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Catastrophe Finance: An Emerging Discipline

While the recent disasters in the world's financial markets demonstrate that finance theory remains far from perfected, science also faces steep challenges in the quest to predict and manage the effects of natural disasters. Worldwide, as many as half a million people have died in disasters such as earthquakes, tsunamis, and tropical cyclones since the turn of the 21st century [*Wirtz,* 2008]. Further, natural disasters can lead to extreme financial losses, and independent financial collapses can be exacerbated by natural disasters.

In financial cost, 2008 was the second most expensive year on record for such catastrophes and for financial market declines. These extreme events in the natural and financial realms push the issue of risk management to the fore, expose the deficiencies of existing knowledge and practice, and suggest that progress requires further research and training at the graduate level.

Seeking capital to recover from catastrophes, insurance and financial markets have begun to merge. As a result, weather derivatives and catastrophe (cat) bonds, whose payout is determined more by the physics of the catastrophe (e.g., hurricane wind speed) than by performance metrics of the markets themselves (e.g., the Dow Jones Industrial Average (DJIA)), are now routinely offered to investors who seek assets they hope will be impervious to market volatility. The evaluation of these new investments requires a scientific judgment of hazard and risk.

In academia, the environmental science and finance communities have little opportunity to interact. However, the rapid growth of markets for weather derivatives, cat bonds, and carbon emissions trading presents evidence of a need for an integrated program. The markets constitute a valuable real-world laboratory to support research and education and suggest new career opportunities for graduates.

Catastrophe Finance in the Market

Catastrophe finance is an emerging academic field at the intersection of geohazards and market finance. It analyzes, models, and predicts catastrophes for the efficient transfer of risk through derivatives markets and cat bonds, which allow individuals or corporations to buy and sell risk (see "Transferring Risk" sidebar).

Climate and weather derivates are currently traded on the Chicago and New York mercantile exchanges. Cat bonds also are now integral to modern risk management practices. In 2007 the cat bond market broke all previous issuance records with US$7 billion in publicly disclosed transactions, up 49% from the previous year's record of $4.7 billion and a 250% increase over the $2 billion issued during 2005 [*Guy Carpenter & Co., LLC,* 2008]. This is expected to increase at a compound annual rate of 25–40% [*Lane and Beckwith,* 2007], as there is a fundamental shortfall between the amount of property value at risk and the amount of available insurance and reinsurance capital globally.

According to Barney Schauble, a partner at Nephila Capital, a Bermuda-based hedge fund specializing in insurance risk, cat bond prices are relatively immune to general market sentiment (bull and bear markets). In fact, the correlation between cat bond prices and the DJIA is extremely weak, as market slumps will not lead to more or stronger hurricanes (or earthquakes).

But more frequent or intense natural disasters are only a part of the picture—even a weak earthquake can cause damage if a community has poor infrastructure. Thus, insuring against earthquake damage in seismic regions with poor infrastructure would likely come with a high premium.

The Need for Specialists in Catastrophe Finance

While the growth of cat bonds has been relatively rapid, it remains constrained by the investment community's general lack of familiarity with quantifying the risks of a hurricane or earthquake catastrophe. Greater education in understanding the physical mechanisms behind the risk and in evaluating the probability of loss is needed by investors to create a fully functioning and liquid market for these trading instruments.

The requisite education involves a combination of geosciences and environmental sciences and modern finance, particularly derivatives. These disciplines are similar in their reliance on applied probability, which should make it straightforward to combine them into a coherent program. The advent of a vibrant market for trading catastrophe risk will allow an education program to achieve a sharp focus while it uncovers new opportunities for research in each discipline.

According to John Rollins, vice president of AIR Worldwide, a leading risk-modeling company, companies exposed to hazard risks are now aggressively seeking well-trained, well-rounded risk managers with strong backgrounds in geoscience, financial concepts, and insurance [*Rollins,* 2008]. He notes that companies are searching universities for recent graduates with the requisite intelligence and analytical background but are resigned at least for now to train in-house. The increasing awareness of catastrophe risk, greater transparency demands by regulators and rating agencies, interest by insurance executives in having catastrophe modeling experts, and increasing capital in the markets are driving this demand. The demand will likely increase and could possibly lead to a new profession of catastrophe risk management.

Environmental science and geoscience students have the math and statistics abilities needed to understand and predict relationships associated with hazards, and a program that includes exposure to the financial world would greatly expand career opportunities. Moreover, in addition to being numerically adept and aware of finance and markets, these students will have specific familiarity with the physical processes that govern the Earth and atmosphere that math graduates have not yet gained. They will fit firms looking to invest in assets that are uncorrelated with other financial instruments, thus providing good diversification and hedging opportunities for the firms. According to a recent article in the *Financial Times*, the business schools at Massachusetts Institute of Technology, Harvard, Oxford, Columbia, London School of Economics, and elsewhere have brought the courses and expertise of public health, arts, and sciences faculty into their schools.

A graduate program in catastrophe finance would bring courses and expertise of environmental sciences and geosciences into risk management and insurance. Learning outcomes for a graduate program in catastrophe finance would include the ability to analyze and model correlated "random walks," to forecast the probability of catastrophes in geosciences and finance, and to apply knowledge in the insurance, risk management, and investment banking industry. Successful catastrophe finance programs will have faculty and graduates who feel comfortable at the interface of science, finance, and insurance. It would likely provide the career skills and contacts needed to succeed in a variety of career paths outside traditional geoscience disciplines, providing trainees with essential professional skills other than research capabilities.

Example: Hurricane Risk

The logic behind a graduate program in the area of catastrophe finance can be seen through the potential evolution of the science and technology of catastrophe modeling into the practice of catastrophe risk management. For example, a climatologist with no background in financial markets could be tasked to examine what regions of an exposed coast are most vulnerable to high wind speeds from hurricanes conditional on a warmer planet. But a climatologist with business knowledge could work with a hurricane risk modeler to determine what regions contain a company's highest potential losses per exposure unit. Further, a climatologist with a background in financial markets could be tasked to evaluate the adequacy of pricing models by location, perhaps conditional on continued warming, and could make pricing suggestions that are acceptable to the sponsor and investor.

Hurricane catastrophe models incorporate the frequency and severity characteristics of the modeled peril in today's climate regime. Therefore, there are basic questions for the catastrophe modeler to answer: (1) Does the historical record of the peril—the most dependable portion of which is generally 50–150 years long—have a signature that is clearly distinguishable from what we are experiencing today? (2) How is the signature going to change in the future if the Earth continues to warm? Insurers and risk managers use catastrophe modeling to assess the risk in a portfolio of exposures. This might help guide an insurer's underwriting strategy or help him or her decide how much reinsurance to purchase.

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By J. B. Elsner, R. K. Burch, and T. H. Jagger

Transferring Risk

Imagine a scenario of a farmer awaiting the rainy season, which typically arrives at the beginning of June. For every month of rain, say she earns $100. However, if it does not rain in June, she earns nothing. To mitigate her risk of earning nothing, she makes a bet with a financial agent that if it does rain in June, she'll pay $25. The financier takes the bet, knowing that he will probably win. Thus, when it does rain, the financier earns $25 and the farmer nets $75. If, by chance, it does not rain, the farmer gets $25 from the financier.

At the same time, a hotelier knows that when the rainy season starts, his business, which usually earns $100 a month, will slow to a stop. He makes a bet with the same financier that if it does not rain in June, he will pay the financier, say, $20. Because the odds are not in the hotelier's favor, the financier will take the bet only if the amount he pays the hotelier if it rains is less than the amount he earns from the farmer when it rains. Thus, when it does rain, the hotelier gets $20 from the financier. Because the financier earned $25 from the farmer, the financier's net earnings if it rains in June are $5. However, if it does not rain, the financier gets $20 from the hotelier but has to pay $25 to the farmer—he is out $5. This is a risk the financier is willing to take because the probability of him earning outweighs that of losing, given that it usually rains in June.

The farmer and the hotelier have essentially purchased insurance. The financier can even hedge his own risks of loss by charging a flat transaction fee. The numbers above are contrived; the market will set the value of payouts and premiums.

But what happens when people want to purchase insurance against a catastrophe? Imagine an insurer of coastal properties concerned about the next hurricane season. A severe storm happens once every few decades; if the severe storm hits this year, she'll have to pay out most of her money in claims. To help remain solvent, she could buy reinsurance. Alternatively, she could sponsor a catastrophe (cat) bond, which would pass the risk on to an investor. An investor would buy the bond valued at, say, $100,000; over time, the insurer would repay the bond with, say, 15% interest. If no hurricane hits during the year, the investor makes 15% on his investment. The insurer also turns a profit because she continues to collect premiums. But if this low-probability severe hurricane does hit, then the investor loses his $100,000, which is used by the insurer to pay claims.

The insurer and the investor will need a broker, who will charge a transaction fee to issue the bond, ensure payments of the interest, and define what "hit" allows the insurer to forgo her debt. Again, the numbers above are contrived; the market will set the bond value. But pricing depends on the probability of hurricanes. This is how scientists, armed with models and with knowledge of expected climate changes, can help set market values.

Catastrophe Finance

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Some state insurance departments (like Florida's) allow insurers to use catastrophe modeling to set premiums. Insurance-rating agencies use catastrophe modeling to assess the financial strength of insurers that take on catastrophe risk. Reinsurance companies and brokers use catastrophe modeling in the pricing and structuring of reinsurance treaties. Likewise, cat bond investors, investment banks, and bond-rating agencies use catastrophe modeling in the pricing and structuring of insurance, cat bonds, and hedging strategies.

A New Cross-Disciplinary Opportunity

Catastrophe risk management is a process that involves using the correct catastrophe model specification (meteorological, climatological, geological), obtaining the exposure information and ensuring its continuing availability and quality (actuarial), choosing analysis options (financial), running and managing analysis jobs, structuring securities for risk transference (risk managerial), and synthesizing the output into decision support (financial). Interdisciplinary graduate training in a program focused on catastrophe finance will be transformational: from asking questions about return periods of wind events conditional on climate change to asking questions about writing new contracts conditional on climate change while considering deductibles within probable maximum loss regulatory guidelines, which will lead to increased professionalism and skills in corporations bearing and insuring hazard risks.

There is still much to be discovered about the science of catastrophes and the financial methods underlying catastrophe-linked instruments. *Mills* [2008] has drawn attention to existing deficiencies found in the current state of insurance regulation, catastrophe modeling, and climate change. With cat bonds, some of which may cover multiple perils including hurricanes and earthquakes, pricing is an issue, in part because of the opaque, proprietary nature of those who create and distribute catastrophe models. Pacific Investment Management Company, the world's largest bond investor, advises that to evaluate cat bond prices, investors need access to expertise in probability modeling, weather forecasting, seismology, and other technical factors. This situation has led some to advocate creation of an open-source hurricane catastrophe model (R. J. Murnane, New directions in catastrophe risk models, World Bank brown-bag lunch presentation, 9 October 2007), similar to the Organization for Economic Co-operation and Development's Global Earthquake Model [*Nature Geoscience,* 2008].

Toward a Sustainable Future

"The culture of our scientific enterprise is on the brink of a sea change." So advised *Fortes and Hempel* [2002, p. 306] in *Oceans 2020*, a book about science, trends, and the challenge of sustainability. They were referring to the issue of how sustainable use of the oceans will require new human and technological capacity as well as greater financial commitment and, ultimately, new forms of partnerships and collaboration in the scientific community. The themes that geoscience needs to broaden the scope of its educational programs through cross-disciplinary training [e.g., *Weiler,* 2007] and to seek new, possibly market-based, funding sources have been expressed by other authors [*Spinrad,* 2007; *Farrington,* 2008] and were, in fact, the subjects of significant focus at the AGU/American Society of Limnology and Oceanography (ASLO) conferences in Honolulu, Hawaii (2006), and Orlando, Fla. (2008), respectively.

Markets are beginning to provide innovative opportunities to implement the wisdom of Fortes and Hempel's counsel. Society's need to respond to the series of spectacular disasters from around the globe in recent years and the threat from global warming is now compounded by great turmoil in world financial markets. From this will come greater recognition that financial innovations like cat bonds, which depend on knowledge of the geosciences, are an important and complementary means of addressing the problems caused by catastrophes. As it turns out, providing the public with insurance against catastrophes can also provide investors with an important risk management tool, which increases the need for trained professionals. To the degree that these innovations achieve their purpose and market success, it brings the science community a powerful new ally in its effort to spread knowledge and interest (capacity) outside the scientific community. It is time for faculties from geosciences and finance to collaborate and to train a new generation of students to better manage a sustainable future.

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NEWS

Large Subduction Thrust Earthquake Shakes Southern New Zealand

At 9:22 P.M. local time on 15 July 2009, the largest earthquake in New Zealand in the past 80 years occurred in the southern Fiordland subduction zone of the country's South Island. The M_w 7.6 earthquake ruptured the interface between the subducting Australian plate and the overlying Pacific plate, with the deeper end of the rupture underlying the coast of Fiordland, a sparsely populated region in the southwestern corner of the South Island. The proximity of the rupture to land, together with the recent deployment of seismographs and continuous Global Positioning System (GPS) receivers in Fiordland as part of the GeoNet project run by GNS Science (http://www.geonet.org.nz), ensures an abundance of recordings close to the rupture. As a result, this event promises to be one of the better recorded subduction thrust earthquakes to date.

Tectonic Setting

In the Fiordland region, the Australian and Pacific plates are converging very obliquely at about 34 millimeters per year. This has resulted in the subduction of the Australian plate and the development of strike-slip faulting in the Pacific plate, notably the Alpine fault. Since 1988, northern Fiordland has been very active, with a series of six large, shallow earthquakes (M_w 6.7, 6.4, 6.8, 6.1, 7.2, and 6.7). In contrast, southern Fiordland had been relatively quiet. The recent earthquake has made up for this quiescence, with the aftershock zone of the 15 July earthquake abutting that of the 2003 M_w 7.2 subduction thrust earthquake in northern Fiordland.

Main Shock Rupture

Centroid moment tensor solutions for the main shock indicate low-angle thrusting on a plane that has the same strike and dip as the shallow part of the plate interface. This interface has been well defined from the relocation of previous seismicity with a three-dimensional seismic velocity model. Finite fault inversions for the rupture using teleseismic as well as local data are in general agreement (e.g., http://earthquake.usgs.gov/eqcenter/eqinthenews/2009/us2009jcap/#scitech, http://www.eri.u-tokyo.ac.jp/topics/200907_NewZealand/index_e.html). The earthquake initiated at a depth of 30 kilometers, and it ruptured about 50 kilometers updip and 70 kilometers southwestward along strike, with a maximum slip of about 5.5 meters.

Coseismic displacements measured by continuous GPS receivers also are in good agreement with the seismological rupture models. The continuous GPS receiver at Puysegur Point within Fiordland National Park, close to the bottom edge of the rupture zone, has shown 300 millimeters of coseismic horizontal displacement and 20 millimeters of postseismic horizontal displacement (mostly in the first few days after the earthquake). Differential interferometric synthetic aperture radar (DInSAR) images also have revealed significant ground displacement associated with the earthquake (e.g., http://www.eorc.jaxa.jp/ALOS/en/img_up/dis_pal_nzeq_090717.htm).

A notable feature of the rupture was the relatively small amount of radiated seismic energy; the corresponding energy magnitude (*Me*) was only 7.3. This fact, combined with the seaward directivity of the rupture, may explain the low level of damage resulting from the earthquake. The few single-story structures overlying the rupture zone suffered no structural damage. Also, the incidence of landsliding in the steep-sided fiords was much less than in the smaller M_w 7.2 earthquake to the north in 2003. As the rupture of the 2009 event occurred mostly beneath the land and continental slope, it only generated a modest tsunami. The largest measured wave was 1.0 meter peak to peak at Jackson Bay, some 250 kilometers northeast of the rupture zone.

Aftershocks and Stress Changes

The earthquake has produced a rich aftershock sequence. Immediately after the event, seven portable seismographs were installed in southern Fiordland to make the GeoNet network denser, and about 20 campaign GPS sites previously observed in 2006 soon will be reoccupied. Data from these seismographs and GPS instruments will be valuable for defining an accurate geometry for the rupture zone. This will be important for calculating Coulomb failure stress (CFS) changes on faults in the overlying plate, particularly on the offshore portion of the Alpine fault, resulting from the earthquake. CFS change is a measure of how far a fault has been moved toward or away from failure. Preliminary calculations suggest that the CFS on the deeper part of the Alpine fault has increased by up to 0.8 megapascal, while the CFS on normal faults beneath the offshore outer rise has increased by up to 3.0 megapascals. These significant CFS increases indicate that the large subduction thrust earthquake of 15 July has moved these nearby faults closer to failure.

For updated information on the earthquake and its aftershock sequence, visit http://www.geonet.org.nz/news.

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