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A role for capital markets in natural disasters: a piece of the food security puzzle

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Abstract

Natural disaster can create significant shocks in food supplies for small country-states. These events are very disruptive to the development process. Market-based means for managing natural disaster risk are emerging. For example, despite the failure of government-subsidized crop insurance around the world, it is now possible to create index-based contracts that would trigger when events that create serious crop failure problems occur. This paper investigates the logic for such contracts and some basic designs using measures of rainfall. © 2000 Elsevier Science Ltd. All rights reserved.

Introduction

Agricultural development is the key to food security in many countries around the world. Many factors, including disasters, can slow the development process by reducing domestic food supplies in the short term. Natural disasters are a major source of risk for production.[1] And while many alternatives are used to cope with this type of risk, careful consideration of the consequences of these alternatives is essential.

The challenge for introducing market-based solutions is evaluated by focusing on one source of natural disaster risk—drought. Market-based policies that pay when there is a shortfall in rain offer some promise for coping with many of the problems identified. Such "index-based" policies could be applied to many natural disasters.

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[1] By natural disasters I am referring to events that cover a wide area at the same time. For example, a major drought, excess rain, hurricanes, or volcanoes can inflict widespread damage to production agriculture. In small countries, these types of disasters also create short-term food security problems.

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Risk-sharing using these methods will require active participation from capital markets. However, there may be a role for government in developing the market for natural disaster risk-sharing. This paper evaluates the consequences of alternatives to cope with natural disasters by first developing a conceptual frame for understanding these risks. It concludes by offering a specific alternative—index contracts—for managing natural disaster risk.

The role of risk-sharing in agricultural development

In a market-based economy risk must be internalized. Farm managers have many means for coping with risk. Diversification in enterprise mix or in use of family labor for both on- and off-farm jobs is a common and dominant choice. Diversification does not come without a cost. The benefits of specialization in production are well documented in economics (Debreu, 1959). When farmers diversify they give up the higher expected income that would come with specialization to reduce the variation in income. In effect this can be thought of as an insurance premium. Another means of managing risk involves use of credit reserves. If the farm decides to limit the use of credit below a level that may be optimal, the opportunity to borrow funds will be open in the event of a major disaster. Again, there is an opportunity cost associated with maintaining a credit reserve for major disasters.

Possibly more significant, if farmers do not have the means to manage catastrophic risk from natural disasters, bankers will be forced to internalize these risks. When bankers recognize that loan defaults are tied to natural disasters they will either (1) ration credit or (2) build in a credit premium to cover these risks (i.e., charge higher interest rates). Agricultural risks are an impediment to fully developed financial markets in many developing countries. Access to affordable credit is a key to development. With affordable credit farmers can adopt new technologies and take more risk in developing improved farming systems. The dilemma is that if farmers had access to credit they could manage agricultural risk better—if bankers did not have to worry about loan defaults from agricultural risks they would provide more access. In many countries, the financial markets are incomplete. Effective risk-sharing markets for natural disaster risks are largely lacking the world over. If such markets existed, one might expect: (1) more access to affordable credit; (2) more rapid adoption of new technologies; (3) more specialization in production; and (4) a more adaptive and flexible agricultural sector.

Most economists agree that using insurance allows decision makers to engage in new productive activities with benefits for the entire economy (Arrow, 1996). However, farmers must pay for the risk protection and the market contract must be structured so that it cannot be abused if the Arrow principles are to prevail. These two conditions are fundamental to a sustainable risk-sharing program and to one that results in welfare gains to society. If farmers are given risk protection via various subsidies, significant inefficiencies will follow, some of which may have negative environmental consequences. If the contract is subject to abuse, the losses must be added to future premiums and soon there will be no private interest in either purchasing or supplying insurance.

With classic insurance, pooling independent loss events yields a mean loss for the pool that has a variance that is less than the mean of the individual variances. This result is derived from the classic statistical property of the "law of large numbers." Thus society benefits from pooling independent risks since the risk faced by the pool is less than the pre-aggregated sum of individual risks (Priest, 1996). In short, insurance markets *reduce* the risk faced by society and thus the aggregate cost of managing risk.

Attempts to manage natural disaster risk

Numerous alternatives have been used to protect societies against the adverse effects of natural disasters. Free assistance is probably the most common. While such assistance may be necessary for humanitarian reasons, there are reasons to proceed with caution. Free or heavily subsidized assistance sends the wrong signals. Consider the response. Decision makers will soon value the free assistance and change their behavior in ways that will ultimately lead to more losses. If the government gives free assistance to farmers who lose their crops on a regular basis, the farmers will plant more crops and collect more disaster payments in the future. Such a decision creates a cycle that may be burdensome to the government budgets, the environment, and to the people taking the undue risks (Dacy and Kunreuther, 1969; Kaplow, 1991; Kunreuther, 1996).

Governments have also been active in providing government-supported insurance. In many cases the government has been the direct retailer and risk-bearer of such insurance programs. For the US crop insurance program, the government uses the private sector to deliver subsidized crop insurance and share the risk of the crop insurance through a special reinsurance agreement with the government. Whether the government sells insurance directly or uses the private sector, there are problems. Most government insurance is subsidized as a percentage of premium. Providing subsidies as a percentage of premium still favors high-risk areas more than low-risk areas, sending signals similar to free disaster aid. Furthermore, the transaction costs of providing individual insurance can offset any welfare gains for society. Finally, allowing the private sector to sell government insurance and share the risk creates rent-seeking behavior that can destroy the efficiency gains for society (Hazell et al., 1986; Goodwin and Smith, 1995; Mishra, 1996; Skees, 1999a). Hazell et al. (1986) comprehensively sets out reasons why multiple-peril crop insurance programs have failed in developing countries.

Incomplete risk-sharing markets for natural disasters

There are several reasons why private markets have not developed for risk-sharing from natural disasters that damage agriculture. First, it may be that government actions have crowded out such market development. Second, the transaction costs of insuring farm level yields are high because of information asymmetries. Third, the risk from natural disasters is widespread and correlated, creating huge losses and requiring special forms of risk-sharing. Indeed, this is a reason given by many for needing government involvement. Finally, it is possible that there is a cognitive failure problem on the part of many decision makers who undervalue insurance.

Government crowding out markets

Governments may simply crowd out private sector interest. After all, private insurance does exist for earthquakes and hurricanes in the US. Many governments provide assistance to communities ravaged by natural disasters and operate highly subsidized public crop insurance programs. Such government activities have been blamed for competing unfairly with private insurers, stifling development of innovative insurance products. Governments also tend to regulate the insurance sector heavily, creating another burden to innovation.

Information asymmetries

Incomplete agricultural and rural risk markets also stem from information asymmetries. Farmers will always know more about their yield risks than the government or any private company. Thus the classic problems of adverse selection and moral hazard can create serious problems for any multiple-peril crop insurance program. There is extensive literature on these problems (Ahsan et al., 1982; Skees and Reed, 1986; Goodwin and Smith, 1995). If individual risks are not properly classified prior to selling insurance, then high-risk growers may be the only ones to participate. Such adverse selection will create losses that are greater than the insurance premium rates, creating a need to continually raise rates. By the same token, if insureds change their behavior after they purchase insurance in ways that create more losses because they are insured (called moral hazard), rates will need to be increased on a regular basis. Controlling adverse selection and moral hazard requires investments in information. Investing in information will add to the transaction costs of delivering insurance. This increases premiums and reduces demand for insurance.

Correlated risk

Independent risk is a classic precondition for insurance (Vaughan, 1989; Rejda, 1995). When risks are not independent, markets may be incomplete. The widespread nature of natural disaster losses undermines the ability of insurance companies to pool risks and offer affordable insurance coverage. Although crop losses are often widespread, they may not be completely correlated. In contrast, general price movements for a bulk agricultural commodity are correlated. Such correlated risks can be managed with futures exchanges. In many ways, crop and natural disaster risks are "in-between risks." They are neither completely correlated nor independent (see Fig. 1). When insurance is offered for natural disaster risks the rates must be loaded (adjusted upward) for catastrophes because of the nature of the risk.

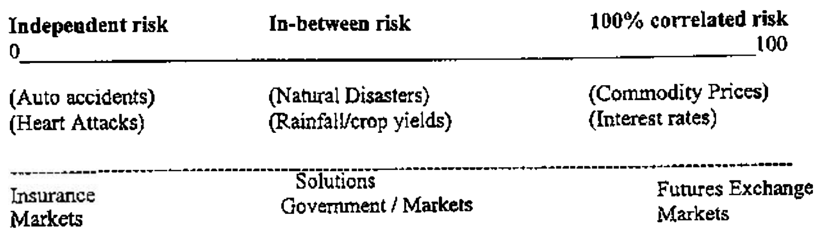

Fig. 1. Independent versus correlated risk.

Cognitive failure by decision makers

Cognitive failure problems may also contribute to the problem of incomplete risk-sharing markets (Tversky and Kahneman, 1973; Kunreuther and Slovic, 1978; Kunreuther, 1996). If decision makers underestimate the risks they face, they will be less willing to purchase risk-sharing products. Interestingly, decision makers seem to underestimate risks from natural causes and overestimate risks from man-made causes (Camerer and Kunreuther, 1989). If potential purchasers of insurance underestimate the risk and potential sellers overestimate the risk, a market will not evolve.

Insuring natural disasters

Insurance is available for natural disaster risk in developed economies. Homeowners can insure against damage from hurricanes and earthquakes. These risks are clearly different from most insurable risk. Unlike automobile insurance where the risks are largely independent, natural disaster risks are correlated with some low probability of very high losses as a widespread area is damaged by a single event. This requires special arrangements to share these risks in the capital markets. Primary insurers pass on certain levels of risk to an international reinsurance market (Cutler and Zeckhauser, 1997; Miranda and Glauber, 1997).

The simplest form of reinsurance is a stop loss where the primary insurer pays a premium to get protection if losses exceed certain levels. The reinsurer has an interesting problem—how does one rate a policy for a low-probability, high-loss event? While there are very sophisticated models used to address this problem, most wise reinsurers will load the risk beyond levels experienced in the past (Anderson, 1976; Hogarth and Kunreuther 1989, 1992). Anyone in the risk management business will say "just because it has never happened, doesn't mean it won't." The other problem is intertemporal. Suppose the big hit comes in the first year. This will require capital reserves to pay large losses. Rate makers load to build these reserves quickly for early losses. Finally, keep in mind that all of the issues of asymmetric information also apply to the principal–agent relationship between the primary insurer and the reinsurer. Reinsurers must invest in monitoring and information systems to balance the information. This increases transaction costs. In the end, all of these costs must be summed together with the pure risk of the contract to develop a premium rate, as presented in Eq. (1).

$$\text{Premium rate}=\text{Pure premium rate}+\text{Catastrophic load}+\text{Reserve load} \\ +\text{Charge to cover transaction costs}+\text{Return on equity} \tag{1}$$

After all of the components of rating insurance are considered, it is little wonder that premium rates can exceed the expectations of decision makers who tend to forget bad events. In short, decision makers will not value the risk services the same as those who develop the rates. Thus, a market may never emerge. This argument is used to justify government involvement. Efficiencies are needed. Large international reinsurers can spread risks around the world—applying all of the principles of portfolio theory. Still, improved efficiencies are needed in reinsurance markets. The transaction costs of putting together large sums of capital can be high. There are new developments that hold promise for reducing the transaction costs (Doherty, 1997; Lamm, 1997; Skees, 1999b). There is some promise that futures exchange markets can be used as risk-sharing institutions for disasters. The Chicago Board of Trade (CBOT) trades a Catastrophic Insurance Options Contract (CAT). Another important development is the emergence of catastrophic bonds. This is truly using capital markets to share catastrophic risk. These take on a variety of structures. In essence, they represent contingent capital should the disaster occur. Since catastrophes are not correlated with other market equities, they should be a good diversification strategy for portfolio managers.

The use of the capital markets for sharing "in-between" risk remains in the infant stages, leaving the issue of capacity and efficiency in doubt. This raises questions about the role of government in sharing such risk. For the US, Lewis and Murdock (1996) recommend government catastrophic options that are auctioned to reinsurers. Skees and Barnett (1999) expand upon this idea for some agricultural risks. Part of the thinking is that the government has adequate capital to cover large losses from such options and may be less likely to load these options as much as the reinsurance market.

Using index contracts to insure natural disasters

Serious questions should be asked about trying to insure individual crop risks. Potential societal welfare gains can quickly disappear when there are high transaction costs for monitoring the micro-level problems of adverse selection and moral hazard or if extra resources are needed by rent-seekers to keep subsidies. Without investments in monitoring, actuarial performance will almost certainly be poor (Hazell, 1992). The nature of the systemic risk also presents major challenges in reinsurance. When a significant systemic risk component is present, index contracts may be optimal. In other words, if most potential insureds face losses from the same events, then offering a contract that pays when those events occur can offer significant risk protection. Crop insurance that pays indemnities based on yield shortfalls from normal area yields is a case in point (Miranda, 1991; Mishra, 1996; Skees et al., 1997).

Basis risk—when individuals have a loss and don't get paid or don't have a loss and do get paid—can be a problem with index contracts (just as in using futures markets to hedge prices). In the case where individuals get paid when they suffer no losses, traditional insurers may think this is a problem. However, it is this very aspect that makes index contracts attractive. The insured paid the premium based on the underlying risk of the index so that is not an issue. Most importantly, the insured's management decisions after planting a crop will not be influenced by the index contract. There is no moral hazard. The insured farmer still has the same economic incentives to make a crop as the uninsured farmer.

The most serious aspect of basis risk for an index contract is that a farmer can have a loss and not get paid. If the basis risk is not too high, this issue is also not as serious as many make it to be. First, consider that an index product should be more affordable than individual insurance. Second, since this may be the only choice, it will be a useful risk-sharing alternative so long as it protects against most major events that create serious losses. Third, offering an index contract that takes most of the risks out and leaves only independent risks opens the possibility that an insurance company can offer an insurance contract for the independent risk. Such a wrap-around contract would still be subject to the same problems of high transaction costs due to monitoring and information needs by the insurer. If buyers are not willing to pay for the transaction costs then maybe a market should not evolve.

In short, index contracts trade off basis risks for transaction costs. Transaction costs of index products are generally much less than for individual insurance. Everyone should have access to the same information. Again, if premiums do not have to be loaded for transaction costs, a market is more likely to evolve. Still, one must be concerned about the level of loading that may be necessary for an index contract. When one is writing index contracts on natural disasters, the degree of systemic risks can be significant.

Besides being largely free of adverse selection and moral hazard problems, index contracts can be made widely available. Traditional farm-level crop insurance is available to farmers only. In reality many individuals are at risk when there is a natural disaster that does severe damage to crops. For example, the lender is clearly at risk if a large number of its borrowers suffer serious financial losses from the same event. Furthermore, agribusinesses selling inputs to farmers or purchasing the final product are at risk. In particular, an agribusiness that earns revenues based only on throughput of a basic commodity might find an area-based index contract attractive. Finally, individual consumers of basic foodstuffs could purchase the index contract that would indemnify them when there is a food shortage in their area. There is no reason to limit who can purchase an index contract that pays when a natural disaster damages a crop. Farmers are not the only ones at risk.

Rainfall index contracts

One index contract that merits consideration for many developing countries is a rainfall index. While an area-yield contract may be preferred to a rainfall contract in many cases, there are a number of reasons why a rainfall contract may be better. First, it is more common for countries to have a long history of measuring rainfall with a government meteorological agency than to have quality statistics on crop yields. Second, it is less costly to set up a system to collect rainfall for specific locations than to develop a reliable yield estimation procedure for small geographical areas. Third, in some cases rain shortfalls or excess rain will influence income and not crop yields, for example if someone has to incur the extra cost of irrigation when there is a drought. Finally, either shortages or excess rainfall are the major source of risk for crop losses in many regions.

For purposes of discussion some terms need to be defined:

Liability—the face value of the contract or the most the insured could ever be paid
Pure premium rate—the expected losses in percentage of liability terms (frequency of loss×severity of loss)
Strike—the level of rainfall where payments begin (usually as a percentage of average)

An area-based rainfall contract can be quite simple or complex. In order of complexity, there are three basic alternatives that merit consideration: (1) a zero–one contract that pays all liability when cumulative rain is at or below the strike; (2) a layered contract that pays an additional fixed amount of the liability as each layer is penetrated; (3) a percentage contract that pays based on percentage below the strike. While the simple contracts may be more attractive as they are easier to understand, the more complex contracts are more likely to offer the best risk protection.

The zero–one contract

In its most simple form, a rainfall contract would simply pay the full face value any time there was a rain shortfall in a specific location. For example, let's say that the most critical period for rainfall is the first 2 months after planting. One could design a policy that would pay when rainfall is below a specific percentage of the average rainfall during that period. The payment schedule would simply be the full face value (liability) of the contract.

Consider the probability distribution (pdf) represented in Fig. 2. In this pdf, the rainfall is positively skewed and has an average of 500 mm of rain with a standard deviation of 200 mm. If an individual purchases a US$100 contract that pays if rainfall drops below 50% of the 500 mm average rainfall for the 2-month period, the strike is 250 mm. All US$100 of liability would be paid for rainfall at or below 250 mm. For this pdf, such an event will occur 8.3 percent of the time. Since all liability is paid for rainfall at or below the strike, the pure premium rate would also equal 8.3 percent. Thus, if the individual were charged only the pure premium rate for this contract, he/she would pay US$8.30.

While the simplicity of the zero–one design is attractive, there are some shortcomings. First, the loss function is rarely bimodal. Second, making things so precise places pressure on individuals to try to manipulate the system in some fashion. As

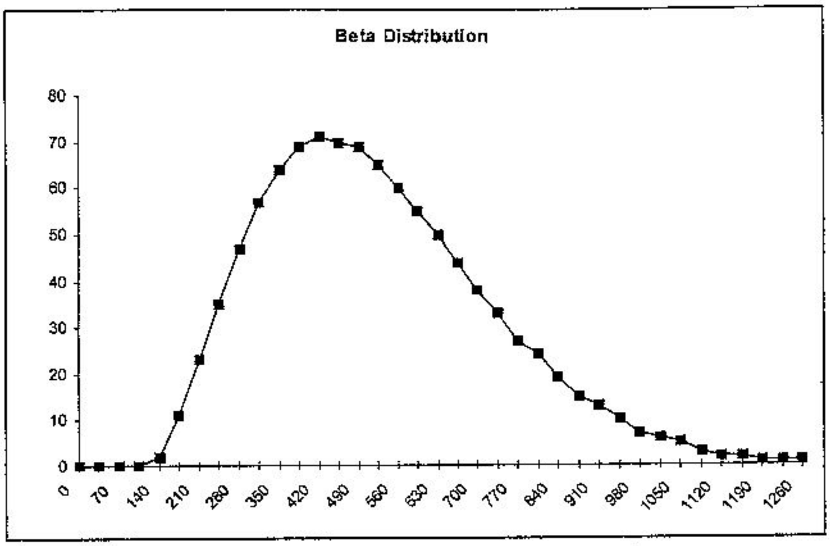

Fig. 2. Distribution of rainfall (in millimeters) for three meteorological stations in Northwest Nicaragua.

the rainfall gets close to the strike, a fraction of a centimeter of rain either way can make the difference between paying all or nothing. Third, either premium rates would have to be very high or some very low levels of rainfall would need to be insured. Again, consider the pure premium rate of 8.3 percent for the distribution in Fig. 2. To complete the rating all factors introduced in Eq. (1) would need to be added to the pure premium rate. This may double that rate. Rates in excess of 10 percent are generally not attractive to potential purchasers of these types of contracts. Therefore, a zero–one contract may have to be written for very low and infrequent events—say one in 20 years or a 5 percent chance. Receiving some level of payment frequently is important because of some of the cognitive failure problems discussed above.

A layered contract

To address some of the shortcomings of the zero–one contract, consider a layered contract with multiple strikes paying a fixed additional amount when each layer is penetrated. Again consider the distribution in Fig. 2. One can design a policy that would pay one-third of the face value (liability) for three levels of rainfall. For a US$100 policy, consider the following payment schedule that starts paying for rain below 60 percent of the average:

If rain >200 mm but ≤300 mm pay US$33.33 (odds of rain below 300 mm=15.8%)
If rain >100 mm but ≤200 mm pay US$66.66 (odds of rain below 200 mm=3.0%)
If rain ≤100 mm pay US$100 (odds of rain below 100 mm=0.0%)

To rate this policy, sum frequency×payouts (severity) for each layer:

0.158×US$33.33=US$5.3 per US$100 of liability
0.030×US$33.33=US$1.0 per US$100 of liability
0.000×US$33.33=US$0 per US$100 of liability

Total pure premium = US$6.3 per US$100 of liability or a pure premium rate of 6.3 percent.[2]

A percentage contract

The third way to structure these contracts is to develop payouts as a function of rain below a strike level. Using percentages below the strike and multiplying those percentages by the liability selected is the most straightforward functional relationship. Using the same strike rainfall of 300 mm, one would pay as follows:

$$\text{Payment}=[(300-\text{actual rain})/300]\times\text{liability} \tag{2}$$

The rate is simply the average of the percentage shortfalls below the strike. For the distribution in Fig. 2 at the strike of 300 mm, the pure premium rate is 3.2 percent. Now it is possible to offer protection at higher levels. For example, offering coverage at 70 percent of the average or a strike of 350 mm has a pure premium rate of 5.6 percent.

Obtaining risk protection from a rainfall index

Extensions of portfolio theory are needed to evaluate the utility of a rainfall index. For the farm manager, the rainfall index simply becomes another enterprise in the portfolio of choices for risk sharing. In some cases, the rainfall index enterprise may offer a better portfolio than adding another crop, especially if better terms of credit are available when the rainfall index is purchased. While the full evaluation of these choices is complex and requires good data, there are important considerations that will give some indication about the utility of a rainfall index. Formal models have evolved from the original portfolio work by Markowitz (1952). Capital asset pricing models, hedging models and contingent claims models all use the same basic constructs and principles: expected values of the alternatives, variance of the alternatives, and the covariance of the alternatives.

The advantages of rainfall contracts is that they could:

1. Lower moral hazard and adverse selection.

[2] If the same procedures are used with a starting coverage level at 60 percent of average and five layers, the pure premium rate drops to 5 percent.

2. Lower administrative costs since no on-farm inspections are needed and no individual loss adjustments are required.
3. Reduce the need to track yields or financial losses (one need only measure rainfall). The insurance can be sold to anyone who has income that is correlated to the rainfall event, including bankers, agricultural traders and processors, farm input suppliers, shopkeepers, consumers of basic commodities, and agricultural workers.
4. Be sold as a simple certificate in low denominations.
5. Facilitate development of other kinds of insurance to handle independent risk.
6. Facilitate a secondary market enabling people to cash in the tradable value of a standard unit contract at any time.

The potential difficulties include:

1. The need to have reliable and secure rainfall measures for a large geographical area
2. The need to model intertemporal weather events such as El Nino.
3. The possibility of mistakes in selection of the critical rainfall periods and in other contract design features.
4. The difficulty of potential purchasers in understanding how to use the contracts.
5. The high degree of correlated risk, making it necessary to have reinsurance.

Using government to address the potential difficulties

To the extent that the government helps in development of rainfall contracts, it will lower the transaction and start-up costs. Some government assistance would be needed in most developing countries. There is a public good in developing research needed to understand the critical periods for rainfall (i.e., those periods that are most highly correlated with income). Public research to model El Nino events is needed. Investing in the infrastructure for secure and reliable rainfall stations also has some public good dimensions. Governments may also engage in the educational efforts needed to help potential users know how to evaluate purchase decisions. These public investments help to assure transparency in information, an important condition for efficient markets.

Secure and reliable rainfall measures are critical for all parties. New technologies hold significant promise. One company in the US offers a rain-gauge operated by a battery with a 5-year life. Tiny buckets trip the measuring device so that rainfall at 2.5 mm can be recorded. No rain is collected. By using a data-jack with windows-based software, a worker simply plugs into the rainfall-measuring device and downloads the data. Downloading of data need only be done once a month. A complete system of 50 such gauges, software and data-jack costs about US$240. This is affordable and offers the opportunity to densely populate a region with rain-gauges. Finally, geographical smoothing can be used with a heavily populated set of rain-gauges to provide point estimates for rainfall. This has great promise for reducing opportunities for any individual to tamper with a single gauge and to reduce the basis risk of offering a contract on a rain-gauge that is several miles from the crop. Security can be enhanced by placing the rain-gauges on telephone poles with shields around them from below.

To give companies the comfort needed to insure rainfall in a developing country, the government may consider writing low-probability insurance contracts on individual rainfall stations. Primary insurers and reinsurers would determine how many and what mix of such contracts to purchase from the government. These contracts could be simply rated at the historical break-even rate, or they could be auctioned to the highest bidder. The World Bank or others in capital markets could back up these contracts with a contingency loan so that the government would have sufficient capital to pay all losses if the bad year came early in the pilot test. In effect, the capital markets would be offering a stop-loss type contract to the government.

The host-country government could also sell individual rainfall contracts to reinsurers. For example, the government may sell a rainfall contract for each station that pays in two stages: (1) 50 percent of the face value for rainfall below 40 percent of the average; and (2) 100 percent of the face value for rainfall below 20 percent of the average. There are many possible contracts. The government would sell very low-level coverage for each station. The reinsurer would have to purchase the mixture of these that would best protect its risk. As the government sells these, they must have the capital to pay if the bad year comes early. For small countries this could be a problem. The World Bank, an international reinsurer, or a financial entity that is ready to write CAT bonds could offer simple "stop-loss" coverage via a contingency loan. For example, if the government sold premium of US$500,000 for these contracts, at premium rates of 5 percent, the maximum possible loss would be 20 times the total premium or US$10 million. While the expectations are that the government would break even over the long run, they could have the bad event early. The World Bank or the international capital markets would cover such an event with a loan. As things are phased in, the government may want to offer these contracts in a limited number via an auction to facilitate the development of a private insurance market.

Conclusion

Food security has many dimensions. Natural disasters challenge food security in the short term with food shortages and in the long term with underdevelopment of the agricultural economy if there are incomplete risk-sharing markets. Attempts to introduce multiple-peril crop-insurance programs in developing economies have largely failed. This paper reviews some of the reasons for that failure. Based on this review and the discussion of international reinsurance markets for natural disasters and new capital markets, an alternative is presented.

The case for using a rainfall index in developing countries rather than traditional crop insurance is strong. Among the more important advantages is the absence of moral hazard and adverse selection and that an index can be sold to anyone at risk. Three major challenges must be addressed before effective rainfall contracts are introduced: (1) determination of the critical rainfall periods and how correlated they are to income for those at risk; (2) the need for a secure and reliable infrastructure to measure rainfall; and (3) the role of government versus international reinsurers in protecting against the systemic risks embedded in a portfolio of rainfall contracts. If effective rainfall contracts are offered, they can take much of the systemic risk out of the equation and open the possibility for private efforts at insuring independent risk.

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References

Ahsan, S.M., Ali, A.A.G., Kurian, N.J., 1982. Towards a theory of agricultural insurance. American Journal of Agricultural Economics 64 (3), 520–529.

Anderson, D.R., 1976. All risks rating within a catastrophe insurance system. Journal of Risk and Insurance 43 (4), 629–651.

Arrow, K.J., 1996. The theory of risk-bearing: small and great risks. Journal of Risk and Uncertainty 12 (2/3), 103–111.

Camerer, C.F., Kunreuther, H., 1989. Decision processes for low probability events: policy implications. Journal of Policy Analysis and Management 8 (4), 565–592.

Cutler, D.M., Zeckhauser, R.J., 1997. Reinsurance for catastrophes and cataclysms. NBER Working Paper Series, Working Paper 5913. National Bureau of Economic Research, Cambridge.

Dacy, D.C., Kunreuther, H., 1969. The Economics of Natural Disasters: Implications for Federal Policy. The Free Press, New York.

Debreu, G., 1959. Theory of Value: an Axiomatic Analysis of Economic Equilibrium. Wiley, New York.

Doherty, N.A., 1997. Financial innovation in the management of catastrophe risk. Fifth Alexander Howden Conference on Disaster Insurance, August, Gold Coast, Australia.

Goodwin, B.K., Smith, V.H., 1995. The Economics of Crop Insurance and Disaster Aid. The AEI Press, Washington.

Hazell, P.B.R., 1992. The appropriate role of agricultural insurance in developing countries. Journal of International Development 4, 567–581.

Hazell, P., Pomareda, C., Valdes, A., 1986. Crop Insurance for Agricultural Development: Issues and Experience. The John Hopkins University Press, Baltimore.

Hogarth, R.M., Kunreuther, H., 1989. Risk, ambiguity, and insurance. Journal of Risk and Uncertainty 2 (1), 5–35.

Hogarth, R.M., Kunreuther, H., 1992. Pricing insurance and warranties: ambiguity and correlated risks. The Geneva Papers on Risk and Insurance Theory 17, 35–60.

Kaplow, L., 1991. Incentives and government relief for risk. Journal of Risk and Uncertainty 4 (2), 167–175.

Kunreuther, H., 1996. Mitigating disaster losses through insurance. Journal of Risk and Uncertainty 12 (2/3), 171–187.

Kunreuther, H., Slovic, P., 1978. Economics, psychology, and protective behavior. American Economic Review 68 (2), 64–69.

Lamm Jr., R.M., 1997. The catastrophe reinsurance market: gyrations and innovations amid major structural transformation, 1–13. Bankers Trust Research. Bankers Trust Company, New York.

Lewis, C.M., Murdock, K.C., 1996. The role of government contracts in discretionary reinsurance markets for natural disasters. Journal of Risk and Insurance 63 (4), 567–597.

Markowitz, H.M., 1952. Portfolio selection. Journal of Finance 7 (1), 77–91.

Miranda, M.J., 1991. Area-yield crop insurance reconsidered. American Journal of Agricultural Economics 73 (2), 233–254.

Miranda, M.J., Glauber, J.W., 1997. Systemic risk, reinsurance, and the failure of crop insurance markets. American Journal of Agricultural Economics 79 (1), 206–215.

Mishra, P.K., 1996. Agricultural Risk, Insurance and Income: a Study of the Impact and Design of India's Comprehensive Crop Insurance Scheme. Avebury Press, Brookfield.

Priest, G.L., 1996. The government, the market, and the problem of catastrophic loss. Journal of Risk and Uncertainty 12 (2/3), 219–237.

Rejda, G.E., 1995. Principles of Risk Management and Insurance. Harder Collins College Publishers, New York.

Skees, J.R., 1999a. Agricultural risk management or income enhancement? Regulation 22 (1), 35–43.

Skees, J.R., 1999b. Opportunities for improved efficiency in risk-sharing using capital markets. American Journal of Agricultural Economics 81 (5), 1228–1233.

Skees, J.R., Barnett, B.J., 1999. Conceptual and practical considerations for sharing catastrophic risks. Review of Agricultural Economics 21 (2), 424–441.

Skees, J.R., Reed, M., 1986. Rate-making for farm-level crop insurance: implications for adverse selection. American Journal of Agricultural Economics 68 (3), 653–659.

Skees, J.R., Black, J.R., Barnett, B.J., 1997. Designing and rating an area yield crop insurance contract. American Journal of Agricultural Economics 79 (2), 430–438.

Tversky, A., Kahneman, D., 1973. Availability: a heuristic for judging frequency and probability. Cognitive Psychology 5 (2), 207–232.

Vaughan, E., 1989. Fundamentals of Risk and Insurance. Wiley, New York.