality rating, and (4) the stated reason for the offering.

They find that those factors are unrelated to the stock price effects and that the type of offering is the single most important factor in explaining the stock price effect.

For the valuation effects in markets other than the US, Abhyankar and Dunning (1999) use UK firm data to examine the announcement of different convertible bonds and find significant negative effects on shareholder wealth. Abhyankar and Dunning (1999) find that the stock price effects can be divided according to type of issue, with a (1) negative effect on privately placed convertible bonds, a (2) negative effect on convertible bonds for refinancing, and a (3) positive effect on convertible bonds for capital expenditure schemes. Burlacu (2000) finds similar results for 141 French convertible bond issues. Burlacu (2000) also finds that, if convertible bonds contain information about investment opportunities, then the market reaction will be significantly positive and that, if convertible bonds contain only information about current assets-in-place, then the market reaction will be negative. Ammann, Fehr, and Seiz (2006) confirm the findings of previous research on convertible bonds by using Swiss and German data from 1996 to 2003 and additionally find that the negative stock market price effect will be more pronounced if previous price reactions have been negative. Overall, the empirical evidence for the valuation effect of bonds point to one direction across the literature: the valuation effect of straight bonds is non-positive, and the valuation effect of convertible bonds is negative.

Miller and Puthenpurackal (2001) test the stock price reaction for the Yankee bond, a bond that sounds like a foreign bond but is actually denominated by domestic currency, the US dollar, and should be classified as a domestic bond. They record positive price reaction on average for the issuance of these Yankee bonds in a sample of 90 issues. Their finding is contrary to the negative price reaction among the entire domestic bond population found by Eckbo (1986) and many others. They attribute their finding to the quality of the issuing firm and believe that the higher issuing requirement for Yankee bond could be viewed as a signal of quality. Their result shows that the abnormal returns on first time issues is 1.52% (at a 5% significance level) within a two-day announcement window and that the abnormal return on second time issues is 0.56% (at a 5% significance level). Their results for the overall sample are not as significant as those for the sub-sample, showing the abnormal return at only 0.8% (at a 10% significance level).

2.3.5. Evidence on Foreign Bonds

Aside from examining the traditional straight bonds and convertible bonds, some researchers broaden their view and try to examine the valuation effect on other types of bonds. The most notable target is the foreign bond. Foreign bonds, unlike straight bonds and convertible bonds mentioned in the previous section, are denominated by a foreign currency other than the domestic currency used in the issuing country. We will go through this line of research on valuation effects, as this is closely linked to our study.

Kim and Stulz (1988) tested the valuation effect of Eurodollar bonds on a sample of 183 issues of US firms between 1975 and 1985 and found a positive average abnormal stock return associated with the offering announcement. Their result differs from the literature on the stock price effect of domestic bond issues, which reports a negative or zero impact. Using cross-sectional tests, they find that the abnormal returns can largely be explained by the yield difference between US and Eurodollar bonds. Hence, they argue that the yield difference represents a financing bargain to the firms and that the firm can increase its stock price by exploiting such financing bargains in foreign bond issuance. Fundamentally, this clientele hypothesis rests on the rationale that bargains cannot be instantly hedged away on the Eurodollar market. They believe that arbitrage does not work in the Eurodollar market because (1) the supply of such Eurodollar bonds is inelastic, as only reputable firms can issue them and the bargains are small enough that only those firms that have already planned to issue debt can profit; (2) a particular clientele of foreign investors can unexpectedly increase the demand for these Eurodollar bonds.

Kim and Stulz (1992) show that the stock price reaction of a convertible issue in the domestic market was significantly negative prior to 1984, while the reaction to European convertible issues was smaller in absolute value and not consistently negative. After 1984, the stock price reaction to US domestic convertibles tends to be the same as to the offshore issues. Kim and Stulz (1992) consider the change in tax regulations around 1984 as a potential explanation for these stock price reaction differentials and report that the difference in firm characteristics is not a cause of this phenomenon. They argue that the market segmentation was probably caused by the 30% tax due on the interests of the domestic convertible bonds before 1984. They believe that European convertible issuers could capture this tax advantage, transfer it into real firm value, and hence generate a less negative stock impact. They also test whether the issue and firm characteristics are a potential source for the disappearance of the differentials after 1984. From the estimates, they find no supporting evidence to explain the time-varying differential, but they do observe a negative relationship between the conversion ratio and the degree of stock price reaction.

Kang, Kim, Park, and Stulz (1995) investigated the stock price reaction to issues of offshore dollar-denominated convertible bonds issued by Japanese firms using a sample of 451 issues from 1977 to 1989. They found a significantly positive abnormal return of 0.5% over the three-day announcement window; their results sharply contradict the negative abnormal return for the US domestic convertible bonds issues found by Dann and Mikkelson (1984). They view the convertible bond as two parts: a bond and a fractional holding of shares. They believe that the bond part of the convertible bond generates a positive stock price reaction because the principal and coupon part of the convertible issues are implicitly or explicitly insured by the banks and conveys positive information about the issuing company. They also believe the stock part of the convertible bond generates a non-negative price reaction because Japanese *keiretsu* firms are more concerned about taking advantage of positive NPV project than about the possible mispricing of new equity.

Ardalan (2008) confirmed the positive stock price effect of the Eurodollar bond by examining 224 issues from 1987 to 1991. In his example, the launch will impact stock price positively after two days of the announcement with an average abnormal return of 0.4% and a T-value of 2.872. He also found the spread variables explain the abnormal return at a 7% significant level and that variables such as issue size, frequency of issues, and maturity term will not help after all. Finally, Ardalan (2008) find that it is the first-time issuer of the Eurodollar bond rather than frequent issuers that drives the strong empirical evidence in his sample.

2.4. The Theory

2.4.1. The Model of Foreign Bond Issuance on Firm Value

The model we propose is a combination of Merton's (1974) option pricing model and Turvey and Yin's (2002) cross currency future options model. Through this hybrid model, we make the following predictions:

1. Foreign bonds carry more exchange rate risk than do domestic bonds.
2. The additional exchange rate risk increases a foreign bond's volatility.
3. The volatility of debt value correlates with the volatility of firm value. Thus, the volatility of firm value is higher for a firm issuing foreign bonds than domestic bonds.
4. Holding others constant, the equity value of a firm issuing foreign bonds is higher than the same firm issuing domestic bonds, based on the Black and Scholes equation.

First, we will model the volatility of debt value in the environment of foreign exchange risk, borrowing the techniques of Turvey and Yin (2002) used to deal with cross currency future options. The general cash relation between a foreign currency denominated debt and the consumable payoff a local investor receives is

$$P_D = P_F * E = f(P_F, E) \tag{1}$$

where, P_D = bond price in local currency; P_F = bond price in foreign currency; E = exchange rate; and $f(P_F, E)$ is twice differentiable.

The model makes several assumptions. First, let us assume P_F and E follow geometric Brownian motions. By assuming that the exchange rate follows the Brownian motion, we introduce the exchange rate risk to this system.

$$dP_F = P_F[\mu_1 dt + \sigma_1 dw_1] \tag{2}$$

$$dE = E[\mu_2 dt + \sigma_2 dw_2] \tag{3}$$

Where,

μ = the natural growth rates;

σ = the standard deviations of the percentage change of the stochastic variables;

dw = Wiener processes of the form $et^{0.5}$.

Since equation 2 and 3 satisfy the Brownian motion, we can apply Ito's Lemma to equation 1 and yield:

$$\begin{aligned} dP_D = &\left[\frac{\partial f(P_F, E)}{\partial P_F}\mu_1 P_F + \frac{\partial f(P_F, E)}{\partial E}\mu_2 E + \frac{1}{2}\frac{\partial^2 f(P_F, E)}{\partial {P_F}^2}{\sigma_1}^2 {P_F}^2 \right. \\ &\left. + \frac{1}{2}\frac{\partial^2 f(P_F, E)}{\partial E^2}{\sigma_2}^2 E^2 + \rho_{12}\frac{\partial^2 f(P_F, E)}{\partial P_F \partial E}\sigma_1\sigma_2\right] dt \\ &+ \left[\frac{\partial f(P_F, E)}{\partial P_F}\mu_1 P_F dw_1 + \frac{\partial f(P_F, E)}{\partial E}\mu_2 E dw_2\right] \end{aligned} \tag{4}$$

Simplifying equation 4 and deleting zero terms, we obtain a reduced form:

$$dP_D = [P_D(\mu_1 + \mu_2 + \rho_{12}\sigma_1\sigma_2)]dt + P_D(\sigma_1 dw_1 + \sigma_2 dw_2) \qquad (5)$$

From equation 5, we can see that the motions of a foreign bond's price in local currency depend not only on the motion of its price in foreign currency but also on the motion of the exchange rate. Therefore, the first prediction is that foreign bonds carry additional exchange rate risk for local investors. When local investors receive payment from foreign bonds, they receive foreign currency that has to be exchanged to local currency before any meaningful purchases can take place. Of note, ρ_{12} in equation 4 and 5 describes the covariate risk between the bond and the exchange rate.

We can further assume that P_D, the bond price in local currency, also follows a geometric Brownian motion:

$$dP_D = P_D[\mu_3 dt + \sigma_3 dw_3] \qquad (6)$$

By comparing equation 4 and 6, we obtain the natural growth rate and, especially, the volatility of the bond price in local currency, as shown in equation 7 and equation 8:

$$\mu_3 = \mu_1 + \mu_2 + \rho_{12}\sigma_1\sigma_2 \qquad (7)$$

$$\sigma_3{}^2 = \sigma_1{}^2 + \sigma_2{}^2 + \rho_{12}\sigma_1\sigma_2 \qquad (8)$$

The extra term in the volatility expression of this foreign bond is $\sigma_2{}^2 + \rho_{12}\sigma_1\sigma_2$, compared to the expression of a straight domestic bond. Between these two terms, σ_2 is the extra volatility generated by exchange rate risk, and ρ_{12} is the covariate term between the risks of bonds and the exchange rate risk. The risks of the bonds include default risk, political risk, and liquidity risk. Many bond risks originate from macroeconomic factors that also influence the exchange rate risk in the same direction. This way, it is reasonable to assume that the risks of bonds correlate with exchange rate risk positively as

$$\rho_{12} > 0 \quad (9)$$

With equation 8 and 9, it is enough to show that the per-unit volatility of a foreign bond is higher than that of a straight bond, due to the involvement of exchange rate risk:

$$\sigma_3{}^2 = \sigma_1{}^2 + \sigma_2{}^2 + \rho_{12}\sigma_1\sigma_2 > \sigma_1{}^2 \quad (10)$$

We have thus proved the second prediction, that additional exchange rate risk makes a foreign bond more volatile than a domestic bond, as shown in equation 10.

Now we need to prove the third prediction—that the volatility of firm value, defined as σ_A, is correlated to the volatility of the debt value (market value of course, as face value has zero volatility), defined as σ_D. In Merton's (1974) work, he assumes that, for any security (including debt), the following partial equation holds:

$$dD = (\alpha_D B - C_D)dt + \sigma_D B dZ_D \quad (11)$$

where,

dD is the instantaneous change in the market value of the debt. Moreover, α_D is the instantaneous expected rate of return per unit time on the debt and is multiplied by B, the face value of the debt; C_D is the coupon payment per unit time to this debt; σ_D is the volatility of the debt value; and dZ_D is a standard Gauss-Wiener process. Since the market value of the debt can also be written as a function of firm value and time as $D = D(V, t)$, we can apply Ito's Lemma to equation 11 and derive the dynamics for D as

$$dD = D_V dV + \frac{1}{2} D_{VV} (dV)^2 + D_t \tag{12}$$

The dynamics for the value of the firm, V, is assumed to follow a diffusion-type stochastic process with a stochastic differential equation:

$$dV = (\alpha V - C)dt + \sigma V dZ \tag{13}$$

where,

α is the instantaneous expected rate of return on firm value per unit time; C is the total dollar payouts to either its shareholders or debt-holders per unit time; σ is the instantaneous variance of the return on the firm value per unit time; and dz is a standard Gauss-Wiener process.

Substituting equation 13 into equation 12, we can write the dynamics for the debt as

$$dD = \left[\frac{1}{2} \sigma_A^2 A^2 D_{AA} + (\alpha A - C) D_A + D_t\right] dt + \sigma_A A D_A dZ \tag{14}$$

Comparing the second term of equation 11 with that of equation 14 and trimming dZ from the comparison, we see the following relationship:

$$\sigma_D \frac{B}{A D_A} = \sigma_A \tag{15}$$

From equation 15, we see that σ_D, the volatility of debt value, can directly impact σ_A, the volatility of firm value. Let us assume that there are two firms with the same B, A and same debt value function $D(A, t)$. The only difference between these two firms is that firm one only issued domestic debts and firm two only issued foreign debts. Let us add a prime sign to all firm two's parameters to differentiate these two firms. From the previous analysis, we know that firm one has volatility σ_1 on its debt value, and firm two has volatility σ_3. Given the inequality $\sigma_3 > \sigma_1$ shown in equation 10 and the correlationship shown in equation 15, we can predict that the volatility of the firm value is greater for firm two than firm one, as shown in equation 16.

$$\sigma_3 \frac{B}{AD_A} = \sigma_A' > \sigma_A = \sigma_1 \frac{B}{AD_A} \tag{16}$$

The above analysis shows mathematically why a firm with all foreign debt may have a higher volatility on firm value than an otherwise identical firm. However, it doesn't tell us through which channel a higher volatility on bond would transform into a higher volatility on firm value. To illustrate this relationship, we will describe a simple scenario that perfectly explains this process. Consider a firm issuing dollar bonds in Europe. Its investor base is mainly European institutions and investors. Assuming that the US dollar depreciates tremendously against the Euro, the investors would experience a huge loss in real purchasing power once they convert their interests and principal from USD to EUR. Foreseeing such interruption in the foreign exchange trend, investors may transfer the potential purchasing power loss into additional requests on the yields of those bonds. This yield will be considered a part of the weighted average cost of capital and incorporated into the discounting factor applied in firm valuation. Therefore, the firm value of the issuing firm would be changed, all sourced from the initial turbulence of the exchange rate. From this scenario analysis, we can see that any zigzagging in the foreign exchange market would translate into the choppiness of firm value. In other terms, a higher volatility on debt would elevate the volatility of firm value. Up to this point, equation 15 and 16 along with a simple scenario analysis prove the third prediction for us.

Now we know that σ_A, the volatility of firm value, would increase to σ_A' if a firm issues only foreign debt instead of domestic debt. How will this higher σ_A' affect the equity value? Merton (1974) has related the volatility of firm value to the equity value of a firm. First, some assumptions are made to derive Merton's model:

A. 1: There are no transactions costs or taxes. Assets are perfectly divisible.

A. 2: There are sufficient investors with comparable levels of wealth such that they can buy or sell as much as they want at a given market price.

A. 3: There exists an exchange market for borrowing and lending at the same interest rate.

A. 4: There are no short-selling restrictions.

A. 5: Trading in assets takes place continuously in time.

A. 6: The Modigliani-Miller theory holds that the value of a firm is invariant to its capital structure.

A. 7: The term structure is flat in shape and is known with certainty.

A. 8: The dynamics for the value of firm's asset, debt, and equity through time can be uniformly described by a diffusion-type stochastic process with the stochastic differential equation $dA = (\alpha A - C)dt + \sigma A dz$, where, A is the firm value; α is the instantaneous expected rate of return on the firm value; C

is the total dollar payment to either debt holders or stock holders; σ is the instantaneous variance of the return on the underlying per unit time; and dz is a standard Gauss-Wiener process.

In Merton's model, we specify that the firm issues through only two classes of securities: equity and debt. The debt is a zero coupon bond where the only repayment B is scheduled at maturity date T. Thus, B is the face value of the firm's debt; E is defined as the value of the firm's equity, and A as the market value of the firm's assets. Let the equity value be a function of firm assets and time as $E = E(A, t)$; E_0 and A_0 be the values of E and A today. Also, r is defined as the continuously compounded risk-free rate of interest, which is assumed to be constant. In Merton's framework the partial differential equation (PDE) for the equity value should be written as:

$$\frac{1}{2}{\sigma_A}^2 A^2 E_{AA} + rAE_A - rE - E_t = 0 \tag{17}$$

Subject to the boundary conditions that

$$E_0 = \max(A_0 - B, 0) \tag{18}$$

$$E(0, t) = 0 \tag{19}$$

$$\frac{E(A, t)}{A} < 1 \tag{20}$$

The partial differential equation 17 and its associating boundary conditions are identical to the equations for a European call option on a non-dividend-paying common stock, shown in Black and Scholes (1973) and Merton (1973). Therefore, we can treat the equity value as a call option on the assets of the firm with a strike price equal to the promised debt payment. We can directly write down the solution of equity value to equation 17 from the solutions of Black and Scholes equation, and then evaluate it at time 0 as:

$$E_0 = A_0 N(d_1) - Be^{-rT} N(d_2) \tag{21}$$

where,

$$N(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} exp[-\frac{1}{2} z^2] dz \tag{22}$$

$$d_1 = \frac{ln\left(\frac{A_0 e^{rT}}{B}\right)}{\sigma_A \sqrt{T}} + 0.5\sigma_A \sqrt{T};\ d_2 = d_1 - \sigma_A \sqrt{T} \tag{23}$$

To understand how the increase of σ_A impacts the equity value at time 0, we need to evaluate E_0's sensitivity against σ_A, which is commonly called "Vega" in the derivative textbooks:

$$\frac{\partial E_0}{\partial \sigma_A} = A_0 N'(d_1)\sqrt{T} > 0 \tag{24}$$

Let us revisit our simple scenario that firm one issued only domestic bond and firm two issued only foreign bonds. Given that $\sigma_A' > \sigma_A$ and $\partial E_0 / \partial \sigma_A > 0$, we can easily infer that firm two's equity value would be higher than firm one's, as shown in equation 25.

$$E_0{}' > E_0 \tag{25}$$

From the above analysis, we can conclude that, if a firm issues only foreign debts, its equity value would be higher than the case that it issues only domestic debts. This simple scenario serves to reduce the complexity of our discussion, and we can maintain the sign of the inequality even if a firm only issues a proportion of foreign debt. We have thus proved the fourth prediction.

2.4.2. The Extension to Coupon Bonds Case

The option-pricing model we used in the last section is directly inherited from Black and Sholes (1973) and Merton (1974). In this model, however, the debt held by the firm is defined only as a single zero-coupon bond. What happens if a firm holds a portfolio of coupon bonds that have overlapping terms of maturity and maintains a roughly sustained debt to asset ratio? We need to modify this model to accommodate this kind of recurring structural debt, a very common debt capital structure in firm practice. Hsia (1991) uses the concept of duration to cope with the coupon bond problem, and I will incorporate this framework into our model.

We start from the key option-pricing model:

$$E_0 = A_0 N(d_1) - Xe^{-rT} N(d_2) \tag{26}$$

where,

$$Z = Xe^{-rT} \tag{27}$$

In equation 27, Z is the present value of a zero-coupon bond, X is the face value, T is the time to maturity and r is the interest rate. By definition, the duration of a bond, *D(x)*, is equal to its price elasticity with respect to changes in interest rates:

$$D(Z) = -\frac{\partial Z}{\partial r}\frac{1}{Z} \tag{28}$$

We can easily calculate the duration of a zero coupon-bond by combining equation 27 and 28:

$$D(Z) = -\frac{\partial Xe^{-rT}}{\partial r}\frac{1}{Xe^{-rT}} = T \tag{29}$$

Now we need to consider the duration for a structural coupon bond. First, let us define *A* as the annual coupon payment of the bond and *C* as the present value of the coupon bonds. Second, let us assume the coupon payment is constant over a firm's life. Therefore, the present value of the coupon bonds could be discounted like a perpetual debt with annual payment *A*:

$$C = \frac{A}{r} \tag{30}$$

Now, combining equation 29 and 30, we obtain the duration of the structural coupon bond:

$$D(C) = -\frac{\partial (A/r)}{\partial r}\frac{r}{A} = \frac{1}{r} = \frac{C}{A} \tag{31}$$

Since structural debt is recurring and does not have a fixed expiry date, we can use its duration as the expiry date parameter in the option-pricing model. This way, we are treating the structural debt as a zero-coupon debt and forcing it to match up with the option pricing model.

Next, we need to determine the face value of the coupon bonds. Face value X does not directly exist here because structural debt contains bonds with different face values. The theory of immunization by Bierwag (1977) shows that interest rate risk is immunized if the holding period of a bond portfolio is set equal to the duration of the portfolio. Hence, we obtain

$$X = Ce^{rD} = Ce^{r\frac{1}{r}} = Ce \tag{32}$$

Finally, we can extend the option pricing model to the coupon bond case and rewrite equation 21 as

$$E_0 = A_0 N(d_1) - Ce^{1-rT} N(d_2) \tag{33}$$

where,

$$T = \frac{C}{A} \tag{34}$$

The expiration date of a structural debt is not directly observable. To cope with the issue, we will use the derived one as the inputting parameter of the model.

Comparing equation 21 with equation 33, the equity value function is only different in terms of the face value of the debt and the time to maturity. The directional relationship between E_0 and σ_A is unchanged if we replace equation 21 with equation 33 as the main option pricing model. Thus, our predictions made with respect to the zero coupon bond case will be intact in the coupon bond case.

2.5. Empirical Results

2.5.1. The Data

The data of this study are composed of 23 Eurodollar bond launches and 25 dim sum bond launches covering the time period from Q1 2010 to Q2 2011. The small sample size is mainly due to three reasons. First, the dim sum bond was merely introduced in the beginning of 2010 and our dim sum database only covers the issues until Q2 2011. Although Eurodollar bonds were introduced earlier, in the '70s, we still include the Eurodollar issues in the time period matching that of our dim sum samples to make sure the two sample groups are comparable. Therefore, we have only about 20+ observations in each sample group. Second, only straight corporate bonds were included in our study. Foreign bonds issued by sovereign and financial institutions were excluded due to their complexity and non-market characteristics. Also, warrant bonds and convertible bonds were excluded due to their equity-alike natures. Third, not all bond issuers in the original data were listed companies. Since our research involves stock prices analysis during the announcement period, non-listed companies were excluded from the sample. For these three reasons, the sample size is limited in our study.

For every Eurodollar bond launch in the sample, the corresponding announcement date, the tenor duration, the coupon rate and the principal amount were collected from the Security Data Company (SDC platinum). The offer yield and the credit rating given by Moody's were checked through the Bloomberg terminal. Table 1 shows the details of each Eurodollar bond launch in our sample.

Table 1 *Sample Data Description for Eurodollar Bonds (N=23)*

Company name	Event date	Tenor	Coupon	Principal	Yield	Credit rating
CSX Corp	2/19/2010	10	3.700	500	3.706	Baa2
The Dow Chemical Co	2/19/2010	5	2.500	750	2.531	Baa2
Honeywell International	2/23/2010	10	4.250	800	4.281	A2
Texas Instruments	2/24/2010	3	1.375	1000	1.418	A1
Ryder System	2/25/2010	6	3.600	300	3.623	Baa1
Time Warner	3/3/2010	5	3.150	1000	3.176	Baa2
AT&T	3/18/2010	5	2.950	1750	2.989	A3
Thermo Fisher Scientific	4/20/2010	5	3.200	900	3.213	Baa1
IBM Corp	7/27/2010	3	1.000	1500	1.139	Aa3
Vodafone Group PLC	7/28/2010	5	2.875	600	2.982	A3
Moody's Corp	8/2/2010	10	5.500	500	5.582	BBB+
Goodyear	8/10/2010	10	8.250	1000	8.375	B1
Juniper Networks	8/10/2010	5	3.100	300	3.137	Baa2
Limited Brands	11/5/2010	10	6.625	1000	6.625	Ba1
Johnson & Johnson	2/28/2011	3	1.200	1000	1.240	Aaa
Amgen	3/4/2011	10	4.100	1000	4.132	Baa1
Verizon Communications	3/22/2011	3	1.950	1500	1.996	A3
Gilead Sciences	3/23/2011	10	4.500	1000	4.608	Baa1
Verisk Analytics	3/29/2011	10	5.800	450	5.831	Ba1
Time Warner Cable	4/28/2011	30	5.500	1250	5.624	Baa2
Google	5/16/2011	3	1.250	1000	1.258	Aa2
Applied Materials	6/1/2011	10	4.300	750	4.326	A3
Lockheed Martin Corp	8/23/2011	5	2.125	500	2.141	Baa1

Source: SDC Platinum, Bloomberg

For every dim sum bond launch in the sample, the corresponding announcement date was collected from financial news search engine Factiva since the HKMA database covers only the issue date and not the announcement date. The tenor duration, the coupon rate, and the principal amount were collected from the HKMA database. There is no existing database such as SDC, WRDS, or Bloomberg that covers the offer yield of dim sum bonds. We managed to find some offer yields in one analyst's research report. Only some of the issues were rated by credit agencies, so we collected ratings from the Bloomberg terminal. Table 2 shows the details of each dim sum bond launch in our sample.

Table 2 *Sample Data Description for Dim Sum Bonds (N=25)*

Company name	Event date	Tenor	Coupon	Principal	Yield	Credit rating
Sinotruk (Hong Kong)	10/4/2010	2	2.950	2700	-	
China Resources Power	11/2/2010	3	2.900	1000	2.90	BBB-
China Merchants	10/25/2010	3	2.900	700	2.71	
Caterpillar	11/24/2010	2	2.000	1000	2.00	A
Galaxy Entertainment	12/1/2010	3	4.625	1380	-	
China Power	12/10/2010	5	3.200	800	4.83	
Sinochem	1/10/2011	3	1.800	3500	3.62	
PCD Stores (Group)	1/18/2011	3	5.250	750	-	
Yuen Foong Yu	1/21/2011	3	3.100	300	-	
Beijing Capital Land	2/14/2011	3	4.750	1150	-	
Road King Infrastructure	2/1/2011	3	6.000	1300	16.38	BB-
TPV Technology	3/14/2011	3	4.250	500	-	
Unilever N.V.	3/28/2011	3	1.150	300	-	A+
China WindPower Group	3/22/2011	3	6.375	750	-	
HKCG (Finance)	3/31/2011	5	1.400	1000	-	
Chenming (HK)	3/11/2011	3	2.950	500	-	
Zhongsheng Group	4/10/2011	3	4.750	1250	11.02	
BYD (H.K.) Company	4/11/2011	3	4.500	1000	16.93	
China Power New Energy	4/12/2011	3	3.750	500	4.83	
Melco Crown	4/26/2011	2	3.750	2300	-	

Global Logistic	4/25/2011	5	3.375	2650	3.87	
Global Bio-Chem Tec	4/18/2011	3	7.000	450	-	
Hopewell Highway	5/3/2011	3	1.550	600	-	
China Chengtong	5/11/2011	3	4.500	600	-	
Volkswagen	5/16/2011	5	2.150	1500	2.99	A-

Source: HKMA database, Bloomberg, Research Reports

Stock and market return information was directly retrieved from the CRSP database via the WRDS service. The three-month implied volatility of currency pairs, including EUR/USD and CNY/HKD, was retrieved from the Bloomberg terminal.

2.5.2. Methodology

The empirical test of this study consists of two major steps. The first is to test whether there is an effective stock price reaction to the foreign bond issuance. The second step is to test whether these stock price reactions could be explained by a series of bond characteristics and also the foreign exchange risks.

In the first step, we use event-study methodology to examine the reaction of stock prices to dim sum bonds or Eurodollar bonds issuances. This event-study methodology relies on the assumption that the stock market is efficient enough to expect and evaluate the impact of new bond issuance. It basically takes four stages to complete an event-study test. These stages are the following: (1) identify the effective events of interest and define the relative event window for each security; (2) use a pre-event window to estimate a market model for the sample securities; (3) calculate the abnormal return in the event window using observed returns and parameters from the market model; (4) define the null hypothesis, aggregate the individual firm level abnormal returns, and test if the abnormal return is statistically different from zero. Now, we will explain in detail how we completed each step and what results we achieved in the event study.

In the first stage, we declare that our event of interest is foreign bond issuance and the announcement day of the bond issuance is defined as day 0 of the targeted event. Then we choose three days from day -1 to day +1 as our main event window for three reasons: (1) most studies tend to use the three-day time window around the event; (2) the stock reaction of day +1 matters because sometimes the announcement is released after the regular trading hours of day 0; (3) the stock reaction of day -1 matters because the announcement data we collect are mainly US-based, and there is a time zone difference between the US and Hong Kong and Europe. Thus, the announcement date of day 0 in the US might be day -1 in Hong Kong and Europe.

In the second stage, we run a market model to extract the necessary parameters as equation 35 shows. In equation 35, t stands for the time index; $i=1,2,\dots,N$ is security index; R_{it} and R_{mt} stand for the security i's daily stock return and the index return respectively; and e_{it} is the zero mean disturbance term with variance of $\sigma_{e_i}^2$. equation 35 will be estimated over 360 trading days, from day -370 to day -10 prior to the event date. The estimation window is slightly longer than usual to increase the reliability of the parameters and to smooth out the seasonality (if any) of the stock returns.

$$R_{it} = \alpha_i + \beta_i \cdot R_{mt} + e_{it}$$
$$\text{with } E(e_{it}) = 0 \text{ and } Var(e_{it}) = \sigma_{e_i}^2 \tag{35}$$

The time line for the foreign bond issuance is summarized in Figure 10 below. It is beneficial for the estimation window to not overlap with the event window. In the case of overlapping, the impact of bond issuance is captured by both the normal return and the abnormal return; the basic assumption of this study, that the impact of an event is locked into the abnormal return, would no longer be valid.

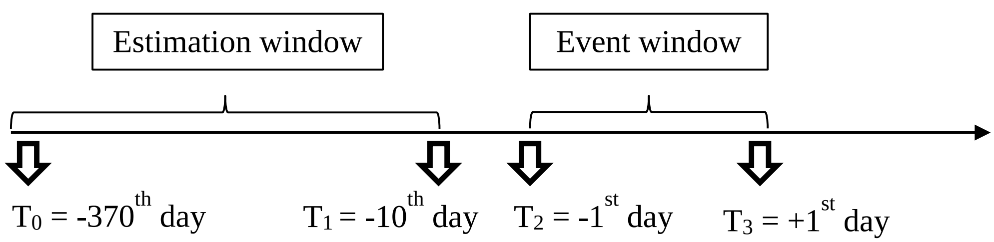


Figure 10 *Timeline for Foreign Bond Issuance*

The reason why we do not apply a multiple factors model or a CAPM model at this stage is worth discussing. Unlike in other empirical studies, the statistical goal of running a factor model in an event study is to reduce the variance of abnormal returns in the event window. However, a multiple-factors model does not provide much improvement on the variance of abnormal returns, unless the sample firms come from the same industry or share similar characteristics. In our case, since we randomly include firms from different industries and they share limited similarities, the effect of a multiple factor model is not warranted. The CAPM model used to be common in event studies in the '70s. However, it has been discovered that the results of those studies are sensitive to the specific CAPM restrictions and biases are introduced into abnormal return by the CAPM model. For all these reasons, multiple factors models and the CAPM model are not very popular in event studies; hence, we are applying the market model, as the majorities have done.

In the third stage, we predict the "normal" return for a security in the event window with the estimated parameters from equation 35. Here, the normal return is defined as the expected return of a security conditioning on the information of a market return. Then we can deduct this predicted normal return from the observed actual return, resulting in the abnormal return in the event window, as equation 36 shows:

$$\widehat{AR}_{it} = R_{it} - E(R_{it}|R_{mt}) = R_{it} - \hat{\alpha}_i - \hat{\beta}_i \cdot R_{mt} \tag{36}$$

In the final stage, we want to aggregate the individual abnormal return across the securities and over the testing period to construct the cross-sectional mean abnormal return for a sample of N firms. Of course, we can test each security's abnormal return to see if they significantly deviate from zero. However, we are more interested in testing the events collectively to see if the debt announcement could impact the return over all debt issuance. The aggregation process is written as equation 37, where $\widehat{AR}_{it}$ is the abnormal return for security i at day t and $\widehat{CAR_i}$ is the cumulative abnormal return for security i during the event window. The aggregation sequence over time and across firms is interchangeable, and the end result is the same.

$$\overline{CAR} = \frac{1}{N}\sum_{N} \widehat{CAR}_i^{T_2,T_3} = \frac{1}{N}\sum_{N}\sum_{T_2}^{T_3} \widehat{AR}_i^t \tag{37}$$

Next, we need to specify a null hypothesis to test our event of interest. The null hypothesis is that all securities in the sample collectively generate a zero cross-sectional mean CAR in the event of a foreign bonds issuance.

$$H_0: \overline{CAR} = 0 \text{ and } H_1: \overline{CAR} \neq 0$$

We need to construct the testing statistics as a base to either reject or not reject the null hypothesis. There are several testing statistics that serve this purpose. One of the most popular statistics is summarized by MacKinlay (1997), as shown below.

Equation 38 defines the sample OLS estimator of error terms' variance in the market model. In equation 39, the variance of one security's CAR during the event window is asymptotically defined as the product of the length of the event window and the variance of the error terms in the market model, as the estimation window (T_1-T_0) grows larger. In equation 40, the variance of the cross-sectional CAR is aggregated through the variances of the individual CAR.

$$\hat{\sigma}_{\varepsilon_i}^2 = \frac{1}{T_1 - T_0 - 1} \sum_{t=T_0+1}^{T_1} (R_{it} - \hat{\alpha}_i - \hat{\beta}_i \cdot R_{mt})^2 \tag{38}$$

$$\sigma_i^2\left(CAR_i^{T_2,T_3}\right) \approx (T_3 - T_2 + 1)\hat{\sigma}_{\varepsilon_i}^2 \tag{39}$$

$$var(\overline{CAR}) = \frac{1}{N^2} \sum_{i=1}^{N} \sigma_i^2\left(CAR_i^{T_2,T_3}\right) \tag{40}$$

Now we have the cross-sectional mean CAR defined in equation 37 and the variance of the cross-sectional CAR defined in equation 40. We can construct the Z testing statistics, or the so-called "standardized CAR," as equation 41 shows. It asymptotically follows the normal distribution as the estimation window (T_1-T_0) grows larger:

$$Z = \frac{\overline{CAR}}{var(\overline{CAR})} \sim N(0,1) \tag{41}$$

The *Z* statistics, a more conservative method of testing the stock price reaction, uses the error term's variance in the estimation window. Another way to test the stock price reaction is to create the traditional *T* statistics. The *T* statistics directly uses the variance in the cumulative abnormal return during the event window. The *Z* statistics captures more information than the *T* statistics, as its estimation window is much longer than the event window. However, the *Z* statistics may be less effective than *T* statistics if the targeted variable exhibits symptoms of volatility clustering such that the real variance of CAR during event period is not the same as the real variance of the CAR during the estimation period.

2.5.3. Testing Results

According to the results reported in Table 3, we record a positive stock price reaction upon the launch of the Eurodollar bond. In other terms, the investors will earn a positive abnormal return if they hold the related security throughout the Eurodollar bond launch event. The *T* statistics for the three-day CAR and day 1's abnormal return are significantly positive at the 0.08% and 0.20% confidence levels. Under a more stringent standard, the *Z* statistics for the three-day CAR and day 1's abnormal return are significantly positive at the 11.03% and 8.19% confidence levels. It is thus very clear that it is the day 1's positive abnormal return that drives up the three-day CAR's abnormal return. In terms of magnitude, the day 1's abnormal return is 0.65% on average and the three-day CAR's is 1.04% on average, equivalent to a 237.25% annualized abnormal return and a 126.53% annualized abnormal return respectively.

Table 3 *Stock Reaction around Eurodollar Bond Issuance: Abnormal Return = 0?*

	Coefficient	**Std. Error**	**T-Statistics**	**Prob. > T**
Three days CAR	1.04%	0.0029	3.62***	0.0008
Day -1 AR	0.15%	0.0021	0.74	0.2347
Day 0 AR	0.23%	0.0027	0.88	0.1943
Day 1 AR	0.65%	0.0020	3.21***	0.0020

	Coefficient	**Std. Error**	**Z-Statistics**	**Prob. > Z**
Three days CAR	1.04%	0.0065	1.60*	0.1103
Day -1 AR	0.15%	0.0038	0.40	0.6863
Day 0 AR	0.23%	0.0038	0.62	0.5338
Day 1 AR	0.65%	0.0038	1.74**	0.0819

Note: *, **, *** denote coefficient estimates statistically significant at the 0.15, 0.10, and 0.05 levels, respectively.

According to the results reported in Table 4, we record an oppositely negative stock price reaction upon the launch of the dim sum bond. In other terms, the investors will earn a negative abnormal return if they hold the related security throughout the dim sum bond launch event. The *T* statistics for the three-day CAR and day -1's abnormal return are significantly negative at the 0.20% and 0.51% confidence levels. In a more stringent standard, the *Z* statistics for the three-day CAR and day 1's abnormal return are significantly negative at the 5.66% and 0.75% confidence levels. It is thus very clear that it is the day -1's negative abnormal return that drives down the three-day CAR's abnormal return. In terms of magnitude, the day -1's abnormal return is -1.08% on average and the three-day CAR is -1.33% on average, equivalent to a -394.20% annualized abnormal return and a -161.82% annualized abnormal return respectively.

Table 4 *Stock Reaction around Dim Sum Bond Issuance: Abnormal Return = 0?*

	Coefficient	**Std. Error**	**T-Statistics**	**Prob. > T**
Three days CAR	-1.33%	0.0042	-3.19***	0.0020
Day -1 AR	-1.08%	0.0039	-2.78**	0.0051
Day 0 AR	0.06%	0.0037	0.17	0.5686
Day 1 AR	-0.32%	0.0030	-1.05	0.1527

	Coefficient	**Std. Error**	**Z-Statistics**	**Prob. > Z**
Three days CAR	-1.33%	0.0070	-1.91**	0.0566
Day -1 AR	-1.08%	0.0040	-2.68***	0.0075
Day 0 AR	0.06%	0.0040	0.16	0.8725
Day 1 AR	-0.32%	0.0040	-0.79	0.4310

Note: *, **, *** denote coefficient estimates statistically significant at the 0.15, 0.10, and 0.05 levels, respectively.

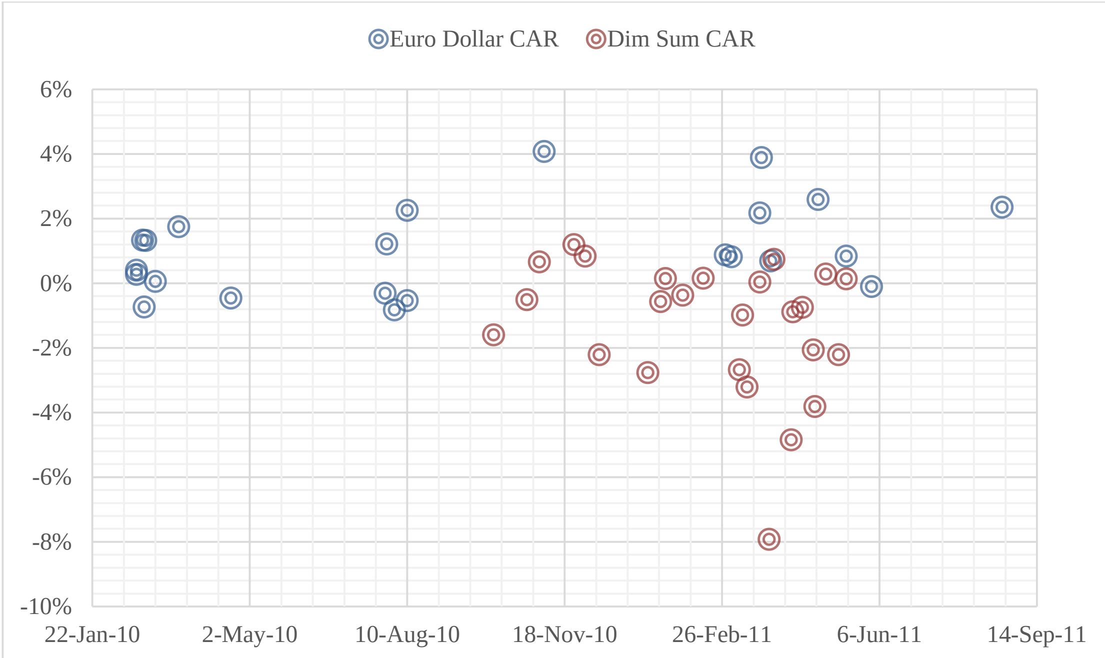


Figure 11 *Three Days Abnormal Returns for Eurodollar and Dim Sum Bonds*

From Figure 11 above, we see the three-day CARs of different securities triggered by two sets of events. It is visually clear that most Eurodollar bond-triggered abnormal returns are higher than the dim sum bond-triggered abnormal returns. We can also see that most Eurodollar bond-triggered abnormal returns are lying in the positive domain of the figure; while most dim sum bond-triggered abnormal returns are lying in the negative domain of the figure. Given this visual check, it is not difficult to understand the directional differences in our stock price reaction results for these two bonds.

We check the stock reaction for both issuances in the three-day issuance window. The result from this period is clear and significant: dim sum bonds and Eurodollar bonds generate negative and positive stock price reactions, respectively. In the real world, how long one event can impact the stock price is hard to tell. Thus, it is natural to extend the event window to a longer horizon and see the cumulative return by holding an equally weighted portfolio with issuers of both types of bonds. In Figure 12, we can see that the 10-days cumulative abnormal return for Eurodollar issuers will be 0.91% around the event window of each Eurodollar bond issuance. Although not very significant on a daily basis, the upward sloping trend is visually clear, and the steepest part occurs on days 0 and 1. We can also see a downward correction phase from day 1 to day 3. However, the downward correction brings merely a -0.35% return in two days and is largely cancelled out by the positive returns in day 4 and day 5.

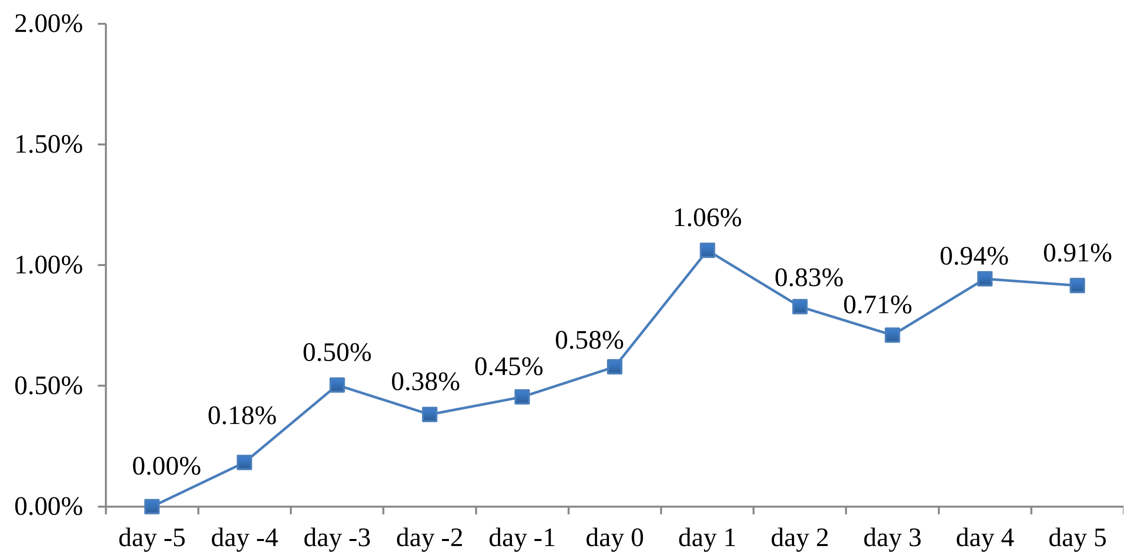


Figure 12 *Average Cumulative Abnormal Returns on Eurodollar Bond Issuance over a 10-days Event Window*

Figure 13 shows that the 10-days cumulative abnormal return for dim sum bonds will be 0.05% around the event window of each dim sum bond issuance, which is almost 20 times lower than the return generated by holding a Eurodollar portfolio. There is no clear overall trend; the most notable curvature is the drop in cumulative return from day -2 to day -1. This drop was largely caused by the huge negative return in day -1 and is partially offset by the correction in day 0 and day 1. Comparing the returns of the Eurodollar portfolio and the dim sum portfolio, we can see a clear buy-and-hold difference between these two bond issuance events: the Eurodollar issuance is providing a positive return and the dim sum issuance is providing a roughly zero return to investors over the 10-days time window.

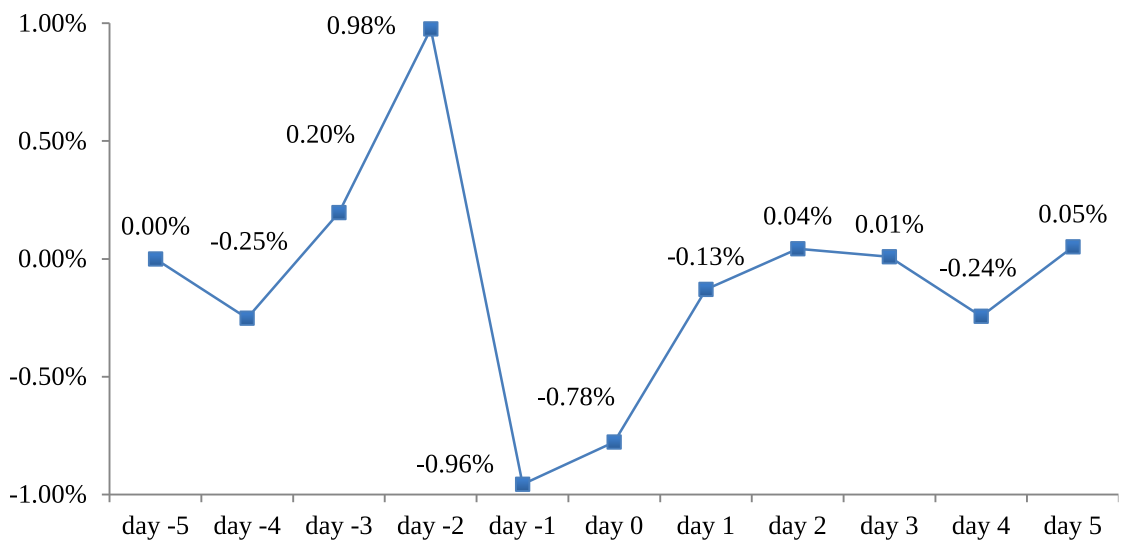


Figure 13 *Average Cumulative Abnormal Returns on Dim Sum Bond Issuance over a 10-days Event Window*

Why would Eurodollar bonds exhibit a positive abnormal return while dim sum bonds exhibit a negative abnormal return? We know that the RMB is not a floating currency and is pegged to a basket of currencies but mainly to the USD, and we also know that the HKD is closely pegged to the USD. Given the high correlation between the RMB and HKD, it is not difficult to understand that the foreign exchange risk is minimal between the RMB and HKD pair. Also, the RMB appreciates against the HKD in the experimental period, a long-term trend that would further stabilize the foreign exchange risks between the RMB and HKD. On the other hand, the USD and EUR are both floating currencies, and the foreign exchange risk between them contains more randomness and thus is not negligible. Therefore, considering the differential in the foreign exchange risks, the opposite valuation effects we observed on the dim sum bonds and Eurodollar bonds are understandable.

After observing these cumulative abnormal returns, we need to further investigate the origin of this directional difference. Why the Eurodollar bond impacts the stock price positively while the dim sum bond impacts the stock price negatively? Is it caused by some well-known bond characteristics or by our proposed foreign exchange risks? In our theoretic chain, we believe the impact of the foreign exchange risks is transferred into equity price in three steps that (1) foreign exchange risks impacts the volatility of a foreign bond; (2) volatility of the bond correlates the volatility of the firm value; and (3) volatility of the firm value can influence the equity price. Since the volatility of the bond and the volatility of the firm value are not directly visible at bond launch, we were not able to test the entire chain of our theory. To mitigate the empirical shortage, we can alternatively test the two ends of our theoretic chain and check if the foreign exchange volatility could ultimately influence the equity price. From previous event study, we already detected some significant abnormal returns on equities with Eurodollar and dim sum issuances. Then the next mission is to test whether such abnormal returns could be associated with foreign exchange risks. We will undertake this mission by conducting a cross-sectional regression with the CARs extracted from the previous event study. The dependent variables in the regression are the statistically significant abnormal returns derived from the event study. In details, we include the 3 days CAR and day -1 to +1 abnormal returns for the Eurodollar bonds and the dim sum bonds events. We use the foreign exchange implied volatility as a proxy of the foreign exchange risks in the regression equation. Other independent variables for the Eurodollar bonds include tenor, coupon rate, principal, yield at issue and credit rating. Later discussion on multi-collinearity will eliminate yield at issue out of this equation, but we will keep it for now. The regression equation to explain the positive stock return triggered by Eurodollar bond issuance is:

$$\begin{bmatrix} Three\ days\ CAR_i \\ day - 1\ AR_i \\ day\ 0\ AR_i \\ day\ 1\ AR_i \end{bmatrix} = \alpha_i + \beta_i^1 * FX\ implied\ vol + \beta_i^2 * tenor + \beta_i^3 * coupon\ rate + \beta_i^4 * principal + \beta_i^5 * yield\ at\ issue + \beta_i^6 * credit\ rating + e_i \quad (42)$$

For the dim sum bonds, the regression is further trimmed down from 6 independent variables in the Eurodollar's case to 4 independent variables because the information of yield at issue and credit rating on dim sum bonds is not available for most listings. The regression equation to explain the negative stock return triggered by dim sum bond issuance is:

$$\begin{bmatrix} Three\ days\ CAR_i \\ day-1\ AR_i \\ day\ 0\ AR_i \\ day\ 1\ AR_i \end{bmatrix} = \alpha_i + \beta_i^1 * FX\ implied\ vol + \beta_i^2 * tenor + \beta_i^3 * coupon\ rate + \beta_i^4 * principal + e_i \quad (43)$$

Now before presenting the regression results, we want to go through the descriptive statistics of the Eurodollar bond sub-sample and dim sum bond sub-sample as it also reveals some complementary information over the event study. First, day +1's abnormal return for Eurodollar sub-sample is on average the largest on a daily basis. Day -1's abnormal return for dim sum sub-sample is on average the smallest on a daily basis. Second, the average tenor of Eurodollar bonds is more than two-fold larger than the average tenor of dim sum bonds, implying that the former is enjoying a more matured and developed market. Third, the foreign exchange implied volatility between the USD/EUR pair is much larger at an average level of 11.6 than the HKD/CNY pair at an average level of 3.4. This difference in foreign exchange implied volatility between Eurodollar bonds and dim sum bonds serves as the key to explain the cross-sectional difference of abnormal returns.

Table 5 *Descriptive Statistics for Eurodollar Bonds Data (N=23)*

Variables	Description	Mean	S.D.	Min	Max
Dependent Variables					
Three days' CAR	Cumulative abnormal return for the three days' announcement window	1.04%	1.38%	-0.83%	4.08%

Day -1 AR	Abnormal return for the day before announcement	0.15%	0.99%	-1.66%	2.57%
Day 0 AR	Abnormal return for the announcement day	0.23%	1.27%	-2.33%	2.79%
Day +1 AR	Abnormal return for the day after the announcement	0.65%	0.98%	-1.19%	2.43%
Independent Variables					
FX implied volatility	3 Month implied volatility extracted from option value	11.6	0.8	10.4	13.6
Tenor	Initial term length of a bond in years	7.7	5.7	3.0	30.0
Coupon rate	Annualized coupon rate (in %)	3.60%	1.85%	1.00%	8.25%
Principal	Amount of bonds offered (in US$ Bn)	0.9	0.4	0.3	1.8
Yield at issue	Yield calculated from day 0 close price	3.65%	1.86%	1.14%	8.38%
Credit rating	Transformed credit rating with a numerical scale of 1-9	6.3	1.1	4.0	9.0

Source: SDC platinum, Bloomberg, and WRDS

Table 6 *Descriptive Statistics for Dim Sum Bonds Data (N=25)*

Variables	**Description**	**Mean**	**S.D.**	**Min**	**Max**
Dependent Variables					
Three days' CAR	Cumulative abnormal return for the three days' announcement window	-1.33%	2.09%	-7.93%	1.19%
Day -1 CAR	Cumulative abnormal return for the day before announcement	-1.08%	1.94%	-7.77%	1.09%
Day 0 CAR	Cumulative abnormal return for the announcement day	0.06%	1.85%	-3.83%	4.97%
Day +1 CAR	Cumulative abnormal return for the day after the announcement	-0.32%	1.52%	-4.75%	2.04%
Independent Variables					
FX implied volatility	3 Month implied volatility extracted from option value	3.4	0.8	2.5	5.0

Tenor	Initial term length of a bond in years	3.2	0.9	2.0	5.0
Coupon rate	Annualized coupon rate (in %)	3.7%	1.5%	1.4%	7.0%
Principal	Amount of bonds offered (in US$ Bn)	1.1	0.8	0.3	3.5

Source: SDC platinum, Bloomberg, and WRDS

The problem of multi-collinearity damages the legitimacy of the coefficient estimates. To avoid multi-collinearity, we check the correlation matrix for the independent variables. From Table 7, we can see the problem that the yield on Eurodollar bonds is perfectly correlated with the coupon rate. It is not surprising to us because the yield at launch would be very close to coupon rate for larger and safer issuance and most Eurodollar issuances in our sample qualify for such criteria. Because of this multi-collinearity issue, we will have to delete yield at launch from the regression equation for Eurodollar bonds. Other highly correlated variables are credit ratings and coupon rates with a negative correlation ratio of -0.76. This high correlation is simply caused by the tradeoff between risk and return. Since it is not yet 100% collinear, it is still beneficial to include both variables into the regression as information not explained by this collinearity may be of use to dependent variables. Table 8 shows that the implied volatility and tenor are negatively correlated with a correlation ratio of -0.7 for dim sum bonds; while the implied volatility and tenor for Eurodollar bonds are completely unrelated. One possible answer to this finding could be the implied volatility of CNH/HKD was decreasing along time as China appreciated its RMB against HKD constantly, and hence beat the volatility down. At the same time, the tenor of dim sum issuance was increasing along time as market was gaining more confidence on dim sum bonds and started to issue long-term bonds as a consequence. So these two trends along the time coincided in our sample and created this seemingly high correlation between implied volatility and tenor for dim sum bonds.

Table 7 *Correlation Matrix for Eurodollar Bond Independent Variables (N=23)*

	FX implied volatility	Tenor	Coupon rate	Principal	Yield	Credit rating
FX implied volatility	1.00					
Tenor	0.03	1.00				
Coupon rate	-0.01	0.62	1.00			
Principal	-0.27	0.01	-0.19	1.00		
Yield	-0.01	0.62	1.00	-0.18	1.00	
Credit rating	-0.05	-0.35	-0.76	0.34	-0.76	1.00

Table 8 *Correlation Matrix for Dim Sum Bond Independent Variables (N=25)*

	FX implied volatility	Tenor	Coupon rate	Principal	Yield	Credit rating
FX implied volatility	1.00					
Tenor	-0.70	1.00				
Coupon rate	-0.36	-0.14	1.00			
Principal	-0.96	0.87	0.19	1.00		
Yield	-0.49	-0.08	0.98	0.31	1.00	
Credit rating	0.12	0.21	-0.95	0.00	-0.89	1.00

After confirming the positive return on Eurodollar issuance and negative return on dim sum issuance, we want to conduct further analysis to determine what characteristics of foreign bonds are truly explaining the cross-sectional differences of abnormal returns. The results of our regressions are presented in Table 9 for Eurodollar bonds. The coefficient of our concerned variable, *FX implied volatility*, is positive and significant at the 8.9% level on day +1 AR. The magnitude of the coefficients implies that the daily abnormal return of equity will be 0.45% (equivalent to 113% compounded annual return) higher if the *FX implied volatility* at the issuance day is 1 point higher. *FX implied volatility* is not significant on the other three dependent variables. The non-significant loadings of *FX implied volatility* on the other three dependent variables might be caused by: (1) 3 days' CAR is driven up by the strong positive day +1 AR but brought down by the weak negative day -1 and day 0 ARs; (2) the *FX implied volatility* in this example does not show enough variation due to the short experiment time. This finding reveals that the foreign exchange volatility did impact equity value right after the bond issuance. It also implies our three steps' theoretic chain is successfully tested by linking the beginning cause and the ending symptom. All the other factors play a minimal role in explaining the cross-sectional difference in abnormal returns following Eurodollar bond issuances. The loading of coupon rate is closely linked to the test of financial bargain theory in Eurodollar bond event. Financial bargain theory by Kim and Stulz (1988) generally believes firms issuing Eurodollar bonds can benefit from lower yield than domestic bonds, and thus increase firm value. Since the lower coupon rate does not effectively drag down the abnormal return, we can see the financial bargain theory is not applicable to our sample of Eurodollar bond issuance.

Table 9 *Cross-Sectional Regression Results for Eurodollar Bonds (N=23)*

	Dependent variables			
Independent variables	Three days' CAR	Day -1 AR	Day 0 AR	Day +1 AR
FX implied volatility	0.0049	0.0040	-0.0037	0.0045
	1.25	*1.47*	*-0.99*	*1.81***

Tenor	0.0006	0.0000	0.0003	0.0003
	0.87	*0.02*	*0.46*	*0.66*
Coupon rate	-0.0493	-0.1601	-0.1275	0.2383
	-0.16	*-0.74*	*-0.43*	*1.19*
Principal	0.0069	0.0017	0.0038	0.0014
	0.77	*0.27*	*0.45*	*0.25*
Credit rating	-0.0013	-0.0043	0.0006	0.0025
	-0.28	*-1.36*	*0.13*	*0.85*
Constant	-0.0477	-0.0138	0.0402	-0.0741
	-0.79	*-0.33*	*0.71*	*-1.92***

Note: T statistics are reported underneath the estimated coefficients
*, **, *** denote coefficient estimates statistically significant at the 0.15, 0.10, and 0.05 level, respectively.

Next we will take a look at the results of our cross-sectional regression testing for dim sum bonds presented in Table 10. The coefficient of variable *FX implied volatility* is positive and significant on 3 days' CAR and day +1 AR at the 5.6% level and 6.9% level, respectively. The magnitude of the coefficients on 3 days' CAR implies that the 3 days' CAR of equity will be 1.12% (equivalent to 94% of annual return) higher if the *FX implied volatility* at the issuance day is 1 point higher. The magnitude of the coefficients on day +1 AR implies that the daily return of equity will be 0.77% (equivalent to 194% of annual return) higher if the *FX implied volatility* at the issuance day is 1 point higher. According to this result, we can attribute the negative abnormal returns on dim sum bonds to the statistical significance and lower value of the *FX implied volatility* variable. So the validity of our theory has been tested again from the evidence of dim sum bonds that the foreign exchange volatility can impact the equity value through the channel of bond volatility and firm value volatility. It is worth noting that the coefficient of *Coupon rate* is negative and significant on *day -1 AR* at a 4.6% level. It implies if the coupon rate of the dim sum bond is 1% lower, then the daily abnormal return for the issuing company will be 0.16% (equivalent to 40% annual return) higher. This finding may suggest that the financial bargain theory still play a role when abnormal return is deep in the negative area. In other terms, the market is not sensitive to coupon rates in the Eurodollar bond case where issuances are rewarded by the issuers; but the market is sensitive to coupon rates in the dim sum bond case where issuances are punished by investors. This finding may be linked with some psychological aspects of investors and it may deserve further investigation with larger data sample. Finally, the coefficient of variable *Principal* is negative and significant on 3 days' CAR and day +1 AR at 11.2% level and 10.4% level. It implies that 3 days' CAR of equity will be 0.086% (equivalent to 21.6% of annual return) lower if the *principal* of dim sum bond issued is USD100 million more. It also implies that day +1 AR of equity will be 0.064% (equivalent to 216% of annual return) lower if the *principal* of dim sum bond issued is USD100 million more. This finding may be associated with the missing variable of company size. The higher a firm's size is, the higher principal amount of its bond issuance could be. The abnormal return under the bond issuance event may be higher for a small company and lower for a large company. Thus, the negative relationship between abnormal return and bond principal may just be a projected correlation between abnormal return and company size.

Table 10 *Cross-Sectional Regression Results for Dim Sum Bonds (N=25)*

	Dependent variables			
Independent variables	Three days' CAR	Day -1 AR	Day 0 AR	Day +1 AR
FX implied volatility	0.0112	0.0002	0.0033	0.0077
	*2.03****	*0.03*	*0.61*	*1.92***

Tenor	0.0042	-0.0019	0.0018	0.0043
	0.84	*-0.40*	*0.37*	*1.17*
Coupon rate	-0.1063	-0.5914	0.3310	0.1541
	-0.37	*-2.13****	*1.16*	*0.73*
Principal	-0.0086	-0.0024	0.0002	-0.0064
	*-1.66**	*-0.48*	*0.04*	*-1.71**
Constant	-0.0508	0.0192	-0.0287	-0.0413
	*-1.53**	*0.60*	*-0.88*	*-1.70**

Note: T statistics are reported underneath the estimated coefficients
*, **, *** denote coefficient estimates statistically significant at the 0.15, 0.10, and 0.05 levels, respectively.

2.6. Summary

In this chapter, we examine the relationship between firm value and foreign bonds on the theoretical and the empirical fronts. We include two types of foreign bonds in our study. One is the dim sum bond, which is denominated in offshore RMB and issued in Hong Kong. The other one is the Eurodollar bond, which is denominated in offshore USD and issued in Europe. Dim sum bonds and Eurodollar bonds share many similarities, including their denomination rule, the embedded foreign exchange risk, and the less restrictive regulations governing them. However, the foreign exchange risk of Eurodollar bonds is higher than that of dim sum bonds, since the USD/EUR pair has a higher volatility than does the HKD/RMB pair.

We review several capital structure theories on how firm value would change in response to a change in capital structure. In a perfect world with no frictions, the capital irrelevance theory is the dominant view among researchers. One group of researchers developed the tradeoff theories of capital structures, which generally believe that firm value will achieve an optimal value at an inflection point where the marginal benefits of debt equal its marginal costs. Another group of researchers hold to the pecking order theory, which generally believes that firm managers would prefer debt to equity due to asymmetric information and that firm value should increase following debt issuance due to its positive signal. On the empirical side, many researchers have studied the valuation effect of bond offerings and have found that the valuation effect is non-positive for straight bonds and is negative for convertible bonds, although this conclusion varies to some extent under different methodologies, samples, and time periods. Furthermore, the valuation effect of foreign bonds is limited to the sample of Eurodollar bonds; most researchers report a positive stock price reaction following the announcement of foreign bonds. For Eurodollar bonds, the cross-sectional difference of the valuation effect is explained by the financial bargain theory (Kim and Stulz, 1988).

We propose a theoretical model for predicting the response of firm value following the issuance of foreign bonds. We prove this model following a sequential order: (1) foreign bonds carry more exchange rate risk than domestic bonds; (2) this additional exchange rate risk increases a foreign bond's volatility; (3) the volatility of debt value correlates with the volatility of firm value, and foreign debt's extra volatility increases the volatility of firm value; (4) with the higher volatility of firm value, holding others constant, the equity value of a firm should increase. The conclusion of our model is derived from the case of zero coupon bonds but can be extended to the case of coupon bonds as well.

In our empirical test, we test whether there is any significant stock price reaction to the foreign bond issuances of dim sum bonds and Eurodollar bonds. Then, we test whether these stock price reactions could be explained by a series of bond characteristics and foreign exchange risks. We find a positive stock price reaction upon the launch of Eurodollar bonds. The three-day abnormal return around the launch window is 1.04% on average, equivalent to a 126.53% annualized abnormal return. We also find a negative stock price reaction upon the launch of dim sum bonds. The three-day abnormal return around the launch window is -1.33% on average, equivalent to a -161.82% annualized abnormal return. We believe the opposite stock reactions across dim sum bonds and Eurodollar bonds occur because the foreign exchange risk is lower in the HKD/RMB pair than in the USD/EUR pair. From the cross-sectional regression, we find the foreign exchange risk, represented by the foreign exchange implied volatility, could significantly explain the three-day abnormal return for dim sum bonds and the +1 day abnormal return for Eurodollar bonds.

Our contribution to the literature is three-fold: (1) we theoretically show how the issuance of foreign bonds will increase firm value through a hybrid model; (2) we examine the opposite valuation effects for two foreign bond categories, dim sum bonds and Eurodollar bonds; (3) and we explain the opposite valuation effects through the differential of foreign exchange risk in dim sum bonds and Eurodollar bonds. We believe further research should be done on the following fronts: (1) the incorporation of other types of risks into our theoretic model; (2) the examination of valuation effects for additional bond categories; (3) an extension of the bond characteristics in the cross-sectional regression.

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CHAPTER 3

ECONOMIC DEVELOPMENT AND RISK FINANCING TOPICS OF CATASTROPHE BONDS

3.1. Motivation

Catastrophic events have posed significant covariant risks to small and least-developed countries (LDCs). Droughts in Africa, earthquakes in South America, and tsunamis in Asia Pacific all caused tremendous economic losses and human injuries. The damage of catastrophes may persist in the affected countries, since uninsured catastrophe risks can induce poverty traps for the victims. Furthermore, the lack of financial or insurance markets in LDCs amplifies the severity of catastrophe-induced poverty traps. Thus, it is beneficial for LDCs to choose the right economic development tool and risk financing strategy to alleviate the damage of natural disasters and foster post-catastrophe recovery.

The CAT, or catastrophe, bond could serve as a key economic development tool and risk financing strategy for those LDCs. The CAT bond is catastrophe-linked, provides reimbursement to losses, and represents a securitization effort of catastrophe insurance. As an economic development tool, CAT bonds helps increasing the flexibility of post-crisis project selection and providing higher insurance penetration for catastrophe risks. As a risk-financing strategy, CAT bonds helps solving the low insurability problem of catastrophe risks caused by adverse selection, moral hazard, and basis risk. The CAT bond also helps moderating the cost structure of disaster insurance. Due to these unique features and advantages, the World Bank recommended the CAT bond to LDCs for the coping of catastrophe risks. Mexico was the first nation to issue a CAT bond to cover its seismic risks through the World Bank's MultiCat program. The sequential rollover of the MultiCat program and the strong demand from investors confirm the CAT bond as an attractive and successful risk-financing strategy and economic development tool.

This chapter is organized as follows. Section 3.2 discusses how catastrophe risk impacts the development of agricultural economies and induces the poverty trap. Section 3.3 outlines the role of the CAT bond as an advantageous economic development and risk-financing strategy. Section 3.4 summarizes this chapter and discusses possibilities for future development.

3.2. Catastrophe in Agricultural Development

3.2.1. Catastrophes Create Large Uninsured Covariate Risks for Agrarian Economies

Zimmerman and Carter (2003) suggest that household incomes in agrarian economies are subject to covariate as well as idiosyncratic shocks. Idiosyncratic shocks stem from individual household characteristics and affect single-member households only. Examples of idiosyncratic shocks include illness and health difficulties. Covariate shocks mainly stem from market movements or natural disasters affecting most households in a region at the same time. Examples of covariate shocks include commodity price collapse, drought, floods, earthquakes, or even wars. Idiosyncratic risks can be hedged away on a national level, as the negative income of one household might be cancelled out by the positive income of another. However, covariate risks cannot be easily netted out on an aggregate level because one disaster might simultaneously drag down the incomes of many households. From a macroeconomic perspective, Collier (2002) believes the most desirable insurance pattern is insuring the covariant risks while leaving the idiosyncratic risks alone. He detects a paradox in insurance provision by which farmers are far more likely to insure idiosyncratic risks than covariant risks. Skees et al. (2002) also suggest that market mechanisms are generally available for managing some market-related covariate risks, while the market-based instrument for managing disaster-based covariate risks is underdeveloped and unavailable. Thus, the uninsured covariate risks created by catastrophes remain problematic for the risk management of agrarian economies. Chantarat et al. (2013) point out that uninsured risk has long been recognized as a serious obstacle to poverty reduction in poor agrarian nations. Indeed, reliance on agricultural outputs, the arid environment, and poorly developed financial markets all add to the danger of covariant risks in agrarian economies.

3.2.2. Cases of Kenyan and Ethiopian Droughts and Consequences

The impact of catastrophic events cannot be underestimated, especially for arid and semi-arid lands (ASAL) characterized by low productivity and persistent poverty. Carter, Little and Mogues (2006) document the drought case in North-Eastern Ethiopia, in which the failure or near-failure of three successive short rainy seasons triggered massive crop yield reduction. Between 1998 and 2000, it is estimated that the harvest in Ethiopia's main Belg growing region represented 40%, 10% and 25% of a normal harvest in each respective year. The victims' nutritional levels didn't return to normal until 2001, the year after the long rain normalized and international aid became widespread. In 1999, this area also experienced severe livestock reduction due to massive cattle death and sales. According to a group interview conducted by Little et al. (2006), the aggregate number of oxen and total herds declined by around 40% from 1998 to mid-2000, and 90% of male and 71% of female herd owners sold their livestock to cope with the drought. Using household data covering 1989 to 1997, Dercon (2004) also found evidence that a rainfall shock of about four to five years earlier had slowed the current growth rate by 1%. The Ethiopian case shows that the short-term impact of droughts on both household income and assets is severe and that the medium-term impact on economic growth is also not negligible. The crop yield drop, souring cattle mortality, and slow down of economy are well documented to demonstrate the destructive consequences of a drought disaster.

We also illustrate the impact of agricultural catastrophes by examining the frequent droughts in Kenya. According to the Government of Kenya (2010), the long rain season from March to May has seen a general decline in rainfall in recent years, causing droughts to be more frequent and prolonged in the long rain seasons. Recent droughts in Kenya have trimmed the crop yield heavily. Using data from the central division of the Laikipia district, Huho, Ngaira and Ogindo (2010) report that maize yields were 41.5% and 84% below average in 1999 and 2000 respectively during the La Niña droughts. They also report that bean yields were 38.9% and 72.2% below average during the same period. However, the covariate risk doesn't stop with maize and bean production. It also destroys the production of other major cash crops, like tea and sugar. The increased import of food crops and the reduced export of cash crops reduce the country's balance of payments and its budget capability to relieve the drought. Consequently, the drought triggered crop failure, putting an estimated 4.7 million Kenyans at risk of malnutrition, hunger, and starvation in 2000 (Government of Kenya, 2010). In addition to farmers, more than three million pastoralists live in Northern Kenya, who make their living through livestock output. They were severely wounded during the 2000 drought as well. Using data from Chalbi and Laisamis areas, Chantarat et al. (2013) document the seasonal herd mortality rates in Northern Kenya. The rate reached over 60% in one region of the Chalbi area in the long rain season of 2000 and exceeded 40% in another region of the Laisamis area; the normal rate had seldom exceeded 20% and usually fell below 10% under normal weather conditions. Thus, drought in Kenya exposes households to significant income and asset shocks and prevents the government from maintaining its balance of payments and offering emergency relief. All these covariate risks create substantial threats to the fragile agrarian economies in Africa.

3.2.3. Uninsured Catastrophic Risk Induces Poverty Trap

In development studies, the poverty trap is persistent poverty that cannot be explained by traditional models such as Solow's growth model. Bowles, Durlauf, and Hoff (2006) review three explanations for the persistence of poverty in their book - *Poverty Trap*. First, there may be a critical threshold for overall wealth or human capital that must be reached before the forces of the traditional growth model take hold. Second, dysfunctional institutions in poor countries may hinder growth by making property rights insecure, protecting a small elite, or intensifying social inequality. Third, the persistence of poverty may be determined by one's membership in a group defined by factors such as race, neighborhood, or school. The first explanation, using the threshold theory, is particularly relevant to the catastrophic risks we are discussing. The threshold theory requires the existence of bifurcated equilibrium (see Barrett and Swallow 2006, Carter and Barrett 2006, and Barrett et al. 2006). In this theory, households above the so-called Micawber threshold accumulate assets and follow a promising path of growth, while households below the critical Micawber threshold lose assets and follow a doomed path of downward spiral. Barrett and Carter (2013) review the most important implication of the threshold theory, emphasizing a shock's permanent consequences on households. A catastrophic shock could knock one household from a positive growth trajectory onto a negative one, thus impairing the household's effort to grow out of the low-level equilibrium and permanently change its course of development.

Zimmerman and Carter (2003) show that households' *ex ante* portfolio decisions and *ex post* behavioral responses are not optimal in the face of catastrophic risks. In their dynamic programming model, poorer households below an initial wealth threshold will acquire a conservative low-risk/low-yield portfolio and pursue asset smoothing after a shock (i.e., by rationing consumption to buffer assets). Richer households above an initial threshold will adopt an entrepreneurial high-risk/high-return portfolio and pursue consumption smoothing after a shock (i.e., by liquidating assets to buffer consumption). The conservative portfolio of the poor consists of a higher proportion of grains, while the entrepreneurial portfolio of the rich consists of a higher proportion of lands. The conservative portfolio of the poor is clearly not the optimal one because their cheap labor could provide a higher competitive advantage through the productive asset of land. The asset smoothing of the poor is not the optimal response either, because they are more likely than the rich to drop below a critical nutritional level and fall into illness and malnutrition. Although it is not welfare-optimal, the poor settle for the conservative portfolio mainly because they lack a forward-looking risk management tool to smooth their income when a catastrophic shock hits. The asset-smoothing behavior of the poor is caused by the derived assets price risk. Assuming that all households coordinate to purse consumption smoothing by liquidating lands, land prices will sharply drop post-shock and create a huge asset price risk for all households. Therefore, productive land's insurance role is reserved only to the rich who can afford the asset price risk. From this perspective, we see that catastrophe risk can aggravate the poverty trap problem by de-routing poor households from their optimal *ex ante* portfolio and *ex post* behavioral response.

Barrett and Carter (2013) review two important remedies of the poverty trap: targeted asset transfer and risk reduction. Targeted assets transfer matters because they allow households marginally below the threshold to reach a high level of development. Once on the high-level path, those households will switch their assets portfolio from a conservative one to an entrepreneurial one, crowding in more investment opportunities and accelerating their technology adoption. Through a simulation, Barrett et al. (2008) show that an unanticipated triage transfer policy that prioritizes threshold-targeted social protection for intermediate wealth and ability households creates a "productive safety net" that eliminates persistent poverty and boosts growth through endogenous asset accumulation and the adoption of improved technology. Risk reduction also matters because an asset insurance contract that indemnifies the shock-hit poor has four positive impacts on the poverty trap. Under the assumption of mandated permanent insurance, Janzen, Carter, and Ikegami (2012) identify four effects in their dynamic programming: the vulnerability effect, the smoothing effect, the shifting equilibrium effect, and the shifting threshold effect. In the vulnerability effect, the probability of collapse into a lower-level equilibrium is reduced for households that purchase fair insurance. In the smoothing effect, the variability of asset accumulation decreases across households that become permanently insured. In the shifting equilibrium effect, the insured household gains a higher terminal asset value than that of their uninsured counterparts, regardless of the initial endowments. In the shifting threshold effect, the initial Micawber threshold will shift to a lower level, and more households will be able to enjoy the high-level equilibrium path, if insurance schemes are adopted. Among these effects, the vulnerability and shifting threshold effects are related to the crowding-in effect of investment. The vulnerability effect brings the hope of reduced vulnerability to households and hence incentivizes investment. The shifting threshold effect moves those households, through an endowment between the pre-insurance and post-insurance threshold, into a high-level equilibrium, making investment more affordable for them. Therefore, targeted assets transfer and risk reduction will significantly alleviate the damage of the poverty trap. For this reason, government, donors, and financial institutions should design policies and market instruments aimed at targeted assets transfer and risk reduction in ASAL countries.

3.2.4. Financial Market Failures Amplify the Severity of the Poverty Trap

Typical financial market failures in poverty trap models include missing capital and insurance markets or the exclusion from such markets. These failures amplifies the severity of poverty traps caused by catastrophic risks. Dercon (1998) shows that, because investment in livestock is discrete (i.e., livestock investment is a "lumpy" investment), it is harder for the poor to enter into livestock production, especially in the absence of credit markets. A proper credit market makes it much easier for poor households to grow out of low-level equilibrium. Carter et al. (2006) suggest that a household with good access to capital (via credit markets or informal social arrangements) can borrow against future earnings to immediately rebuild asset stocks after shocks. They can thus leverage the borrowed capital to achieve the competitive advantage of their cheap labor on productive assets and finally re-enter the growth trajectory. Barrett et al. (2008) also conclude that, if financial markets permit people to insure shocks *ex ante* or borrow against shocks *ex post*, then risks need not contribute to poverty traps. Thus, the poverty trap could be addressed in ASAL countries with the help of developed credit and insurance markets. However, financial markets are known to be under-developed in those countries for a number of reasons.

Barrett, Barrett, and Skees (2008) identify three important factors in financial market failure in ASAL countries: covariate risk, asymmetric information, and transaction costs. Covariate risk damages financial markets because (1) it creates excessive systematic risks that hinder insurance's risk-pooling mechanism, and (2) it creates right-tail risks too large for insurers to absorb. Asymmetric information is more pronounced in least-developed countries because of their poor infrastructure, statistical bureaus, and communication channels. In the context of the principal–agent problem, asymmetric information generally leads to two kinds of undesirable insured behavior: adverse selection and moral hazard. In the insurance market, those behaviors will increase everyone's premium burden, wipe out the well-behaved insurance buyers, and damage the insurance market. Adverse selection and moral hazard are traditionally believed to cause the poor to be disproportionately rationed out of credit markets. Santos and Barrett (2011) suggest that informal credit could also exhibit a bifurcated dynamic based on initial wealth and social network, reinforcing wealth-driven credit rationing. The transaction costs of operating a credit or insurance market are tremendous in terms of collecting information (e.g., crop yield, herd mortality), assessing credit worthiness or actual losses, and deploying service representatives. The lack of cost-based scale economies in ASAL countries is another transaction cost issue. Most ASAL insurance buyers are farmers with a few acres or pastoralists with a few herds, whose credit balances and insurance policies are small in absolute value. Transaction cost represents a higher percentage of interest/premiums in small credit line/insurance policies than in large ones. Therefore, the high transaction costs and the scarce scale economy further hinder the financial markets in ASAL countries. Financial markets sometimes fail to work due to other country-specific reasons, such as the legal system, civil war, or corruption. Overall, the lack of insurance and credit markets at the individual level increases the difficulty of risk management and amplifies the poverty trap in ASAL countries.

3.2.5. Current Risk Management and Risk-Coping Mechanisms are Insufficient for Catastrophic Risks

As mentioned, formal insurance and credit markets barely exist in ASAL countries. However, informal risk-management and risk-coping mechanisms are widely utilized in those countries. Barrett, Barrett, and Skees (2008) classify those mechanisms into three broad categories; self-insurance, risk mitigation, and risk transfer. However, each mechanism contains certain flaws.

Self-insurance includes measures such as precautionary saving and currency saving. Precautionary savings in the form of productive assets cause a negative price impact after covariate shocks because the market will be driven down by the excessive supply of such assets. A negative price impact is costly to the self-insurer and hence limits the use of such precautionary savings. Currency savings are closely related to the monetary condition of a country. High inflation, which increases the holding cost of currency savings, is typically seen in developing countries when their economies are bubbling. Once catastrophe strikes, it can damage a country's balance of payments, weaken its exchange rate, and reduce the purchasing power of its residents' currency savings. Therefore, high inflation in a bubbling period and low purchasing power in the aftermath of a catastrophe will reduce the usage of currency savings. Risk mitigation typically involves measures such as intercropping lower-risk outputs, cropping in different microclimate, and diversifying income sources. However, as Barrett, Barrett, and Skees (2008) conclude, the extent to which households can utilize any of these strategies is highly conditioned by local climatic, technological, and market factors as well as by household asset levels. Finally, informal risk transfer usually includes mechanisms such as reciprocal agreement or assistance from one's social network. However, reciprocal agreements may be limited by problems such as covariate risks, poor contract enforcement, and information asymmetry. If two parties live spatially close to each other, the covariate risk is high; if they live far away from each other, problems with contract enforcement (e.g., no social tie to enforce the payment) and information asymmetry (i.e., ignorance of counterpart's true income) will start to emerge. Social network assistance rarely works for the poor because their relatives and friends also tend to be poor and the resources and help available from the network are barely enough to cover the damage. Given all these limitations, it is difficult for existing informal mechanisms to address all the risk-management needs of farmers and pastoralists in ASAL countries.

3.3. CAT Bond as a Risk Financing Strategy and Economic Development Tool

3.3.1. What is a Catastrophe Bond?

The CAT bond belongs to a broad category of event-linked bonds that pay off on the occurrence of a specific event. In catastrophic events such as earthquakes, drought, floods, and hurricanes, the interest or principal of the CAT bond may be forgone or delayed to the investors under the bonds' terms and provisions. CAT bonds represent an insurance securitization product that transfers the catastrophe risks from the issuers to the investors.

The typical structure of a CAT bond will involve the interaction of four parties: the sponsor, the special purpose vehicle (SPV), the collateral, and the CAT bond investors. In the beginning, the sponsor (insurance company or government) will sign a reinsurance agreement with the SPV, paying the SPV a certain premium in exchange for the coverage of a catastrophic event. The SPV will issue CAT bonds to the investors on behalf of the sponsor and deposit the issuance proceeds into a collateral account. The SPV will use the money in the collateral account to invest on treasury bills and then pay coupons based on the investment return and the premiums collected from the sponsor. If no qualifying event triggered the provisions, the collateral account will be liquidated at maturity to repay the principal to the investors. If a qualifying event triggered the provisions on or before maturity, the collateral account will also be liquidated to reimburse the losses of the sponsor. Figure 14 illustrates the cash flow structure of CAT bonds at issuance and a catastrophe event.

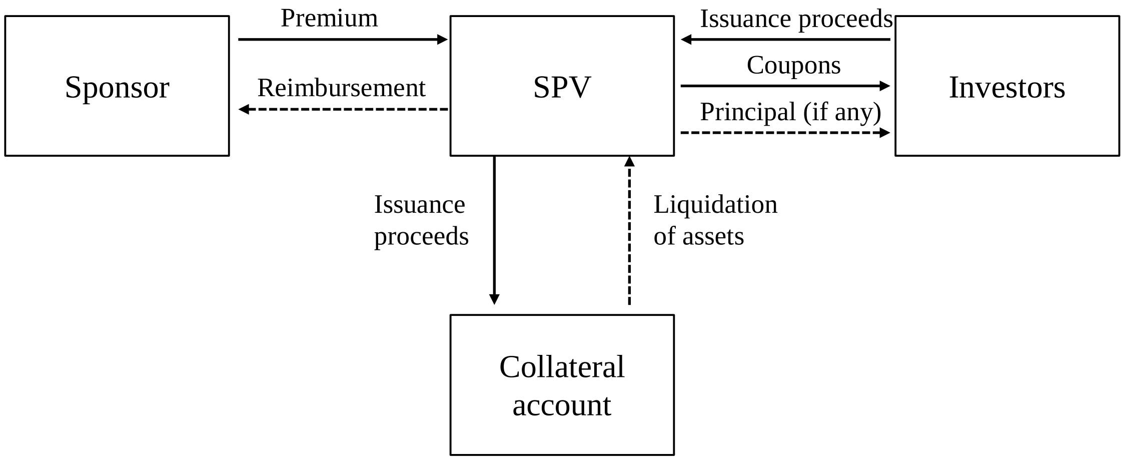

Figure 14 *Cash Flow Structure of a CAT Bond* [9]

Four generic types of triggering mechanism are adopted by the CAT bond market: indemnity loss, industry loss, modeled loss, and parametric. For indemnity loss, the reimbursements are triggered by the sponsor's actual losses. For the industry loss index, the reimbursements are triggered by the industry loss aggregated by a third party agency. For modeled loss, the parameters of a catastrophe are inputted into a model to estimate the expected losses, and the reimbursement will be triggered by those losses. For parametric, the reimbursement is triggered by the predetermined physical parameters of the catastrophe. The basis risk and the transparency of the trigger types increase in the above order (i.e., from indemnity to parametric). Thus, transparency and basis risk are part of the trade-off consideration when choosing a trigger type. One can also combine any two generic trigger types to create hybrid triggers for payout determination.

[9] Note: solid lines represent cash flow at issuance. Dashed lines represent cash flow at catastrophe events

3.3.1. CAT Bond as an Economic Development Tool

Mahul and Ghesquiere (2007) discuss the risk financing difference between developing countries and industrialized countries. For example, OECD countries usually fund their catastrophe losses through private risk financing arrangements and taxation reserves, while mid-income countries rely heavily on multilateral financial agencies (e.g., the World Bank, IMF, United Nations) and *ex post* borrowing. Low-income countries receive more support from bilateral donors (e.g., other governments) than from any other channels. Michel-Kerjan et al. (2011) map the risk financing strategy of a country into four levels depending on its current economic development (shown in Figure 15 below). Lowest-income countries mainly adopt *ex post* financing and rely heavily on international donor assistance. Lower-income countries also use *ex post* financing; however, as their tax base increases along with economic development, they will adopt government funding as a major resource of relief. Middle-income countries have started to adopt somewhat *ex ante* risk-financing instruments such as insurance. However, the scale of *ex ante* risk financing is limited, and governments remain as the major funding source. In rich countries, *ex ante* risk financing strategies are mainly used, and substantial payments are reimbursed through pre-determined insurance mechanisms. This mapping of *ex post* vs. *ex ante* risk financing strategies across countries is not fixed for one type of country. The proper risk-financing strategy depends on the country's risk type and magnitude, technical expertise, and political leadership.

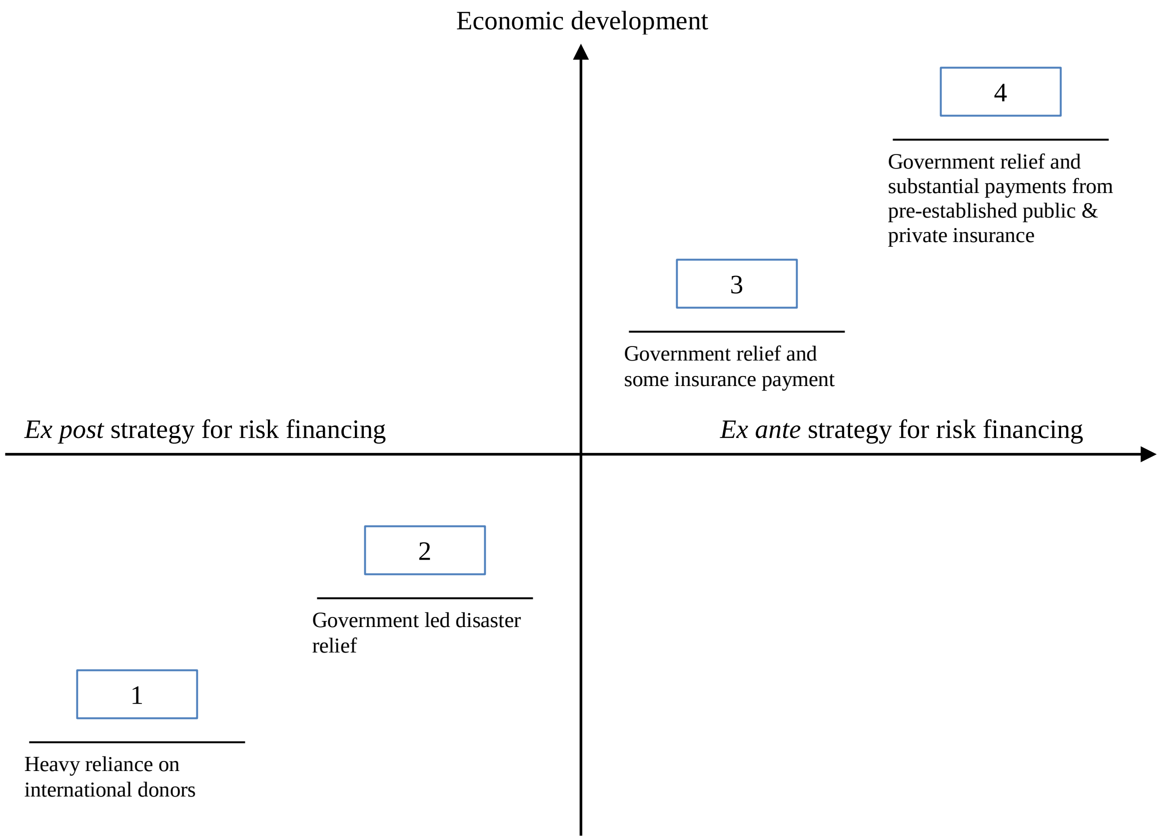

Figure 15 *Governments' Responses to Disasters as a Function of their Economic Development*[10]

How efficient are risk-financing strategies for post-crisis development and recovery? Funding from donors may be the least desirable instrument for post-crisis recovery and development for several reasons. First, donor countries or organizations may need time to realize the situation, assess the losses, and collect the necessary funding. Delay is inevitable and will impede post-crisis development and recovery. Second, conflicts of interest about how and when the donors' funds should be used is another issue, as Michel-Kerjan et al. (2011) suggest. Funding from donors may come with additional terms concerning usage and may thus not be the best alternative for the country.

[10] Source: Michel-Kerjan *et al.*, 2011

Specifically, Mahul and Ghesquiere (2007) point out donations' limited capacity to finance general budget outlays such as civil servants' salaries, debt services, and other government obligations. Third, donors may suffer from the so-called "donor fatigue" (Michel-Kerjan, 2010) when donor countries' rescue funding proves insufficient for a series of disasters.

Government funding is superb to donation, as its arrival is fairly certain, and its usage is better aligned with the interests of the victims and their government. However, government funding has three deadly effects on post-crisis development. First, government relief funding may crowd out other beneficial investment projects that were planned before the catastrophe. Second, government funding may come from taxation. A higher tax rate may depress rather than incentivize economic activities after the crisis. Third, government funding may also come from post borrowing, which may severely affect the nation's sovereign debt sustainability, as we will discuss at length in chapter 4. Although government funding avoids several of the major drawbacks of donations, it still contains some defects that affects the post-crisis development.

Insurance is an attractive economic development tool because it can help allocate the risk costs to the people who need coverage the most. It thus helps eliminate mismatched cost–benefit connection (i.e., the charity hazard) and provides better incentives for risk reduction and recovery. Insurance also has a time advantage over donations and doesn't crowd out other potential investment projects. However, insurance still lacks two important features that CAT bonds possess. Clarke and Doherty (2004) present an interesting comparison between the CAT bond and traditional insurance that simply replaces destroyed assets in the context of post-shock economic development. They argue that the CAT bond is a nonspecific hedge and that funding from it can be used for any purpose. The risk financing of insurance is bounded by replacement usage, while the risk financing of CAT bonds is not bounded at all; this greater flexibility can lead to more rational post-loss project selection, feed more opportunistic ventures, and foster significant post-crisis development. Another important advantage of CAT bonds is that they provide higher insurance penetration for catastrophe risks. Thieken et al. (2006) report that flood insurance has only a one-tenth penetration among single-family houses, indicating that people tend to under-insure with traditional private insurance. The scale of a catastrophe may make insurance companies unable to participate. However, CAT bonds, by transferring catastrophe risk among global financial investors, clearly tackle households' under-insurance issue and the under-participation of insurance companies. Thus, the CAT bond not only inherits the time advantage and no-crowd-out advantage of traditional insurance but also brings the additional benefits of investment flexibility and higher penetration. Through those features, the CAT bond could inspire more post-crisis development than any other risk financing mechanism. Based on respective levels of post-crisis development, a simple diagram illustrating the efficiency of various risk-financing strategies is shown in Figure 16 below.

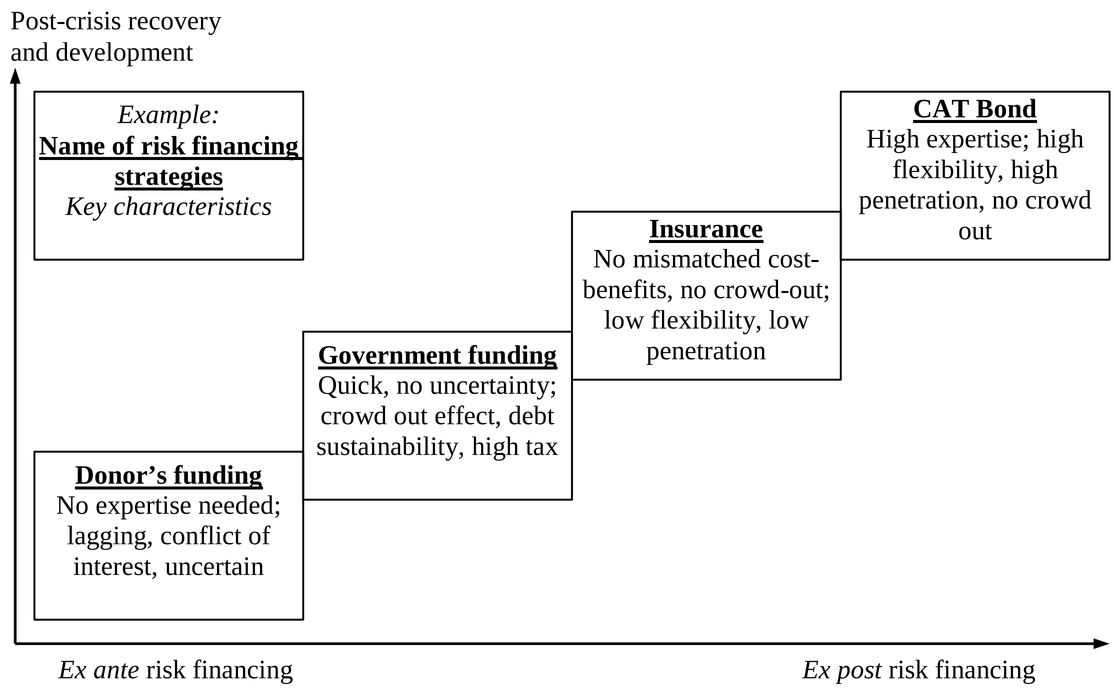

Figure 16 *Risk-financing Strategies and Post-crisis Economic Development*

3.3.3. CAT Bond as a Risk-Financing Strategy

In the preceding section, we compared the features of different risk-financing strategies in the context of post-crisis economic development. Having established the benefits of CAT bond as an effective development tool, we now want to examine its role in the field of risk management. Our discussion will be anchored around two key questions: whether a risk-financing strategy is necessary on a country level, and what kinds of advantages CAT bonds enjoy as a risk-financing strategy.

So far, we have been discussing the catastrophe risk on a country level. The well-known economic theorem of Arrow and Lind (1970) predicts that a country-level risk-financing strategy (such as insurance or a CAT bond) is not necessary, as governments will behave risk-neutrally on their public investment projects. From this perspective, a risk-neutral government should not purchase any insurance product unless its premium is actuarially fair. This government response may rule out the involvement of risk financing on a country level, since insurers are also risk averse and may not be willing to accept a premium equal to or less than the expected losses. Although somewhat counter-intuitive, this prediction is not without theoretical foundation; the risk-neutrality of governments is well supported by the ideas of risk pooling and risk spreading. On the one hand, a government can pool risks by holding a series of independent and uncorrelated assets. The idiosyncratic risks of those assets cancel out, making the aggregate risk at the country level negligible. In more statistical terms, risk pooling is based on the law of large numbers because the variance of the mean return decreases when the number of assets grows. On the other hand, government can spread the risk among its citizens through the channel of taxation. Even if one investment fails, the cost borne by each individual would be minimal due to the large population. However, the theorem of Arrow and Lind doesn't hold for catastrophe risk in developing countries (Mahul and Ghesquiere, 2007). First, we show in section 3.2 that catastrophes create large covariate risks in agrarian economies, which will reduce the degree of risk pooling on a country level, as the assets are no longer independent and uncorrelated. Second, the tax base of developing economies is relatively small compared to the size of economic losses caused by catastrophes. Therefore, risk spreading is not viable in developing countries because the catastrophic impact might be too big to be absorbed by a smaller group of poor citizens. Therefore, the theorem of risk neutrality is challenged by the infeasibility of risk pooling and risk spreading when countries are exposed to natural disaster risks. Moreover, country-level risk aversion will provide enough rationale and incentive for seeking risk-financing strategies for catastrophes, especially *ex ante* ones such as catastrophe insurance and CAT bonds. Ultimately, country-level risk financing is necessary for, and should be pursued by, developing countries to cope with catastrophe risks.

Given the necessity of a risk-financing strategy, we will identify several key advantages of the CAT bond as a risk-financing tool. First, CAT bonds help overcoming the low insurability problem of catastrophe risk. We believe that this low insurability stems from several well-known factors: adverse selection, moral hazard, and basis risk.

Under adverse selection, people prone to catastrophe risks are more likely to purchase insurance than are those immune to such risk. Adversely selected insurance buyers will inflate the equilibrium premium and undermine the insurance market. However, by issuing CAT bonds at the country level, government can equivalently buy insurance for both those prone to catastrophes and those immune. This way, the adverse selection behavior that reduces the insurability of catastrophe risk will be eliminated by the issuance of CAT bonds.

Under one type of moral hazard, people who bought catastrophe insurance may opt not to invest in risk-reduction projects (e.g., improvements in public infrastructure). Their behavior will increase the insurance premium and hence harm the insurance market. Traditionally, insurance companies have to rely on deductibles to cope with this problem because monitoring individual risk mitigation efforts is very costly. Issuing CAT bonds could be a better way to reduce this type of moral hazard. The bond market will typically incorporate all available information to determine an appropriate spread for the CAT bonds issued. If government moderates its risk reduction by adjusting its policy guidance, the capital market will easily monitor the policy changes of the government and punish it by charging a higher spread for the bonds issued. Fearing a spiking spread, the government will not slack on risk mitigation projects in the first place. Thus, the market-determined spread of CAT bonds under the capital market's monitoring helps alleviating the first type of moral hazard behavior without incurring the dead-weight loss of deductibles.

Another type of moral hazard is induced by the expectation of assistance from either the government or donors in the aftermath of catastrophic events. In this scenario, people believe government will eventually bail them out and will thus not purchase insurance *ex ante*. Even deductibles will not help tackle this type of moral hazard. For these people who decline to purchase insurance in the hope of a government bailout, CAT bonds actually represent a compulsory group insurance contract that the government purchases on their behalf and funds with their taxes. Therefore, the CAT bond helps preventing both types of moral hazard issues commonly seen in individual insurance contracts because of its market-based pricing mechanism and centralized decision-making process.

The moral hazard and adverse selection problems are related more closely to traditional indemnity insurance than to the newly emerged index/parametric insurance. Index insurance calculates individuals' indemnity payments based on an index rather than the actual loss; thus, individuals may be overpaid or underpaid for their loss. This risk of mismatched losses and payments is called "basis risk." When the index CAT bonds were triggered, the government could actively calculate and distribute the indemnity payment to the victims based on the observed losses. This way, the index CAT bond along with an indemnity distribution mechanism help approximating the payments to the actual losses and thus reduce the basis risk on an individual level. We have thus identified the CAT bond's major advantage of improving natural disasters' insurability through its capacity to address issues such as adverse selection, the moral hazard, and basis risk.

Another potential advantage of the CAT bond as a risk-financing strategy is its lower cost structure relative to traditional insurance and reinsurance products for natural disasters. Mechler (2004) believes that large losses from US catastrophes strained the capacity of the reinsurance market and raised the price of reinsurance in the 1990s. In response, CAT bonds were designed to avoid the reinsurance cycles arising from reinsurers' practice of static premium adjustment between peak years and years with reduced catastrophe activity. Mechler (2004) further suggests that CAT bonds could enjoy lower costs because they avoid the load (or the required profit margin) of insurers, which can be over and above the transaction costs and return on risk absorption. Litzenberger et al. (1996) point out that CAT bonds are attractive to investors because catastrophic events have low correlations with returns from securities markets and hence are valuable for diversification purposes. Due to this diversification value, investors may reward CAT bond issuers with lower spreads than those enjoyed by high-layer reinsurance. Finally, Cummins (2008) finds that the cost of CAT bonds, gauged by the ratio of yield to expected loss, declined between the 1990s and 2007 except during Hurricane Katrina in 2005. This declining yield could be explained by favorable market development including growing market liquidity, rating agency support, and investor interest. Michel-Kerjan et al. (2013) conclude that the ratio of yield to expected losses for CAT bonds dipped to the 2.5 to 3 range in the post-Katrina era (2007–08), while the same ratio for reinsurance remained in the 3 to 5 range. Overall, there are several potential cost advantages of CAT bonds as a risk-financing strategy; however, they can be diluted once numerous transaction costs (e.g., risk assessment fee, legal fee, administrative cost of SPV and underwriting fee) are considered.

3.3.4. Case Study of Mexican CAT Bond Issuances

Mexico was among the first countries to deploy alternative risk transfer (ART) instruments such as the CAT to protect itself from natural disasters. Mexico suffered from severe seismic and hurricane activities that had caused enormous damage. For example, Mexico City and the surrounding area suffered two sequential earthquakes with magnitudes of 8.1 and 7.3 Mw Richter scale on September 19 and 20, 1985. The earthquake killed 6,000 people and generated direct and indirect losses estimated at US $8.3 billion in 2010 terms (World Bank 2012). The insurance payouts for the disaster were estimated to be 4 billion USD by Mexican insurance industry officials (Hardle and Cabrera 2010).

In response to those devastating disasters, the Mexican government had to shift its financial resources from committed projects to recovery and reconstruction projects. This caused delays and scaled back planned investment projects. To avoid this competition of resources and to ensure immediate post-disaster reconstruction, the Mexican government established a special budget line called "FONDEN" (Mexico's Natural Disaster Fund) in 1996. The budget has three mandates: (1) to finance emergency assistance to the affected population; (2) to finance the post-disaster reconstruction of public infrastructures; and (3) to finance the reconstruction of low-income housing (World Bank 2012). With the help of FONDEN, the Mexican government can directly dedicate budget funds to post-disaster reconstruction efforts without compromising other important projects.

Funded by taxes, FONDEN occasionally runs short when a series of disasters hits. In years with extreme and frequent disasters, FONDEN's trust reserve becomes insufficient to cover the losses, requiring government funds from other budget line items to fill the gap. In 2006, a new budget law was approved to address the regular shortfall in FONDEN's trust reserves, simplify FONDEN's allocation approval process, and expedite its resource authorization (World Bank 2012). Along with these legislative changes, the government also started to use ART instrument to reduce its budgetary pressure by transferring certain risk exposures to the capital market.

In May 2006, FONDEN sponsored the world's first government CAT bond, called "CatMex." CatMex is a pure parametric CAT bond covering earthquake risk in three earthquake zones. This issuance has a total worth of $160 million: one larger tranche of the CAT bond ($150 million) covering the Central Cocos area pays LIBOR plus 235 basis points to the investors and has an annual expected loss (AEL[11]) of 0.96%; one smaller tranche ($10 million) covering the Northwest and Outer Mexico City areas pays LIBOR plus 230 basis points and has an AEL of 0.93% (Hardle and Cabrera 2010). This $160 million CAT bond is part of a $450 million reinsurance package provided by Swiss Re. The payout of the principal would be triggered if (1) an official state of emergency is declared by the government, or (2) an earthquake reaching a pre-determined magnitude and depth is registered in the selected zones. Once a qualifying earthquake event is triggered, Swiss Re will receive the principal amount of CatMex from the escrow account of the SPV and pay the Mexican government for the insured coverage.

The Mexican government entered into a second CAT bond issuance in 2009 after the expiration of CatMex in the same year. This new issuance was guided by the newly established World Bank's MultiCat program with four tranches and three years of maturity. A major new feature that distinguishes the MultiCat 2009 CAT bond from the CatMex is that it covers multiple risks. As with the CatMex, earthquake risks are covered, but the MultiCat transaction also includes hurricane risks, on both the Pacific

[11] Annual expected loss (AEL) is defined as a percentage of the total insurance payout

and Atlantic costs of the country. This issuance of MultiCat 2009 has a total worth of $290 million: Class A tranche, covering the earthquake risks ($140 million), pays 11.5% over the US Treasury Money Market Fund rate and has an AEL of 4.65%; Class B, C, and D tranches, covering the hurricane risks ($50 million each), pay 10.25% over the US Treasury Money Market Fund rate and have an AEL of 4.07%, 4.22%, and 4.29%. MultiCat 2009 was reviewed and rated by S&P, with B ratings given for classes A, B, and C and a BB- rating for class D. MultiCat 2009 is also a parametric CAT bond, and the payout of its principal would be related to binary triggers on both earthquakes and hurricanes. The payout will be triggered if (1) an official state of emergency is declared by the government, (2) an earthquake reaching a pre-determined magnitude and depth is registered in the selected zones, or (3) a hurricane reaching a pre-determined central pressure is registered in the selected zones. To avoid the risk of manipulation, third-party agents were invited to report the parameters of the triggering event: the U.S. Geological Survey was brought in for earthquakes and the U.S. National Hurricane Centre for hurricanes (World Bank 2012). The risk-modeling firm Applied Insurance Research (AIR) Worldwide Corporation will verify if the payout should be triggered based on those parameters. It is worth noting that MultiCat 2009 exceeded its subscription by 2.5 times and that the issuing size was upwardly revised from an initial quote of $250 million to $290 million because of the strong investor appetite for catastrophe risk products.

To capture a favorable capital market demand and roll over protection, FONDEN sponsored a third CAT bond issuance in 2012, with protection for another three years.

This MultiCat 2012 has a structure similar to that of MultiCat 2009 but comes with a slightly larger issuance size of $315 million to extend the coverage. MultiCat 2012 also enjoys a better pricing: its Class A tranche covering earthquake risks ($140 million) pays 8.0% over the US Treasury Money Market Fund rate and has an AEL of 4.40%; its Class B and C tranches covering hurricane risks ($75 million and $100 million) pay 7.75% and 7.50% over the US Treasury Money Market Fund rate and have an AEL of 2.73% and 4.36% respectively (ARTEMIS 2012). MultiCat 2012 was also reviewed and rated by S&P and given a B rating for Class A, a B+ rating for Class B, and a B- rating for Class C. This class is unique in that it pays out either 50% or 100% to the sponsor depending on the severity of the triggering events, thus providing a broader spectrum of protection than the other classes, which pay out 0% if not triggered and 100% if triggered.

The successful implementation of the Mexican CAT bond has taught us several lessons. First, countries prone to natural disaster risks and suffering from the related budgetary pressure should seriously consider transferring these risks to the capital markets through CAT bonds. Second, the global capital market has increased its demand for CAT bonds, as the growing issuance and sizable over-subscription of Mexican CAT bonds show. Third, the World Bank, AIR, Swiss Re, and other institutions have developed the functional expertise and institutional knowledge to launch CAT bonds on behalf of governments. Interested countries could directly inherit the framework and procedures set up by these participants, thus achieving faster execution and lower costs.

3.4. Summary

This chapter has many policy implications for the governments of LDCs. We show that the covariant risks created by catastrophes will impact LDCs in many ways that might be easily overlooked. For example, a catastrophe may shock the victims into persistent poverty because victims below certain assets threshold may lose assets and enter a downward spiral. Therefore, catastrophes not only create near-term economic losses and human injuries but also induce long-term poverty traps. In LDCs, the severity of catastrophe-induced poverty traps is amplified, since formal insurance and credit markets at the household level barely exist. To tackle this challenge, policymakers in LDCs should consider insurance products such as the CAT bond that allows both *ex ante* risk financing and *ex post* economic development at the country level.

We recommend CAT bonds as an advantageous economic development tool and risk-financing strategy, based on our comparison with other strategies, such as donor funding, government funding, and insurance. We prefer CAT bonds as a development tool because (1) the reimbursement of CAT bonds could be used on any post-crisis project rather than purely for replacement and thus achieves a higher flexibility on investment return; (2) the CAT bond could be issued at the country level, providing a higher insurance penetration than traditional insurance at the household level. We prefer CAT bonds as a risk-financing strategy because (1) CAT bonds could help overcome the low insurability problem of catastrophe risks caused by adverse selection, moral hazard, and basis risk; and (2) the CAT bond enjoys a lower cost structure than do traditional insurance and reinsurance products for natural disasters. In the CAT bond issuance after the Mexican earthquake, the Mexican government believes that CAT bonds help avoiding competition among resources and ensuring immediate post-disaster reconstruction. The case of Mexican CAT bond issuance provides nice learning materials for policy makers in other LDCs.

Our contribution to the literature is threefold: (1) we show the relationship between catastrophe and poverty trap; (2) we compare the CAT bond with other risk financing strategies; and (3) we document the advantages of the CAT bond as a development tool and a risk-financing strategy. We believe further research could be done to (1) develop a model to show how CAT bonds relieves the problem of poverty traps; and (2) test whether an *ex ante* risk financing strategy like CAT bond could generate better measurable returns than other risk financing strategies for LDCs.

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CHAPTER 4

CATASTROPHE BONDS AND SOVEREIGN DEBT SUSTAINABILITY

4.1. Motivation

The sustainability of public debt is a key issue in macroeconomic research, as it is closely related to the growth and development of a country. A debt crisis triggered by economic downturns, over borrowing, plummeting commodity prices, or even natural disasters would incur social welfare and permanent income losses in the debtor country (Caselli and Malhotra 2004). The sovereign debts of many least-developed countries (LDCs) are especially prone to natural disasters for several reasons: (1) the tax base of many LDCs relies heavily on a few disaster-prone sectors like agricultural and tourism; (2) the GDPs of LDCs are too small to absorb the hits of natural disasters; and (3) LDCs typically don't prepare budget buffers for emergency aid in case of a natural disaster. To prevent natural disasters from causing a sovereign debt crisis, a country needs to insure against natural disasters and create automatic debt stabilizers. CAT bonds just serve as an insurance contract, help relieve the budgetary pressure, and allow the debtor country to avoid sovereign default. Therefore, it is worthwhile discussing the relationship between CAT bonds and sovereign debt default in a static social wealth maximizing framework. Within this framework, we ask several questions. (1) Under what conditions will a debtor country issue a CAT bond, and will it increase social welfare? (2) Will the newly issued CAT bond crowd out the previously optimal amount of sovereign bonds? (3) Will the debtor country have less incentive to default on its sovereign bonds if more CAT bonds are issued? The answers to those questions would help LDCs better understand the importance of the government-sponsored CAT bond in the sustainability of sovereign bonds.

4.2. What is Sovereign Debt?

Sovereign debt is the debt issued by a national government to finance the debtor country's growth and development. In the literature, sovereign debt generally refers to external sovereign debt, which is often issued under the legal jurisdiction of foreign governments, denominated in reserve currencies, and held by foreign investors. Eaton and Fernandez (1995) mention two key differences between sovereign and private debt. First, they believe that there is often little that a sovereign entity can use as collateral to guarantee the value of a loan. Second, they argue that a court's ability to force a sovereign entity to comply with its wishes is extremely limited. Borensztein and Panizza (2009) also point out that creditor rights concerning sovereign debt are weaker than those concerning private debt because many assets in debtor countries are immune to legal action. Given this immunity and the weak base of collaterals, sovereign debt is often associated with higher default risks, especially for developing countries. Foreign investors typically demand a high interest rate in compensation for the risk of default. According to Morningstar, the average mutual fund investing in emerging-market debt has returned 10.4% per year since 1998, beating the average 8.2% return of emerging-market stock funds and the average 7.8% return of mutual funds investing in long-term T-bonds over the past 15 years.

4.3. Sovereign Debt Default and its Costs

Due to the ineffective repayment enforcement of sovereign debt, sovereign debt default is not uncommon in the international finance market. Notable recent defaults include the Latin American debt crisis of 1982, the Russian default of 1998, and the Greek debt crisis of 2011. Linbert and Morton (1989) offer a simple definition of a sovereign debt crisis: a debt crisis exists if, in the absence of a better offer, the debtor would rather impose unilateral non-repayment than repay fully. Given this definition, one may wonder what the rationale is for a national debt default and whether a "tipping point" in the default process is there.

Economic theories posit that sovereign default happens when the cost of servicing the remaining debt overweighs the cost of default. The cost of serving the debt is easy to compute with the coupon rate, but the cost of default is difficult to gauge and thus attracts most research attention. Borensztein and Panizza (2009) shortlist four types of default costs: reputational costs, international trade exclusion costs, costs to the domestic economy through the financial system, and political costs to the authorities. About reputational cost, early work by Eaton and Gersovitz (1981) shows that, under certain conditions, the threat of losing access to future credit is a sufficient condition for debt repayment. However, a threat to exclude a country from future borrowing may not be credible. For example, Bulow and Rogoff (1989) point out that reputational cost can be avoided by investing the debt repayment in financial assets that generate a higher level of social welfare; empirical evidence found by English (1996) and Tomz (2007) tends to support this view. Borensztein and Panizza (2009) find that the higher borrowing cost caused by default is tainted and significant but also short lived. About trade sanction cost, Sachs and Cohen (1982), Bulow and Rogoff (1989), and Fernandez and Rosenthal (1990) conclude from their models that the debtor country repays its debt due to the fear of direct trade sanctions from the creditor countries; Rose (2005) and Borensztein and Panizza (2009) find supportive empirical evidence for this view. Past studies focus on the external cost of default enforced by creditors such as reputational cost and sanction cost, while most recent research focuses on the domestic costs of default through the financial or political systems. For example, Borensztein and Panizza (2009) argue that sovereign defaults can lead to banking crises or a domestic credit crunch and thus incur costs to the domestic economy. Broner, Martin, and Ventura (2009) claim that secondary markets may serve to reallocate bond holdings in such a way as to deter default by making the costs of default fall primarily on domestic residents. Concerning examples of the political costs, Borensztein and Panizza (2009) believe that the political consequences of a debt crisis are dire for incumbent governments and finance ministers. They empirically demonstrate that sovereign defaults significantly shorten the term length of governments and officials in charge of the economy.

4.4. Natural Disasters and Sovereign Debt Default

Natural disasters often pose an enormous challenge for the budgeting and debt sustainability of LDC governments because they are not fully insured against catastrophic risk at both the individual and the government level. Rasmussen (2004) finds that the 12 large natural disasters in the Eastern Caribbean Currency Union

(ECCU) produced a median reduction in annual GDP growth of 2.2% and a median increase in the current account deficit equal to 10.8% of GDP. In another example, Mexico City was hit by an earthquake of magnitude 8.1 in 1985, killing 10,000 people and causing economic damage of 3 billion USD. Given a real GDP of 200 billion USD in 1985, the earthquake caused damage of at least 1.5% of annual GDP output.

Despite the threat of natural disasters, implementing disaster insurance in LDCs is still difficult. Borensztein et al. (2009) argue that market unavailability and political resistance are two of the major obstacles. They claim that the insurance markets have traditionally been insufficiently developed or simply do not exist in LDCs. They also believe that politician are reluctant to engage in insurance purchase because insurance costs money today, but the payoff will occur in the future, when the government may have changed hands.

Eaton and Fernandez (1995) identify three types of distortion emerging at different stages in the relationship between borrowers and lenders: (1) when creditors originally make the loans, (2) when debtors face the burden of repaying debt, and (3) when the lending community reacts to those burdens. Corresponding with these three stages, we can also identify three types of distortion in countries that periodically experience natural disaster-triggered sovereign debt crises: (1) when the debtor country borrows less money *ex ante* to reserve the necessary financial resources for drought; (2) if, once a drought hits, the debtor country either defaults and then suffers from default costs (e.g., higher sovereign risk premium and exclusion from future credit markets) that are deadweight losses or withholds emergency aid and thus creates social welfare losses; (3) if the debtor country imposes a tighter fiscal policy to relive the burden of repaying debts, leading to the abandonment of profitable investments and damaging the domestic output.

Several natural disaster triggered sovereign defaults have occurred before. In 1931, a hurricane caused the Dominican government to default. In 1999, Turkey was hit by its worst-ever earthquake, causing GDP to decline by 3.4% and inflation to rise by 68.8%. Following the economic depression triggered by the earthquake, the Turkish government partially defaulted and imposed a withholding tax on all sovereign bonds denominated in domestic currency. In 2004, Grenada suffered heavily from Hurricane Ivan, which caused more than 200% of GDP damage. Because of the hurricane, two interest payments on two large sovereign bonds were missed at the end of 2012. In 2010, Haiti was also hit by a devastating earthquake. Although Haiti didn’t officially default, the World Bank and other international institutions voluntarily cancelled Haiti’s debt to help its reconstruction efforts.

4.5. CAT Bonds and Social Welfare

We will use a wealth-maximizing model to discuss the social welfare dimension of CAT bonds. Our approaches are similar to those of Borch (1962) and Lakdawalla and Zanjani (2012). We assume that there are two state contingent claims or assets in this economy—sovereign bond and the CAT bond, both issued to external investors and with special features. First, if a natural disaster hits the economy, the government can choose to default certain portion of its sovereign bonds and transfer the repayment owing to the sovereign bond investors to the disaster victims. Second, the CAT bond will be triggered during natural disasters, with its principal fully reimbursed from the SPV back to the government. To facilitate our discussion, we first consider the first case in which only the sovereign bond is available to the debtor country. Then we consider the second case that both sovereign bond and CAT bond become available to the debtor country. Comparing the two cases, we find encouraging results from our wealth maximizing model: (1) the debtor country will subscribe to positive amount of CAT bonds and create welfare increase if the opt-in condition of CAT bond is met; (2) the positive amount of the CAT bonds subscribed will crowd out the previously optimal amount of sovereign bonds; (3) a country that had no incentive to default will continue to have no incentive to do so even with the introduction of CAT bonds; (4) a country that previously had certain incentive to default will have less incentive to default on its sovereign bonds if more CAT bonds are issued; and (5) the debtor country will have more incentive to repay the defaulted sovereign bond with the proceeds of CAT bonds.

In the first case, we assume that only the sovereign bond is available. The economy is endowed with an initial wealth of W, and it will issue sovereign bonds of amount A in the first period. This economy uses one production technology, and its only input is the national wealth endowment in that period. The technology is captured by an increasing and concave production function $P(W)$, which is twice differentiable. In the second period, the economy will incur a loss of L should a natural disaster happen.

For simplicity, we specify only two states in the second period: X denotes the state of natural disaster, and its probability is defined as $Pr(X)$; Y denotes the good state, and its probability is defined as $Pr(Y)$. Once the disaster hits, we assume that the government may choose to default α portion of its sovereign bond. It is also reasonable to assume that social planners will pass the coupon cost associated with the bonds with tax collected in both states. The coupon cost of sovereign bonds will be denoted by r_A. Finally, we cannot forget that the economy will suffer from a certain default cost. We will use an increasing and concave damage function $D(Z)$ to capture it, which is also twice differentiable. We can define the social wealth maximizing problem for this economy as

$$P(W+A)+Pr(X)P[(W+A)-L-A+\alpha A-T]-Pr(X)D(\alpha A) \\ +Pr(Y)P[(W+A)-A-T] \tag{44}$$

In the first period, the initial wealth of W was added to by the sovereign bond proceed of A. In the second period, the wealth in period 1 is carried over. Then in the disaster state, a portion of the sovereign bond, αA, will be defaulted to the investors. In the normal state, the entirety of the sovereign bond will be repaid to the investors. The national wealth function 44 can be reduced as

$$\max_{\alpha,A,T} P(W+A)+Pr(X)P[W-L+\alpha A-T]-Pr(X)D(\alpha A) \\ +Pr(Y)P[W-T] \tag{45}$$

subject to

$$[\mu]: T \geq r_A A \tag{46}$$

$$[\lambda]: 0 \leq \alpha \tag{47}$$

If we record function 45 in short as $f(W)$, the first-order conditions for this wealth-maximizing problem can be derived as

$$\left[\frac{\partial f}{\partial A}\right]: \frac{\partial P}{\partial W} + \alpha * Pr(X) * \frac{\partial P^X}{\partial W} - \alpha * Pr(X) * \frac{\partial D}{\partial Z} - \mu * r_A \leq 0 \tag{48}$$

$$\left[\frac{\partial f}{\partial T}\right]: - Pr(X) * \frac{\partial P^X}{\partial W} - Pr(Y) * \frac{\partial P^Y}{\partial W} + \mu \leq 0 \tag{49}$$

$$\left[\frac{\partial f}{\partial \alpha}\right]: Pr(X) * \frac{\partial P^X}{\partial W} * A - Pr(X) * \frac{\partial D}{\partial Z} * A + \lambda \leq 0 \tag{50}$$

Based on these FOCs, we will show how an analytical solution could be found. We will split the discussion into two cases: (1) $\alpha = 0$ and (2) $\alpha > 0$. We didn't limit the upper bound of α to 1 because it is impossible to initiate discussion on this upper bound without knowing the production function and the values of each variable.

In case (1), if $\alpha = 0$, Lagrangian multiplier λ will be non-negative. The marginal return of α, shown by FOC (50), will be non-positive. Therefore, the necessary condition for $\alpha = 0$ would be that the term $\frac{\partial P^X}{\partial W} - \frac{\partial D}{\partial Z}$ is non-positive. This necessary condition would hold if the damage of the default is greater or equal to the benefits of not repaying the principal.

If A and T exist with positive values, FOC (48) and (49) would become zero at the optimal point and thus be reduced as

$$\left[\frac{\partial f}{\partial A}\right]: \frac{\partial P}{\partial W} - \mu * r_A = 0 \tag{51}$$

$$\left[\frac{\partial f}{\partial T}\right]: -Pr(X) * \frac{\partial P^X}{\partial W} - Pr(Y) * \frac{\partial P^Y}{\partial W} + \mu = 0 \tag{52}$$

From FOC (51) and (52), a set of optimal solutions for $\alpha = 0$ could be derived as

$$when\ \alpha = 0, \exists [A_1, T_1] : \frac{\partial P}{\partial W} - \left[Pr(X)\frac{\partial P^X}{\partial W} + Pr(Y)\frac{\partial P^Y}{\partial W}\right] * r_A = 0\ subject\ to\ T = r_A A \tag{53}$$

In case (2), if $\alpha > 0$, Lagrangian multiplier λ will be zero. Since α is positive, FOC (50) should come with equality and be written as

$$\left[\frac{\partial f}{\partial \alpha}\right]: Pr(X) * \frac{\partial P^X}{\partial W} * A - Pr(X) * \frac{\partial D}{\partial Z} * A = 0 \tag{54}$$

By dividing A and $Pr(X)$, FOC (54) could be further reduced to

$$\left[\frac{\partial f}{\partial \alpha}\right]: \frac{\partial P^X}{\partial W} = \frac{\partial D}{\partial Z} \tag{55}$$

We can substitute equation (55) into FOC (48). If A and T exist with positive values, FOC (48) and (49) can be forced into equality and be further transformed into

$$\left[\frac{\partial f}{\partial A}\right]: \frac{\partial P}{\partial W} - \mu * r_A = 0 \tag{56}$$

$$\left[\frac{\partial f}{\partial T}\right]: -Pr(X) * \frac{\partial P^X}{\partial W} - Pr(Y) * \frac{\partial P^Y}{\partial W} + \mu = 0 \tag{57}$$

Although equations (56) and (57) look similar to equations (51) and (52), it should be noted that the $\frac{\partial P^X}{\partial W}$ components in equations (56) and (57) contain the α term, while equations (51) and (52) do not. Thus, a new set of optimal solutions for $\alpha > 0$ could be derived as

$$when\ \alpha > 1, \exists[\alpha_2, A_2, T_2] : \frac{\partial P}{\partial W} - \left[Pr(X)\frac{\partial P^X}{\partial W} + Pr(Y)\frac{\partial P^Y}{\partial W}\right] * r_A = 0\ subject\ to\ T = r_A A \tag{58}$$

Given these solutions, we need to ask what happens if the CAT bonds become available to this economy. How will the optimal amount of sovereign bond and its defaulting portion change? What are the necessary conditions for the economy to switch to CAT bonds? Will this economy use the reimbursed payment from CAT bonds to repay the default-able portion of its sovereign bonds? These questions are closely related to the welfare of this economy once it is open to CAT bonds. We will define the wealth maximizing problem with the introduction of CAT bonds as

$$\begin{aligned} P(W + A + B) + Pr(X)P[(W + A + B) - L - A + (\alpha A - \beta B) - T] \\ - Pr(X)D(\alpha A - \beta B) \\ + Pr(Y)P[(W + A + B) - A - B - T] \end{aligned} \tag{59}$$

As captured in equation (59), the amount of CAT bonds is denoted by B, and the economy will use β portion of its CAT bond reimbursement to repay the default-able portion of the sovereign bonds in the disaster state. The government can choose to use the CAT bond reimbursement as a transfer payment to reduce the amount of sovereign default. Thus, the actual defaulted amount of sovereign bonds will become $\alpha A - \beta B$, and the damage to the economy will be $D(\alpha A - \beta B)$, based on the damage function. Since the principal of the CAT bond will be forgone in the disaster state, we don't subtract B in the bad state of period 2. The national wealth function (59) will be further reduced as

$$\max_{\alpha,\beta,A,T} P(W + A + B) + Pr(X)P[W - L + B + (\alpha A - \beta B) - T] \\ - Pr(X)D(\alpha A - \beta B) + Pr(Y)P[W - T] \tag{60}$$

subject to

$$[\mu]: T \geq r_A A + r_B B + Pr(X) * B \tag{61}$$

$$[\lambda]: \alpha \geq 0 \tag{62}$$

$$[\delta]: \beta \geq 0 \tag{63}$$

The tax revenue the government collected is used to satisfy the required returns of the sovereign bond and the CAT bond. Aside from the coupon costs r_A and r_B, the required return also includes the expected loss of the CAT bond, which will be demanded by external CAT bond investors. This expected loss of the CAT bond is based on the expected probability of the disaster event and is defined as the actuarially fair return of $Pr(X) * B$.

The first-order condition for this wealth-maximizing problem can be solved as

$$\left[\frac{\partial f}{\partial A}\right]: \frac{\partial P}{\partial W} + \alpha * Pr(X) * \frac{\partial P^X}{\partial W} - \alpha * Pr(X) * \frac{\partial D}{\partial Z} - \mu * r_A \leq 0 \tag{64}$$

$$\left[\frac{\partial f}{\partial B}\right]: \frac{\partial P}{\partial W} + (1-\beta) * Pr(X) * \frac{\partial P^X}{\partial W} + \beta * Pr(X) * \frac{\partial D}{\partial Z} - \mu * r_B - \mu * Pr(X) \leq 0 \tag{65}$$

$$\left[\frac{\partial f}{\partial \alpha}\right]: Pr(X) * \frac{\partial P^X}{\partial W} * A - Pr(X) * \frac{\partial D}{\partial Z} * A + \lambda \leq 0 \tag{66}$$

$$\left[\frac{\partial f}{\partial \beta}\right]: - Pr(X) * \frac{\partial P^X}{\partial W} * B + Pr(X) * \frac{\partial D}{\partial Z} * B + \delta \leq 0 \tag{67}$$

$$\left[\frac{\partial f}{\partial T}\right]: - Pr(X) * \frac{\partial P^X}{\partial W} - Pr(Y) * \frac{\partial P^Y}{\partial W} + \mu = 0 \tag{68}$$

Let us first assume that $\alpha = 0$. In this case, we note that the actual defaulted amount of sovereign bond, $\alpha A - \beta B$, is no less than zero because a negative value of such term implies that the government is willing to pay more than what it owes. To make it greater than zero, β should be zero if the optimal amount of the CAT bond is greater than zero. If the optimal amount of the CAT bond is zero, it is meaningless for β to stay positive. Therefore, β will always be zero when $\alpha = 0$. So the condition that $\alpha, \beta = 0$ will become the first scenario for our analysis.

In the second case, we alternatively assume that $\alpha > 0$. This implies that the Lagrangian multiplier λ is zero and that FOC (66) needs to be forced into equality. By rearranging FOC (66), we can see that $\frac{\partial P^X}{\partial W}$ equals to $\frac{\partial D}{\partial Z}$. These two terms appear again in FOC (67) and will cancel each other out. For this reason, the remaining term δ in FOC (67) must be no greater than zero. According to constraint (63), δ should be no less than zero. Combining these two constraints on δ, we can conclude that δ always equals zero. According to the complementary slackness condition, β will be greater or equal to zero when $\delta = 0$. Thus, $\alpha > 0, \beta \geq 0$ will be the second scenario for our analysis.

In the scenario of $\alpha, \beta = 0$, FOC (64) and (65) will be simplified as

$$\left[\frac{\partial f}{\partial A}\right]: \frac{\partial P}{\partial W} - \left[Pr(X)\frac{\partial P^X}{\partial W} + Pr(Y)\frac{\partial P^Y}{\partial W}\right] * r_A \tag{69}$$

$$\left[\frac{\partial f}{\partial B}\right]: \frac{\partial P}{\partial W} + Pr(X) * \frac{\partial P^X}{\partial W} - \mu * r_B - \mu * Pr(X) \tag{70}$$

Now, let us assume that this economy will transform from a financially disadvantaged and not-willing-to-default economy with $\alpha = 0$ and A_1 in solution (53) to a financially advantaged economy in which CAT bonds are available. What will happen? Substituting $A = A_1$ and $B = 0$ in FOC (69) makes FOC (69) equal to zero, which produces $\frac{\partial P}{\partial W} = \mu * r_A$. Therefore, we can re-write FOC (70) as

$$\left[\frac{\partial f}{\partial B}\right]: Pr(X) * \frac{\partial P^X}{\partial W} - [\mu * (r_B + Pr(X) - r_A)] \tag{71}$$

We will substitute $A = A_1$ and $B = 0$ again into the $\frac{\partial P^X}{\partial W}$ part of FOC (71) and evaluate the marginal return of B from the first order condition. If the marginal return is greater than zero, the economy will start issuing CAT bonds, as additional bonds will reduce the value of $\frac{\partial P^X}{\partial W}$ due to the production function's concavity. Therefore, the national opt-in and welfare-increasing conditions for CAT bonds is

$$Pr(X) * \frac{\partial P^X}{\partial W} > \mu * [r_B - r_A + Pr(X)]\ at\ (A = A_1; B = 0) \quad (72)$$

Opt-in condition (73) is simply saying that an economy will start issuing CAT bonds if the CAT bonds' marginal return of smoothing the consumption in the bad state overweighs the difference of required returns multiplied by the marginal return of tax. This evaluation of the marginal return of CAT bonds should be conducted with $A = A_1; B = 0$, which is obtained in solution (53).

Suppose opt-in condition (72) is satisfied. Another effect of increasing CAT bond issuance is to crowd out and reduce the optimal amount of sovereign debt. Additional B will reduce the value of $\frac{\partial P}{\partial W}$ and $\frac{\partial P^X}{\partial W}$, but increase the value of $\frac{\partial P^Y}{\partial W}$ in FOC (69). The changes in $\frac{\partial P}{\partial W}$ and $\frac{\partial P^Y}{\partial W}$ will help reduce the value of FOC (69), while the change in $\frac{\partial P^X}{\partial W}$ will help increase its value. Since the probability of disaster is small (e.g., 1%), the impact of $\frac{\partial P^X}{\partial W}$ should be relatively small compared with the other two terms. For this reason, the optimal value of A should be reduced once condition (72) is met and additional CAT bonds are introduced into the economy. The crowding out effect can be expressed as

$$\frac{\partial R_A}{\partial B} < 0 \therefore \frac{\partial A}{\partial B} < 0 \quad (73)$$

In the scenario of $\alpha > 0$ and $\beta \geq 0$, FOC (64) to (67) will be reduced as

$$\left[\frac{\partial f}{\partial A}\right]: \frac{\partial P}{\partial W} - \mu * r_A \tag{74}$$

$$\left[\frac{\partial f}{\partial B}\right]: \frac{\partial P}{\partial W} + Pr(X) * \frac{\partial P^X}{\partial W} + Pr(X) * \frac{\partial D}{\partial Z} - \mu * r_B - \mu * Pr(X) \tag{75}$$

$$\left[\frac{\partial f}{\partial \alpha}\right]: Pr(X) * \frac{\partial P^X}{\partial W} * A - Pr(X) * \frac{\partial D}{\partial Z} * A \tag{76}$$

$$\left[\frac{\partial f}{\partial \beta}\right]: - Pr(X) * \frac{\partial P^X}{\partial W} * Pr(X) + Pr(X) * \frac{\partial D}{\partial Z} * B \tag{77}$$

Now, let us assume that this economy will transform from a financially disadvantaged and willing-to-default economy with α_2 and A_2 in solution (58) to a financially advantaged economy with CAT bonds available. What will happen? Substituting $\alpha = \alpha_2$, $A = A_2$ and $B = 0$ into FOC (74) and FOC (75) produces a similar CAT bonds opt-in condition:

$$Pr(X) * \frac{\partial P^X}{\partial W} > \mu * \left(r_B - r_A + Pr(X)\right)\ at\ (\alpha = \alpha_2; A = A_2; B = 0) \tag{78}$$

We can further assume that the opt-in condition (78) is satisfied and a positive amount of B is issued. What will happen to the optimal value of α and β? Holding other factors constant, we know that $\frac{\partial P^X}{\partial W}$ will decrease as B increases and $-\frac{\partial D}{\partial Z}$ will decrease (if $\beta > 0$) or at least stay the same (if $\beta = 0$) as B increases. Therefore, the marginal return of α will become negative along with the increase of B; hence, α should decrease to get R_α back to zero. We note that the marginal return of β is just the negative R_α. Thus, R_β will become positive along with the increase of B, and β should increase to get R_β back to zero. These two effects can be captured by

$$\frac{\partial R_\alpha}{\partial B} < 0 \therefore \frac{\partial \alpha}{\partial B} < 0 \tag{79}$$

$$\frac{\partial R_\beta}{\partial B} > 0 \therefore \frac{\partial \beta}{\partial B} > 0 \tag{80}$$

Our finding could be summarized as in Figure 17: (1) the debtor country will subscribe to positive CAT bonds and create a welfare increase once its marginal return, created by smoothing disaster state consumption, overweighs the difference of required returns multiplied by the marginal return of tax; (2) the positive amount of CAT bonds subscribed will crowd out the previously optimal amount of sovereign bonds (if the disaster has only a small chance of occurring); (3) the debtor country will have less incentive to default its sovereign bonds if more CAT bonds are issued; (4) a country that previously had no incentive to default will continue to have no incentive to do so even with the introduction of CAT bonds.; and (5) the debtor country will have more incentive to repay the defaulted sovereign bond with the proceeds of CAT bonds if it previously had a default incentive on its sovereign bonds.

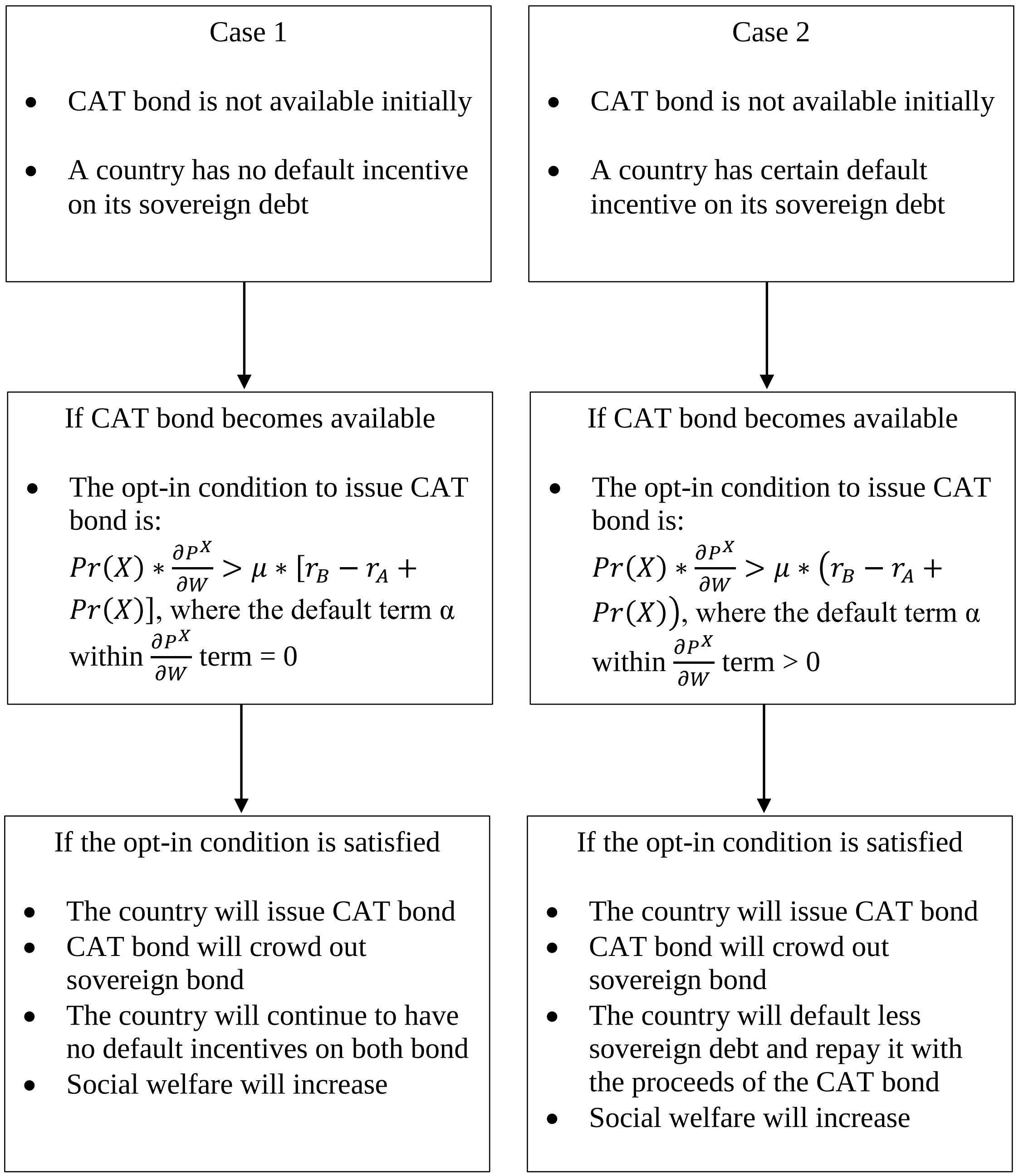

Figure 17 *Propositions Derived from the Wealth-maximizing Problem*

4.6. Summary

The sovereign debts of many LDCs are especially prone to natural disasters because of their small GDP size, tax base, and budget buffers. To prevent a sovereign debt crisis after a natural disaster, a country must insure against natural disasters and create automatic debt stabilizers. The CAT bond can serve as an insurance contract, help repay the sovereign bond, and help a debtor country avoid sovereign default. Using a static social wealth-maximizing framework, we prove that CAT bonds could increase social welfare, crowd out the sovereign debt issued, and reduce the default incentive on sovereign debt. Therefore, CAT bonds could enhance LDCs' debt sustainability. We contribute to the literature by examining the social welfare and debt sustainability implications of CAT bonds using a static wealth maximizing model. We believe further research could be done by empirically testing the sovereign debt yields before and after CAT bond issuance or by extending the existing static model into an inter-temporal model.

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CHAPTER 5

PRICING AND SIMULATION OF CATASTROPHE BONDS FOR A SMALL AND LEAST-DEVELOPED COUNTRY

5.1. Motivation

We examine CAT bonds from the perspectives of economic development, risk financing, and debt sustainability in chapter 3 and chapter 4. We find that the CAT bond is a superior insurance strategy that can help foster *ex post* recovery and development, provide *ex ante* risk management, and improve sovereign debt sustainability. Given the benefits of CAT bonds, we believe the most essential technique and expertise to their practical implementation in least-developed countries (LDCs) would be the pricing of CAT bonds.

The pricing of CAT bonds has been studied within several frameworks. The more complex the pricing approach, the more difficult it is to implement in LDCs. The best pricing approach should be immune to the calibration inaccuracy of complex models and be robust to factors in different Libor term structures. We want to identify a pricing formula that makes the price discovery process of CAT bonds more transparent and reduces the technical hurdle of pricing for issuers in LDCs. Computational ease is also an important criterion when selecting the most appropriate pricing formula.

After the right pricing formula has been identified, we will illustrate its viability and its application to a real catastrophe in a LDC. We use the drought catastrophes in Kenya to develop our simulation. Drought catastrophes in Kenya exposed households to significant income and asset shocks and made it difficult for the government to maintain its balance of payments and offer emergency relief. The simulation involves the analysis of historical data, the simulation of drought risk, and the valuation of CAT bond prices via the chosen formula. Sensitivity tests are also conducted to examine the robustness of the pricing techniques.

This chapter is organized as follows. Section 5.2 reviews different types of CAT bond pricing model and identifies the best one to apply in LDCs. Section 5.3 illustrates the simulation process of a drought-linked CAT bond using historical rainfall data in Kenya and presents our methodologies. Section 5.4 presents a numerical experiment on the pricing of the drought CAT bonds. Section 5.5 summarizes this chapter and discusses possibilities for future research.

5.2. The Pricing of CAT Bonds

5.2.1. Literature Review

Cox and Pedersen (2000) believe that the financial market is incomplete once catastrophe risks are added into the model. Therefore, they develop an arbitrage-free valuation model in discreet time for CAT bonds, using representative agent equilibrium. Egami and Young (2008) apply an indifference pricing technique via expected utility to evaluate the CAT bond in an incomplete market environment. They apply their model to the more sophisticated CAT bond, with more than one tranche, and introduce the alterative action of "less reinsuring" into the agent's value function. Reshetar (2008) develop a model for the pricing of the multiple-event coupon CAT bond, whose payoff is linked with catastrophic property losses and catastrophic mortality. This model is also built on the basis of representative agent equilibrium with the assumption of market incompleteness.

Baryshnikov, Mayo, and Taylor (1998) develop an arbitrage-free pricing formula for CAT bonds in an environment of a compound doubly stochastic Poisson process, which captures not only the occurrence of catastrophe events but also their economic losses. Burnecki and Kukla (2003) extend the doubly stochastic Poisson pricing method of Baryshnikov, Mayo, and Taylor (1998) to calculate the non-arbitrage prices of a zero-coupon and coupon CAT bond. They also estimate the intensity of such processes using historical catastrophe loss data and run Monte Carlo simulations. Hardle and Cabrera (2010) apply the approach of Burnecki and Kukla (2003) and calibrate a real parametric CAT bond for Mexican earthquakes. In their findings, the intensity rate recovered from the reinsurance market largely coincides with that from the capital market, in comparison to a higher historical intensity rate. They believe that the lower market perceived catastrophe intensity is largely due to the well-structured financial strategy of the government, which helps reduce the bond premium and the associated perceived intensity.

Lee and Yu (2002) develop a contingent claim model to price CAT bonds in an environment of stochastic interest rate and catastrophe loss process. This structure also enables them to evaluate the impacts of default risk, moral hazard, and basis risk on CAT bond pricing. Lee and Yu (2007) apply a contingent claim framework to value reinsurance contracts and examined how a reinsurance company can increase the value of a reinsurance contract and reduce its default risk by issuing CAT bonds. Their results indicate that the issuance of CAT bonds, even with the potential basis risk, still raises the value of a CAT reinsurance contract and lowers its default risk. Ma and Ma (2013) present a contingent claim model similar to that in Lee and Yu (2002) in a stochastic interest rate environment with the losses following a compound nonhomogeneous Poisson process. They further estimate and calibrate the parameters of the pricing model using historical catastrophe loss data. To overcome the problem of no-closed form solutions, they propose a mixed approximation method to find the numerical solution for the price of catastrophe risk bonds.

Vaugirard (2003a, 2003b) extend the jump-diffusion model of Merton (1976) to develop an arbitrage-pricing framework for CAT bonds, allowing for market incompleteness and non-traded state variables. In this model, bondholders are deemed to be in a short position on an option based upon a risk index. A closed form expression of CAT bond valuation is thus developed based on the first-passage time distribution that measures the chances of a pre-specified threshold of risk index being hit. Norwak and Romaniuk (2013) extend the framework of Vaugirard (2003a, 2003b) by introducing additional payoff functions and interest rate dynamics to the general pricing formula.

5.2.2. The Closed Form Solution of CAT Bond Pricing

We are going to examine a simple closed form solution for the valuation of CAT bonds; this methodology will also serve as the basis of our numerical experiment. This closed form solution is drawn from Jarrow (2010), based on the spirits of reduced form models (Jarrow & Turnbull 1995; Jarrow 2009). We apply this closed form solution to the valuation of CAT bonds for several reasons. First, the default time in a reduced form model is usually defined as the first jump of a point process; the default time is inaccessible, and the default hits the market as a surprise in this model. This setup makes perfect sense when dealing with the catastrophe-triggered defaults of CAT bonds because catastrophes are also unpredictable. Second, this closed form valuation formula utilizes inputs inspired by historical data, including the likelihood of catastrophe, the realized loss rate, and the initial zero coupon Libor bond price curve. This approach makes the valuation formula immune to the calibration inaccuracy of complex models and robust to factors in different Libor term structures (like Hull-White or Cox-Ingersoll-Ross). Third, the simple closed solution provides computational ease for both the issuer and investor. This advantage makes the price discovery process of CAT bonds more transparent and reduces the technical hurdle of pricing for issuers in developing countries.

5.2.3. Assumptions of the Model

The setup of Jarrow's (2010) closed form solution contains several basic assumptions. First, it is assumed to have no counterparty risk and assume that all cash flows will be paid off for sure should no catastrophe happen; this assumption is consistent with the fact that most sponsors use the issuing proceeds as collateral and deposit them into the custody of a trust. Second, it is assumed that the first fundamental theorem of asset pricing holds true in this model, implying an arbitrage-free market for the Libor rates and the CAT bonds. The theorem also indicates the existence of an equivalent martingale measure Q, such that the discounted Libor zero coupon bond price and the CAT bond price are martingales. This assumption makes sense, as the CAT bond itself is just one type of credit derivatives and can be traded between investors. Finally, it is assumed that the second fundamental theorem of asset pricing doesn't necessarily hold in this model, implying that the market is not complete and the martingale measure may not be unique.

We now define some of the key parameters and variables used in this model:

1) $[\Omega, F, P, (F_t)_{t\in[0,T]}]$ is a filtered probability space satisfying common conditions

2) t is the time when the CAT bond is evaluated

3) T is the time when the CAT bond matures

4) Δ is the coupon payment interval for the CAT bond in the unit of year (if one CAT bond pays coupon semi-annually, then $\Delta = 1/2$)

5) k is the time interval from the evaluation time t to the next coupon date in the unit of year (if the next coupon will be dispersed in 30 days, then $k = 30/365$)

6) $B(t)$ is the CAT bond price at time t

7) $p(t, T)$ is the time t price of a Libor deposit paying one Eurodollar at time T

8) L_t is the annualized forward Libor rate for the period of Δ at time point *t*

9) l_t is the annualized spot Libor rate at time point *t*

10) $\theta = L_t - l_t, \forall\, t > t + k$; θ is assumed to be the shift between the forward rate and the spot rate after the first coupon payment

11) c is the spread received by the CAT bond investors, on top of the floating Libor payment

12) A is the face value of the CAT bond

13) τ is a random time point at which the catastrophe hits and the CAT bond is triggered

14) Y_τ is the recovered principal, if any, after the catastrophic event

15) $E(\cdot)$ is the expectation with respect to martingale measure Q and conditioned on F_t

After defining some key variables in the valuation formula, we need to consider the catastrophe event process. In Jarrow (2010), the catastrophe is defined as a point process $N_t = 1_{\tau \geq t}$. This point process is assumed to follow a non-homogeneous Poisson distribution with time-varying intensity, λ_t. From the properties of the non-homogeneous Poisson distribution, we can derive two probabilities used repeatedly in the later proof:

16) $\int_a^b \lambda_s e^{-\int_a^b \lambda_t dt} ds$ is the probability of one catastrophe event happening between time a and time b

17) $e^{-\int_a^b \lambda_t dt}$ is the probability of no catastrophe event happening between time a and time b

To save subscript space in the pricing formula, it is necessary to assign some simple numerical time indexes to the coupon disbursement date. Time $t+k$ represents the date when the first coupon is disbursed and is assigned with index *1*. Time $t+k-\Delta$ is the date when the last coupon prior to time t is disbursed and is assigned with index *0*. Finally, time $t+k+\Delta$ is the date when the second coupon is disbursed and is assigned with index *2*. Generally, the coupon date will jump with a special gap of k and will then grow at the regular rate of Δ. This relationship is shown in the table below:

Table 11 *The Time Index of the Pricing Formula*

Index	Date	Coupon disbursement
0	$t+k-\Delta$	last coupon
1	$t+k$	first coupon
2	$t+k+\Delta$	second coupon
3	$t+k+2\Delta$	third coupon
⋮	⋮	⋮
T	$t+k+(T-1)\Delta$	maturity of bond

5.2.4. The Valuation Formula

We start the pricing practice with the analysis of CAT bonds' cash flows. The coupon of CAT bond is determined by the floating Libor rate L_t plus a fixed spread c if no event occurs. The investor will receive a full principal at maturity should no event occur and receive a partially recovered principal should any event occur before the maturity. Following this logic, we will have four probability-weighted cash flows for a CAT bond, which includes the floating rate payments, the fixed spread payments, the full principal, and the partially recovered principal.

First, we can write the value of all future floating rate payments at time *t* as

$$E_t\left(A\sum_{s=1}^{T}L_{s-1}\Delta 1_{\tau>s}e^{-\int_t^s l_u du}\right) \tag{81}$$

Expression (81) is simply the discounted future floating payment, weighted by the probabilities of no catastrophe at coupon dates. There are several components in this expression that require detailed explanation. Future floating payment at a certain time *s* is determined by the forward Libor rate of L_{s-1}. L_{s-1} is the forward rate covering the period of [s-1,s], and investors receive the (s-1)th floating payment when the forward rate realizes at the end time of period *s*. Since the forward rate is annualized, we need to adjust the rate by multiplying the coupon interval, Δ. The term of $1_{\tau>s}$ represent the probability of no catastrophe event during one period. Finally, the term of $e^{-\int_t^s l_u du}$, which is the integral of spot rates, serves as the discounting factor. After writing out the initial equation (81), we will take a first transformation to split equation (81) into the first floating payment at time *t*+*k* and the remaining payments from time *t*+*k* onwards:

$$E_t\left(A\sum_{s=1}^{T}L_{s-1}\Delta 1_{\tau>s}e^{-\int_t^s l_u du}\right)$$

$$= E_t\left(AL_{t+k-\Delta}\Delta 1_{\tau>t+k}e^{-\int_t^{t+k} l_u du}\right) \tag{82}$$

$$+ E_t\left(A\sum_{s=2}^{T}L_{s-1}\Delta 1_{\tau>s}e^{-\int_t^s l_u du}\right)$$

The first term on the RHS of equation (82) is the first discounted floating payment at time *t+k*, and the second term on the RHS is the remaining discounted floating payments. For the first term on the RHS, we can take the face value of the bond, *A*, and the coupon interval, Δ, out of the expectation bracket, since their values are certain. Then, we can use the probability of no event occurring (definition 17), $e^{-\int_t^{t+k}\lambda_u du}$, to replace $1_{\tau>t+k}$. Since the intensity parameter is deterministic, we can take the probability term out of the expectation bracket. The value of the discounting factor should coincide with the time *t* price of a Eurodollar deposit paying one dollar at time *t+k*. Therefore, the discounting factor can be replaced by the expected value of the corresponding Eurodollar deposits. After these steps, the first term on the RHS of equation (82) becomes

$$E_t\left(AL_{t+k-\Delta}\Delta 1_{\tau>t+k}e^{-\int_t^{t+k} l_u du}\right) = AL_{t+k-\Delta}\Delta \mathrm{p(t, t + k)}e^{-\int_t^{t+k}\lambda_u du} \tag{83}$$

The second term on the RHS of equation (82) needs some extra treatments. Recall that we had defined a constant shift, θ, between the forward rate and spot rate in definition 10. We will apply this definition here and split the forward rate term, L_{s-1}, on the

RHS of equation (81) into one spot rate component of l_{s-1} and one shift component of θ:

$$E_t\left(A\sum_{s=2}^{T}L_{s-1}\Delta 1_{\tau>s}e^{-\int_t^s l_u du}\right)$$

$$= E_t\left(A\sum_{s=2}^{T}l_{s-1}\Delta 1_{\tau>s}e^{-\int_t^s l_u du}\right) + E_t\left(A\sum_{s=2}^{T}\theta\Delta 1_{\tau>s}e^{-\int_t^s l_u du}\right) \tag{84}$$

For the spot rate term on the RHS of equation (84), we can create a continuous integral of the cash flows to approximate the discrete cash flows. This step is done with

$$E_t\left(\sum_{s=2}^{T}l_{s-1}\Delta 1_{\tau>s}e^{-\int_t^s l_u du}\right) \approx E_t\left(\int_{t+k}^{T}l_{s-1}e^{-\int_t^s \lambda_u du}e^{-\int_t^s l_u du}ds\right) \tag{85}$$

Next, we can write the RHS of equation (85) more simply by examining it in the following equation:

$$p(t,t+k)e^{-\int_t^{t+k}\lambda_u du}$$

$$= E_t\left(\int_{t+k}^{T}l_{s-1}e^{-\int_t^s \lambda_u du}e^{-\int_t^s l_u du}ds\right) + \int_{t+k}^{T}\mathrm{p(t,s)}\lambda_s e^{-\int_t^s \lambda_u du}ds + p(t,T)e^{-\int_t^T \lambda_u du} \tag{86}$$

We cannot directly utilize the equality of (86) without any proof. An easier way to prove it would be to use our intuition. Equation (86) simply express that a "risk free" dollar at time $t+k$ equals a contingent claim that 1) pays spot interest rates in good states and repays one dollar once a bad state hits; and 2) pays spot interest rates in good states and repays one dollar on maturity (if no bad state hits before maturity). No matter how the probabilities are assigned to different states, the discounted value today for either cash flow 1) or cash flow 2) is always one dollar, since the spot interest rate is just the discounting factor we used. Thus, summing up the probability-weighted discounted "one dollars" over different states, we still end up with "one dollar." In equation (86), a "risk free" dollar at time $t+k$ corresponds to the LHS term; the spot interest rates correspond to the first term in the RHS; the debt repayment when a bad state hits corresponds to the second term in the RHS; and the debt repayment on maturity (if no bad state hits before maturity) corresponds to the third term in the RHS. The expectation bracket is taken off from the second term on the RHS because the intensity of Poisson distribution (λ_u) is deterministic.

Combining equations (82), (84), (85), and (86) produces a new expression for the floating payment:

$$E_t\left(A\sum_{s=1}^{T} L_{s-1}\Delta 1_{\tau>s} e^{-\int_t^s l_u du}\right)$$

$$= AL_{t+k-\Delta}\Delta \mathrm{p}(\mathrm{t},\mathrm{t}+\mathrm{k})e^{-\int_t^{t+k}\lambda_u du}$$

$$+ p(t,t+k)Ae^{-\int_t^{t+k}\lambda_u du} \qquad (87)$$

$$-\int_{t+k}^{T}\mathrm{p}(\mathrm{t},\mathrm{s})A\lambda_s e^{-\int_t^s \lambda_u du} ds - p(t,T)Ae^{-\int_t^T \lambda_u du}$$

$$+ A\theta\Delta E_t\left(\sum_{s=2}^{T}\mathrm{p}(\mathrm{t},\mathrm{s})e^{-\int_t^s \lambda_u du}\right)$$

In equation (87), LHS is the floating payment cash flow we defined in equation (81). On the RHS, the first term represents the first coupon payment; the sum of the second, third, and fourth terms represents the spot interest part of future floating cash flow after the first coupon; the last term represents the shift part of future floating cash flow after the first coupon.

Second, we will define the fixed spread component of future coupon cash flows:

$$E_t\left(\sum_{s=1}^{T} \mathrm{c}\Delta 1_{\tau>s} e^{-\int_t^s l_u du}\right) \qquad (88)$$

Expression (88) is equivalent to the discounted fixed spread payments, weighted by the probabilities of no catastrophe at coupon dates. We can apply the techniques we used for the floating payment component. The spread c and the coupon interval Δ can be taken out of the expectation bracket since their values are certain. The probability of no catastrophe can be replaced with definition (17). The discounting factor can be replaced by the time *t* price of a Eurodollar deposit paying one dollar at time *s*. After these transformations, we can write the fixed spread part of the CAT bond value as

$$AE_t\left(\sum_{s=1}^{T} \mathrm{c}\Delta 1_{\tau>s} e^{-\int_t^s l_u du}\right) = \mathrm{c}A\Delta \sum_{s=1}^{T} \mathrm{p(t,s)} e^{-\int_t^s \lambda_u du} \tag{89}$$

We can split the fixed spread payment in equation (89) into the first payment and the remaining payments as shown in equation (90):

$$\begin{aligned} \mathrm{cA\Delta} \sum_{s=1}^{T} \mathrm{p(t,s)} e^{-\int_t^s \lambda_u du} \\ &= \mathrm{c}A\Delta \mathrm{p(t,t+k)} e^{-\int_t^{t+k} \lambda_u du} \\ &+ \mathrm{c}A\Delta \sum_{s=2}^{T} \mathrm{p(t,s)} e^{-\int_t^s \lambda_u du} \end{aligned} \tag{90}$$

Third, we define the full principal component of the CAT bond should no catastrophe hit:

$$E_t\left(A1_{\tau>T} e^{-\int_t^T l_u du}\right) \tag{91}$$

As before, we can replace the discounting factor with the price of the Eurodollar deposit, plug in the probability of no event, and take some terms out of the expectation bracket. Following these steps, we can write the full principal part as below:

$$E_t\left(A1_{\tau>T} e^{-\int_t^T l_u du}\right) = p(t,T)Ae^{-\int_t^T \lambda_u du} \tag{92}$$

Fourth, we define the partial recovery component of the CAT bond should one catastrophe hit before maturity:

$$E_t\left(\int_t^T Y_s\lambda_s e^{-\int_t^s \lambda_u du} e^{-\int_t^s l_u du}\, ds\right) \tag{93}$$

Expression (93) describes the discounted partial recovery cash flows, weighted by the probability of one catastrophe event hitting before maturity. We can take the probability related terms out of the expectation since the intensity values are deterministic. Then, we can replace the discounting factor with the price of the Eurodollar deposit. After these steps, we can re-write expression (93) as

$$E_t\left(\int_t^T Y_s\lambda_s e^{-\int_t^s \lambda_u du} e^{-\int_t^s l_u du}\, ds\right) = \int_t^T E_t(Y_s)\lambda_s e^{-\int_t^s \lambda_u du} \mathrm{p}(\mathrm{t}, \mathrm{s})\, ds \tag{94}$$

After providing the simplified expressions for all four cash flows of a CAT bond, we can sum up the RHS of equations (87), (90), (92), and (94) to derive the bond valuation as a whole:

$$B_t = AL_{t+k-\Delta}\Delta \mathrm{p(t, t+k)} e^{-\int_t^{t+k}\lambda_u du} + p(t, t+k)Ae^{-\int_t^{t+k}\lambda_u du}$$

$$- \int_{t+k}^{T} \mathrm{p(t,s)} A\lambda_s e^{-\int_t^s \lambda_u du} ds - p(t,T)Ae^{-\int_t^T \lambda_u du}$$

$$+ A\theta\Delta E_t \left(\sum_{s=2}^{T} \mathrm{p(t,s)} e^{-\int_t^s \lambda_u du} \right) \tag{95}$$

$$+ \mathrm{c}A\Delta \mathrm{p(t, t+k)} e^{-\int_t^{t+k}\lambda_u du}$$

$$+ \mathrm{c}A\Delta \sum_{s=2}^{T} \mathrm{p(t,s)} e^{-\int_t^s \lambda_u du} + p(t,T)Ae^{-\int_t^T \lambda_u du}$$

$$+ \int_t^T E_t(Y_s)\lambda_s e^{-\int_t^s \lambda_u du} \mathrm{p(t,s)}\, ds$$

In equation (95), the fourth term, $p(t,T)Ae^{-\int_t^T \lambda_u du}$, cancels out with the eighth term. After rearranging the terms, we obtain the new valuation formula:

$$B_t = A(L_{t+k-\Delta} + \mathrm{c})\Delta \mathrm{p(t, t+k)} e^{-\int_t^{t+k}\lambda_u du}$$

$$+ Ap(t, t+k)e^{-\int_t^{t+k}\lambda_u du}$$

$$+ \int_t^{t+k} E_t(Y_s)\lambda_s e^{-\int_t^s \lambda_u du} \mathrm{p(t,s)}\, ds \tag{96}$$

$$- \int_{t+k}^{T} [\mathrm{A} - E_t(Y_s)] \mathrm{p(t,s)} \lambda_s e^{-\int_t^s \lambda_u du} ds + A(\theta$$

$$+ \mathrm{c})\Delta E_t \left(\sum_{s=2}^{T} \mathrm{p(t,s)} e^{-\int_t^s \lambda_u du} \right)$$

There are five terms in equation (96); we describe them below:

i. The first term is the discounted value of the next coupon payment with both the floating forward Libor rate and the fixed spread, weighted by the probability of no catastrophe event.

ii. The second term is the discounted price of a Libor floating rate note with face value *A* at time *t*+*k*, weighted by the probability of no event during *t* to *t*+*k*.

iii. The third term is the discounted recovery of principal, weighted by the probability of a catastrophe event between time *t* and *t*+*k*.

iv. The fourth term is the expected losses after the next coupon, which is the difference between the principal and the recovered portion, weighted by the probability of a catastrophe event between time *t*+*k* and *T*.

v. The last term is the fixed payment after the next coupon, which contains both the shift term and the spread term, weighted by the probability of no catastrophe event.

To evaluate the CAT bond formula (96), we need to collect and input the following values into our computational program:

i. The last coupon date, $t + k - \Delta$, and the next coupon date, $t + k$. From these two dates, we can calculate the coupon interval, Δ, and utilize this parameter in equation (16).

ii. The expected recovery rate, $E_t(Y_s)$, during catastrophes.

iii. The fixed spread component of the coupon payment, *c*.

iv. We need to collect the zero coupon Libor bond price curve, from which we can extract the time t price of the Eurodollar deposit paying at time s $\mathrm{p}(\mathrm{t}, \mathrm{s})$, spot Libor rate l_s, forward Libor rate L_s, and their difference θ.

v. The intensity at which the catastrophe hits, λ_s.

Of these, i and iii can be obtained from the bond prospectus. We can estimate ii and v based on the occurrence of historical events and realized loss data. For item iv, we can find the zero coupon Libor bond price curve from information providers such as Bloomberg and Thomson Reuters.

5.3. Simulation of Drought CAT Bond in Kenya

5.3.1. Introduction

This section shows how a drought-linked CAT bond is practically priced. The methodology and techniques shown below can be applied to other types of catastrophe as well. However, we will define the drought in northern Kenya as the default triggering event and construct the underlying CAT bond therefrom. Our pricing practice requires a series of techniques, including distribution fitting, the extrapolation of financial data, a Monte Carlo simulation, and the programming of the closed form solution. The main goal of this section is to illustrate the viability of CAT bond pricing and its application to a real-world catastrophe.

The pricing of a drought-linked CAT bond comprises four major steps, as Figure 18 shows below. In the first step, we analyze the rainfall data from the region of interest.

We collected monthly rainfall data for the Moyale region[12] in Northern Kenya. The data series derived from precipitation data recorded by local weather stations and was retrieved from the National Climatic Data Center.[13] Then, we fit these monthly rainfall data with a distribution that is commonly accepted in the hydrology literature. We also need to derive the correlation matrix between each month's rainfall data because the rainfall simulation in the next step uses the correlation matrix as one important input. In the second step, we run a Monte Carlo simulation to generate the simulated monthly rainfall before the expiration of the CAT bond. The inputs for the simulation are the distribution parameters and correlation matrix from step one. Based on the pre-specified rainfall thresholds/triggers, we generate the intensity of drought occurrence from the rainfall simulation. In the third step, we analyze the zero coupon curve and collect the price of Libor futures and swaps from the financial market. We then use the bootstrapping technique to calculate the Libor spot and forward rates, from which we generate the discounting factors and the shift terms between the forward and the spot. In the last step, we convert the occurrence of drought into the intensity of the homogeneous Poisson process. We then plug all the information we generated from the simulation and the financial market into our program for the closed form solution.

[12] Latitude: -1.317; Longitude: 36.917.
[13] website: http://www.ncdc.noaa.gov/cdo-web/

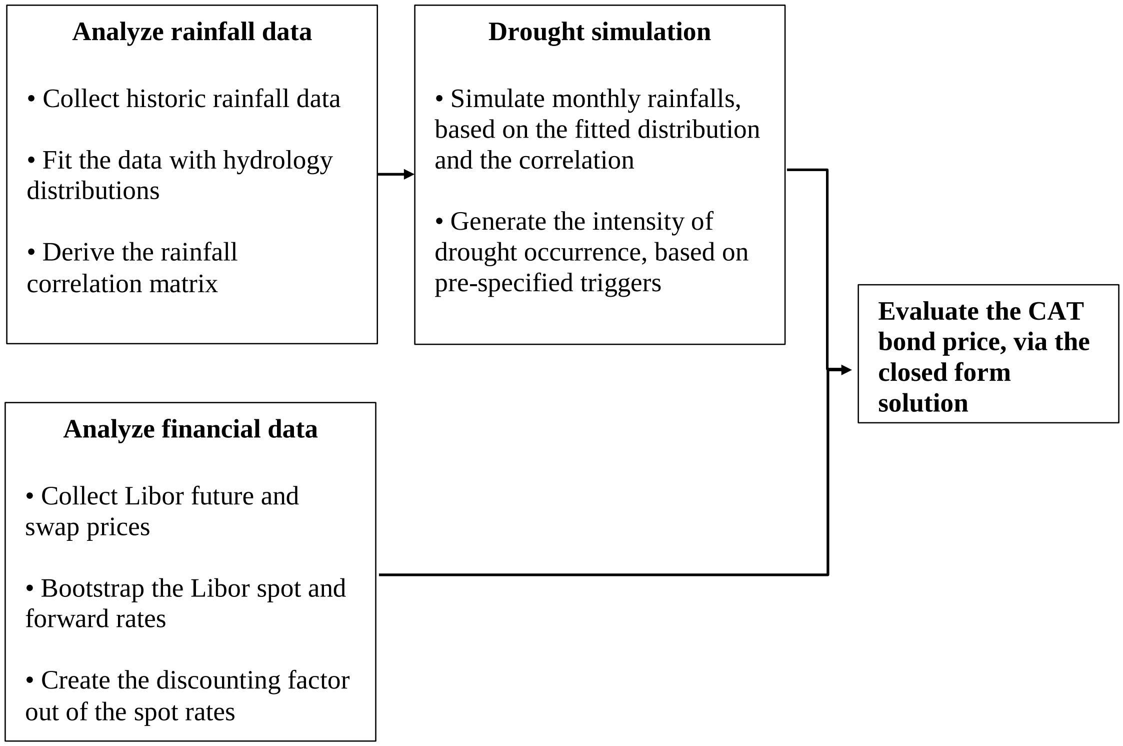

Figure 18 *Simulation and Pricing Process of the Drought CAT Bond*

5.3.2. Parameters and Data

Since drought-linked CAT bonds have never been issued in the financial market, we refer to the Mexico MultiCat bond to hypothesize our drought bond's triggering mechanism. Kenya's long rain season starts in March and finishes in May; the short rain season starts in October and finishes in December. The failure of either season could pose significant catastrophic risks to the local agrarian economies. We thus design two parametric triggers for our CAT bond: one for the long rain season, and one for the short rain season. We will specify June as the assessment month for the long rain season and January of the follow year as the assessment month for the short rain season. The rainfall in either rain season will be checked in the assessment months; if it dips below the pre-determined trigger, the drought CAT will default, and a certain proportion of the principal will be impaired by the end of the assessment month. Our drought CAT bond thus has only two defaulting chances per year, following the long and short rain seasons.

In the baseline model, we assume this drought CAT to be issued on March 4, 2014, with a maturity of three years, as shown in Table 12. The face value of this CAT bond is given as $1000 for simplicity. The coupon spread over Libor is 4% (annualized) and should be paid off to the investors every quarter. The shift is calculated as the difference between the forward rate and the spot rate on June 4, 2014, which is the first coupon disbursement date. The recovery rate is assumed to be 50% of the face value. The drought triggers are 200 millimeters and 50 millimeters for the long and short rain seasons, respectively. The CAT bond will default if the corresponding rainfall is below either trigger mentioned above. In the sensitivity analysis, we will change values of the coupon spread, recovery rate, and drought triggers to see if our method is robust and consistent under different parameter values.

Table 12 *Parameters of the Baseline Model*

Parameter	Description	Value of the baseline model
t	Launch date of the CAT bond	March 04, 2014
T	Maturing date of the CAT bond	March 04, 2017
Δ	Frequency of coupon payment	Per quarter
L_t	Annualized Libor forward rate	Figure 19 upper line
l_t	Annualized Libor spot rate	Figure 19 lower line
θ	Shift between the forward & spot on $t + \Delta$	0.011%

c	Coupon spread over Libor	4% (annualized)
A	Face value of the CAT bond	$1000
$E(Y_\tau)/\text{A}$	Pre-specified recovery rate	50%
K_L	Drought trigger in long rain season	200 millimeters
K_S	Drought trigger in short rain season	50 millimeters

We retrieve the prices of the Libor deposit rates, Eurodollar futures, and Libor swaps with different expirations from Bloomberg terminal. We start building the zero coupon curve and the Libor forward curve using bootstrapping and interpolation techniques. The short end of the curve is built out of the Libor deposit rates; the intermediate end is built out of the Eurodollar futures; and the long end is built out of the Libor swaps. The final spot and forward rates are displayed in Figure 19. Based on those spot rates, we will create the discounting factors, which are the $\mathrm{p(t, s)}$ and $\mathrm{p(t, t + k)}$ terms in the pricing formula.

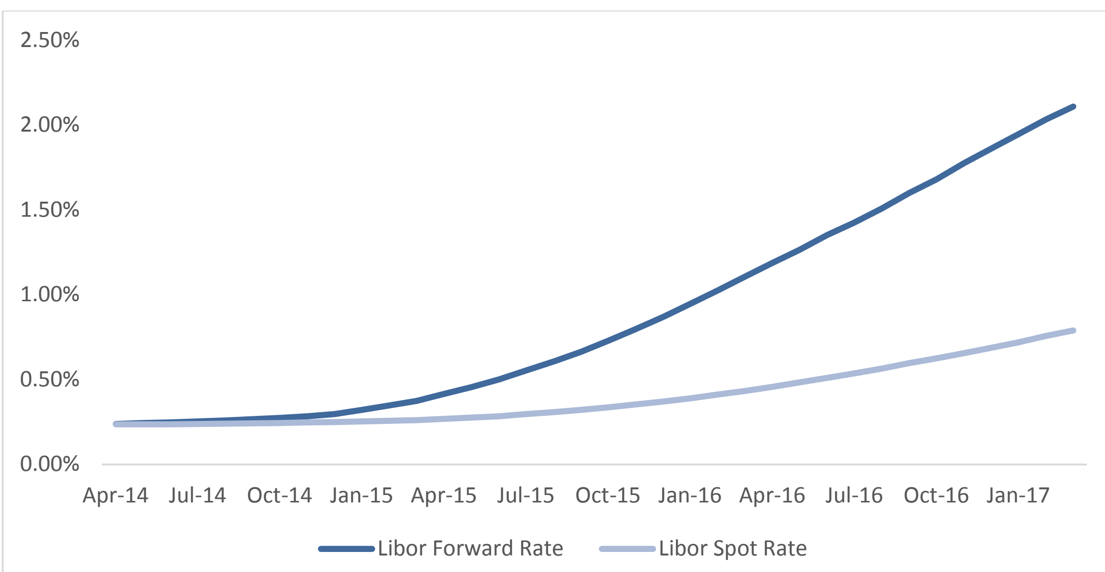

Figure 19 *Zero Coupon Curve and Libor Forward Curve*

To properly price the drought CAT bond, we also need to collect the historical rainfall data for northern Kenya. Since the precipitation data for the Moyale region has the longest history and is the most complete, we will use them as the rainfall inputs in the pricing practice. We retrieve the total monthly precipitation data for Moyale from 1935 to 1997, with a total of 756 observations. As seen in Figure 20, most precipitation happens in the long rain season, followed by the short rain season. Therefore, the dual-trigger design of the CAT bond is well supported by the precipitation data we saw in northern Kenya. Table 13 provides a deeper look at the data statistics. The months of the long and short rain seasons have not only the highest mean but also the largest standard deviation and maximum value. As the skewness and kurtosis suggest, moreover, the rainfall data exhibit a heavy tail skewed to the right end (i.e., the right end of the pdf curve is longer than the left end). Therefore, we should consider these statistical characteristics when choosing the right distribution to fit the precipitation data.

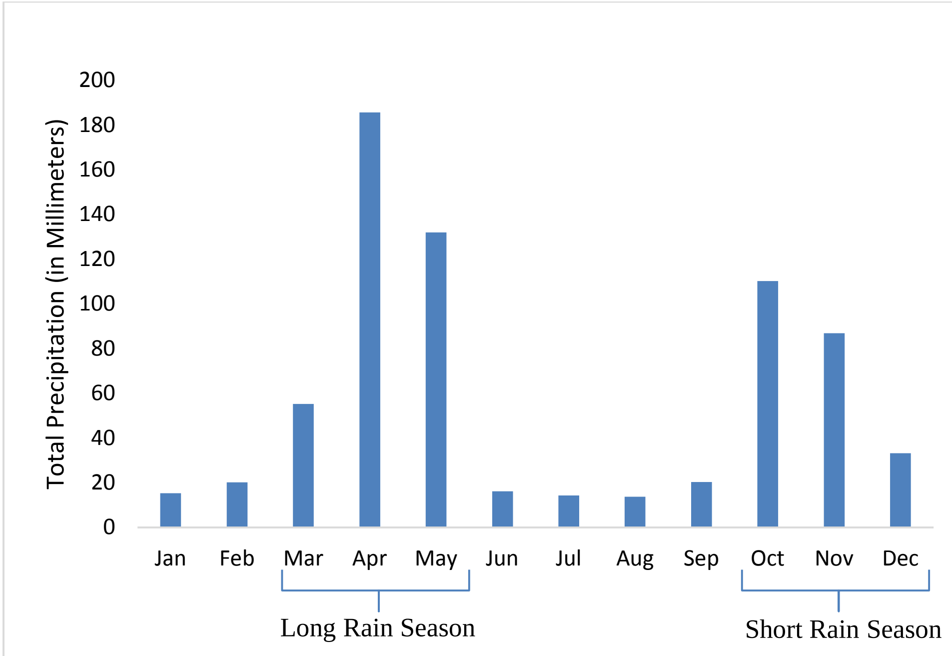

Figure 20 *Monthly Average Rainfalls in Moyale (1935 to 1997)*

Table 13 *Statistics of Rainfall Data in Moyale*

Month	Mean	S.D.	Min	Max	Skewness	Kurtosis
January	15.0	26.6	0.0	176.4	4.1	23.5
February	19.8	25.0	0.0	124.9	2.0	7.6
March	55.3	46.5	0.0	182.4	1.1	3.4
April	185.5	123.8	0.0	767.3	1.9	9.0
May	132.0	93.2	0.0	470.2	1.3	5.1
June	15.9	12.6	0.0	55.3	1.0	3.8
July	14.1	12.9	0.0	60.6	1.7	6.4
August	13.8	15.0	15.0	94.3	2.8	14.8
September	20.3	26.2	0.0	118.1	2.0	6.2
October	110.2	106.5	0.0	608.4	2.3	9.7
November	86.9	60.1	0.0	277.1	1.1	4.1
December	33.2	34.9	0.0	160.9	1.6	5.4

5.3.3. Simulation of Monthly Precipitation

We selected the log-logistic distribution to fit our precipitation data for several reasons. First, the value of rainfall is non-negative, and the log-logistic distribution is just a continuous probability distribution for a non-negative random variable. Second, the log-logistics distribution could accommodate the shape of a heavier tail, which just matches the feature of our data. Third, log-logistic distribution has been commonly accepted for the study of precipitation in the hydrology literature. A series of goodness of fit tests have been deployed to see if the data follow the specified log-logistic distribution, as shown in Table 14. The Kolmogorov–Smirnov test indicates that such distribution indices have a good fit at the 5% level for most months except January and February. The chi-square test also shows that most monthly data follow the log-logistic distribution at the 5% level, except January, February, and August. The poor fit for January, February and August could be largely due to the dry weather and the low rainfall volume in those months. The poor fit on those months wouldn't significantly influence our simulation since our result relies heavily on the precipitation during the long and short rain seasons. Aside from the statistical tests, we also ran some graphical checks on the fitness of the log-logistic distribution, as Figure 21 shows. The histogram and the chosen distribution have high degrees of similarity in the long and short rain seasons.

The log-logistic distribution has a probability density function:

$$\mathrm{f}(\mathrm{x}; \alpha, \beta) = \frac{(\beta/\alpha)(x/\alpha)^{\beta-1}}{[1+(x/\alpha)^{\beta}]^2} \tag{97}$$

In this function, α is the scale parameter, and β is the shape parameter. The fitness values of α and β are reported in Table 14.

Table 14 *Parameters of the Fitted Distribution and Testing Results*

Month	Fitted distribution	α	β	K-S[14] test	χ^2 test
January	Loglogistic	0.655	2.399	0.238	18.8
February	Loglogistic	0.533	2.720	0.227	16.7
March	Loglogistic	1.909	43.238	0.087*	1.9*
April	Loglogistic	2.880	158.520	0.065*	3.7*
May	Loglogistic	2.465	113.080	0.082*	4.3*
June	Loglogistic	1.978	12.959	0.097*	4.4*
July	Loglogistic	2.171	11.443	0.104*	5.6*
August	Loglogistic	1.412	9.793	0.144*	15.0
September	Loglogistic	1.573	11.945	0.168*	5.6*
October	Loglogistic	2.001	80.537	0.085*	3.6*
November	Loglogistic	2.517	73.607	0.093*	5.7*
December	Loglogistic	1.628	23.861	0.138*	4.8*

*: critical value is 0.205 for K-S test and 14.07 for χ^2 test at the 5% significant level

[14] Kolmogorov–Smirnov test

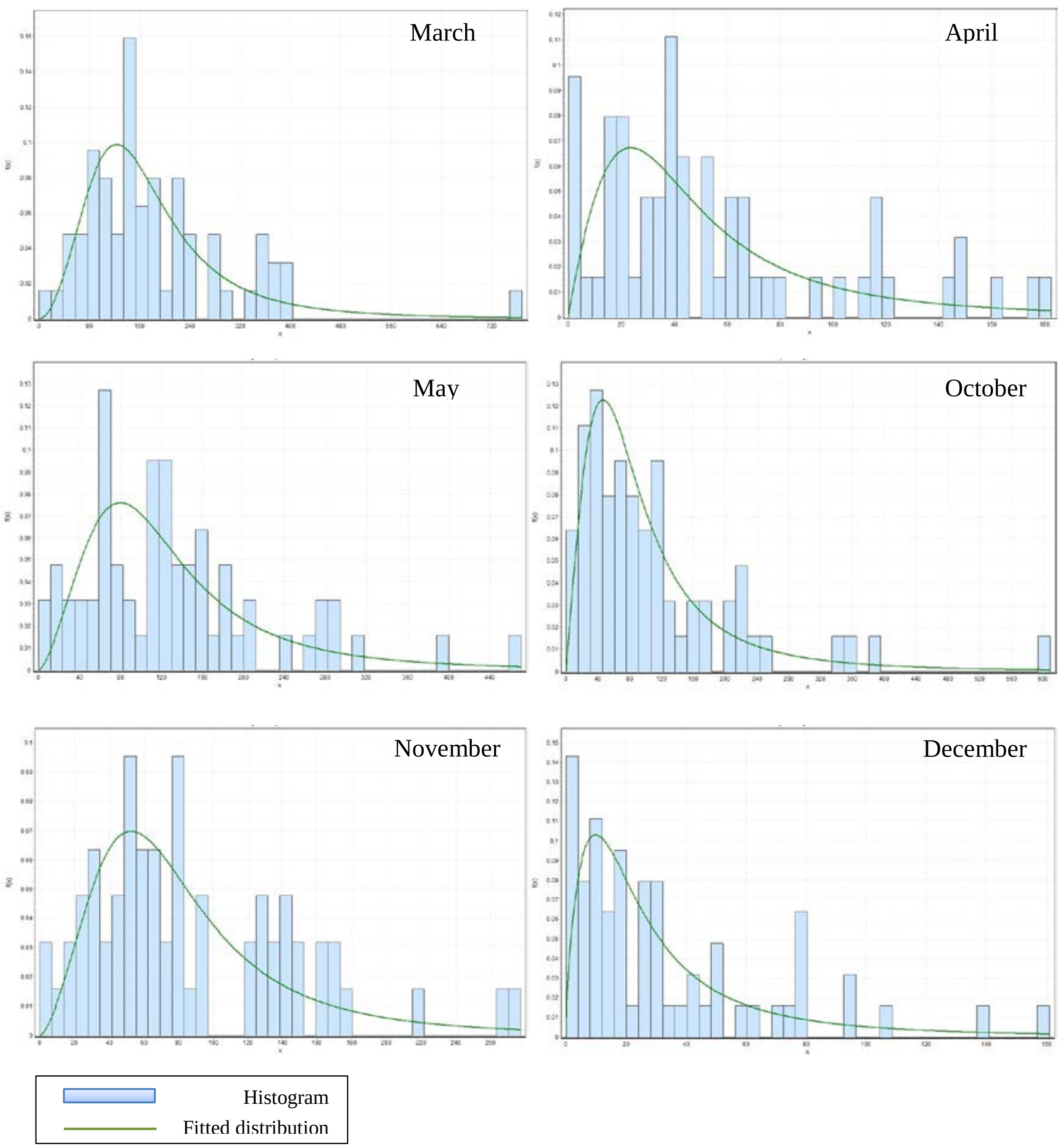

Figure 21 *Histogram and Fitted Distribution for Long and Short Rain Months*

Aside from the parameters of the log-logistic distribution, we also created a correlation matrix for monthly precipitation as a simulation input to allow us to better simulate the case of consecutive rainy months or of prolonged dry months.

Table 15 *Correlation Matrix for Monthly Precipitations*

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.00											
2	0.05	1.00										
3	0.12	0.20	1.00									
4	0.00	0.33	0.24	1.00								
5	0.06	-0.06	0.14	-0.08	1.00							
6	-0.05	-0.01	0.08	0.10	-0.05	1.00						
7	0.37	0.13	0.05	-0.13	-0.01	0.15	1.00					
8	-0.01	-0.04	-0.02	-0.12	-0.02	-0.06	0.10	1.00				
9	-0.17	-0.04	-0.26	-0.02	0.16	0.02	-0.05	0.29	1.00			
10	-0.03	-0.06	0.11	0.05	0.11	0.02	-0.03	0.10	0.03	1.00		
11	-0.19	-0.18	-0.10	0.01	-0.14	0.00	0.00	0.20	0.21	0.50	1.00	
12	-0.13	-0.03	0.09	0.05	-0.06	0.15	0.16	0.08	0.03	0.14	0.35	1.00

Finally, we conduct a Monte Carlo simulation with the estimated distribution parameters and the correlation matrix. The simulation is run on a monthly basis with 10,000 iterations. Using the simulated rainfall data, we assess the total precipitation for the long rain season and the short rain season. The occurrence of drought will be recorded in the simulation process. Since we assume that this occurrence follows a homogeneous Poisson distribution, the intensity of the distribution can also be generated from the simulation, which will be the key to the pricing of the CAT bond in the following section.

5.4. Numerical Experiments

To price the drought CAT bond, we rely on the closed form formula introduced in section 5.3. We illustrate the viability and robustness of the pricing model under different settings. In the baseline mode, we have the recovery rate at 50%, coupon spread at 4%, and drought triggers at 200 and 50 millimeters for the long and short rain seasons (respectively). We use the unmodified zero coupon curve as the input for our pricing formula.

In the first experiment, as shown in Table 16 and Figure 22, we examine the CAT bond price with respect to differences in trigger levels and time after launch. We increased the trigger levels by 10 millimeters in the long rain season and 5 millimeters in the short rain seasons. The CAT bond prices are then computed semi-annually. First, we find that the bond prices approach its face value as it comes closer to its maturity. Second, the bond price decreases as the trigger level increases, since higher trigger levels will make the bond easier to default. Finally, the CAT bond price exhibits a higher sensitivity to time as it reaches a higher trigger level. This last finding makes sense because a higher trigger level indicates a higher default risk and such risk needs to be compensated with a higher holding return per unit time.

Table 16 *CAT Bond Price with Respect to Trigger Levels and Time after Launch*

	230, 65	220, 60	210, 55	**200, 50**	190, 45	180, 40	170, 35
0 YEAR	702.2	746.6	790.1	838.5	892.4	937.2	976.0
0.5 YEAR	721.1	764.7	807.3	852.5	902.4	943.3	978.1

1 YEAR	767.0	805.9	842.2	881.0	922.3	955.2	982.9
1.5 YEAR	796.2	831.7	865.1	898.4	933.8	961.8	984.8
2.0 YEAR	859.8	885.6	908.6	932.0	955.9	974.1	989.0
2.5 YEAR	904.2	922.3	939.1	954.1	969.6	981.5	990.8
3 YEAR	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0

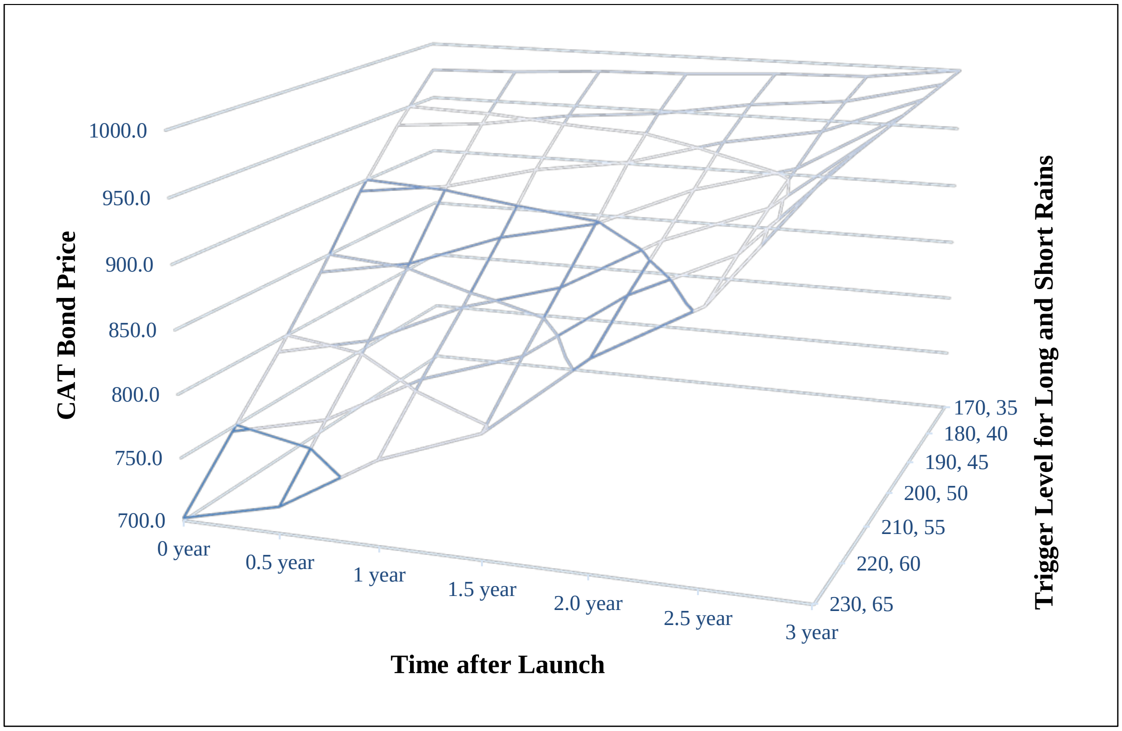

Figure 22 *CAT Bond Price with Respect to Trigger Levels and Time after Launch*

In the second experiment, as shown in Table 17 and Figure 23, we examine the CAT bond price with respect to differences in trigger levels and recovery rates. We increase the recovery rates by 10% each time and then compute the CAT bond prices at launch. First, the bond price decreases as the trigger level increases, since higher trigger levels will make the bond easier to default. Second, the bond price decreases significantly when the recovery rate decreases, since less principal will be recovered in the event of catastrophe. Finally, the CAT bond price exhibits a higher sensitivity to recovery rates when it reaches a higher trigger level, as CAT bonds with higher trigger values have a higher default risk. And such higher default risk needs to be compensated with a higher return on every 10% increase of recovery rate.

Table 17 *CAT Bond Price at Launch with Respect to Trigger Levels and Recovery Rates*

	230, 65	220, 60	210, 55	**200, 50**	190, 45	180, 40	170, 35
0%	331.5	415.1	497.1	588.4	690.2	774.8	848.1
10%	405.7	481.4	555.7	638.4	730.6	807.3	873.7
20%	479.8	547.7	614.3	688.4	771.1	839.8	899.2
30%	553.9	614.0	672.9	738.4	811.5	872.3	924.8
40%	628.1	680.3	731.5	788.5	852.0	904.7	950.4
50%	702.2	746.6	790.1	838.5	892.4	937.2	976.0
60%	776.3	812.9	848.7	888.5	932.9	969.7	1001.5
70%	850.5	879.2	907.3	938.6	973.3	1002.2	1027.1
80%	924.6	945.5	965.9	988.6	1013.8	1034.6	1052.7
90%	998.7	1011.8	1024.5	1038.6	1054.2	1067.1	1078.2
100%	1072.9	1078.1	1083.1	1088.7	1094.7	1099.6	1103.8

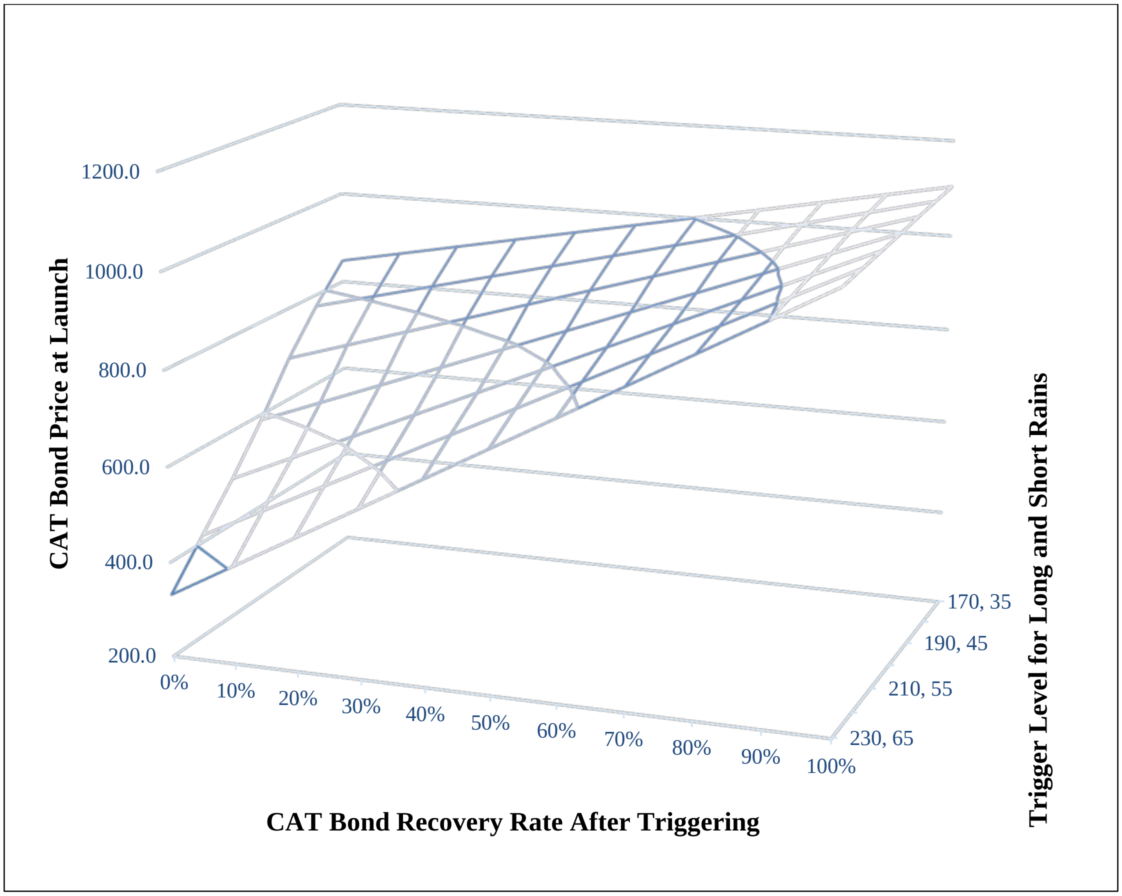

Figure 23 *CAT Bond Price at Launch with Respect to Trigger Levels and Recovery Rates*

In the third experiment, as shown in Table 18 and Figure 24, we examine the CAT bond price with respect to differences in trigger levels and coupon spreads. We increase the coupon spread over Libor by 1% each time and then compute the CAT bond prices at launch. First, the bond price decreases as the trigger level increases. Second, the bond price increases when the coupon spread increases. Finally, the CAT bond price exhibits a higher sensitivity to coupon spread when it has a lower trigger level. We know that CAT bonds with lower trigger values would have a lower chance of defaulting. When the triggers levels are low, the additional cash flow brought by the higher coupon spread would become more certain to the bondholders. For this reason, the price at launch is more sensitive to coupon spreads as trigger levels decrease.

Table 18 *CAT Bond Price at Launch with Respect to Trigger Levels and Coupon Spreads*

	230, 65	220, 60	210, 55	**200, 50**	190, 45	180, 40	170, 35
0%	629.5	668.7	707.2	750.1	798.0	837.9	872.4
1%	647.7	688.2	727.9	772.2	821.6	862.7	898.3
2%	665.9	707.7	748.6	794.3	845.2	887.5	924.2
3%	684.0	727.1	769.4	816.4	868.8	912.4	950.1
4%	702.2	746.6	790.1	838.5	892.4	937.2	976.0
5%	720.4	766.1	810.8	860.6	916.1	962.0	1001.8
6%	738.5	785.6	831.5	882.7	939.7	986.9	1027.7
7%	756.7	805.1	852.2	904.8	963.3	1011.7	1053.6
8%	774.9	824.5	873.0	926.9	986.9	1036.6	1079.5

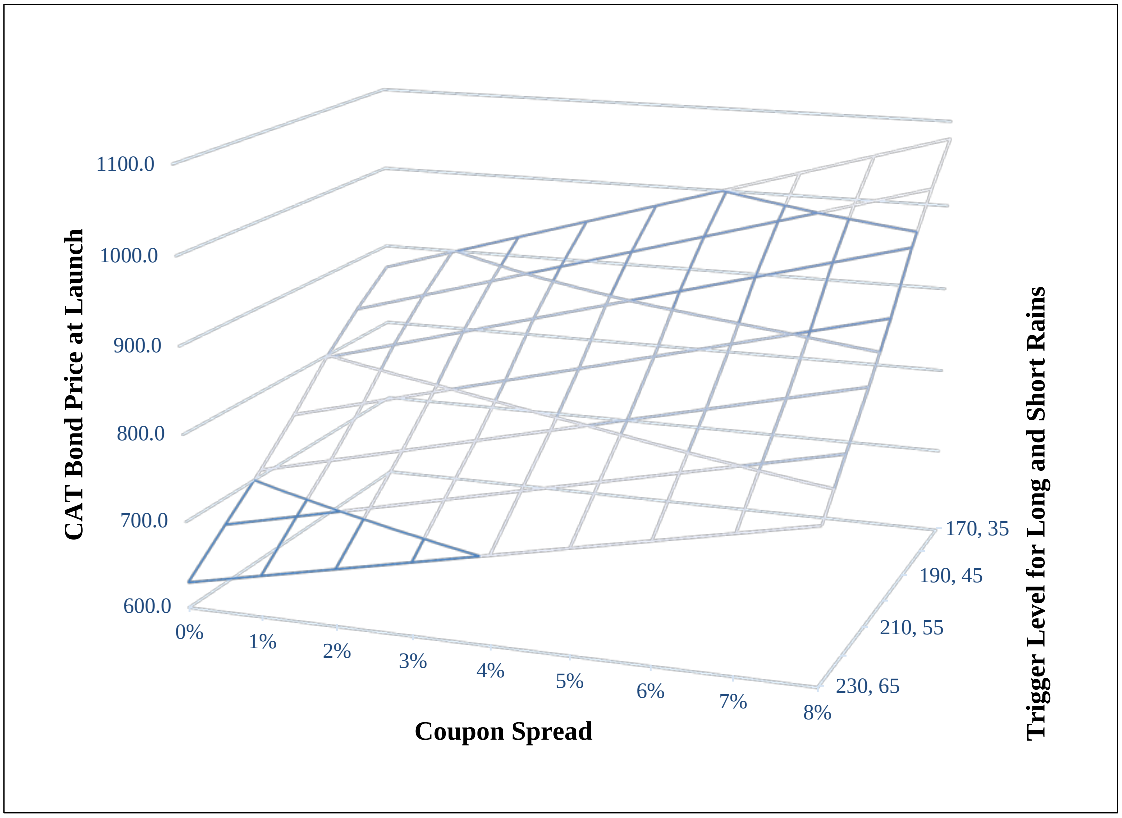

Figure 24 *CAT Bond Price at Launch with Respect to Trigger Levels and Coupon Spreads*

In the last experiment, as shown in Table 19 and Figure 25, we examine the CAT bond price with respect to differences in trigger levels and zero coupon curves. The zero coupon curve will drift up or down by 20 basis points each time. We do not drift the zero coupon curve down by more than 20 basis points since the current spot rate at launch is about 23 bps, and it is unreasonable to have a negative spot rate. First, the bond price decreases as the trigger level increases. Second, the bond price becomes slightly higher when the zero coupon curve drifts up. In our pricing formula, the zero coupon curve has two effects. Since our bond pays Libor plus the coupon spread, a higher zero coupon curve increases the floating component of the coupon and hence increase the CAT bond price. A higher zero coupon curve also increases the discounting factor, lowering the present value of future cash flows and hence reducing the CAT bond price. In our experiment, the first effect slightly outweighs the second. Therefore, we see a higher CAT bond price when the zero coupon curve drifts up. Finally, the CAT bond price exhibits a slightly higher sensitivity to the drift of the zero coupon curve when it has a higher trigger level. We know that CAT bonds with a higher trigger value have a higher chance of defaulting. When the trigger levels are higher, the additional floating coupon produced by the upward drift of the zero coupon curve becomes more certain to the bondholders. For this reason, the price at launch is more sensitive to the drift of the zero coupon curve as trigger levels increase.

Table 19 *CAT Bond Price at Launch with Respect to Trigger Levels and Drifts of the Zero Coupon Curve*

	230, 65	220, 60	210, 55	**200, 50**	190, 45	180, 40	170, 35
- 20 BPS	701.4	745.9	789.5	838.0	892.1	937.0	975.9
+ 0 BPS	702.2	746.6	790.1	838.5	892.4	937.2	976.0
+ 20 BPS	703.0	747.3	790.7	839.0	892.8	937.4	976.0
+ 40 BPS	703.8	748.1	791.3	839.5	893.1	937.6	976.1
+ 60 BPS	704.7	748.8	791.9	839.9	893.4	937.8	976.2
+ 80 BPS	705.5	749.5	792.5	840.4	893.7	938.0	976.2
+ 100 BPS	706.3	750.2	793.1	840.9	894.1	938.2	976.3

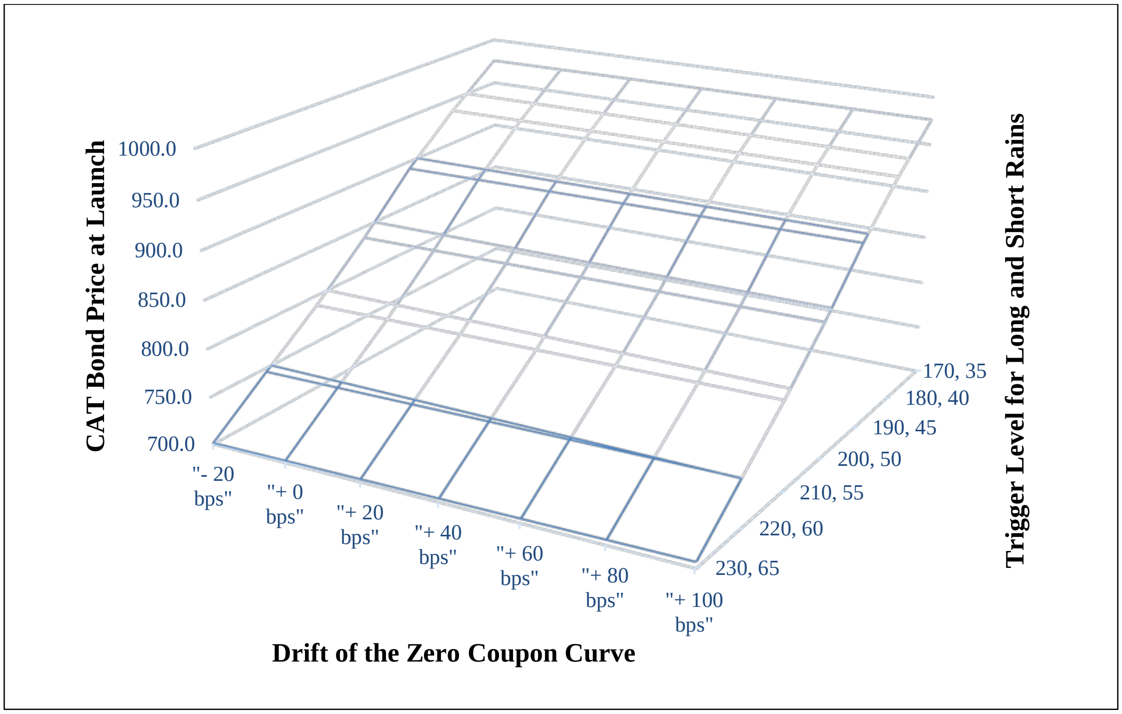

Figure 25 *CAT Bond Price at Launch with Respect to Trigger Levels and Drifts of the Zero Coupon Curves*

Our numerical experiments tested the sensitivity of CAT bond prices with respect to trigger levels, time, recovery rates, coupon spreads, and the drifts of the zero coupon curve. We find our pricing method is robust and consistent under different parameters. The CAT bond price is more sensitive to the changes in recovery rates and trigger levels but less sensitive to the changes in coupon spread and drift of the zero coupon curve. This finding shows that the risk from catastrophe events dominates the pricing of our drought CAT bond because the interest rate risk is minimal in this easing monetary environment. Our finding also reveals that the sponsor of this drought CAT bond needs to select trigger levels and recovery rates delicately, since they are the most impactful parameters in the pricing process.

5.5. Summary

This chapter discusses the pricing and simulation of the CAT bond. We employ a closed form solution developed by Jarrow (2010) and in the spirit of the reduced form model. In this closed form formula, default time is defined as the first jump of a point process, and historical data are utilized as inputs to calculate the likelihood of catastrophe. The model also uses the zero coupon Libor curve to calculate both the floating payment cash flows and the discounting factors. The Q martingale is assumed, since the CAT bond is just one type of credit derivative and can be traded between investors. It is also assumed that the second fundamental theorem of asset pricing doesn't necessarily hold in this model. The final evaluation formula contains five terms, all properly discounted and weighted by the corresponding probabilities, including the next coupon payment, the face value of the bond at next coupon date, the recovery of the principal, the expected losses, and the fixed coupon payment after the next coupon date.

Many institutions in LDCs lack the expertise required to simulate the price of CAT bonds using their own historical data. Therefore, we illustrate the simulation process and apply the closed form solution to a real-world catastrophe risk. The drought catastrophe in Kenya is our research target. We collect monthly rainfall data for the Moyale region in Northern Kenya and fit these data with a log-logistic distribution and derive the correlation matrix between each month's rainfalls. Using distribution parameters and the correlation matrix, we simulate the monthly rainfall before the maturity of the CAT bond with 10,000 iterations and generate the intensity of drought occurrence based on pre-determined rainfall triggers. We then input the drought intensity and zero coupon Libor curve into the closed form solution to derive the CAT bond price. In our numerical experiments, we test the sensitivity of the CAT bond price with respect to trigger levels, time, recovery rates, coupon spreads, and the drifts of the zero coupon curve. We find our pricing method to be robust and consistent under various parameter settings. Our pricing example is thus one from which LDCs can learn.

We contribute to the literature by (1) reviewing different CAT bond pricing formulas and identifying the closed form solution as the one most suitable for catastrophe risk in LDCs; (2) simulating the price of a CAT bond based on the drought risk in Kenya; and (3) testing the robustness of our pricing method under various parameters. Further research could be conducted to (1) apply the closed form solution to other types of catastrophe risk; (2) calibrate the closed form solution using the real-world price of certain CAT bonds; and (3) compare the simulation results of the closed form solution with those of other pricing approaches.

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CHAPTER 6

CONCLUSION

This dissertation represents the latest research efforts to study two newly emerging bond varieties, the foreign bonds and the CAT bonds. Both foreign bonds and CAT bonds are characterized with unique features that clearly distinguish them from straight bonds. For example: foreign bonds are denominated by a foreign currency other than the domestic currency used in the issuing country and CAT bonds' payoff are linked to the occurrence of a pre-specified catastrophe. By studying the economics and pricing of these bond varieties, researchers such as us will have a chance to test our new theories and document some new phenomenon; practitioners such as CFOs and finance ministers will have a chance to learn how those financial instruments impact the equity value of their firms or the welfare of their countries.

In our study of the foreign bonds (chapter 2), we develop a theory to explain the valuation effects following the issuance of the foreign bonds. Through our model, we show that, if a firm issues only foreign debts, its equity value would be higher than the case that it issues only domestic debts. And the reason for that higher equity value is because foreign bonds carry more exchange rate risk than the domestic bonds. To test our theory, we choose dim sum bonds and Eurodollar bonds as our research targets. It is worth noting that both of them belongs to the foreign bond category, and especially, the Eurodollar bonds carry a higher exchange rate risk than the dim sum bond. Based on our model, we hypothesize that the stock return following the Eurodollar bond issuance would be higher than that following the dim sum bond issuance. We setup a two stage test that the first stage is to check whether there is any significant stock price reaction to the foreign bond issuances. Our first stage results indicate a positive return upon the launch of Eurodollar bonds but a negative return upon the launch of dim sum bonds, which fits our initial hypothesis. In the second stage, we test whether the stock return divergence between dim sum bonds and Eurodollar can be explained by a series of bond characteristics, including the foreign exchange risks. We find that the foreign exchange risk loads significantly positive on the three-day abnormal return of dim sum bonds and the +1 day abnormal return of Eurodollar bonds. Therefore, we confirm that the cross-sectional difference in valuation effect is explained by the foreign exchange risks carried by the foreign bonds. In addition to what we have learnt about the foreign bonds, we believe further research could shed lights in the areas such as the incorporation of other types of risks into our model, the examination of the valuation effects for additional bond categories, and an extension of bond characteristics in the cross-sectional regression.

In our study of the CAT bonds (chapter 3, 4, and 5), we show that catastrophe events have historically posed significant covariant risks to LDCs and the consequences of catastrophe events cannot be overlooked, due to the poverty trap problem and the lack of financial and insurance market. To efficiently manage the catastrophe risk, we investigate the feature of CAT bonds and compare it with other risk financing strategies. We find that the CAT bond is an effective economic development tool and an advantageous risk financing strategy, given its higher flexibility in project selection, higher insurance penetration, higher insurability and lower cost structure. Catastrophes not only creates direct economic losses for LDCs but may also trigger secondary damages like sovereign debt default, adding more fuel to the fire. We discuss the relationship between the government sponsored CAT bond and the sovereign bonds, in a static social wealth maximization framework. Our model indicates that CAT bond could potentially crowd out the issuance of sovereign bond, reduce the default incentive on sovereign debt and improve the overall social welfare. Knowing all the benefits of the CAT bonds, issuers, traders and intermediaries still need to obtain certain pricing techniques to develop this market. We review different types of CAT bond pricing model and identify the closed form solution as a valid and appropriate methodology to apply on catastrophe risks in LDCs. We collect the monthly rainfall data from the Moyale region in Northern Kenya and fit these monthly rainfall data with the log-logistic distribution that is commonly accepted in hydrology. Based on parameters of such distribution, we simulate the monthly rainfall and generate the intensity of drought occurrence. We calculate the price of a drought linked CAT bond out of intensities of drought occurrence and the zero coupon curve. We show that our simulation technique is adaptive and robust to different settings. In addition to what we have done about CAT bonds, we believe further research could shed lights in the areas such as the incorporation of CAT bonds into additional welfare or macroeconomic model, the test of sovereign debt yields following CAT bond issuance, and the comparison of simulation results of the closed form solution with those of other pricing approaches.

APPENDIX 1

STATA CODES FOR DATA MERGE AND CLEANING

```
use eventdates, clear
sort company_id
by company_id: gen eventcount=_N
by company_id: keep if _n==1
sort company_id
keep company_id eventcount
save eventcount
use stockdata, clear
sort company_id
merge company_id using eventcount
tab _merge
keep if _merge==3
drop _merge
expand eventcount
drop eventcount
sort company_id date
by company_id date: gen set=_n
sort company_id set
save stockdata2
use eventdates, clear
sort company_id
by company_id: gen set=_n
sort company_id set
save eventdates2
use stockdata2, clear
merge company_id set using eventdates2
tab _merge
list company_id if _merge==2
keep if _merge==3
drop _merge
egen group_id = group(company_id set)
```

APPENDIX 2

STATA CODES FOR TESTING 3-DAY CUMULATIVE ABNORMAL RETURN

```
sort group_id date
by group_id: gen datenum=_n
by group_id: gen target=datenum if date==event_date
egen td=min(target), by(group_id)
drop target
gen dif=datenum-td
by group_id: gen event_window=1 if dif>=-1 & dif<=+1
egen count_event_obs=count(event_window), by(group_id)
by group_id: gen estimation_window=1 if dif<-10 & dif>=-370
egen count_est_obs=count(estimation_window), by(group_id)
replace event_window=0 if event_window==.
replace estimation_window=0 if estimation_window==.
set more off
gen predicted_return=.
gen sd_i1=.
egen id=group(group_id)
forvalues i=1(1)29 {
        l id group_id if id==`i' & dif==0
        reg ret market_return if id==`i' & estimation_window==1
        predict p if id==`i'
        replace predicted_return = p if id==`i'
        drop p
        gen sd = e(rmse) if id==`i'
        replace sd_i1 = sd if id==`i'
        drop sd
        }
sort id date
gen abnormal_return=ret-predicted_return if event_window==1
by id: egen cumulative_abnormal_return = sum(abnormal_return) if
event_window==1
by id: gen test =cumulative_abnormal_return/(sqrt(3)*sd_i1)
list group_id cumulative_abnormal_return sd_i1 test if dif==0
gen var_i3=3*sd_i1^2
collapse (sum) sum_CAR=cumulative_abnormal_return (sum) sum_var_a3=var_i3,
by(event_window)
gen sd_a3=sqrt(sum_var_a3/3)/29
gen mean_CAR=sum_CAR/29/3
gen new_test=mean_CAR/sd_a3
```