“Sovereign Cat Bonds and Infrastructure Project Financing”

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Abstract:

We examine the opportunities for using catastrophe-linked securities to reduce the total costs of funding infrastructure projects in emerging economies. Our objective is to elaborate on methods to reduce the necessity for unanticipated (emergency) project funding immediately after a natural disaster. We also place the existing explanations of sovereign-level contingent capital into a catastrophic risk management framework. In doing so, we address the following questions:

(1) Why might catastrophe-linked securities be useful to a sovereign nation, over and above their usefulness for insurers and reinsurers?

(2) Why are such financial instruments ideally suited for protecting infrastructure projects in emerging economies, under third-party sponsorship, from low-probability, high-consequence events which occur as a result of natural disasters?

(3) How can the willingness-to-pay of a sovereign government in an emerging economy (or its external project sponsor), who values timely completion of infrastructure projects, for such instruments be calculated?

To supplement our treatment of these questions, we use a multi-layer spreadsheet-based model (in Microsoft Excel format) to calculate the overall cost reductions possible through the judicious use of catastrophe-based financial tools. We also report on numerical comparative statics on the value of contingent-capital financing to avoid project disruption based on varying costs of capital, probability and consequences of disasters, the feasibility of strategies for mid-stage project abandonment, and the timing of capital commitments to the infrastructure investment.

We use these results to identify high-priority applications of catastrophe-linked securities, so that maximal protection can be realized if the total number of catastrophe instruments is initially limited. The paper concludes with potential extensions to our model and opportunities for future research.
I. Introduction

Insurers and reinsurers, private entities who bear risk on behalf of their clients, use catastrophe-linked securities to protect themselves against insolvency in the case of a natural catastrophe (Croson and Kunreuther, 1999; Lewis and Murdock, 1996). Although private enterprise has already begun to find catastrophe-linked securities useful in reducing the variation of their costs, this hedge against disaster comes at a price: 100% of the expected cost of these catastrophes, plus a generous premium for assuming the risk, is paid to investors (Froot and Seasholes, 1997; Bantwal and Kunreuther, 1999; Canbarro et al., 1998).

To our knowledge, there has been neither a theoretical analysis nor even a compendium of potential motivations for sovereign governments to use such instruments. Given this lack of analysis, it is not surprising that no sovereign governments (or third-party infrastructure project funders, such as the World Bank) have issued such securities to protect themselves against catastrophe. We therefore address the question, "Why might the sovereign government of an emerging nation be interested in employing catastrophe-linked instruments to protect infrastructure investments, funded by a third party, from low-probability, high-consequence events such as natural catastrophes?"

II. Government Concern with Catastrophes

A private insurer or reinsurer worries about catastrophes because they trigger financial obligations which may result in insolvency. It uses catastrophe-linked securities to prevent this insolvency and preserve its franchise value as a profitable ongoing concern (Cummins and Doherty, 1997).

A sovereign government worries about catastrophes because they trigger obligations to preserve the welfare of its affected citizenry, in addition to damaging
infrastructure projects in progress.\textsuperscript{1} Catastrophes generate sudden funding requirements for emergency humanitarian aid, at the same time as they generate additional funding requirements to continue with works in progress. The consequence of omitting (or skimping on) such humanitarian aid is not insolvency, but rather increased suffering for the population, as well as political unpopularity, potential civil unrest, and a potentially guilty conscience for politicians. In particular, disbursing such humanitarian aid at generous levels seems incentive-compatible for government officials, who act as agents for the citizens, as well as prescribed by the charter of the government. That efforts of government officials to succor the populace will be pursued at a maximal level is practically guaranteed by political and media pressures (in addition to the force of genuine heartfelt sympathy for afflicted citizens.) A government may find it worthwhile to issue state-contingent catastrophe securities to assure its ability to provide humanitarian aid at an efficient level, completely independent of any other reasons.

The government may also wish to protect its investment in wholly-owned infrastructure features such as roads, schools, dams, electric utilities, and the telecommunications infrastructure.

Although the expected capital requirements for completing these projects are completely known \textit{ex ante}, the stochastic character of the capital requirements (which we will term “emergency repair costs” in our example) requires some contingency planning to ensure that needed project funds are available. The government may in particular wish to assure liquidity immediately after a catastrophe, given that it rationally anticipates that all liquid resources will be devoted to humanitarian aid, to assure that these projects can be completed in a timely manner and without extraordinary costs caused by interruption. Such possibility of either sudden and unexpected financial distress due to catastrophe, or the adoption of inferior construction strategies because of the potential for future financial distress, leads to higher expected costs to complete such projects. The simple strategy of holding “capital inventory” to avoid these costs is, unfortunately, very costly for emerging economies.

\textsuperscript{1} Particularly for emerging-economy governments, these governments may not want to serve as insurer of last resort -- a traditional role of government -- because of these high capital costs, representing large
III. Basic Structure of Catastrophe-Linked Securities

A catastrophe-linked security (or “cat bond” for short) is a contract between an issuer and an investor. The investor puts up a sum of cash at the beginning of the coverage period; this cash is held in escrow, and invested in low-risk short-term securities until either a catastrophe occurs or the coverage period ends, whichever occurs sooner. The issuer offers to supplement this escrowed principal with a coupon payment, provided that no catastrophe occurs during the coverage period, at the end of the period and return both principal and interest to investors. In the event of a catastrophe, the investors will receive no coupon payment, and some or all of their principal may be distributed to the issuer.²

The major benefit that these instruments offer to the issuer is an instantaneous inflow of cash (here, to the government) immediately following a prespecified catastrophic event (such as a flood, earthquake, or hurricane). This payment flows from an escrow account established at the time of issuance, and is not a loan or sovereign obligation -- the principal need not ever be repaid by the government to any party, whether a catastrophe occurs or not. The principal is placed in escrow (under the control of a neutral third party.) If there is no catastrophe during the coverage period, the escrowed principal is returned to the investors with the country having never had the use of it. If there is a catastrophe, the escrowed principal flows to the country free and clear of any repayment obligations. Under no circumstances does the country get the use of the capital under an obligation to repay it. This feature is likely to be quite important to an emerging economy which already carries a substantial debt burden -- particularly if the country's existing sovereign debt carries a covenant restricting the amount of additional debt which can be assumed.

Given the rather substantial premium which investors receive in return for accepting the risk to their principal, we might ask “Why might such a security be more attractive to a sovereign government than more traditional types of financing?”

² For structures and conditions of recent cat bonds, see Bantwal and Kunreuther (1999).
(a) *Funds of the magnitude required to rebuild damaged infrastructure investments may not be available to emerging economies in advance.* Although substantial amounts of borrowing at the sovereign level may be desirable to support economic growth, the total amount of sovereign debt which a government can support may be sharply limited, either through explicit restrictive covenants on existing debt or by the market’s unwillingness to advance additional funds for general purposes. A government nearing its total allowable-debt constraint has a substantial incentive to ensure that this constraint will not be violated in case of a catastrophe.

(b) *Even if these funds would be available during normal circumstances, they may not be available after a sufficiently severe catastrophe.* Unless provisions for emergency capital are arranged in advance, investors may be reluctant to make large new capital commitments if a catastrophe occurs which is sufficiently severe to threaten the stability of the national currency, create civil unrest, or cause default on outstanding sovereign debt. A rational response before additional investment might be to “wait and see” whether the country’s ability to repay the new debt has been compromised by the catastrophe.

(c) *Portions of these funds are required immediately after the catastrophe to address catastrophe-induced difficulties.* The demand for liquid funds immediately after a catastrophe is extremely high, and the short-term opportunity cost of not having capital available immediately after a catastrophe is considerable, both for emergency humanitarian aid and for reconstruction. It is this high short-term social value of liquid assets that leads governments to divert capital flows earmarked for sponsored infrastructure projects to emergency humanitarian aid when all other sources of liquid assets have been exhausted. This short-term cash flow problem is exacerbated when the infrastructure projects themselves suffer damage from the catastrophe and require reconstruction. A new roof for a nearly-finished school may be required after a hurricane hits the area, for example; if this roof is not immediately installed, rain damage may dramatically increase the total cost of finishing the school. Delays in the availability of emergency-repair funds may therefore generate significant costs of financial distress after a disaster.
(d) The government may not desire to borrow more money in the future, even if allowed to do so at a competitive rate. The government's overall financial strategy (prior to a catastrophe, but rationally anticipating its possibility) may be to reduce its overall level of borrowing, or to maintain its current optimal level, rather than potentially increase it if a catastrophe were to occur. The government may be willing to pay a premium to avoid disruption of the rationalizing of its financial structure on a national level, in much the same way we describe the gains from avoiding disruption on the project level in our later analysis.

(e) The cost of capital for an emerging economy is high. Holding excess funds idle in inventory, against the possibility of unexpected cash needs, has a very high cost for an emerging economy – either an explicit cost of borrowing in the capital market, or a high opportunity cost based on depriving a socially desirable investment project of capital. It does not make sense to withhold large amounts of capital every year, to hedge against an event which occurs only one year in ten.

Introduction to Project Disruption Costs

Funds may be diverted from these projects -- even despite the sovereign governments' genuine long-term commitment to the desirability of investing in these projects -- to assuage short-term humanitarian and political needs immediately following a catastrophe. The timely application of these loaned funds to infrastructure development is a condition of the original loan agreement. Such diversion creates not only a technical default on the original agreement, but also a shortage of capital to be invested in the ongoing project. This unexpected lack of funds will certainly lead to increased costs over and above the damage that might have been done to the infrastructure project itself. These costs may be explicit, through increased costs of project completion due to the disruption in a smooth flow of capital (requiring unexpected mothballing of the construction projects, relocation of construction materials, equipment, and personnel, as well as frictional hiring-and-firing costs and forced idling of capital equipment.)

These costs may also take the form of implicit, or opportunity, costs, simply through the inevitable delay in having the completed project come on-line, and therefore
pushing the onset of benefits from the completed project further into the future. In the special case of a durable investment (where, once paid for, the stream of benefits continues indefinitely) a one-year delay (for example, the completion of a school) amounts to losing one year's worth of service (for example, one full graduating class of students) forever.

While the government's diversion of funds to these humanitarian needs is certainly a justifiable need (and may, indeed, represent the best use of available funds given that a catastrophe has occurred) it exerts an unintended negative externality on project costs. Planning for the contingency that all available liquid funds will be diverted can thus reduce the total expected costs of project completion. By assuring a ready source of capital when needed, construction progress on the infrastructure project can continue, avoiding not only project disruption costs but also avoiding delays in the project coming on-line.

The external sponsor of the infrastructure project may also benefit from the creation of a source of liquid capital, to be accessed only in the case of catastrophe. The sponsor is frequently forced to renegotiate the terms of the loan under unfavorable conditions, with the diversion of the original loan principal a fait accompli. Additional loan capital is requested to finish the partially complete project, even though the social benefits (and, thus, the potential payback capabilities) from the completed project have not been increased. Although this unfavorable prospect (and the government's revealed history of unilateral renegotiation) would seem to discourage a lender from advancing more funds at the beginning of a project, the lender may feel compelled to invest additional funds in the middle stages of a project. Because, without additional funding, investments previously sunk into the project will amount to nothing -- and the original loan principal will need to be written off as unrecoverable -- the benefits from such previous investments are effectively “held hostage” to the funder's acquiescence to these terms. Commitment to project completion may improve lenders' long-term willingness to provide funds.

Pre-arranged sources of contingent capital, such as event-triggered cat bonds, can generate cash quickly and thereby capture the benefit of immediate liquidity. On-the-spot
post-catastrophe arrangements may take several weeks to accomplish, even for a creditworthy country, far away from its maximal debt constraint, using previously established contacts at investment banks (Eccles and Crane, 1988; Bhide, 1986). A financial device, such as a catastrophe-linked security, will thus reduce the costs of financial distress and thereby generate value to a sovereign government and external project sponsor to the extent it can

(a) eliminate the risk of project disruption due to damage to infrastructure projects in progress when emergency repair funds are not otherwise available, by supplying these emergency repair funds immediately upon damage to the project, and

(b) provide a ready source of immediate contingent capital for project completion when humanitarian aid requirements force diversion of all liquid resources including ongoing project funding, even when the project itself is not damaged.

**Enabling Commitment to Continued Project Funding**

A sovereign government desires to split its current expenditures between consumption (emergency humanitarian aid after a catastrophe) and investment (continued funding for projects in progress). Its obligations extend first to the welfare of its citizenry, and only secondarily to the continued success of its investment projects (even though the fruits of these projects will determine future welfare of future citizens.) Even though the optimal decision involves an intertemporal tradeoff balancing present humanitarian aid with future investment gains, there is always a strong temptation for the current government to overspend on present citizens. Resisting this temptation, although good for the country in the long term, may be politically infeasible (or undesirable) in the short term.

A government may therefore be able to improve its intertemporal capital management by investing in instruments which generate benefits that cannot be used for humanitarian aid, and which thereby commit the nation to continuing investment in
infrastructure projects – a classic example of benefiting by following rules rather than discretion (Kydland and Prescott, 1977).

This commitment benefit cannot be captured if the proceeds from catastrophe securities are paid in cash (which is, of course, fungible between investments in infrastructure and current consumption) to the government itself (which is the party caught in the invest/consume dilemma.) For the government to create and capture this commitment benefit, the proceeds must be either:

(a) paid in a “currency” which advances the infrastructure investment task but cannot be readily converted to cash (e.g., bulldozers, construction labor, etc.) and/or

(b) distributed not to the central government, but rather to a party which has no temptation to spend on immediate emergency aid at the expense of investment. Whether the most effective distribution mechanism is to disburse directly to local project managers, to the third-party sponsor, or a wholly disinterested party remains a topic for future research.

IV. Model of Expected Costs of Financial Distress

As we have discussed, a multitude of costs may be avoided, and social benefit realized, by avoiding project disruption due to financial distress -- whether through enabling defense of previously sunk costs against instantaneous depreciation due to the catastrophe, supporting cost-minimizing construction strategies, or accelerating the coming on-line of the new project. We now turn to a model of the size of these costs, and explicitly calculate values of these costs in a series of numerical examples.

We use a simple model to illustrate the magnitude of potential advantages from a sovereign cat bond or other form of state-contingent access to capital, such as a pre-arranged non-recourse line of credit. We further assume that all projects currently under way are worth continuing.\(^3\) We consider a sovereign acting as project manager for a

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\(^3\) If this condition is not currently satisfied in the portfolio of funded investments, a simple supplementary method to free capital would be to discontinue those projects for which incremental future costs exceed incremental future benefits. We assume that the infrastructure investment portfolio have already been so rationalized before the decision about cat-risk financing arises.
certain project with a deferred payoff $b$, which is to be realized only on successful project completion. For convenience we assume two periods of required investment before the benefit occurs.

**Project Cost Structure**

The necessary investments are $i_1$ at the beginning of the first period and $i_2$ at the beginning of the second. Both investments must be made to achieve the benefit $b$ at the end of period 2.

A catastrophic event causes damage to the project with probability $p$ in each period. If a disaster occurs, all progress made on the project to date will be completely lost, unless the project is “defended” by immediately carrying out an emergency repair. In the event of a disaster, the costs of emergency repair ($e_1$ and $e_2$ in periods 1 and 2 respectively) must be invested by the end of the period in which the disaster occurred. If the emergency repair investments are not made, the project returns to the original state, and must be rebegun at the beginning of the next period.

**Information Structure**

The magnitudes of $e_1$ and $e_2$ are known *ex ante*, as are other relevant parameters such as the net present value of the social benefit ($b$) which accrues to the country once the project is completed, the probability of a disaster ($p$) which is the same across all periods, and the discount rate ($r$). This is a single-decision-maker problem; the probability of disaster is assumed to be independent of any model parameters, financing arrangements, or construction strategies used by the project manager.

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This may, indeed, have led to a slight error in project selection by eliminating those projects which, in the absence of contingent capital availability, are not worth continuing, but for which the added presence of contingent capital makes worthwhile. As will be seen in our example, there will be situations when the attractiveness of the project depends critically on the availability of capital to see it through to completion.

Although we assume that disasters in period 1 and period 2 are independent, our model is easily adapted to account for serial correlation (either positive or negative) of disaster likelihood, allowing the capture of some interdependencies among events.

Each time the project is allowed to fail we assume it will indeed be begun again in the next period, as the project was initially attractive and has the same positive expected net present value at the point immediately following the disaster, independent of its history, as it did at the initial decision point.
Strategy Alternatives

The project manager chooses an investment strategy to maximize the (expected) net present value of the project opportunity. A strategy for this investment problem is thus characterized by the decisions concerning emergency repair in case of a disaster occurring in the different project stages. Assuming that no additional information can be derived during the process (e.g., on the disaster probability), and if there are no limitations to the availability of funds for emergency repair if needed, the decisions do not depend on the project history -- in particular, on whether a disaster has already occurred. There are then five strategies a project manager must choose from:

(R,R): Emergency repair will be done if a disaster occurs in the first period, the second period, or in both.

(F,R): Emergency repair will be done only in the second period; if a catastrophe occurs in the first period, the project will be allowed to fail and restart.

(R,F): Emergency repair will be carried out only in the first period; if a catastrophe occurs in the second period, the project will be allowed to fail and restart.

(F,F): No emergency repair will be carried out, regardless of timing; the project will be allowed to fail and restart after any catastrophe.

Of course the project manager also has the option of not investing at all (0) which will be chosen if the net present value of the result of the best strategy among [(R,R), (F,R), (R,F), and (F,F)] is negative.

Strategy Selection

The optimal strategy for the problem described above depends on whether it is attractive to pay for emergency repair in one or both project stages. Consider at first the situation without any capital constraints, which means that there is always enough capital available to defend the project after a disaster if doing so would form a part of the optimal solution at that stage. Under these circumstances the net present value of the project at the beginning \( NV_0 \), based on the optimal strategy for dealing with disasters, is

\[
NV_0 = \max(0; \delta^2 \cdot b - i_1 - \delta \cdot i_2 - \delta \cdot p \cdot c_1 - \delta^2 \cdot p \cdot c_2)
\]
where \( c_2 = \min(e_2, b - NV_0) \), \( c_1 = \min(e_1, \delta \cdot b - NV_0 - i_2 - \delta \cdot p \cdot c_2) \) and \( \delta = \frac{1}{1+r} \).

The net present values of the project opportunity under the four strategies described are

\[
NV_0^{R,R} = \delta^2 \cdot b - i_1 - \delta \cdot i_2 - \delta \cdot p \cdot e_1 - \delta^2 \cdot p \cdot e_2,
\]

\[
NV_0^{F,R} = \frac{1}{1-p \cdot \delta} \cdot \left[ \delta^2 \cdot (1-p) \cdot b - i_1 - \delta \cdot (1-p) \cdot i_2 - \delta^2 \cdot (1-p) \cdot p \cdot e_1 \right],
\]

\[
NV_0^{R,F} = \frac{1}{1-p \cdot \delta^2} \cdot \left[ \delta^2 \cdot (1-p) \cdot b - i_1 - \delta \cdot i_2 - \delta \cdot p \cdot e_1 \right],
\]

and \( NV_0^{F,F} = \frac{1}{1-p \cdot \delta - p \cdot \delta^2 + p^2 \cdot \delta^2} \cdot \left[ \delta^2 \cdot (1-p)^2 \cdot b - i_1 - \delta \cdot (1-p) \cdot i_2 \right]. \)

Consider the following numerical example:

Example 1: \( r = 0.1 \quad i_1 = 10 \quad i_2 = 10 \quad e_1 = 10 \quad e_2 = 15 \quad p = 0.1 \quad b = 40 \)

The net present values for the different strategies are shown in Figure 1:

**Figure 1: NPV of Investment Strategies**

\[
NV_0^{R,R} = 11.82 \quad NV_0^{F,R} = 11.5 \quad NV_0^{R,F} = 10.63 \quad NV_0^{F,F} = 10.3
\]

The best of these strategies would be \( NV_0^{R,R} \) -- to carry out emergency repair each time a disaster occurs -- which yields an initial NPV for the project opportunity of 11.82. Since \( NV_0^{R,R} \) is positive this strategy is preferred to the strategy (0), which yields a payoff of 0.

**Financial Distress**

Financial distress occurs when, during the investment process, a catastrophe occurs and a shortage of capital forces the sovereign to let the project fail in a case where emergency repair would otherwise be the preferred solution. Although financial distress does not occur in the absence of a catastrophic event, the potential for the costs of
financial distress must be included in the original calculation of the value of the project opportunity. The expected cost of financial distress (ECFD) can be measured as the reduction in the expected net present value of the project opportunity due to the constraint-induced switch of strategy.

We denote the funds available for emergency repair by \( f \). These funds represent, conceptually, the difference between the project manager’s initial capital endowment and the funds which would be earmarked for the construction of the project (i.e., \( i_1 \) and \( i_2 \)) if no catastrophes were to occur. Formally,

\[
ECFD = NV^\infty_0 - NV^f_0,
\]

where \( NV^\infty_0 \) represents the value of the project opportunity if an infinite amount of capital were available for emergency repair, and \( NV^f_0 \) represents the value of the project opportunity given that only \( f \) units of capital are available for emergency repair, and thus that strategies which might require amounts greater than \( f \) are infeasible.

Noncontingent Repair Strategies

Consider, as an illustrative example, the extreme case of no capital being available for emergency repair (i.e., \( f = 0 \)) in a situation when \((R,R)\) would be the best strategy given unlimited capital. Here the only feasible strategies are \((0)\) and \((F,F)\). Thus the expected cost of financial distress can easily be quantified as the lesser of the entire project value (that is, the difference between \( NV^{R,R}_0 \) and 0) or the difference between \( NV^{R,R}_0 \) and \( NV^{F,F}_0 \). This cost of financial distress is always positive, assuming that the emergency repair cost is not prohibitively high and that the project is attractive to begin in the first place.

Using the numbers introduced as Example 1 and under the assumption \( f = 0 \), the best feasible strategy (i.e., the best strategy which does not require the availability of any emergency-repair capital) is \((F,F)\). So the expected cost of financial distress is

\[
ECFD = NV^{R,R}_0 - NV^{F,F}_0 = 1.52
\]
for the parameters in Example 1.
Contingent Repair Strategies

In order to calculate the cost of financial distress for the general case we first must introduce one additional possible strategy, which allows the decision of whether to repair in the second period to depend on the outcome of the first period:

(R, \tilde{R}) Emergency repair will be carried out in the first period if necessary; in case of a catastrophe in the second period, the project will be defended only if there were no disaster in the first period.

Of course this strategy cannot be more favorable than the ones mentioned above in the case of no capital restrictions (being inferior to either (R,R) or (R,F)), but it might be a constrained-optimal (second-best) solution if the project manager has just enough capital to carry out emergency repair one time, but not twice. The expected net present value under (R, \tilde{R}) is

\[ NV_{0}^{R,\tilde{R}} = \frac{1}{1 - p^2 \cdot \delta^2} \cdot \left[ \delta^2 \cdot (1 - p^3) \cdot (1 - \delta) \cdot l - \delta \cdot p \cdot e_1 - \delta^2 \cdot (1 - p) \cdot p \cdot e_2 \right]. \]

As can be easily verified, (R, \tilde{R}) turns out to be the constrained-optimal strategy for Example 1 in all cases where \( 15 \leq f < 20 \). (In particular, if \( f = 15 \), (R, \tilde{R}) is the best strategy that does not ever require more than 15 units of capital.) It yields an NPV of \( NV_{0}^{R,\tilde{R}} = 11.71 \) and a substantially lower cost of financial distress (ECFD = 0.11) in comparison to the \( f = 0 \) case.

From this simple example, we can make two observations:

1. The optimal strategy of whether to defend the project in period 1, 2, or both depends on the amount of capital available. Also, the decision of whether to begin the project at all depends, via the choice of strategy, on the amount of capital anticipated to be available to conduct emergency repairs.

2. The costs of financial distress can be greatly reduced (by 93% in our example) by holding enough capital in reserve to accommodate one disaster. For events which become catastrophic only when they occur in series, this is a powerful strategy. The reduction in ECFD for insuring against the second disaster in
the series (in our example, 0.11) is modest compared to the benefit from
insuring against the first disaster (in our example, 1.41).

We will now use a series of comparative static analyses to show the effects of
varying important parameters.

*ECFD as a Function of Initial Capital*

At first, we consider how the expected cost of financial distress depends on the
amount of capital available for emergency repair. Based on the parameters given in
Example 2, Figure 2 shows the relationship between the value of EFCand \( f \), the initial
capital available.

*Example 2*: \( r = 0.1 \quad i_1 = 10 \quad i_2 = 10 \quad e_1 = 10 \quad e_2 = 15 \quad p = 0.1 \quad b = 40 \)

*Figure 2. ECFD and Initial Capital*

Note that, in accordance with intuition, the expected cost of financial distress is
very high for the case of \( f = 0 \) (no capital being available for emergency repair).
other extreme, because the best strategy is \((R,R)\) in our example, the ECFD equals 0 only when the initial capital suffices for repairs in both periods.

In this example, the emergency repair cost in the second period is higher than in the first. In the case of amounts of available capital that allow defending the project only in the first period but not in the second, the best feasible strategy becomes \((R,F)\) and the EFCD drops slightly from its highest level. The most dramatic reduction of EFCD can be obtained by enabling the project manager to repair in either the first or the second period, but not both -- equivalent to having capital available to assuage one catastrophe but not two. This leads to the strategy \((R,R)\) being optimal, which results in a different outcome from \((R,R)\) only if catastrophes occur in both periods.

We thus note that the strategy \((R, R)\), in conjunction with a limited amount of emergency capital reserves, can thus accomplish a significant portion of the benefit of the strategy \((R,R)\) with an unlimited capital reserve. Note that this limited emergency capital reserve might be provided through a contingent financing instrument such as a cat bond, rather than representing idle funds held in inventory against catastrophe. A cat bond designed to eliminate most of the costs of financial distress, while limiting the total amount of investor capital at risk to that of a single disaster, ought to be constructed to pay for the first disaster which occurs, regardless of whether this disaster occurs in period 1 or period 2. A cat bond which pays for the second disaster which occurs will be tapped much less often, but will also create much less reduction in ECFD.

**Sensitivity of ECFD to Time Structure of Required Investment**

We now consider how the expected cost of financial distress depends on the speed with which capital is committed to the project -- i.e., for a given project cost, what percentage of this cost must be committed during the first period, and how much may be deferred until the second.\(^6\) Based on the parameters given in Example 3, Figure 3 shows the relationship between the value of EFCD and this time structure of required investment.

\(^6\) Note that, in Example 3, \(i_1 + i_2 = 20\) in all cases; only the balance between \(i_1\) and \(i_2\) will be changed.
Example 3: \[ f = 0 \quad r = 0.1 \quad i_1 + i_2 = 20 \quad e_1 = 10 \quad e_2 = 15 \quad p = 0.1 \quad b = 40 \]

Figure 3. ECFD vs. Time Structure of Required Investment

From Figure 3, we see that ECFD rises with the percentage of the total construction costs which must be committed during the first period. The dependency is piecewise linear, as can be seen directly from the equations governing ECFD. For a low percentage of first-period investment commitment, the project manager would tend to choose to let the project fail (and restart) if a disaster were to occur in Period 1, even if unlimited repair capital were available. The larger this fraction of first-period commitment, the more attractive is the strategy \((R,R)\). The kink in the curve marks the switch from \((F,R)\) to \((R,R)\) as the best unconstrained strategy.

**Sensitivity of ECFD to the Cost of Capital**

We now consider how the expected cost of financial distress depends on the cost of capital. The same cost of capital, \(r\), is assumed to apply both for the pure rate of discounting project benefits (effectively, the opportunity cost of not having a project's
benefits sooner) and for the implied rate of return paid on borrowed funds (effectively, the explicit cash outflow for interest payments). It should be noted that we assumed that \( r \) is relatively high for sovereign project managers in emerging countries, either based on high time value of incremental infrastructure investments or based on high borrowing costs in the financial markets. Based on the parameters given in Example 4, Figure 4 shows the relationship between the value of ECFD and this cost of capital.

\[ \begin{align*} f &= 0 \\ i_1 &= 10 \\ i_2 &= 10 \\ e_1 &= 10 \\ e_2 &= 15 \\ p &= 0.1 \\ b &= 40 \end{align*} \]

**Figure 4. ECFD vs. Cost of Capital**

For the important region, the ECFD behaves like a function concave in the cost of capital and, in addition, does not react in a highly sensitive manner to small changes in the cost of capital. It should be mentioned that ECFD first increases and then decreases, reaching a local max at approximately 0.25 in Example 4. In this example \((R,R)\) is always the unconstrained best strategy and \((F,F)\) is the best capital-constrained strategy as long as these strategies both have positive NPVs. The first kink of the curve is linked to the switch of the constrained best strategy from \((F,F)\) to \((0)\); this occurs when the cost...
of capital becomes so high that the project is no longer attractive to begin (i.e., has a negative NPV.) Once (0) becomes the best alternative strategy to (R,R), the ECFD decreases rapidly in the cost of capital -- not because the problem of contingent capital is solved (because \( f = 0 \), no repairs can be made in any event), but simply because the attractiveness of the project falls rapidly in \( r \) but the constrained best outcome does not decrease any further.

An interesting extension to the model would be to incorporate the costs of borrowing the optimal amount of capital at the beginning of Period 1, with the goal of maximizing the overall expected benefit from the project including these capital costs. This optimal amount of capital to borrow would depend on the cost of capital both directly and indirectly. The direct effect of the cost of capital on the optimal amount to borrow comes about because interest payments would need to be made (and, implicitly, made from available cash) whether a disaster would occur or not -- an expensive proposition when disasters are rare. The indirect effect occurs through the ECFD, which itself depends on the cost of capital as shown in Figure 4. The sensitivity analysis of the ECFD to the cost of capital when the optimal amount of capital were borrowed for each value of \( r \) would differ significantly from our analysis in Figure 4, which assumes that a fixed amount (here, 0) is borrowed regardless of \( r \).

Sensitivity of ECFD to the Probability of Disaster

We now consider how the expected cost of financial distress depends on the probability of a disaster occurring in any given period. The severity of the disaster is assumed to stay constant, although its probability changes. Based on the parameters given in Example 5, Figure 5 shows the relationship between the value of EFCD and this probability that a disaster occurs.
Example 5: $f = 0 \quad r = 0.1 \quad i_1 = 10 \quad i_2 = 10 \quad e_1 = 10 \quad e_2 = 15 \quad b = 40$

**Figure 5. ECFD vs. Probability of Disaster**

![ECFD vs. Probability of Disaster](image)

In the left-hand portion of the curve, the net value of the constrained best strategy [(F,F) in this example] falls much more quickly than that of the unconstrained best strategy (R,R). Defending the project, especially in the second period, becomes more beneficial as $p$ increases. One major difference between (R,R) and (F,F) as strategies is that (R,R) guarantees that the project will come on-line at the end of period 2, at which time the benefit $b$ will be realized for certain (albeit at a random cost.) As $p$ increases, the expected length of time until the project is completed increases under the (F,F) strategy. In addition, defending the project in Period 2 is particularly valuable as $p$ increases, because a completed project does not need to “run the gauntlet” of two periods of relatively frequent risks.

The kink in the curve (at around $p = 0.3$ in our example) is due to the switch from (F,F) to (0) as the optimal capital-constrained strategy. For large enough values of $p$, the project will never be begun (i.e., will have negative NPV) if no emergency capital is
available. In this case, the cost of financial distress (i.e., the opportunity cost of not having enough capital to defend the project, and therefore not enough to make beginning the project worthwhile) will thus be the same as the full project value under the unconstrained best strategy (R,R). This project value, in turn, decreases in \( p \) because the expected project completion cost is increasing (incorporating the expected costs of emergency repair) while its benefit remains constant. After a certain critical level (approximately 0.63 in our example) the likelihood of disaster is so large, and the expected damages before project completion so great, that the project manager is dissuaded from beginning the project even if an infinite amount of capital is available for emergency repairs.

Example 6: \( f = 0 \quad r = 0.1 \quad i_1 = 10 \quad i_2 = 10 \quad p \cdot e_1 = 1 \quad p \cdot e_2 = 1.5 \quad b = 40 \)

**Figure 6. ECFD vs. Probability of Disaster, (Expected Loss Held Constant)**

![ECFD vs. Probability of Disaster (Expected Loss Held Constant)](image)

For the numbers from Example 6, Figure 6 shows that expected costs of financial distress caused by project disruption are higher for more frequent, less severe events than for infrequent but very severe events. If funding to repair a project is not going to be
available in any event, it does not matter whether the disaster causes a $100,000 loss that cannot be repaired or a $1 million loss that cannot be repaired. The frequency of the loss, however, increases either the expected costs of project completion (if these small losses are to be repaired) or the expected length of time until this completion occurs (when these small losses cause the project to be restarted).

V. Summary of Benefits from Project Risk Management

At the level of the sovereign government or the third-party sponsor, the reduction in ECFD will create three types of benefits that will contribute to an increased number of projects which can be accomplished on a given capital budget. For example, consider a capital budget of $15 billion, $12 billion of which is to be committed to new capital projects and $3 billion to be kept in reserve for emergencies.

Firstly, at the simplest level, a reduction in expected completion costs of a representative project from $120 million to $100 million allows 120 such projects to be funded rather than 100. Alternately, we may be able to use this incremental savings of $200 million to fund some projects less attractive than the initial 100, which otherwise would not be in a priority position to receive capital.

Secondly, reducing the variance of the capital requirements of individual projects enables the government or third-party project sponsor to more efficiently commit its limited capital. The general structure of this financial optimization problem is as follows. Normally, the government or sponsor would commit less than 100% of its available capital, withholding a portion to deal with extraordinary and unexpected funding requirements such as those caused by natural disasters (whether directly by damage to the ongoing infrastructure project, or indirectly due to unilateral diversion of project funds to humanitarian efforts). The optimal percentage of capital to reserve for these emergencies balances the costs of overcommitting (using almost 100% of capital available at all times, maintaining only a small reserve for contingent funding, and thereby running the risk of inadvertently causing project disruption when several portfolio projects require extraordinary infusions of cash at the same time) against the costs of undercommitting
(allowing capital to lie fallow, which could otherwise be directed towards socially beneficial projects).

By increasing the predictability of required project financing, even if the expected amount of project funding remained unchanged, this utilization percentage could be increased without taking on additional risk of overcommitment -- an increase in capital efficiency which comes at no one's expense. So, for example, our effective $12 billion of infrastructure budget might grow to $14 billion of committable capital (with $1 billion left in reserve, rather than $3 billion). This effect combines with the reduction in project cost to enable 140 projects at the new lower cost and lower variance (again compared to 100 projects at the higher cost and higher variance).

Finally, the 40% increase in efficiency (in terms of projects completed per dollar invested) may well attract additional capital into such project financing -- a demand effect. If the original $15 billion total allocation for capital projects were to grow to $20 billion because of this increased efficiency, we could accomplish 200 representative projects vs. the baseline of 100 -- a 100% increase in effective infrastructure projects, without increasing the risk to the investors, based on only a 33% increase in capital.

VI. Model Extensions and Topics for Future Research

We have addressed the question, "Why might the sovereign government of an emerging nation be interested in employing catastrophe-linked instruments to protect infrastructure investments, funded by a third party, from low-probability, high-consequence events such as natural catastrophes?" We conclude by presenting some additional topics -- requiring analysis beyond the scope of this paper -- related to the questions of how the government might use these bonds, how the instruments might be designed, and to what extent the market for such securities interacts with information conditions and government policy.

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7 If we consider investment in infrastructure projects as a good to be consumed, this necessary condition for the sponsor to increase the total amount of capital committed as the price of project completion falls is that the demand for projects to sponsor exceeds unity -- i.e., that \( \text{abs}(\varepsilon) > 1 \). If the third-party sponsor is indeed the monopoly supplier of sponsorship, that this condition will always be satisfied follows directly from the first-order condition of optimal quantity (choosing quantity in the elastic portion of the demand curve.)
Challenges and Limitations Specific to Sovereign Cat Bonds

There are many challenges to implementing catastrophe-linked securities; these challenges have been discussed elsewhere. We consider only one, a unique issue for a sovereign government possessing widely dispersed infrastructure assets.

When considering only infrastructure projects, the sovereign government is the monopoly provider of these projects, and the monopoly buyer of cat risk protection. No other party (except, perhaps, for a third party sponsor such as the World Bank) has an obvious insurable interest in these projects. The government can thus be thought of as having 100% market share in insuring its infrastructure, even though this infrastructure may be spread out over a very large geographic region. On the one hand, this 100% market share would seem to offer an opportunity to design a country-wide cat bond with low basis risk, as catastrophe-related damage to the entire country would correlate well with catastrophe-linked damage to countrywide projects. A portfolio of similar projects (such as a highway system) spread evenly nationwide could thus be protected by a country-level index instrument. Some countries incorporate such extremely large and diverse geographic scope (e.g., China) that it may be difficult to define appropriate triggers for such catastrophe-related instruments on a national scale -- paradoxically, the infrastructure projects are not widespread enough for national coverage to be a good proxy for project coverage.

Ideally, however, instruments to protect specific infrastructure investments would be designed project-by-project, to incorporate customization both at the geographic level (insuring against the appropriate hazards) and at the project level (generating the appropriate cash flows for reconstruction). This project-by-project design is relatively simple to do for a project of limited geographical area (such as a dam or a nuclear power plant) but very difficult to do for an infrastructure asset which, by its very nature, is geographically dispersed (such as a fiber-optic network or a highway system.)

Such projects may be too widespread for customized project coverage, yet not widespread enough for country-level coverage. It is not clear how the divergence between common ownership and geographical dispersion can be resolved. On the one hand, geographical dispersion of a highway system prevents the asset from being totally
destroyed by a local phenomenon (such as a flood or earthquake), a form of built-in diversification and resistance to catastrophic damages from geographically concentrated risks. On the other hand, this same geographical dispersion makes it a challenge to design an instrument to protect the asset without introducing massive basis risk.

**Leveraging Investment in Project Monitoring**

The structure of the project funding arrangement may offer additional opportunities to support catastrophe risk transfer. Infrastructure projects in emerging economies generally involve a third-party sponsor, such as the World Bank, who provides capital and investment advice to the sovereign government, and who may have a supervisory presence during project completion, but who does not generally control the day-to-day management of the project. Investors in project-tied cat-risk securities can rely on the project sponsor to provide at least partial monitoring — especially on large-scale infrastructure projects in emerging economies, for which the sponsor may well have an advisory team on-site during critical portions of the project. This structure allows for the investors in the catastrophe-linked instrument to take advantage of the "delegated monitoring" provided by the project sponsor (Diamond, 1984), reducing investors' costs of providing financing for these risks. Indeed, investments facing severe risks will likely draw more sponsor attention and financial commitment, rather than less [a situation analogous to that examined by Calem and Rizzo (1992) in the private sector]. The project sponsor may thus serve an informational role in project management, as well as a financial role.

If investors can rely on the third-party sponsor for documentation of damage done to the project, recommendations for cost-minimizing ways to conduct emergency repairs, and similar reports — even in the event that a disaster occurs — this monitoring will presumably reduce the extent of moral hazard. Of course, to ensure that the amount of monitoring performed (and the focus of the information gathered) will be optimal, considering the interests both of the sponsor and the investors, requires that the sponsor of the project either be the investor in the catastrophe bonds or have some sort of high-powered incentives as part of a contractual agreement to act in a way consistent with being the investors' agent. Even if this alignment of incentives is only partially achieved,
however, some reduction in moral hazard should ensue. Given that the barrier against constructing perfect hedges against catastrophe involves a tradeoff of moral hazard vs. basis risk (Doherty, 1997a; 1997b) this reduction in moral hazard, in turn, allows the catastrophe-linked instruments to be constructed which behave more like excess-of-loss reinsurance and therefore reduce basis risk.\(^8\) This moral hazard may already be contained by the sponsor's monitoring; quantifying this reduction, and communicating it to investors, will reduce the cost of catastrophic risk coverage provided by financial markets.

**Interaction of Project Financing and Moral Hazard**

One reason why catastrophe-linked securities hold such promise is that, unlike other insurance markets such as health or automobile coverage, the probability with which disasters occurs, and the severity of the disaster measured purely in terms of natural forces (e.g., windspeed, flood height of a river, earthquake magnitude, etc.) cannot be affected (for good or for ill) by any actions of the government, its citizens, or any party interested in the payoff of the catastrophe-linked securities. The *damages* caused by a disaster of arbitrary magnitude may be increased, however, because of the effects of moral hazard (either through lack of effective mitigation investments before a disaster occurs, or error-prone claims adjustment techniques and lack of attention to cost-minimizing repair techniques after a disaster occurs.) Determining how the costs of these *ex post* opportunities for moral hazard can be contained is an interesting subject for further research and simulation.

**Comparing Sovereign and Private Corporate Capital Structures**

The sovereign position of the project sponsor for infrastructure projects has both benefits and drawbacks. In addition to the politically-motivated commitment problem noted above, sovereign governments operate under capital constraints that private

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\(^8\) The optimal design of this security will thus need to trade off efficient incentives for investment in mitigation (arguing for a state-contingent payoff, statistically correlated to but causally independent of the actual losses to the project) versus incentives for accurate reporting of damages done to the project (arguing for an excess-of-loss payoff structure, which can reduce basis risk if payments are conditioned on truthfully-reported actual losses.)
companies do not. A corporation can finance its operations, investments, and expansions through issuing equity, issuing debt, or retaining earnings from operations. Sovereign governments cannot issue equity and typically do not retain earnings – their financing is, by necessity, primarily debt. They therefore, all else equal, will have less flexibility in (and, presumably, higher costs of) financing than would an otherwise similar large corporation who had the choice to issue either debt or equity. A government’s cost of capital will also rise faster than an equivalent company’s in case of losses that would lead to insolvency (default on traditional sovereign debt) because an emergency equity recapitalization is not possible. Incorporating catastrophe-linked securities into the expansion path that a government desiring economic growth might pursue will require additional analysis, to integrate the risk-hedging abilities of the cat-risk securities with the lower (but still significant, for emerging economies) costs of traditional sovereign debt.

**Optimal Construction Technique -- Embedding Efficient Levels of Flexibility**

The correct method of organizing projects -- in terms of materials used, completion schedules, and tradeoffs among amounts of capital, labor, energy, and materials to be committed to the project -- will also depend on how project risk is to be handled. Catastrophe-linked instruments expand the choice set for how project managers can handle such future risks. As we have seen, risk management techniques which eliminate costs of financial distress can lead to reductions in expected completion costs. The main alternative to contingent capital availability for creating resilience to unforeseen project risks is embedded real options. Even optimally-organized projects suffering from capital-availability risk may incorporate such real options as a hedge, which increase production costs in high-probability scenarios to reduce production costs in disaster scenarios (e.g., Dixit and Pindyck, 1994). Inasmuch as such real options are costly to embed in the project, there may be gains through changing the organization of projects, if risk can be hedged using financial instruments, through substituting external sources of capital for the most costly of these embedded real options.⁹

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⁹ Of course, if these embedded options reduce the expected costs, even absent their benefits of reducing uncertainty and the cost-increasing effects of uncertainty, they should be left in -- even if contingent capital is also used to further reduce costs.
Either imbedded options or contingent capital may produce reduced total expected cost of completion, as argued in Simon (1996). Cat bonds will reduce total cost when these real options are expensive to embed, and where their removal or omission will reduce project completion costs when the cat bonds assume their risk-bearing function.

*Interactions between Catastrophe and Fiscal Policy*

A natural catastrophe leads to an instantaneous depreciation of a nation’s capital stock. The optimal speed of replacing this stock depends on many macroeconomic variables. Questions for macroeconomic theory analysis include “Is there any difference, in terms of fiscal stimulus, between a macroeconomic shock caused by disaster vs. the traditional multiplier on government spending?” and “How should government fiscal policy be adjusted both immediately after the disaster, in terms of trading off present consumption and future investment (especially the optimal speed of rebuilding the destroyed capital)?”

*Hidden Benefits of Catastrophe through Forced Modernization*

In this paper, we have focused on completing projects in process, rather than protecting existing capital in place. Not all capital in place, however, is created equal. Some capital in place is particularly productive, and carries high opportunity costs of destruction; some is obsolete. What completed projects may incorporate an implicit advantage of having obsolete capital destroyed and replaced with newer vintage capital, funded by cat bond payments? What implications follow for evaluating various types of infrastructure assets’ economic vulnerability to disaster? In particular, which completed-project assets should be so insured, and at what level of coverage? To what extent are there additional benefits from using a state-contingent risk transfer instrument to protect such complete-project assets by providing one large reimbursement at the national level, rather than purchasing traditional “replacement cost” coverage for each asset individually? These questions can be addressed through a model similar to ours, emphasizing the true opportunity cost of foregone project benefits rather than the “book value” of completed projects.
References


