

Catastrophic Risk and Securities Design

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The anomalies, inefficiencies and difficulties in the market for catastrophic bonds are so pronounced as to lead strongly to the inference that psychological factors have a major impact on the pricing of these bonds, and on the lack of acceptance they have encountered from investors. In this article, we examine major factors influencing the market for catastrophe bonds. Most of the economic factors involved—considered either singly or in combination—are insufficient to account for the magnitude of the anomalies observed. Decades ago, irregularities in the orbit of the planet Uranus allowed astronomers to deduce the existence of another planet, subsequently named Pluto. Since the economic forces at work in the marketplace cannot satisfactorily explain the situation in the catastrophe-bond marketplace, we infer that the gravitational pull of psychological forces is at work. We discuss eight psychological dynamics that may influence the pricing, mispricing, acceptance or lack of acceptance of catastrophe bonds.

Losses from catastrophic events represent an increasing problem for the property and casualty insurance industry. These losses have significant repercussions not only for insurance firms, but also for governmental policy makers and consumers in the insurance market. In principle, one way to deal with these risks is through securitizing them. Doing so would allow spreading risks of local disasters across global capital markets. However, previous attempts at securitizing insurance risks have, by most accounts, met with minimal success. This paper examines possible barriers to securitization, focusing on behavioral responses to such novel instruments. These barriers include the difficulties of conveying the associated risks, even to investors who are sophisticated about finance. Our analyses will draw on research in behavioral decision making and psychology. They will lead to proposals for empirical research and general strategies for making securities design more consonant with investor behavior.

Insuring catastrophic risks represents a significant challenge not only for insurance companies, but also for government agencies, banks, financial institutions, and individuals. Traditionally, risk management has been handled by a network of insurance companies, with some government oversight. A policy holder purchases coverage for some event from a property and casualty (PC) insurer. The PC insurer then typically divests much of that risk by obtaining coverage from reinsurers. The reinsurers transact with one another in order to diversify their own exposures.

When the risk of loss from any individual event is both well-known and small, this system works quite

well (e.g., automobile risks and most health risks). Historically, default rates among insurers have been similar to those among corporations in general.¹ However, with catastrophic losses, the consequences are more concentrated and the probability of occurrence harder to assess. These problems have drawn increasing attention as catastrophic losses have increased in their number and scope. In recent years, catastrophic losses have accounted for an increasing percentage of insurance-company failures. In some cases, like riverine floods, human activities (e.g., land-use changes) have increased the number of severe events. In other cases, like earthquakes and hurricanes, more people and insured property are in harm's way, even if the number of events has remained the same. Despite advances in hazard prediction, the models are still quite imperfect, particularly for limited time periods and geographic areas.² Helbling, Fallegger, and Hill [1996] also note increasing tendencies towards litigation, decreasing burdens of proof in determining liability, and new regulations regarding old, pre-existing risks as additional reasons for the increasing costs of catastrophic losses. All of these trends complicate predicting insurance exposures.

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Other uncertainties arise from the structure of the insurance industry itself. Cummins and Doherty [1997] assess the ability of insurers to pay for the “Big One” and find that, while recent losses of \$10 billion to \$15 billion may seem manageable compared to the industry’s total capital of over \$300 billion, there is a mismatch in the distribution of that capital (across firms) and the distribution of claims following a catastrophic loss. In this context, the capacity of individual insurers is actually quite limited. According to Haag [1995], it is “unusual” for any insurer to obtain more than \$100 million in catastrophe reinsurance per policy. If insurers wanted more, they would find that worldwide reinsurance capacity (*circa* 1994) is approximately \$7.2 billion, much smaller than the possible demand. Claims resulting from some single major catastrophes could reach \$70 billion to \$100 billion [Palm, 1995; *Wharton Alumni Magazine*, 1998]. A repeat of the earthquake that destroyed Tokyo in 1923 could result in damages between \$900 billion and \$1.4 trillion [Valery, 1995].

The gap between the catastrophic coverage that the industry could and does provide might be traced to failures in the market for coverage. One familiar problem is the cyclical nature of the insurance business, reflecting its profit incentives. Some analysts have attributed the laggard performance of insurance and reinsurance firms, relative to other financial companies and the market as a whole, to “excess capital” and “underleveraging” [Moody’s, 1997; Standard & Poor’s, 1997; Wehrly & Friedheim, 1998]. The net written premium-to-surplus ratio declined from 1.82:1 in 1984 to 1.13:1 in 1995 to 0.90:1 at year-end 1997 [Wehrly & Friedheim, 1998]. Regulators allow insurers to leverage their capital twice (2:1). In these terms, the industry had “excess” capital of over \$120 billion. Although the premium-to-surplus ratio is only one measure of capitalization efficiency, its decline suggests that surplus is accumulating at a greater rate than premiums are increasing. That is, firms are generating more cash than they can efficiently manage.³ The resultant pressure on policy prices has diminished profits.

The definition of “excess” capital depends on the time frame used. Given the certainty of eventual catastrophic losses, the capital may *not* be excessive. Rather, it may eventually be required to cover losses. However, those losses may be decades into the future. Only from a short-term perspective is such retained capital excessive. Accounting conventions and the U.S. tax code limit reserves to actual losses or to those losses that may reasonably be expected within a year [USAA, 1998]. Any additional premium capital set-aside (*e.g.*, for longer term, less frequent losses) must be transferred to the insurer’s balance sheet, hence is subject to tax (and possible distribution to shareholders). Liquid capital on an insurer’s balance sheet reduces the firm’s return on equity. In the long run, this reduced return is “fair,” in the

sense of covering shareholders against expected future losses. However, myopic [Mossin, 1968] or self-serving [Babcock & Loewenstein, 1997] managers may see short-term advantage in reallocating that capital to more profitable short-term projects, such as writing additional insurance coverage in non-catastrophic lines or returning it to shareholders. By reducing provisions for losses, they will thereby increase future financial risk. Shareholders should then expect increased returns as compensation for bearing more risk (even if that risk is overlooked by current shareholders and managers).

Some smaller firms are underreserved, especially those with asbestos and environmental liabilities [Standard & Poor’s, 1997]. However, the industry as a whole appears to face a capitalization paradox: it is over-capitalized from a short-term profit perspective, while lacking the long-term ability to cover catastrophic losses when they occur. The paradox could be resolved if the industry made better use of its short-term capacity. As mentioned, the infrequent nature of catastrophic claims means that insurers who prepare *adequately* will suffer long periods of *perceived excess capital* (in the eyes of myopic stakeholders) as well as diminished profits (from taxation of capital held against future liabilities, but not treated as official reserves). Conversely, those who do *not* prepare adequately have higher short-term profits, along with higher likelihoods of failure (bankruptcy). Large catastrophic losses have periodically prompted reorganizations and the tightening of capital. Then, for some (usually brief) period, perceived excess capital disappears, prices increase, and profits remain stable or improve. However, as capital flows back to the industry, firms compete for profits, prices drop, competition intensifies, profits disappear, and the industry finds itself awash in capital (which it cannot invest in projects profitable enough to satisfy shareholders and managers) [Standard & Poor’s, 1997; Wehrly & Friedheim, 1998].

Several recent initiatives have attempted to increase the industry’s capacity by providing insurers access to capital markets [Lewis & Davis, 1998; Osterland, 1998]. Losses of even catastrophic proportion remain almost negligible when compared to the size of global capital markets [Cummins & Doherty, 1997; Jaffee & Russell, 1997]. For example, a \$100 billion catastrophe would consume nearly one third of the PC industry’s total capital and surplus, perhaps pushing some firms into insolvency. Yet, that amount is less than the average daily *variation* in global equity wealth.

Catastrophe bonds (“cat” bonds) are one possible way to access capital markets, building on the wild popularity of securitization for other asset classes and exposures (*e.g.*, mortgages, credit-card receivables, real estate, David Bowie⁴). However, although insurance companies have created a variety of offerings (summarized in Table 1 below), they have generally

experienced but modest success in raising the desired capital at a cost commensurate with the portfolio risk of the security [Lewis & Davis, 1998].

A frequently voiced objection by insurance companies is that such structured finance costs too much for them to use [Penalva-Zuasti, 1997]. For example, catastrophe bonds have typically carried premiums of 300 to 500 (or more) basis points over the LIBOR for medium-term securities with investment-grade ratings (see Table 2 below). Even with these added inducements, buyers have sometimes been scarce. As a result, the critical question facing the creators of this market is whether potential investors are reluctant to purchase *any* security backed by catastrophic risk insurance or just the current offerings. In an excellent overview, Froot [1997] advances eight possible reasons for the appearance of insufficient risk sharing:

- (1) Actuarially insufficient reinsurance capital⁵
- (2) Undue reinsurer market power
- (3) Inefficient corporate form for reinsurance⁶
- (4) High frictional costs of reinsurance
- (5) Moral hazard and adverse selection at the insurer level⁷
- (6) Regulatory interference⁸

- (7) *ex post* third-party financing⁹
- (8) Behavioral factors

The remainder of this paper examines catastrophic risk insurance financing through the lens of behavioral factors, expanding on Froot's work and related research [e.g., Lewis & Davis, 1998] by drawing on general processes identified in the psychology of investment and decision-making behavior. The next two sections further describe the insurance and investment environment for securitization. The fourth section proposes that catastrophe-bond offerings cannot be sold at prices that insurance companies find acceptable unless they address important behavior patterns. The final section suggests courses of future study and future action, and concludes.

The PC Industry and the Nature of Catastrophic Risks

Although we assert in this paper that investor psychology plays a crucial role in the market for catastrophic insurance risk, we certainly recognize that it is not the only factor. There are several institutional and regulatory factors that also influence the development

Table 1. *Catastrophe-Risk Financial Instruments as of 1997*

Reinsurer	Instrument	Amount (in millions)	Status	Date
Nationwide	CSN	400.0	Closed	August 1995
Hannover Re	CSN	100.0	Closed	1995
Arkwright	CSN	100.0	Closed	May 1996
AIG	Cat Bond	25.0	Closed	May 1996
CAT, Ltd.	Cat Bond	50.0	Withdrawn	1996
ACE, Ltd.	Cat Bond	35.0	Withdrawn	1996
USAA	Cat Bond	500.0	Withdrawn	August 1996
Calif. Earthq. Auth.	Cat Bond	1500.0	Withdrawn	1996
RLI	CatEPut	50.0	Closed	October 1996
Hannover Re	Cat Bond	100.0	Closed	December 1996
St. Paul Re	Pro Rata Bond	68.5	Closed	December 1996
Winterthur	Cat Bond	282.0	Closed	January 1997
Reliance	Cat Bond	40.0	Closed	April 1997
Horace Mann	CatEPut	100.0	Closed	April 1997
USAA	Cat Bond	477.0	Closed	June 1997
Swiss Re	Cat Bond	137.0	Closed	July 1997
LaSalle Re	CatEPut	100.0	Closed	August 1997
Tokio-Marine	Cat Bond	100.0	Closed	November 1997

Note: Source: Lewis and Davis [1998].

Table 2. *Three Examples of Early Catastrophe-Bond Offerings*

	ACE Limited	USAA	CAT Limited
Principal	\$25 million	\$500 million	\$50 million
Coupon	6-Month T-bill + 550bp	1-Month LIBOR + 300bp	6.72%
Risk Period	Last 5 months of 1996	8/96 to 7/97	Last 5 months of 1996
Trigger Level	\$25 billion industry loss	\$1 billion of firm losses	\$55 million of firm losses
Region Covered	US	US East Coast	US Northeast
Risk Index	PCS	Company's loss experience	Company's loss experience

Note: Source: Lewis and Davis [1998].

of the market for securitized insurance risk and risk-transfer products. In addition, because there is likely to be interplay between investor psychology and institutional and regulatory factors, it is important to comment briefly on the role such factors play in the overall problem.

The Insurance Market

A. M. Best, an insurance-industry research firm, tracks 2,430 property and casualty insurers [Standard & Poor's, 1997]. Together, they wrote \$259.8 billion in premiums for 1995.¹⁰ Although several large players dominate the industry, particularly for catastrophic risk policies, the industry is still so fragmented that they lack pricing power. In fact, price pressure, the fragmented distribution of capital across firms, and the increasing needs for a multinational presence are spurring consolidation in the industry [Standard & Poor's, 1997]. In 1997, 91 PC mergers were announced [Wehrly & Friedheim, 1998]. However, Wehrly and Friedheim [1998] predict that competition will continue to escalate, increasing the gap between weak and strong companies.

One measure of the strength of an insurance company is its surplus or reserves, relative to its exposures. As mentioned, maintaining sufficiently high reserves is prohibitively expensive, from both an accounting and strategic standpoint [Helbling, Fallegger, & Hill, 1996].¹¹ Additionally, firms that write more catastrophic risk insurance are also more likely to have insufficient capital and surplus [Cummins & Doherty, 1997]. Thus, although the industry as a whole appears to have sufficient capital for even very large catastrophic losses, that capital cannot actually be "pooled" across firms. Securitization could offer contingent access to capital, with firms paying for the option value of that capital, rather than maintaining their own standing reserves.

Regulation

As Klein [1997] notes, "insurance is perceived to be 'vested with the public interest.'" As a result, the PC insurance industry is subject to heavy government involvement. Every state has an insurance commissioner (elected in thirteen), charged with regulating the nature and (in some cases) the premium level of coverage for firms operating in the state. State and federal government institutions enforce entry and exit restrictions on firms (*e.g.*, preventing non-insurance firms from indirectly restricting capital sources). They also limit firms' hedging behavior [Klein, 1997].

Such government intervention can impose costs on insurers and policyholders. Penalva-Zuasti [1997] ana-

lyzed a simulated market for catastrophe bonds and earthquake insurance in California and found that catastrophe bonds carried a 3.7% excess premium (in 1997) relative to estimated competitive prices. The implied efficient market prices were one order of magnitude lower (\$0.29 versus \$3.29 per thousand dollars of coverage) than those proposed by the California Earthquake Authority (CEA, a quasigovernmental agency).¹² Not only was CEA-sponsored insurance highly noncompetitive, but also catastrophe bonds designed to improve market efficiency traded at a premium over competitive prices. Penalva-Zuasti [1997] attributed this premium to the novelty of the product and to the "impact of the highly regulated environment surrounding current insurance markets."

Intra-Industry Competition

Santomero [quoted in *Wharton Alumni Magazine*, 1998] notes that insurers are divided over such non-traditional methods of insurance coverage. For strong firms, with sufficient capital to endure industry cycles, structured products such as catastrophe bonds put downward pressure on prices for catastrophic risk coverage, thereby reducing their profits. For firms chronically short of capital, however, structured finance can strengthen their balance sheets at a reasonable price. This is summarized by the view that "the strong thrive, the weak issue cat bonds."¹³ Access to capital is frequently used to competitive advantage by strong, well-capitalized insurers.

Several firms, in fact, have attempted to thwart the issuance of catastrophe bonds. For example, the CEA decided to issue bonds after concluding that catastrophe insurance offered by Berkshire Hathaway (through its National Indemnity subsidiary) would be too costly. However, at the last minute, Berkshire underwrote the entire issue for approximately \$650 million [Osterland, 1998].¹⁴ In Berkshire Hathaway's 1997 Annual Report, Chairman Warren Buffett [1997] spelled out his dislike of catastrophe bonds in terms of his perception of their exploitation of investor psychology.

"The second word in this term [catastrophe bonds], though, is an Orwellian misnomer: A true bond obliges the issuer to pay; these bonds, in effect, are contracts that lay a provisional promise to pay on the purchaser. ... This convoluted agreement came into being because the promoters of the contracts wished to circumvent laws that prohibit the writing of insurance by entities that haven't been licensed by the state. ... A side benefit is that calling the insurance contract a 'bond' may also cause unsophisticated buyers to assume that these instruments involve far less risk than is actually the case. ... The influx of 'investor' money into catastrophe bonds—which may well live up to their name—has caused super-cat prices to deteriorate materially.

Therefore, we will write less business in 1998." [emphasis added]

Although the premium for catastrophe bonds estimated by Penalva-Zuasti's [1997] model runs contrary to Buffett's assertion, Buffett's opinions and actions carry considerable weight. It is unclear whether his public disdain reflects a desire to preserve the market as is or is, instead, the sort of strategic behavior described by Borch [1962] and others.

Definitions

Adam Smith [1776] noted that the insurance premium must compensate for the expected losses, the expenses of insurer operation, and an appropriate profit on invested capital. Most insured events happen with sufficient frequency to allow accurate estimates of expected losses [e.g., Borch, 1969, 1990]. However, catastrophic losses come from infrequent and relatively unpredictable events. Therefore, any model for predicting losses from them is bound to be critically sensitive to the downside tail of the distributions of dollar losses. It is precisely in those areas, however, that estimation is most difficult. Moreover, it encounters the sorts of ambiguities that threaten the usefulness of forecasts [Fischhoff, 1994].

Estimating a probability distribution for "catastrophic events" requires a definition of that term. Unfortunately, there is little standardization. Standard & Poor's [1997] defines a catastrophe as "an event or series of related events that causes insured losses of \$5 million or more." Swiss Re's *sigma* [e.g., Swiss Re, 1996, 1997, 1998] defines a natural "catastrophe" as, "event caused by natural forces. The following categories are used: flood, storm, earthquake (including seaquake/tsunami), drought/bushfire/heat wave, cold/frost, and other (including hail and avalanche)."

The Guy Carpenter Catastrophe Index (GCCCI), used in many insurance-related contracts (such as catastrophe derivatives), measures "atmospheric damage," defined as "hurricanes, tornadoes, windstorms, hail, and freezing temperatures." It specifically excludes all other perils, including fire, flood, lightning, earthquake, and riot. There is an Event GCCCI, for a single catastrophe, and an Aggregate GCCCI, for a time period. This methodology is used in all states except Texas [IndexCo, 1997]. The other major catastrophe monitoring firm, PCS, defines a catastrophe as an "event resulting in excess of \$5 million in insured property damages and having an effect upon a large number of insurers and insured" [Ray, 1993].

Epstein [1996] describes the difficulty of defining "catastrophe" in a contractually meaningful way. He notes that it must consider the risk relative to the pool of potential insured individuals. It must determine whether

to consider small, but highly correlated losses (such as asbestos damage) as catastrophes. If it is specific enough to be contractually satisfying, a definition may be too idiosyncratic to allow generalization. Epstein concludes by defining a catastrophic event as one "capable of laying devastation to vast numbers of individuals at a single blow." However, even he leaves "devastation," "vast numbers," and "single blow" undefined (see also Zeckhauser [1996]).

A workable definition of catastrophic losses must also treat "collateral" or "collocation" damage, such as debris from a collapsed building damaging neighboring buildings or fires in structures next to those hit by lightning [Dong, Shah, & Wong, 1996]. If a hurricane (considered a catastrophic event) caused damage that led to a fire (not considered a catastrophic event), how would the composite event be classified? Whether these losses are included may determine whether the *total* insurable loss passes the threshold for qualifying as a *catastrophic* loss. A clear definition is essential to investors in catastrophe bonds.

Estimating the Risks of Catastrophic Events

However defined, the expected losses from catastrophes must be estimated, even if they do not happen often enough to establish a track record in the actuarial sense [Dong *et al.*, 1996]. To illustrate this difficulty, Table 3 shows three years of catastrophic losses as reflected in Swiss Re's annual *sigma* research reports. They show the variability over even this short period, including the impact of an unusual event, the January 17, 1995, earthquake in Kobe, Japan. Swiss Re [1996] estimated insured losses at \$2.5 billion, but total damage at \$82.4 billion. In contrast, EQE [1995], a catastrophe monitoring firm, estimated total Kobe losses at \$95 - \$147 billion, not including building contents (such as equipment and inventory), and insured losses at \$6 billion. By either estimate, a much smaller fraction of losses was insured in Kobe than for equivalent American events. In the 1994 Northridge earthquake, \$12.5 billion out of the total of approximately \$20 billion in damage was insured [EQE, 1994; U.S. Geological Survey, 1996]. Palm and Hodgson [1992] note similar coverage rates for the 1989 Loma Prieta earthquake in California. Thus, uncertainty about current coverage rates further complicates evaluating catastrophe bonds.

Although it has improved significantly over the past twenty years, the reporting methodology for catastrophes still creates uncertainty for investors. Changes in the dollar value or number of losses may reflect changes in claims practices (e.g., pressure to reduce fraudulent claims, or governmental pressure to be liberal in claims payments) as well as changes in the number and severity of catastrophes themselves.

Table 3. *Natural Catastrophes in 1995, 1996, and 1997*

	Number of Events				Victims				Insured Losses (in millions)			
	1995	1996	1997	Total	1995	1996	1997	Total	1995	1996	1997	Total
Floods	45	44	478	567	5,835	6,853	4,950	17,638	\$367	\$233	\$1,420	\$2,021
Storms	47	50	42	139	3,826	5,385	5,315	14,526	\$7,452	\$5,252	\$2,460	\$15,165
Earthquakes	13	8	16	37	8,406	544	2,878	11,828	\$2,472	\$0	\$12	\$2,484
Drought, bushfires	8	7	5	20	1,452	97	667	2,216	\$0	\$0	\$0	\$0
Cold, frost	7	10	7	24	421	779	417	1,617	\$536	\$2,360	\$168	\$3,064
Other	7	10	1	18	305	292	157	754	\$1,602	\$61	\$80	\$1,742
Total	127	129	549	805	20,245	13,950	14,384	48,579	\$12,429	\$7,906	\$4,141	\$24,475

Note: The dollar figures of these loss estimates are reported in the dollars of the year of the loss, unadjusted for inflation, and converted to US dollars at the time of the loss (using the appropriate market or official exchange rate). Source: Swiss Re, *sigma* No. 2/1996, No. 3/1997, No. 3/1998.

Furthermore, Property Claims Services (PCS), the organization that estimates catastrophe losses, “does not release exact figures in order to prevent their use by unauthorized third parties.” As a result, even Swiss Re obtains the insured loss figures from PCS only within relatively wide ranges: the 1998 *sigma* report includes the ranges \$25 to \$100 million and \$101 to \$300 million. These uncertainties compound the inherent problems of estimating the probabilities and consequences of catastrophic events.

The frequency distributions of past catastrophic natural events are often well-documented, with future estimates being further refined using basic science. For example, there is a great deal of (physical) understanding¹⁵ of the ENSO (El Niño/Southern Oscillation) phenomenon, which has been described (Zebiak & Cane, 1998) as “second only to the seasons themselves in driving worldwide weather patterns.” The U.S. Geological Survey [Michael *et al.*, 1996] notes that “[a]lthough quake forecasting is still maturing, it is now reliable enough to make official earthquake warnings possible.” Nonetheless, catastrophic events fall in the tails of these distributions, hence are the least predictable. Furthermore, predictions often lack the spatial resolution needed by insurers of specific properties. For example, Gray *et al.* [1998] caution readers of their hurricane forecasts that “landfall probability estimates at any one location along the coast are very low ... no matter how active an individual season is.” Michael *et al.* [1996] voice similar warnings concerning earthquake forecasts.

Estimating the consequences of these events requires understanding a complex web of related events. Flooding causes landslides, earthquakes cause fires, winter storms often lead to flooding, and so on [Swiss Re, 1996]. As mentioned, the available information is disproportionately in the hands of the insurers. That imbalance is a barrier to investors, even if they do not realize that the insurers themselves lack confidence in what they know.

Paradoxically, insurers may also avoid situations where their information is sufficiently good that they

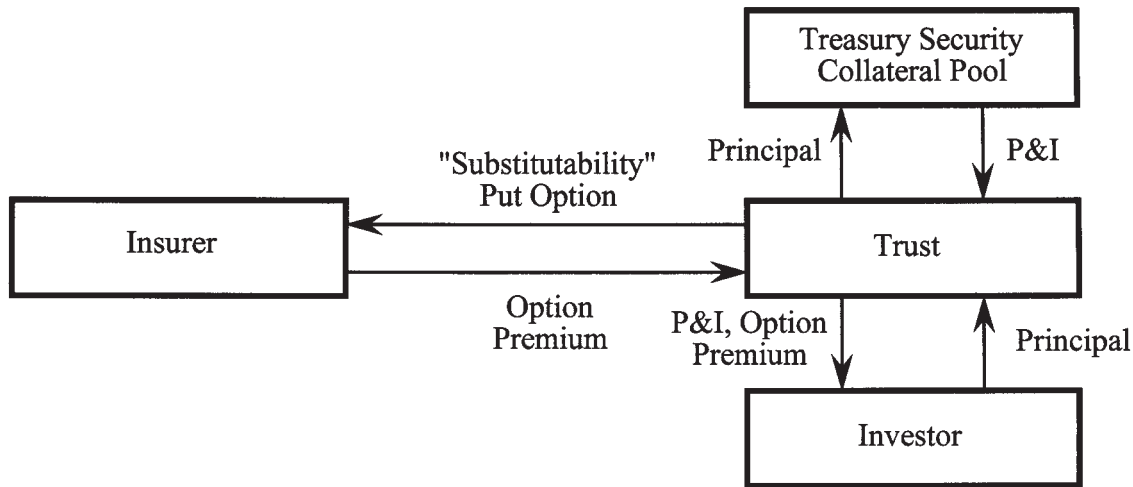
could be held legally responsible for model errors. For example, the State of Florida spent \$1 million on certifying models of catastrophic exposure as scientifically valid. Nonetheless, Florida’s Insurance Commissioner refused to use the certified models and filed legal action to block state adoption of them [Florida Department of Insurance, 1997]. Although other models (such as EQECAT’s USWINDTM and E. W. Blanch’s Catalyst 3.0) have been certified by Florida [*e.g.*, EQECAT, 1998; Property and Casualty Online, 1998], regulators are still reluctant to use catastrophe models [Kibbee, 1997]. Katten [1997] writes “to a great extent, catastrophe modeling, while a useful tool, has caused an unnecessary paranoia that adversely affects the market.”

Structure of Catastrophe Bonds

A catastrophe bond is typically structured as a conventional corporate bond with an embedded option. Other securities share this basic structure (*e.g.*, convertible bonds, mortgage-backed bonds, and even U.S. Savings Bonds).¹⁶ Lewis and Davis [1998] describe the 18 securities offerings incorporating catastrophic risk exposure issued to that date. These 18 securities have three common structures (see Table 1): (a) contingent surplus notes (CSNs), (b) CatEPuts, and (c) catastrophe bonds. In addition to these structures, there was also the unique St. Paul Re Pro Rata bond that will be described in detail in Section IV. CSNs are fully-collateralized securities. The issuing insurance firm invests the proceeds of the offering in Treasury securities. If a catastrophic event occurs, the insurance firm can substitute its own corporate bonds for the Treasury bonds (effectively issuing debt at a prearranged price). Investors receive the interest from the Treasury securities plus the premium (paid as yield) for selling to the issuers the option to substitute its own debt. Figure 1 (adapted from Lewis and Davis [1998]) illustrates the structure of CSN cash flows.

CatEPuts, a contraction of Catastrophic Equity Puts, allow insurance firms to “put” or sell new equity (in contrast to the new debt provided by CSNs) to in-

FIGURE 1
Contingent Surplus Note (CSN) Cash Flow Structure



vestors at a prearranged price, if a catastrophe occurs [Jewett, 1997]. This new equity typically takes the form of newly issued shares (thereby diluting earnings for pre-existing shares). These CatEPuts are a basic option transaction: the insurer pays a premium to investors in return for the right to put its own shares to them should a catastrophic loss occur.

Catastrophe bonds typically involve a standard corporate bond with a provision for reducing its principal or interest (or both) in the event of a catastrophic loss. Thus, they provide capital (or reduced debt) to the issuer when it is needed most. There are two classes of catastrophe bonds: indemnity catastrophe bonds and index (or recapitalization) catastrophe bonds. Indemnity bonds base contract threshold payouts on the issuer's own loss experience. Index-based catastrophe bonds use indices such as PCS and GCCI (see Appendixes A and B). Using indices encourages a liquid market in the bonds, but increases basis risk (insofar as the indices deviate from the issuer's actual loss exposure). Catastrophe bonds were not issued until 1996, despite years of intense interest. Even then, they have been hampered by lack of standardization in both the structure of the bonds and the reference indices [Lewis & Davis, 1998]. (Table 2 illustrates differences in three early catastrophe-bond offerings.) As a result, securities based on one index can only be imperfectly substituted for securities based on the other, introducing additional basis risk.

Catastrophe derivatives address some of these liquidity problems. Although they can be used for risk management in isolation, they are more frequently embedded in other securities and contracts. The Chicago Board of Trade (CBOT) now makes a market in both futures and options for which the underlying asset is catastrophic insurance risk in various regions of the United States [CBOT, 1998].

These securities can be classified in terms of their relative exposure to moral hazard, credit risk, and basis

risk. For example, although reinsurance has a low risk of moral-hazard problems, it carries a high credit risk. Index-based catastrophe bonds have a low credit risk, but carry substantial basis risk. Moral hazard refers to the possibility that purchasing an insurance contract may change firms' behavior. Reinsurance has greater moral hazard than CBOT derivatives because the losses are more exactly matched to the exposure (compared to the index-based derivatives). Issuers left with residual risk (as a result of the imperfect hedge) have a greater incentive to reduce such risks.

If the components of a structured product have liquid markets, then the composite should trade at parity with the market value of those components. If not, then arbitrage is possible. The conventional approach to pricing complex or "exotic" securities is to replicate their cash flow streams with simpler securities that are easier to price [Black & Scholes, 1973]. Thus, the value of a catastrophe bond equals the sum of the values of its constituent components: a corporate bond and an option. The theories for evaluating both corporate bonds [e.g., Fabozzi & Fabozzi, 1995] and options [e.g., Hull, 1993] are widely known. Such arbitrage-supported replication presupposes: (1) that investors approach the valuation of all securities identically (e.g., in estimating volatility) and (2) that the building blocks needed to construct the replicating portfolio exist. Should the true value of a security, such as a catastrophe bond, not be preserved through such arbitrage bounds, investors' *perceptions* of that true value become a relevant factor in the pricing of such securities.

Human Behavior and Catastrophe Bonds

Following Olsen [1998] and Froot [1997], we consider how individuals might perform the cognitively

complex task of evaluating such complex, unfamiliar and frighteningly named investment products as catastrophe bonds. Depending on the circumstances, these processes could lead investors to overvalue, under-value, or refuse to value these offerings. Table 4 briefly summarizes Olsen & Froot's eight cognitive phenomena, along with our analysis of their predicted impact on the market for catastrophe bonds.

Our analyses extrapolate from the research literature of behavioral decision making to a domain in which no direct studies have been conducted. One constraint on such extrapolation is that most behavioral decision-making studies have been conducted on individuals without the financial experience of potential cat-security investors. Currently, individual investors have no (direct) access to the market for these securities. For regulatory reasons, the market is limited to institutional investors. Moreover, even these institutional investors must be licensed to sell insurance by state insurance regulators before they can transact in the catastrophe-bond market [Klein, 1997]. However, the absence of arbitrage-based pricing models means that these experts must rely on their own judgment. One would like to believe that (1) experts can avoid mistakes on tasks central

to their expertise and (2) the stakes would motivate them to do so. Unfortunately, there is enough evidence of imperfect expert judgment to allow the possibility for suboptimal choices in these novel, difficult, and consequential tasks [e.g., Dawes, 1988; Dawes, Faust, & Meehl, 1989; Mowen, 1994; Thaler, 1994; Kammen & Hassenzahl, 1999].

Cognitive Complexity

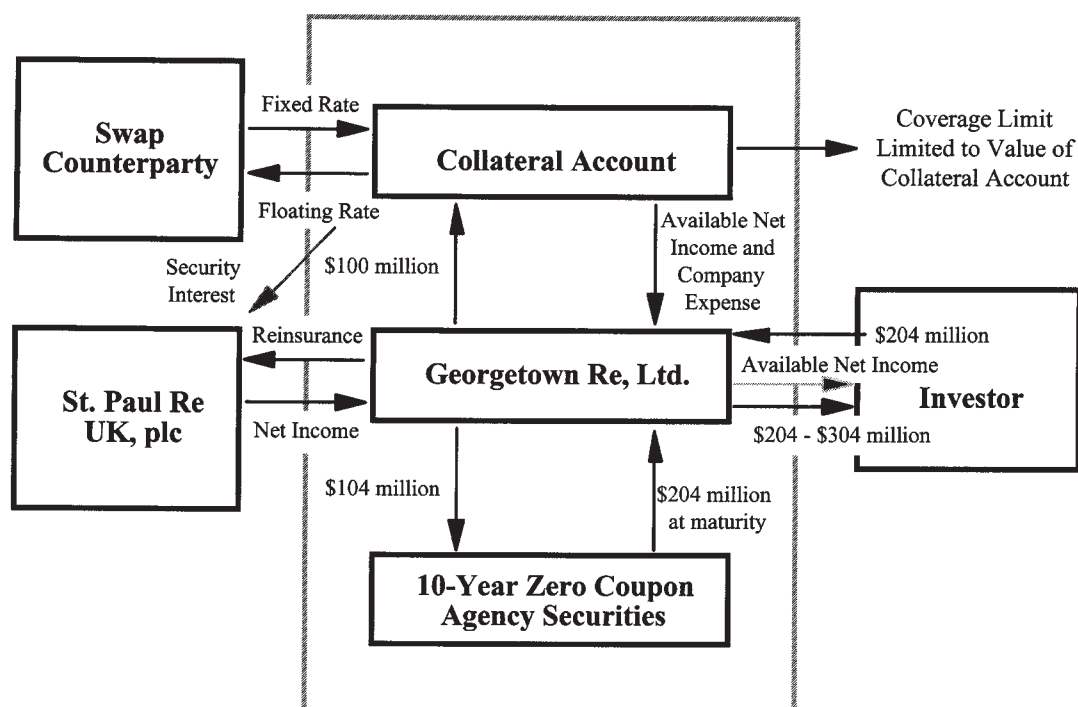
There are cognitive limits to individuals' ability to function effectively in complex decision-making environments [Simon *et al.*, 1987]. Even where financial theory can distill a problem to cash-flow streams, people often cannot. Instead, they rely on heuristic reasoning and "automated" rule-based responses [Newell & Simon, 1972; Cross, 1983; Albers & Laing, 1991; Becker, 1993]. In financial thinking, Neftci [1991] has characterized reliance on technical analysis (essentially a collection of heuristic decision rules) among experienced market participants as showing the pervasiveness of rule-based decision processes.¹⁷

As a result, it would not be surprising to find, as observed by Lewis and Davis [1998], that "investors sent a

Table 4. *Behavioral Anomalies and Implications for Catastrophe Bonds*

Stylized Facts About Human Decision Making	Features of Catastrophe Bonds	Implications for the Catastrophe-Bond Market
Understanding Facts of Transaction		
Cognitively-constrained individuals tend to resort to sub-optimal heuristic decision rules in new and complex environments	Past catastrophe-bond offerings have often exhibited very complex structures making hedging and comprehension difficult	May limit market depth if investors are "overwhelmed." Those who stay may require higher returns as compensation for learning costs.
Exaggerated comprehensiveness; individuals tend to overestimate the completeness of their pictures of complex problems	Catastrophe bonds are linked to insurance portfolios of the issuing firms that involve very complicated risk structures and events which are difficult to forecast	Investors (and issuers) may inaccurately estimate risks and thus costs, leading to different expectations of what an appropriate return would be.
Illusion of control; the perception of risk varies inversely with the perception of control	Catastrophic events are frequently viewed as "acts of God"	Investors (and issuers) may inaccurately estimate risks and thus costs.
Reliance on availability; the likelihood of highly available or vivid events tends to be overestimated	Catastrophic events are infrequent and dramatic	Investors (and issuers) may overestimate risks, and thus costs.
Understanding Relevant Values		
Small probabilities are overweighted	Catastrophic events are, by their nature, very infrequent	Investors (and issuers) may overestimate risks, and thus costs.
Violations of extensionality; the structure of a decision problem often influences individuals' judgments.	Catastrophe bonds have features of both debt and equity, as well as the contingent exposure of options	Inability to think about cat investments with a pre-existing schema raises the cost of entering the market, inhibiting liquidity and increasing required returns.
Dimensions of Risk		
Individuals often perceive and react to differences between psychological and actuarial perceptions of risk	Events that have an actuarial nature to the firm have a visceral impact on individuals	Investors may be pricing (attaching value to) features of risks that are ignored by traditional financial theory.
Asymmetric Information		
Individuals tend to weight different pieces of information improperly; aversion to the risks of asymmetric information	Vast resources and the ability to collect primary data provide a substantial informational advantage to insurers	Liquidity of market is substantially constrained.

FIGURE 2
The St. Paul Re *Pro Rata* Capital Note Cash-Flow Structure



Note: Source: Lewis and Davis [1998].

clear message to the insurance industry - complexity is a liability," after St. Paul Re placed only \$68.5 million of \$204 million in *pro rata* capital notes. The St. Paul Re security, as depicted in Figure 2, was remarkably complicated. It involved not only St. Paul Re, but also two special purpose reinsurers (SPRs) created specifically for the deal, a swap transaction, and two distinct collateral accounts. The *pro rata* capital notes combined debt issuance with participation in returns on the reinsurance provided to St. Paul Re, which was also to cede reinsurance business from five excess-of-loss classes, on a proportional basis, in two pre-specified layers that adjust over time to reflect claims experience [Lewis & Davis, 1998]. The bonds also offered options of two Class B St. Paul Re common shares per \$1 million in invested principal. This structure was actually intended to offer additional protection for investors and, thus, make the bonds more desirable. However, the complexity and attendant uncertainty over hidden risks overwhelmed investors.

In addition to prompting rule-based rejection, complexity can increase rational rejection by accentuating investors' informational disadvantage [Duffie & Rahi, 1995]. Investors must understand the relations in Figure 2, track the various cash-flow streams, and then evaluate the probabilities of different outcomes. They must do this well enough to identify and hedge all sources of risk in the security. Here, this includes not only the risk of catastrophic loss, but also (1) the counterparty risk of the swap, (2) the tax, accounting,

legal, and regulatory risks of the SPRs, including their offshore (UK) foreign-exchange risks, (3) the interest rate risk of the zero-coupon securities held in the collateral account, (4) the basis risk and moral hazard attached to the insurance contract itself, the correlations among these risks, and possibly many others. At each stage, St. Paul Re is ahead of the investors. It may just not be worth the transaction costs of catching up.

Exaggerated Comprehensiveness

Scholes [1996] criticized stock market and accounting regulators for failing to see the "big picture" of corporate risk-management needs. He pointed specifically at regulators limiting the use of derivatives in hedging, even when two highly volatile instruments should hedge one another, thereby reducing overall risk. If his claim is correct, then such behavior would be a special case of the general tendency to overestimate the completeness of one's picture of complex problems [Fischhoff, Slovic, & Lichtenstein, 1978], one source of the overconfidence that has been found with many difficult tasks [Yates & Stone, 1992].

Such exaggeration could also cause those who do invest in catastrophe bonds to overlook the risks involved. If their investments fare surprisingly poorly, then they may be dissuaded from such investments, not understanding just what went wrong. For exam-

ple, they might not realize the full implications of a catastrophic event on the issuing firm, such as the interconnectedness of losses when a hurricane causes landslides, strikes two insured locations, or triggers associated health and life insurance-related claims. Such possibilities can reduce a catastrophe bond's value both by increasing the chances of triggering the embedded option and by diminishing the issuing firm's financial capacity.

Illusion of Control

Olsen [1998] summarizes financial evidence of the general phenomenon of people exaggerating their control over uncertain events, leading, in turn, to underestimating risks. In a classic study, subjects playing a game of pure chance were more aggressive with an opponent who appeared naive than with one who appeared sophisticated [Langer, 1975]. The novelty of these securities, highlighted by the term "Act of God" bonds (used by USAA) may have allowed little room for illusions of control. Inexperienced investors have had little chance to develop heuristics or confidence needed to convince themselves that they could beat the averages. If so, then, ironically, the success of these securities may have been limited by their inability to take advantages of natural biases.

Reliance on Availability

Tversky and Kahneman [1973] proposed that, when individuals do not know the frequency or probability of an event, they judge its frequency by its availability to memory. Although often helpful, this heuristic can exaggerate the likelihood of disproportionately salient events. For example, Lichtenstein *et al.* [1978] and Combs and Slovic [1979] found that subjects overestimated the frequency of deaths from relatively publicized causes (*e.g.*, tornadoes and floods), while underestimating the frequency of deaths from less visible ones (*e.g.*, cancer or heart disease). Potential investors in catastrophe bonds must assess the probability of adverse events. Unless they accept the modelers' claims, they must rely on their own judgments. If catastrophes are disproportionately available, then investors will overestimate their probability. If so, then investors would demand greater compensation for bearing these risks than insurers, relying on model estimates, see reason to pay.

Overweighting Small Probabilities

According to prospect theory's decision weighting function, people pay undue attention to small probabilities, above and beyond any errors in their estimation

(*e.g.*, due to availability). As statistically rare events, catastrophes might receive such weighting (above and beyond any tendency to misjudge their probabilities). For example, Kahneman and Tversky [1979] had subjects choose between a sure loss of \$5 and a 0.001 chance at losing \$5,000. Of 72 respondents, 83% preferred the sure loss, even though the two options had the same expected value. One in a thousand (0.001) is a plausible probability for catastrophe bonds to exceed the preset threshold and trigger the embedded option payout leading to loss of principal.¹⁸ In a normative pricing model, this small probability would imply a comparably small premium. A prospect theory weighting function would lead investors to overweight that admittedly small probability of loss and, thus, demand a higher return.

Violations of Extensionality

Psychologists have long known how formally equivalent ways of describing the same tasks can affect people's choices [Turner & Martin, 1984; Poulton, 1989; Fischhoff, 1991; Schwarz, 1999]. Tversky and Kahneman's [1981] prospect theory provided an integrated account of such effects, cast in terms of rational actor models. For example, they showed that patients are less likely to choose surgery framed in terms of the probability of death rather than the complementary probability of surviving.

In an ideal world, investors would analyze securities on their own merits, in terms of first principles of finance. However, in fact, they are often trained to analyze *types* of investments: bonds, stocks, options, *etc.* Thus, standard textbooks [*e.g.*, Bodie, Kane, & Marcus, 1993; Sears & Trennepohl, 1993] discuss the pricing and trading of fixed income securities, corporate equities, and derivatives in distinct sections, with little overlap. Only advanced books, directed toward more mathematically sophisticated audiences [*e.g.*, Park & Sharp-Bette, 1990; Luenberger, 1998], focus on evaluating pure risky cash-flow streams.

Although called catastrophe *bonds*, these securities' exposure to the equity of the insurance firm (as subordinated, unsecured debt) means that they also can behave like equity. However, they are not really equity because they have no ownership interest in the firm. Table 5 summarizes ways in which cat bonds exhibit both bond and stock behavior. An investor using heuristic rules for either bonds or stocks would miss vital features unique to this hybrid asset class, or would erroneously assume the existence of features not actually found in catastrophe bonds. An investor who realized that neither frame of reference worked entirely might shy away from the investment, not knowing how to think about it. Consider, for example, an investor who thought of catastrophe bonds as traditional fixed-in-

Table 5. *Comparing and Contrasting Catastrophe Bonds with Conventional Securities*

Characteristic	Traditional Corporate Bonds	Common Equity	Catastrophe Bonds
Type of return	Fixed, known return	“Random” return	Partially fixed, partially random, contingent on catastrophe
Ability to hedge payoff	Certain, hedgable payoff; liquid markets	Hedgable payoff; liquid markets	Contingent payoff; illiquid markets for hedging; imperfect ability to hedge (basis risk)
Performance model	Known distribution (lognormal)	Generally known distribution (normal, lognormal)	Discrete, low-frequency data; distribution not precisely known and subject to change
Certainty of payoff	Unequivocal payoff determination	Unequivocal payoff determination	“Event” definition varies widely between indices and issuers
Default claims hierarchy, managerial interests	Secured/guaranteed; top-tier; no managerial interest	Lowest priority, but managerial discretion	Top-tier structure and appearance, but most are subordinated; no managerial discretion
Risk in the context of the firm	Moderate correlated risk	Moderate correlated risk	High correlation risk: ability to repay weakest precisely when catastrophe depresses the bond price (because of the embedded option)

come securities. Redeeming a traditional bond below par at maturity means that the issuer was in such poor financial health that it cannot make full repayment. However, with catastrophe bonds, below-par redemption reflects the occurrence of a catastrophe. The firm might actually be stronger financially because the cat bond reduced its exposure.

When catastrophe bonds trade below par, it indicates high expected losses *that will be paid by the bondholders*. Without paying significant transaction costs, investors may be unable to decode the unique nature of these securities, adding to their cost, confusion, and chance of poor choices [Allen & Gale, 1994].

Dimensions of Risk

The Capital Asset Pricing Models (CAPMs) of Sharpe [1964], Lintner [1965], and Mossin [1966] state that investors should only be compensated for bearing systematic (or undiversifiable, market) risk. The psychological literature indicates, however, that individuals often have rather different notions of risk. In early work, Slovic [1964] found that perceived risk could not be measured by a single index, noting that a “large amount of evidence bearing on the convergent validity of [methods assessing risk-taking propensity] is negative.” As complicating factors, he pointed to emotional arousal and cognitive concerns outside of classical financial theory.

One common approach to studying the multidimensional character of perceived risk is to have subjects judge the riskiness of activities along dimensions like those in Fischhoff *et al.* [1978]. Factor analyses of these judgments typically find that two factors explain much of the variance in subjects’ judgments: *Unknown risk* measures the extent to which potential effects are delayed, unobservable, new, and unknown to science.

Dread risk measures the extent to which the activity is seen as uncontrollable, inequitable, involuntary, catastrophic, or potentially fatal [Slovic, 1987; Jenni, 1997]. Slovic *et al.* [1984] found that, other things being equal, people are more inclined to accept *chronic* risks (*e.g.*, auto accidents) than *catastrophic* ones (*e.g.*, accidents involving nuclear power), and are particularly averse to ones evoking a feeling of dread.

Although catastrophe bonds (and the like) have not been studied in these terms, some reasonable speculation is possible. The dramatic, unpredictable nature of catastrophes may create a visceral response among investors afraid of losing much (or all) of their investments, perhaps akin to the feeling of dread in these studies of life-threatening risks. Investors might want compensation for such feelings, even if they officially subscribe to normative asset pricing models.

Within those models, expected return might be related to dread risk while variance captures some of unknown risk. Higher moments might play a role as well, with skewness capturing some of dread risk and kurtosis related to unknown risk, in the sense of the prevalence of extreme (tail) events. However, Payne [1973] found that the moments were “unacceptable as variables for the theory of risky decision making” because the interactions terms could not be independently estimated in real-life choices. Coombs and Lehner [1981] reached the same conclusion for experiments. Preferences over higher-order and partial moments have been extensively studied in finance [Hogan & Warren, 1974; Kraus & Litzenberger, 1976; Bawa & Lindenberg, 1977; Fishburn, 1977; Holthausen, 1984; Sortino & van der Meer, 1991], with mostly disappointing results. Sharpe [1964] found that partial moments (semivariance) seemed to provide a better fit to the observed data, but rejected them because of computational complexity that continues to make them impractical for real-time use. Thus, formal financial

models ignore these features, so central to the experience of risk.

Asymmetric Information

Asymmetric information (as illustrated by Akerlof [1970]) is particularly important in insurance and risk transfer [Nachman & Noe, 1994]. "Given the potential for adverse selection, ... we might expect markets to collapse if the issuer's information is sufficiently large relative to that of potential investors" [Duffie & Rahi, 1995, p. 2]. As mentioned, such asymmetry exists with catastrophic information, which the insurers collect and in some cases disseminate. Insurers hoping to create a market *should*, in their own self interest, provide as much information as possible to potential investors, at minimal cost.

Credible communication is particularly important when there seem to be incentives for strategic reporting. For example, the loss threshold for many early catastrophe bonds (*e.g.*, the USAA and CAT Limited issues) depended on the issuing firm's own loss estimates. Such informational disadvantages could further discourage investors and increase demands for risk premiums.

Conclusions and Implications for Securities Design

Insurers have an enormous interest in tapping capital markets by securitizing catastrophic insurance risk. Additional capital could help to cover future losses that potentially run in the hundreds of billions of dollars. Creating a market for catastrophic risk would repeat the successes securitization has enjoyed with other cash flows.

In several other introductions of new securities, investors adjusted to new information fairly easily. However, with products like catastrophe bonds, in which the new information is both significantly novel and unusually complex, the adjustment may never take place, because investors are often constrained in their ability to understand and process the necessary information as it is commonly found. With vast, complex, and interconnected sources of uncertainty, new schemata might not be created and existing ones may be misused.

We outlined eight well-known behavioral decision-making results, suggesting how they might affect investor behavior in this arena. When investors cannot muster proper information use, they generally resort to heuristic decision making, attempting to use "similar" schemata to tackle new problems. Unfortunately, such decision making can result in errors of sufficient magnitude to prevent widespread participation in such new markets. For example, Bantwal and

Kunreuther [2000], building, in part, on an earlier version of this paper, illustrate how suboptimal decision-making processes could lead to an excessive risk premium for catastrophe bonds. These processes are likely to play a role in the securitization of *any* significantly new (to investors) cash-flow stream, not just catastrophe bonds.

This analysis suggests a logical course for further research. The next step is to evaluate the hypotheses discussed here in the actual market for catastrophic insurance risk (or analogous novel securities). Once the contours of these problems are better understood, methods of solving them must be developed. Our account suggests that widespread acceptance will require limiting new offerings to relatively simple and standardized products. These will provide investors with a common and cognitively tractable schema for thinking about the nature of their investments. That way, they can focus their attentions on the still challenging task of understanding the world of catastrophes. The design of new securities merits consideration of human behavior equivalent to that devoted to the design and marketing of consumer products.

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Notes

1. Matthews *et al.* [1999] report that failure frequency in the property and casualty insurance industry has averaged roughly less than 1% per year since 1969 and never exceeded 2.5%. Over the entire period that they studied, only 8% of insolvencies were attributed to catastrophic losses. At the same time, they report that in the period from 1989 to 1993, the percentage of defaults attributable to catastrophic losses increases from 8% to 56% of all defaults.
2. As Jenkins [1998] notes, there are problems combining the forecasts of global and regional climate models. Global climate models lack the resolution of the regional models in predicting changes to specific areas (such as coastlines and mountain ranges). Although regional models can accommodate such predictions, they depend on global models for input. Jenkins [1998] writes that "problems arise when interpolating to increase the number of data points [to move from one scale to another] ... [C]oupled global and regional models can not give the best results yet because coupled atmosphere-ocean models

- which provide boundary conditions for the regional climate model are still early in their development.” In essence, the “grave concerns” arise from the newness and extraordinary complexity of most climate models built on a scale useful (to insurers or insurance investors) for hazard prediction.
3. Of course, this situation could be transiently justifiable after a disaster when firms raise premiums to address a decline in surplus. A fuller account would look at multiple measures of financial health.
 4. In 1997, rock star David Bowie issued \$55 million worth of bonds backed by future royalties from 25 of his albums. The bonds, which were rated AAA by Moody’s, were purchased by the Prudential Insurance Company of America and provide a return of 7.9% over 10 years. Although experts were quick to dismiss the issue as “a glamour investment” and claim that they would only be “attractive to people who want to associate themselves with show-business personalities,” the entire issue was in fact, purchased by a major insurance company [*Wall Street Journal*, 1998]. However, recent reports [*Financial Times*, 1999] suggest that the success of the “Bowie Bonds” may have been unique. Apart from various structural impediments in the music business (few recording artists own their own master tapes), the illiquid aftermarket for such securities raises many of the same questions discussed here in the context of catastrophe bonds [Silverman, Sparks, & Osterland, 1998].
 5. By nearly any measure, reinsurance *appears* very expensive. One problem in measuring the cost of insurance, however, is that measurement requires some estimate of the actuarial value of the insurance. Given the limited historical data available on catastrophic losses, such estimates are automatically suspect. However, capital-market reactions to announcements of reinsurance contracts are often positive (*viz.* Berkshire Hathaway’s obtaining the reinsurance contract for earthquake losses in California), indicating that the market as a whole believes that the premiums collected substantially exceed what the market believes the actuarially expected loss to be [Froot, 1997]. Indeed, Berkshire uses its financial capacity to tremendous competitive advantage by emphasizing that it can guarantee access to reinsurance capital where other firms cannot. This may explain Berkshire’s strategic response (*q.v.*), which precluded the issuance of catastrophe bonds in California for earthquake risks, an event that would rob them of what they see as a very lucrative business.
 6. Two reasons are possible: (1) Managers of reinsurance firms regard their capital as equity-based and thus require returns in excess of the riskless rate. Writing reinsurance policies for catastrophic risks at actuarially fair rates is seen as being against the shareholders’ interests. However, given the uncorrelated nature of those risks with most other financial assets (although Dong, Shah, & Wong [1996] question this claim, it is generally supported [Guy Carpenter & Co., 1997]), shareholders’ required returns on catastrophic risks should be low. Agency costs may be one factor forcing up required returns - a factor that would not be present in some other (non-corporate) organizational form. (2) Many reinsurers’ shares strongly covary with the general stock market. This would indicate that there exists some systematic risk that would demand compensation.
 7. That would occur, for example, if insurers only ceded coverage of risks that they had reason to believe would be bad investments. If the original insurer didn’t want the risk, why would anyone else want it?
 8. This does not explain the high prices for catastrophic reinsurance, but it does explain why so little of it is purchased. Froot [1997] uses the analogy of rent control: the only way for insurance companies to increase their profits is to cut expenses - such as reinsurance. Policyholders get what they pay for, because the cheaper insurance is also worth less (given that the firm has an increased likelihood of default). This shifts more of the burden to government insurance pools, financed by taxpayers.
 9. This refers to the government compensating losses *after* the occurrence of some catastrophe, without receiving a premium in advance [Kunreuther, 1996].
 10. Financial results for PC insurers are reported one year in arrears (hence, a 1997 publication reports the accounting results for fiscal year 1996, which rely, in turn, on 1995 earned premium data). Premiums collected in a given accounting period are not recognized as revenue until the following year. Until then, they are considered “unearned premium income” and are held in reserve against losses that might accrue during the interim period. The length of this “vesting” period varies around the world.
 11. Standard accounting practice (U.S. GAAP, namely FASB 5) prohibits companies from keeping “hidden” reserves. As a result, firms must leave large amounts of capital uninvested in the core business. Despite the fact that such assets are “reserved” for (possibly distant) future losses, any earnings from this “non-investment capital” are fully taxable. From a strategic perspective, maintaining large amounts of cash or marketable securities on a balance sheet not only provokes the ire of shareholders (who want their funds invested more profitably), but also can attract the eye of other firms or corporate raiders interested in putting such capital to “better” use. Also, Jaffee and Russell [1997] note that the only potential tax benefits of setting aside reserves (tax-loss carryforwards and backward tax-code provisions) are worthless in the event the firm goes bankrupt under a catastrophic loss, which is precisely when they would be used.
 12. Penalva-Zuasti [1997] estimated, for example, that for households living in earthquake risk-prone areas (mostly the Los Angeles and San Francisco basins), the average cost of full coverage (no deductible) was \$0.29 per thousand dollars. The cost of the proposed CEA coverage (with a 15% deductible) was \$3.29 per thousand dollars. Note also that the efficient rate (\$0.29 per \$1,000) is itself an *overestimation* of the cost of coverage, because it includes only households in risk-prone areas - not in the whole of California.
 13. In fact, the real value of securities such as these comes from the increase in debt capacity that they provide (allowing firms a larger tax benefit without proportionately larger expected bankruptcy costs). If firms had decided instead to issue conventional debt securities, the expected bankruptcy costs may have prevented them from borrowing at all. Thus, even with a higher interest rate, from a traditional corporate finance perspective, catastrophe bonds may be less expensive than equity.
 14. The actual contract provides a fourth layer of coverage to the CEA. Berkshire Hathaway agreed to provide \$1.5 billion in coverage at a cost of \$161 million per year for four years. The CEA’s financing was structured such that, in addition to working capital, the first layer (\$3 billion) was provided by assessments on insurers, the second layer (\$2 billion) was provided by reinsurance contracts at a cost of \$148 million per year under a two-year contract, the third layer (\$1 billion) was provided by possible assessments on policyholders, and the fifth layer again by insurer assessments. It is noteworthy that the fourth layer (Berkshire’s coverage) is more costly than the second, even though it is less likely to be used [California Legislative Analyst’s Office, 1997].
 15. For example, Gray *et al.* [1998] reported correlations of predictions of number of named storms of between $r = 0.65$ and $r = 0.85$ over the past 25 years.
 16. Convertible bonds obviously have the option (which belongs to either the issuer or the investor) of converting (into equity). Mortgages and mortgage-backed bonds typically have the option of prepayment. Savings bonds have the embedded option to extend the maturity of the bond or cash out early at a predetermined rate.
 17. Schwager [1992] contains the transcripts of interviews with several professional traders and investment managers. These interviews frequently include long discussions about the value

of technical analysis, *ex post* rationalization of trading strategies, and descriptions of the use of visceral factors or “gut” instincts in making investment decisions - decisions frequently involving tens and hundreds of millions of dollars. It is important to note that even those traders who claimed not to “believe” in technical analysis personally still paid attention to technical trading statistics “because other traders use them.” One trader said the following of his trading system: “There was no system to it. It was nothing more than, ‘I think the market is going up, so I’m going to buy.’ ‘It’s gone up enough, so I’m going to sell.’ It was completely impulsive. I didn’t sit down and formulate any trading plan. I don’t know where the intuition comes from, and there are times when it goes away.”

18. No catastrophe bond (including all securities in Table 1) has ever had its loss threshold triggered yet. Even events the magnitude of the recent Hurricane Floyd have failed to generate losses for cat-bond investors. One analyst noted “everyone’s been wondering what will the capital markets do when there is a real loss” [*Wall Street Journal*, September 15, 1999].

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Appendix A. Catastrophe Insurance Index Basis Comparisons

Features	PCS	sigma	RMS	GCCI
Geographic Area	State	Country	ZIP code	ZIP code
Insured Property	All major lines	All lines	All major lines	Homeowners
Perils	All significant perils	All perils	Earthquakes and hurricanes	Hurricanes, hailstorms, tornadoes, thunderstorms, winter storms, and freezing conditions
Index Value	Dollars of loss	Dollars of loss	Dollars of loss	Paid loss-to-insured value ratio
Source of Estimate	Insurer survey, computer model, and ground survey	News and other sources	Computer model	39 companies' insurance and paid loss records
Other Information Provided	None	Number of casualties	None	Premiums, deductibles, amounts of insurance, claim counts, paid losses, and construction types
Published	3 to 5 days after event, updated as necessary	Annually	7 days after event, with final value after 28 days	Quarterly

Note: Source: Thomas, 1997.

Appendix B. GCCI versus PCS Coverage in Index-based Contracts

GCCI Regions		PCS Regions		Differences
National	50 States and DC	National	50 States and DC	—
Northeast	CT, DE, DC, ME, MD, MA, NH, NJ, NY, PA, RI, VT, WV	Northeastern	ME, NH, VT, MA, CT, RI, NY, NJ, PA, DE, MD (and DC)	WV
Southeast	FL, GA, NC, SC, VA	Southeastern	VA, WV, NC, SC, GA, FL, AL, MS, LA	WV, AL, MS, LA
Gulf	AL, AR, FL, LA, MS	Eastern	ME, NH, VT, MA, CT, RI, NY, NJ, PA, DE, MD (and DC), VA, WV, NC, SC, GA, FL, AL, MS, LA	Not comparable
Midwest/West	AZ, CA, CO, ID, IL, IN, IA, KS, KY, MI, MN, MO, MT, NE, NV, NM, ND, OH, OK, OR, SD, TN, UT, WA, WI, WY	Midwestern	OK, AR, TN, KY, OH, MI, IN, IL, WI, MN, ND, SD, IA, NE, KS, MO	AR, AK, and HI are not included by GCCI
		Western	HI, AK, WA, OR, CA, NV, AZ, NM, UT, CO, WY, MT, ID	
Florida	FL	Florida	FL	—
Texas	TX	Texas	TX	—
	California	CA	GCCI does not offer isolated CA coverage	

Note: Source: Index Co., 1997; Chicago Board of Trade, 1998.

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