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Weather Indexes for Developing Countries

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The challenge of coping with natural disasters has increased as populations have increased. These challenges have been particularly acute in developing countries where both the human and economic loss can be staggering and financial resources are limited. Reducing economic vulnerability to weather events in developing countries may very well be the most critical economic development challenge of the new millennium. As a proportion of GDP, natural disaster losses in developing countries are 20% greater than in industrial countries.[2] The economies of many developing countries rely heavily on agriculture and agricultural success is directly tied to weather.

In recent years, the international community has focused more attention on the relationship between weather disasters and poverty. Measures taken to reduce the economic impact of weather disasters can provide substantial advances in the fight against poverty. Although weather cannot be controlled, weather risk markets can be used to offset the financial impacts of adverse weather events, and possibly compensate for human suffering in developing countries. This chapter begins with a brief review of the degree to which weather events contribute to the human and economic suffering that accompanies weather events. The story is compelling – extremes in rainfall and temperature account for the vast majority of documented problems. These issues deserve attention from both the public and private sector.

Introduction

The questions raised in this chapter surround the possible linkages between the emerging weather markets and public and private solutions to the problems created by weather-based natural disasters. While this book deals with many of the conceptual issues surrounding weather risks, we also provide our conceptual base that is tied to how these risks can be segmented and layered. By segmenting and layering out weather risks, there are numerous opportunities for risk aggregators within a country to share risks globally. We examine three possible applications of weather insurance in developing countries: providing weather risk coverage to:

1. mutual insurance groups,
2. directly to farmers and agri-businesses; and
3. to governments to protect their exposure when they offer catastrophic insurance and provide disaster aid.

Finally, as is emphasised throughout this book, we close by focusing on the needed infrastructure for measuring weather and making a strong argument that a supporting infrastructure has vast social benefits. These social benefits can only be recognised once the numerous ways that weather indexes can be used to cope with and manage weather-based risks are understood. Private companies within developing countries, global markets that move the weather risks out of developing countries, governments of developing countries and the international donor community that is quick to respond when there are natural disasters in developing countries, can all play a role in using the same information and structure to address the problems brought on by extreme weather events.

Why is weather risk important in developing countries?

The Office of US Foreign Disaster Assistance (OFDA), in collaboration with the Centre for Research on the Epidemiology of Disasters (CRED) has compiled an emergency event database in an attempt to document both technological and natural disasters around the world.[3] While such data are difficult to obtain and certainly do not represent all natural disasters, the picture that emerges from this database is clear: weather events dominate the documented natural disaster problems. Table 1 clearly shows that either too much rain or too little rain account for the vast numbers of people affected by natural disasters. Events back to the early 1900s are documented in this database. The total number of people affected by weather events is well over four billion during this time period. The documented deaths due to flood and drought are ten times greater than those from earthquakes. Windstorms and extreme temperature events also account for significant problems.

The same natural disasters that contribute significantly to human suffering also create economic problems in developing countries. Beyond the direct economic losses, economic growth in many developing countries can be slowed due to adverse weather events. In part, this is because the economy of the majority of developing countries is highly dependent on agriculture. Severe weather events can have devastating impacts on farmers and on the wider population that relies on local agricultural production.

Table 1. Top natural disaster events ranked by total people affected and cost

	Total affected	Damage (US$)
Flood	2,349,000,000	307,800,000
Drought	1,673,900,000	51,042,445
Typhoon	220,550,000	48,419,742
Cyclone	149,600,000	19,377,285
Storm	88,177,056	54,054,337
Earthquake	73,191,744	320,830,000
Drought	26,714,267	–
Food shortage	26,330,940	93,449
Hurricane	16,043,903	85,838,545
Tropical storm	11,397,020	4,786,050
Crop failure	10,168,094	–
Winter storm	5,408,961	39,932,957
Heat wave	4,605,588	6,715,809
Volcano	3,754,080	3,668,779
Forest fire	3,636,236	25,312,899
Cold wave	2,500,063	15,544,150
Tornado	1,378,358	23,940,841

Source: OFDA/CRED International Disaster Database

Consider the example of Morocco. Table 2 shows the historic relationship between rainfall and economic growth. Between 1992 and 2000, real GDP growth was negative or very low in years with poor rainfall during the agricultural growing season. Conversely, high real growth in GDP occurred during years of average or better than average rainfall.

Weather risk markets and developing countries

Weather risk markets are among the newest and most innovative of markets for transferring financial risks. The financial instruments traded in weather risk markets are often called weather derivatives. Though there is some variability in the specific characteristics of weather derivatives, most are essentially index options. That is, they are financial options that settle based on the value of some underlying index measured by an objective third party (Hull, 2000). A common example would be an option on a stock index, such as the S&P500. The underlying index for weather derivatives is a measurement of some weather phenomenon, by an objective third party, at a given location over a specified period of time.

Participants in weather risk markets are drawn from a broad range of economic sectors such as energy, insurance, banking, agriculture, leisure, construction and entertainment. To date, the US energy sector has been responsible for most activity in weather risk markets but new participants from Europe, Asia, Australia, Latin America and Africa are now entering the market.[4] According to a survey conducted by PricewaterhouseCoopers, more than US$7.5 billion of weather risk has been transferred in weather risk markets since 1997.[5] As economic agents from different sectors gain a better understanding of the impacts of weather on their economic activities, weather markets are likely to expand further.

The agricultural sector has thus far made only limited use of weather risk markets. In the Canadian provinces of Ontario and Alberta, weather risk instruments have been used to hedge forage production risk. In late 2001, AGROASEMEX, the state agricultural re-insurance company in Mexico, used weather derivatives to reinsure part of its weather-related crop insurance risk. AGROASEMEX found that weather derivatives offered protection at lower layers of risk exposure and at lower prices than traditional retrocession reinsurance. There are current plans to launch weather risk contracts in Argentina for insuring dairy production against low rainfall and in Morocco for insuring sunflower and wheat production against low rainfall.

Yet many in the agricultural sector are unaware of emerging markets for weather derivatives. Further, in many developed countries highly subsidised agricultural

Table 2. Moroccan rainfall and GDP growth rates

Year	Rainfall (November of previous –March of current year	Real GDP growth (%)
1992	Poor	–4.0
1993	Poor	–1.0
1994	Heavy	10.4
1995	Very Poor	–6.6
1996	Exceptional	12.2
1997	Poor	–2.3
1998	Average–Good	6.5
1999	Poor	–0.4
2000	Poor	0.7

Source: Bank al-Maghrib, EIU

insurance schemes crowd out the demand for agricultural weather risk instruments. Developing countries, on the other hand, typically have no government-subsidised agricultural insurance. They are, however, highly susceptible to weather risks and often, highly dependent on agriculture. Thus, developing countries would seem to be a potential growth market for weather risk instruments.

Classifying risk – tying weather risk to realised losses

Users of weather derivatives must understand the complex relationships between weather events and losses. First, they must identify the specific weather event(s) that caused the losses, such as lack or excess of rainfall, high or low temperatures, high winds, or a combination of these. Second they must establish the period over which the occurrence of certain weather event(s) is critical. Third they must investigate the duration and intensity of the weather event that provoke losses. With frost, freeze, or high winds, losses can occur within a few hours. Drought losses generally occur over extended periods of time. Intense rainfall can cause some losses within a few hours while other losses would not occur unless the rainfall was sustained over several days.

Having identified the source of risk, the time period when losses are most likely to occur, and the duration of the weather phenomenon that triggers losses, one must next determine the frequency, severity, and spatial-correlation of the weather phenomenon. It is important to note that this second set of risk characteristics are conditioned on the first set.

Extreme weather events can cause loss of life, loss of property, and loss of subsistence and/or income-generating production. Sometimes, a single weather event can cause all of these types of losses. For example, in the autumn of 1998, Hurricane Mitch's torrential rainfall and high winds left a wake of death and destruction across the affected Central American countries.[6] Since the same weather events can cause various types of losses, the infrastructure to measure, classify and pay for extreme weather events can serve multiple purposes.

Advances in computer modelling have greatly improved the understanding of the relationships between weather events and losses and meteorological models continue to improve our understanding of weather phenomena. Models of hydrology and plant growth are among the many computer simulation applications that allow us to better understand the relationships between weather phenomena and potential losses. Geographic information systems map the spatial dimensions of affected areas. Many computer applications have been employed to improve our understanding of the relationships between weather events and losses of life, property and sustenance.

Once these important relationships are understood, many uses of weather derivatives are possible. To illustrate, consider the problems associated with extreme rainfall in a developing country. If unusually high rainfall occurs around harvest, crops can be ruined. Even more severe rainfall may cause flooding with resulting loss of life and property. Similarly, unusually cold temperatures in a developing country may damage crops but the extreme cold can be a threat to animal or even human life. Depending on the severity, drought can also cause losses ranging from crops to human or animal life.

A number of studies have examined the relationship between weather events and crop yields. Crop growth processes are complex and multiple weather events during the growing season influence the realised yield. Dischel (2001) describes the impact of both rain and temperature on California almond yields. Skees, *et al*. (2001) examines a portfolio of cereal crops for Morocco and shows that the same rainfall events influence the yields for three different crops. This of course opens the possibility of using the same weather index for managing yield risks on all three crops.

Skees and Zeuli (1999) demonstrates how rainfall derivatives can be used to aid in hedging against irrigation risk. Many developing countries depend heavily upon irrigation for agricultural production. Major conflicts over water are commonplace. Water markets are likely the best mechanism for addressing conflicts over water usage.

Many have argued that water markets can allocate water more efficiently than governments.[7] In developed countries, rainfall derivatives have been used to protect hydroelectric plants from the risk of low water levels when there is limited rainfall in the watershed that feeds the reservoir. Similarly, in developing countries, farmers who depend on reservoirs for irrigation could use rainfall derivatives to protect against insufficient rainfall in the watershed. Further, Skees and Zeuli (1999) argues that the water authority could purchase rainfall derivatives and then sell water rights with an embedded warranty to deliver either water or an indemnity payment to users of water. Such an innovation might make water markets more palatable in many places in the world.

BASIS RISK

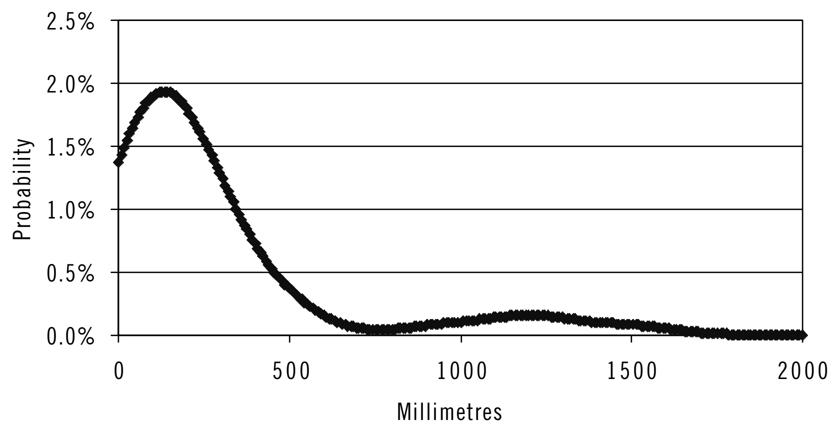
Demand for weather index instruments may be affected by the presence of basis risk. Spatial variability in weather is one source of basis risk. For example, consider a situation where a farmer purchases a weather derivative that will pay an indemnity if rainfall measured at a nearby weather station is below some trigger level. It is possible that rainfall measured at the weather station may be above the trigger level while the actual rainfall at the farm is well below the trigger level. In this case, though the farmer has likely experienced losses, no payment will be received from the derivative. Basis risk can also occur due to less than perfect correlation between the weather event and losses.[8]

It may be possible to offset some basis risk by triggering payments using average measurements over a longer period of time (monthly or even quarterly) and/or using average measurements over more than one weather station. Also, it is important to note that basis risk due to spatial variability in weather is more of a problem for individual buyers of weather contracts (eg, a farmer) than for producer associations, financial institutions and agro-industries, whose exposure to loss risk is spread over much larger geographic regions. Whether basis risk overwhelms the significant benefits of weather index instruments is an empirical question, the answer to which depends largely on the spatial correlation of weather events and the correlation between weather events and actual losses.[9]

LAYERING

A private insurance provider may be interested in designing weather index insurance that protects farmers and others at risk from weather events. There are many possible

1. Hypothetical rain for a 30-day



ways to design weather index insurance and policies could be sold through various market channels. However, for extreme weather events, institutional arrangements may be required that go beyond what insurance markets in developing countries can typically provide.

Figure 1 presents a hypothetical probability distribution for rainfall over a 30-day period.[10] The high frequency of low rainfall likely affects crop yields. Rainfall above 500 millimetres (mm) may also damage crop quality. Very extreme rainfall events likely cause floods with resulting loss of life and property. The extreme rainfall events beyond 1,000mm may be created by hurricanes. Thus, those wishing to hedge against hurricane risk may also desire weather insurance based on wind speed.

Consider a rainfall derivative based on the probability distribution in Figure 1. Suppose the policy pays US$100 for each millimetre of realised rainfall between 500 and 1,000mm. If realised rainfall was equal to 1,000mm, the payoff on the derivative would be US$50,000 ((1,000mm – 500mm) × US$100 per mm). No additional payments would be made for rainfall realisations higher than 1,000mm. In the terminology of weather derivatives, this contract would have a strike of 500mm, a tick rate of US$100 per millimetre and a limit of US$50,000.

Without the limit, the contract would be very expensive. Insuring against the risk in the upper tail of the probability distribution or the "catastrophic" risk is extremely expensive. There are few historical observations in the tail of the distribution so it is difficult to accurately assess the likelihood of these extreme events. Because of this ambiguity, weather risk market participants are often reluctant to trade derivatives with very much exposure to catastrophic risk (sometimes called "tail risk"). Derivatives that do cover tail risk are usually very expensive since sellers will load the price to account for the ambiguity associated with the tail of the distribution.

Within the range of 500–700mm, trading of weather derivatives is more likely (as the distribution is smooth and "well-behaved" up to roughly 700mm). This layer of the rainfall probability distribution may offer adequate protection for many types of risks. Risk protection is often sold in layers. Once the probability distribution has been estimated, it is relatively straightforward to identify different layers of risk.

Different institutional structures seem to work better for transferring different layers; weather risk markets are more efficient at trading layers that are closer to the mean of the probability distribution, whereas standard insurance and reinsurance markets have typically been more efficient at providing protection for tail risk as compared to weather markets standard (re)insurance markets generally have much more liquidity for layers in the tail of the distribution.[11] In weather risk markets there is generally more liquidity for layers that are closer to the mean of the probability distribution. This liquidity improves pricing efficiency. For this reason, some users of weather derivatives prefer to protect against tail risk by scaling up the liability that they purchase in these layers (by buying more protection than they need in this layer) rather than by trying to purchase layers in the tail of the distribution. The additional liability purchased for the layer closer to the mean is then used to compensate for any deeper losses should a weather event in the tail of the distribution occur. Such tactics are common among those who use exchange-traded instruments such as futures and options contracts to hedge risk.

Evolving catastrophe (CAT) bond markets may one day facilitate the bundling of weather derivatives for catastrophic layers, thus allowing for more efficient pricing. CAT bonds offer contingent funding for well-specified natural disasters. Those exposed to losses from the specified natural disaster sell CAT bonds to investors. If the specified natural disaster does not occur, investors recoup their initial investment and earn a highly favourable rate of interest. If the specified natural disaster does occur, investors lose their interest payment and some or all of the initial investment, depending on the structure of the contract. Since natural disasters are not correlated with other equity markets, CAT bonds provide an excellent opportunity to diversify a portfolio of investments.[12]

Possible uses of weather indexes in developing countries

Various institutional arrangements could be used to transfer weather-related risks in developing countries. Once an index is developed for a particular weather phenomenon, there are many potential applications for the index. For example, consider an index for rainfall measured at a particular weather station over a given period of time. The index could be used to:

1. allow collective mutual assistance groups to transfer their systemic exposure to rainfall risk to outside investors;
2. provide private-sector weather-based insurance directly to economic agents at risk from too much or too little rainfall; or,
3. establish weather-based parametric triggers for the provision of government disaster assistance.[13]

WEATHER INDEX INSURANCE AND COLLECTIVE MUTUAL ASSISTANCE GROUPS

Economic agents in developing countries often use informal risk management arrangements. For example, in a village or among a group of farmers, there may exist an informal understanding that the group will assist individuals who suffer losses. These arrangements, which are not unlike mutual insurance companies, provide a very important mechanism for dealing with idiosyncratic risks. However these arrangements can break down when regional weather events generate simultaneous losses for all members of the collective assistance group. Examples of such weather events would include severe droughts, floods, hurricanes or freezes. By providing opportunities to transfer systemic, spatially-correlated, risks, weather risk markets can complement such informal arrangements that are better suited to sharing losses from idiosyncratic risks. Several researchers have proposed similar arrangements in the US for farmer-owned processing or marketing cooperatives.[14] The cooperatives could become mutual insurers of crop yield risk that purchase weather risk instruments to offset their exposure to regional weather events such as drought. A good example of how weather insurance could enhance mutual insurance arrangements amongst farmers is the Mexican *fondos de aseguramiento*, or mutual funds. These are non-profit, civil associations and they operate in such a way that the collected premiums create reserves to pay indemnities and cover operational costs. However, in the event of severe regional (or large-scale) events such as drought, excess humidity and frosts, the collected premiums and reserves are not sufficient to cover losses because the weather events affect all farmers at the same time. Obtaining insurance for these weather perils is critical for the financial viability of the mutual insurance funds in Mexico.

WEATHER INDEX INSURANCE SOLD DIRECTLY TO PRODUCERS AND AGRI-BUSINESSES

In many developing countries, markets for insurance and re-insurance are either underdeveloped or nonexistent. This is particularly true for agricultural insurance. Traditional crop insurance is based on individual yield losses and thus, requires extensive field inspections and human judgments. The administrative costs are quite high, particularly in developing countries where arable land is often divided into very small plots. Crop insurance also has the usual problems of adverse selection and moral hazard.[15] These problems are aggravated in developing countries where information on individual farm yields is scarce.

Weather insurance, based on the occurrence of weather events rather than on actual losses such as crop failure, could be used to cross-hedge agricultural production risk. The underlying assumption is that certain weather events (such as rainfall or temperature) are highly correlated with crop losses. For example, a weather insurance contract could be written that protects against severe rainfall deficiencies over a given period. The contract would specify a rainfall trigger and an indemnity that would be paid for each millimetre that realised rainfall fell below the specified trigger. The contract would settle based on actual rainfall measured at an official weather station.

A number of studies have emphasised the advantages of weather-based insurance over traditional crop insurance in developing countries.[16] The traditional crop insurance problems of moral hazard and adverse selection occur because farmers have better information than the insurer about the probability of crop losses and/or the potential magnitude of losses. But this is unlikely to be the case with weather phenomena measured at official weather stations. Since no field inspections are required, weather-based insurance should also have significantly lower administrative costs than crop insurance. Weather insurance is also more transparent and easier for farmers to understand than traditional crop insurance. Weather insurance could be marketed to farmers through a variety of institutions in developing countries. Among these are banks, farm cooperatives, input suppliers and micro-finance organisations.

Farmers are not the only ones who might be interested in purchasing weather insurance. Agricultural traders, agro-processors, even shopkeepers or landless labourers, anyone whose income stream can be negatively affected by weather events, might benefit from purchasing weather insurance. Banks and rural finance institutions could purchase such insurance to protect their portfolios against defaults caused by severe weather events.[17] In Argentina agricultural input suppliers often provide inputs to farmers on credit. Some suppliers have considered requiring farmer-creditors to purchase a weather insurance policy. The weather insurance policy would help insure that farmers would be able to repay the input suppliers should crops be lost due to extreme weather events. If banks, input suppliers and other creditors can use weather insurance to offset some of their exposure to credit risk, they may be willing to provide more credit and at better terms. This is an important issue for many developing countries as credit availability to agriculture is typically constrained, in part because of exposure to systemic weather risks.

Sellers of weather insurance could use international weather risk markets to transfer their systemic weather risk exposure to investors outside the country. Some developing countries have formal insurance sectors that provide standard insurance products like property and casualty cover. The loss risk from many of these insurance products can be highly correlated with weather risks. If spatially correlated severe weather events occur, all or nearly all of those covered by insurance policies must be compensated at the same time. This can pose an intolerable level of risk exposure for local insurance providers. For this reason, local insurers use mechanisms to spread these financial risks internationally. Until recently, the only viable way for national insurance companies to transfer spatially correlated risks was to purchase reinsurance from various international providers. Reinsurance markets remain an extremely important mechanism for spreading spatially-correlated risks, but these markets are subject to cyclical pricing, high transactions costs and large premium loads.[18] Further, even major international reinsurance companies have limited capacity to absorb large amounts of covariate risks. Weather risk markets provide alternative mechanisms for transferring these covariate risks to entities outside of the region or the country.

INDEX INSURANCE AND GOVERNMENT DISASTER ASSISTANCE

It is not uncommon for governments in both developed and developing countries to provide disaster assistance following major natural disasters. In developing countries, government assistance is often supplemented by international donor organisations. One of the problems with such intervention is that it becomes highly political. Without clear rules for how funds will be distributed when there is a disaster, serious inequities are common.[19] The question of how best to distribute disaster aid is beyond the scope of this paper. However, it can be said that it is important to leverage both government funds and foreign aid to obtain the best possible solutions.

Disaster assistance can also become self-perpetuating. If individuals expect assistance following a natural disaster, economic decisions will be made without the full social costs of those decisions being taken into consideration. In effect, while individuals receive the benefits of their private economic decisions, the risks inherent in those decisions are socialised. Resources that might generate more social benefits if used elsewhere, are instead used to shield risk-takers from the full consequences of their private economic decisions. Thus, private decision-makers are likely to engage in more risky activities setting off yet another cycle of losses and disaster payments.[20]

Various indexes of natural hazard risks are now being used to construct financial instruments. For example, the Richter scale is used to construct financial instruments based on earthquakes; wind speeds are used to construct financial instruments that protect against hurricanes; rainfall is used to protect against drought or flood. Since these indexes can be represented by a probability distribution, parametric estimates can be made of the expected payoff (the pure premium) on the instruments.

Relative to current methods, there are many potential advantages to providing disaster assistance based on weather indexes. The first is transparency. If the criteria for triggering disaster assistance have been well defined *ex ante*, politicians may find it more difficult to use disaster assistance as a means for transferring funds to favoured regions of the country.

The second potential advantage is that with sufficient years of accurate data, the parametric triggers can be set so as to normalise the expected value of disaster assistance across various regions of the country. This would reduce the perverse incentives inherent in disaster assistance programmes that continually compensate those whose private decisions expose them to more risk. Furthermore, the information about relative differences in triggers across regions could be made publicly available. This would provide valuable information to both public and private decision-makers about the relative risk exposure to different extreme weather events in different regions of the country.

National governments might consider providing regions, provinces, communities, or businesses, with either catastrophic weather insurance or disaster assistance based on clear triggering mechanisms for extreme weather events. In effect, the national government would be pooling catastrophic risks across the country. In large countries or climatically diverse countries, such pooling would allow diversification to reduce the aggregate exposure to catastrophic risk.

In small or climatically homogeneous countries, pooling may offer few diversification benefits. In these situations, CAT bonds have been promoted as a means for spreading low probability-high consequence catastrophic risks to risk takers around the globe.

Still, the CAT-bond market has not matured as expected. There are a number of reasons for this. Since CAT bonds are relatively new instruments, many still do not understand how they can be used. Furthermore, there can be significant development costs for CAT-bond contracts. Parametric CAT bonds, which trigger payments based on an objectively measured index of a natural event (eg Richter scale measurements, flood levels, wind speed, etc.), are likely to have the lowest development costs.

Disaster assistance itself can also be too expensive for many developing countries. This is particularly true following a major disaster. To the extent that natural disasters disrupt GDP growth, financing disaster assistance internally (which, in essence, is a form of self-insurance) is even more problematic.

However, societies must provide immediate emergency response to victims of natural disasters. In addition, societies also need markets that allow individuals to protect against financial losses when natural disasters occur. Ironically, parametric

CAT bonds can facilitate both of these needs. Furthermore, the same instrument and structure could be used for both. This, of course, means that transaction costs could be reduced significantly.

A number of international relief agencies are involved in providing disaster assistance in developing countries. These agencies need ready access to cash when a natural disaster occurs. Parametric CAT bonds could also provide this contingent funding. A relief agency could identify donors who are concerned about natural disasters in a specific region of the world. The agencies would ask those donors to provide the funding needed to purchase CAT bonds that provide funding contingent on specific natural hazards occurring in that region. If the natural disaster occurred, the CAT bond would provide funding needed to provide disaster assistance. The same donors could be encouraged to sell the very CAT bonds they are helping to purchase. Then if the event did not occur, the donors would profit from the earnings on the CAT bond. If the event did occur, donors would know that the payments they are required to make on the CAT bonds are, in turn, being used for disaster assistance in their regions of concern. In essence, this is a sophisticated and efficient way to provide contingent funds for relief agencies and spread catastrophic risk around the world. Over time, the expected cost to the donor would equal the expected payoff on the CAT bond. Currently, this is not the case as significant premium loads are added to CAT bonds to account for ambiguity and lack of understanding. If donors become familiar with CAT bonds through philanthropic activities, they might be more likely to include such instruments in their investment portfolios.

POSSIBLE GOVERNMENT STRATEGIES IN WEATHER AND CATASTROPHIC RISK SHARING

Governments in developing countries can use many different strategies, that are not mutually exclusive, to facilitate risk-sharing market activities.

1. The government may assume weather risks for its own account, and explore means to spread that risk outside the country. For example, the Turkish government assumes some of the risk of earthquakes destroying homes. The US government, through the national flood insurance programme, assumes some of the risk of flood damage to homes. In both cases, the governments clearly limit the amount of loss risk they are willing to assume for each home. Further, in most countries the government "owns" the risk of weather events affecting the poorest of the population. These loss risks are socialised across all taxpayers.
2. The government may act as a facilitator that bundles and transfers risk, without assuming the risk itself. The California Earthquake Authority (CEA) is an example. The CEA provides a mechanism to accumulate, and subsequently spread the risk to insurance and capital market intermediaries. It does not assume the risk for its own account. The government provides the technical assistance (with limited, defined, credit support) to facilitate the functioning of the risk transfer markets. Over time, the government intention should be to make the assisted programmes self-supporting.
3. The government may actively work to remove regulatory and structural barriers that limit the operations of private risk-sharing markets. One such example is that insurance regulations in many countries do not envisage the use of weather derivatives as insurance or reinsurance instruments. This is particularly true in developing countries. For example, a local insurance company may wish to use weather derivatives to hedge its portfolio of weather-related insurance policies. However, if insurance regulators do not recognise weather derivatives as an effective mechanism for retroceding risks, they may require the company to keep in reserves the full notional amount of outstanding insured risks. If the potential benefits of new financial instruments, such as weather derivatives, are to be fully realised, regulatory change will be needed so that these instruments are

recognised as legitimate mechanisms for obtaining retrocessional risk protection. Some countries, such as Mexico, are already working on enacting these regulatory changes.

4. With regard to weather risk markets, governments can provide access to meteorological data and make the necessary investments in weather stations to ensure accurate and tamper-proof measurements. Governments can also invest in identifying and modelling weather risks that are particularly important to the overall economy or to specific economic sectors. Governments in developing countries should view the timely availability of quality weather data as an important public good that would greatly enhance the transfer of weather risks through both public and private means.

A ROLE FOR INTERNATIONAL CAPITAL MARKETS

These are just some examples of how contingent claims instruments such as weather indexes and parametric CAT bonds could be used in a developing country context. What is common across these examples is the need to transfer out of the country or region systemic weather risk that is un-diversifiable in a local context. Collective mutual assistance groups, cooperatives, insurance companies, banks or other creditors, government disaster relief agencies, international relief agencies – all are exposed to potentially devastating natural disaster risks. Many of these risks are caused by systemic weather events. Weather risk markets could be an important mechanism for facilitating the transfer of these risks outside of the local area. With reduced exposure to covariate weather risks, economic agents should be willing and able to increase their investments in local economic opportunities.

Weather risk instruments and other instruments for transferring covariate risks offer a unique opportunity to link world financial markets and developing countries in a partnership that is mutually beneficial. Investors and portfolio managers should find these instruments attractive since the returns would be largely uncorrelated with those of most other investments. Systemic weather risk that was undiversifiable at a local level would provide significant diversification benefits in highly aggregated portfolios of financial instruments.

Information Systems

Several important issues must be addressed before weather risk management instruments can be used effectively in developing countries. These issues are not necessarily exclusive to developing countries, but they may be more problematic in a developing country context.

It is critical that reliable and verifiable weather measurement systems be in place. More specifically, there must be:

1. accurate, complete, and available historical weather data; and
2. mechanisms in place to insure the security of future weather measurements.

ACCURATE, COMPLETE, AND AVAILABLE HISTORICAL WEATHER DATA

For most weather derivative applications, a minimum of 30–40 years of historic daily weather data are necessary. It is important to note that data requirements depend, in large part, on where the trigger is set relative to the expected value of the underlying weather measure. The availability, quality and cost of such data can vary greatly across countries. Yet, many developing countries do have historical weather data and, compared to many other types of official government data, it is hard to imagine why anyone would have had an incentive to falsify historic weather data.

A more troubling problem can occur if a region is undergoing long-term climatic change and/or if the region is exposed to climatic cycles of varying length.[21] In these situations, historic data may not provide an accurate measure of the current expected frequency and magnitude of extreme weather events. Thus, it becomes very difficult to price weather derivatives.

In developing countries, problems with historical weather data are often related to missing observations and inconsistencies in measurements.[22] In the US, the UK, Germany and Japan, less than 1% of the observations will typically be missing in a sample of daily weather data. In many developing countries this percentage is significantly higher. In Mexico, for example, it is around 4%.[23] It is extremely important to try and assess whether these missing observations are random occurrences or whether they are in some way related to realisations of the weather phenomenon being measured. For example, serious data deficiencies will exist if missing observations reflect situations where measurement devices were overwhelmed by extreme events.

Due to the possibility of recording errors, it is important to test data for consistency across time (at the same weather station) and across space (compared to nearby weather stations).

Weather data can be quite expensive in many countries. The Weather Risk Management Association, a non-profit organisation for weather derivatives professionals, has recently started lobbying the EU and European governments to lower their prices for weather data. In developing countries, that do not have centralised databases of historic weather data, the costs of collecting weather data and transferring it into an electronic format can be prohibitive. Economic development agencies could provide an important service to developing countries by financing efforts to build readily accessible databases of existing historic weather data.

For a variety of reasons, officials in some developing countries are reluctant to make weather data accessible. In some cases, government leaders are suspicious of how the data will be used – particularly if foreign organisations are requesting the data. In these situations it is important to recognise that weather data are an important national resource. Government leaders are unlikely to make this resource widely available on a timely basis unless they can be convinced that doing so will generate sufficient economic benefits. Thus, it is important that government leaders be educated about the potential economic benefits of weather derivatives.

In other cases, poorly funded local weather service offices recognise that they are a monopoly supplier of a data resource that is now suddenly in demand. Simply giving away, or even selling, their historic weather data greatly reduces the potential to extract further economic rents from the use of that data. Thus, these offices may be willing to provide only limited historic data (specific weather stations and/or specific years) and then only after negotiating an arrangement where they sell their services in the form of "value-added" data rather than raw weather measurements.

SECURITY OF FUTURE WEATHER MEASUREMENTS

Markets for weather derivatives will not develop unless tamper-proof weather stations are in place to ensure reliable readings of insured events. In most developing countries, the infrastructure for measuring and recording weather phenomena is very basic and lacks security. Without adequate security, weather observations could be altered so as to trigger, or not trigger, payments on weather derivative contracts.

Thus, creating a market for weather derivatives may require that automated weather stations be put in place with upgraded weather measuring systems and improved security. New hardware systems, such as optical precipitation sensors, can eliminate any direct human involvement in the recording process. Readings can also be verified by comparing with adjacent stations or with remotely sensed data from satellite imagery. Comparing measurements between several weather stations within a region can indicate inconsistencies in readings, signalling a problem. Satellite instruments can provide estimates of rainfall and perhaps, in the longer run, become the primary means of providing rainfall measurements. At present, calibration is an important issue with satellite measurements of rainfall. For any given location, there is generally not a sufficient time-series of satellite imagery to compare to conventional measurements.

Overall, despite the problems and issues highlighted with weather data from developing countries, weather data may still be the most reliable and verifiable data that can be used for risk management purposes in many of these countries. Further, the utility of these data could be greatly improved if international donors would invest in providing advanced weather stations and in building electronic archives of historic weather data.

Conclusion

Weather risk markets provide new opportunities for developing countries to transfer weather-related loss-risks. Policy-makers can use weather risk markets to develop and reinsure effective disaster assistance programmes that are activated by specific catastrophic weather events that have been defined ex ante. Further, the assistance should not unduly distort economic incentives. In particular, care should be taken to assure that aid does not spur unsustainable new economic activity in areas that are highly vulnerable to natural disaster risks. Failure to do this will only result in more losses and suffering when the next disaster strikes.

Government disaster assistance should also be structured so as not to crowd-out private risk management initiatives. While infrequent catastrophic events may require government assistance, events that are more frequent but still cause serious losses are more appropriately left to formal insurance markets or informal collective mutual assistance groups. Solutions should involve segmenting and layering risks so that the most catastrophic risk is handled with government aid and the less catastrophic risk is left to private market mechanisms. International weather markets can support the development of private insurance and reinsurance markets within developing countries by providing opportunities for transferring locally undiversifiable, systemic weather risk to financial intermediaries outside of the country.

International weather trading companies stand to gain diversification benefits from including developing country weather risk in their portfolios. This may contribute to reducing the overall risk of their weather portfolio and reducing the overall costs of covering weather risks. Weather trading companies and international organisations could try to develop better understanding of weather risks in developing countries and engage in a dialogue with governments and the private sector on issues related to data availability and quality, necessary weather measuring infrastructure, and educational activities to raise awareness.

1 *The views expressed in this paper are entirely those of the authors.*

2 *World Bank (2000).*

3 *EM-DAT: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium, http://www.cred.be/emdat/intro.html.*

4 *Dischel,(2001).*

5 *Lancaster (August 2001)*

6 *See the LANIC newsroom website: http://lanic.utexas.edu/info/newsroom/mitch.html*

7 *Anderson (1983); Gardner and Fullerton (1968); Randall (1981); Wahl (1989); Weinberg, Kling, and Wilen (1993).*

8 *This basis risk is analogous to that faced by one using exchange-traded financial instruments such as futures contracts. For exchange-traded commodities, basis is the difference between the futures market price and local price of the commodity. Variability in the basis over time, or basis risk, introduces a random source of error for those who attempt to hedge price risk using commodity futures contracts.*

9 *For example, in areas with micro-climates, the spatial correlation in weather events may be quite low. The resulting basis risk may be so high that weather index instruments are not a reliable mechanism for transferring local weather risk.*

10 *This distribution is only slightly different than the distribution of rainfall for a select rainfall station for rain during the month of May in Mexico.*

11 *Cole and Chiarenza (1999); Doherty (1997); Lamm (1997); Skees and Barnett (1999); Skees (1999).*

12 *Skees, Varangis and Larson (2001).*

13 *Black, Barnett, and Hu (1999); Skees, (1999); Zeuli (1999).*

14 *Skees and Reed (1986); Quiggin , Karagiannis, and Stanton (1994); Just, Calvin, and Quiggin (1999).*

15 *Gautum, Hazell, and Alderman (1994); Sakurai and Reardon (1997); Skees, Hazell, and Miranda (1999); Skees, (2000).*

16 *For example, see the impact of natural disasters on micro-finance institutions (Nagarajan, 1998).*

17 *Froot (1999).*

18 *Barnett (1999); Rossi, Wright and Weber-Burdin (1982); Freeman and Kunreuther (1997).*

19 *Kaplow (1991).*

20 *An example would be if rainfall levels have a negative trend and/or droughts occur with more frequency over time.*

21 *Inconsistencies in measurements usually result from: 1) relocation of the weather station; 2) human error in measuring or recording the weather observation(s); or, 3) equipment failure.*

22 *These figures are estimates based on the authors' experience working with these data.*

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