Simulating Macroeconomic Impacts of Natural Catastrophic Shocks with the World Bank's "RMSM" (Revised Minimum Standard Model)

Landis MacKellar (mckellar@iiasa.ac.at)
Tania Ermolieva (ermol@iiasa.ac.at)
Paul Freeman (freeman@iiasa.ac.at)

International Institute for Applied Systems Analysis
Laxenburg, Austria

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Abstract

Economic losses from natural catastrophic events (mainly floods, windstorms and earthquakes) are a heavy burden on developing countries. In a previous paper, the authors examined impacts of natural catastrophic losses on economic growth using a growth model based on a Cobb-Douglas production function. We posed the problem "What is the opportunity cost, in terms of foregone GDP growth, of damage to the capital stock caused by natural catastrophes?" In this paper, we examine the inverse of this problem: "Given a planned GDP growth path, what additional investment resources must be mobilized in view of the fact that the capital stock is periodically reduced by natural catastrophic losses?" The country considered is Argentina, and the simulation is implemented using the World Bank's Revised Minimum Standard Model (RMSM). The paper concludes with directions for future research.

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Background

Rising natural catastrophic losses are emerging as an economic issue. Comparing the 1990s to the 1960s**,** the number of catastrophes has increased five-fold, and the damages have increased by a factor of nine (Munich Re 1999). Some of this increase is due to changes in population distribution (more people living in flood-prone regions, for example) and the rising value of infrastructure in harm's way. Evidence is emerging, however, which links windstorms and floods (each accounting for about one-third of total catastrophic damages) to changes in global climate. Warmer surface and ocean temperature results in increased moisture absorption in the atmosphere, and increased moisture absorption leads, in turn, to increased precipitation in the form of floods and windstorm events. Therefore, the worsening catastrophic loss trends of recent decades may be a harbinger of more serious problems to come.

Costs of windstorm are borne primarily by countries in the developed world, costs of flooding by countries in the developing world, and costs of earthquakes are evenly divided between the two regions. In the end, each region bears approximately US$ 35 billion per year in direct costs of natural catastrophes. However, inter-year variation in both the total level of losses and their regional distribution can be large. Of total worldwide economic losses of US$ 65 billion in 1998, close to half were related to a single event in the developing world -- flooding of the Yangtze River. When Hurricane Mitch (the second largest catastrophic event of the year) is figured in, two-thirds of global losses were in the developing world (Swiss Re, 1999). While the interregional distribution is variable, one thing is not: based on income disparities, the per capita burden of catastrophic losses is dramatically higher in developing countries.

Natural catastrophic losses significantly impair development programs by absorbing domestic savings and eroding international development assistance. For example, the Asian Development Bank has estimated that between 1988-98, 5.6% of ADF loans were for disaster rehabilitation. In 1992, nearly 20% of the ADF loans were for rehabilitation assistance related to natural disasters (Arriens and Benson 1999). The World Bank has estimated that in Mexico up to 35% of its lending earmarked for infrastructure during the past decade has been diverted to pay for the costs of Mexican natural catastrophes. Access to public infrastructure comprises a large component of the wealth of the poorest households and rural infrastructure projects (roads, irrigation, and electrification) have been found to be highly effective in reducing poverty (World Bank 1994). Thus, programs and policies to minimize natural catastrophic losses, to improve public and private responses, and to institute appropriate risk transfer mechanisms will have a high anti-poverty impact.

The first step in designing such measures is estimating economic costs of natural catastrophic losses at the national level.

Estimating macroeconomic costs of natural catastrophes

For mot countries in the world, there exist time series data on direct damages caused by natural catastrophes. Typically these data refer to the value of capital (mostly infrastructure and residential structures) damaged. However, surprisingly little work has been

done on translating these data into estimates of total direct and indirect economic costs.[1] We have, in a previous paper (MacKellar *et al.* 1999) posed the problem "What is the opportunity cost, in terms of foregone GDP growth, of damage to the capital stock caused by natural catastrophes?" In this paper, we examine the inverse of this problem: "Given a planned GDP growth path, what additional investment resources must be mobilized in view of the fact that the capital stock is periodically reduced by natural catastrophic losses?" The country considered in this exploratory analysis is Argentina.

We rely on RMSM ("Revised Minimum Standard Model"), a World Bank economic / financial programming model which emphasizes sources-uses accounting consistency. RMSM solutions are driven by calculation of the investment resources necessary to meet a specified GDP growth target. Letting *Y(t)* be real GDP in year t, *ICOR(t)* be the incremental capital-output ratio in year t, and *I(t)* be investment expenditure in year t, the core equation of the model is

$$I(t) = ICOR(t+1)\left[Y(t+1) - Y(t)\right]$$

Having calculated total investment requirements, the task is to find the implied real and financial resources. For the first of these, the model relies on the GDP accounting identity

$$Y(t) = C(t) + I(t) + G(t) + E(t) - M(t)$$

Rearranging and expressing *I(t)* in a way which makes explicit its dependence on the assumed rate of GDP growth and the assumed ICOR, we have the following expression for required investment expenditure:

$$I\left[ICOR(t+1), Y(t+1) - Y(t)\right] = Y(t) - C(t) - G(t) - \left[E(t) - M(t)\right]$$

With *Y(t)* predetermined, *C(t)*, *G(t)* and the "resource balance" *E(t)-M(t)* must be consistent with investment requirements. *E(t)* is essentially exogenous in the model, being driven by international demand and the assumed elasticity of exports with respect to an exogenous real exchange rate. *M(t)* is a function of assumed elasticities with respect to GDP (in the case of capital goods, investment expenditure) and the real exchange rate. Therefore, if investment requirements are high (targeted growth is rapid or the ICOR is large) then the required resources can be mobilized only by reducing public or private consumption, i.e., increasing domestic savings. If one is fixed, the other must follow. This is the essence of RMSM.

[1] An exception is Benson (1997), who surveys a wide range of impacts but does not attempt a comprehensive quantitative estimate.

RMSM and catastrophe modeling

How does this lend itself to modeling macroeconomic impacts of natural catastrophes? The key lies in the concept of "replacement investment." The impact of a downward shock to the capital stock (which we assume to be spread uniformly across all capital) is to raise investment expenditure required to attain targeted GDP growth because some of the expenditure is absorbed by replacing destroyed capital. Like the Red Queen in *Through the Looking Glass*, the economy must run harder just to stay in the same place. Or, in a different interpretation, ICOR is a measure of the efficiency of investment expenditure and natural catastrophes reduce that efficiency.

Let *Cat(t)* be catastrophic damages in year t, calculated as

$$Cat(t) = [1 - Mult(t)]\, K(t) = [1 - Mult(t)]\, k(t)\, Y(t)$$

where $0 \le Mult(t) \le 1$ is a stochastic multiplier (for example, *Mult(t)* = 0.98 implies that 2 percent of the capital stock is destroyed in Year t) and *k(t)* is the capital-output ratio. In the long run, *k(t)* depends on ICOR; in the short run, it is relatively fixed. Making the simplifying assumption that replacement of damaged capital takes in the same year the damage is incurred, the replacement investment necessary in year t is given by *Cat(t)*. Expressing this relative to the change in output, we have

$$\frac{Cat(t)}{Y(t+1) - Y(t)} = \frac{[1 - Mult(t)]\, k(t)\, Y(t)}{g(t,t+1)\ Y(t)} = \frac{[1 - Mult(t)]\, k(t)}{g(t,t+1)}$$

where *g(t,t+1)* is the (exogenous) rate of GDP growth between t and t+1.

In conclusion, we can calculate an adjusted ICOR, where the stochastic adjustment term factors in the efficiency loss caused by catastrophic damages:

$$ICOR'(t+1) = ICOR(t+1) + \frac{[1 - Mult(t)]\, k(t)}{g(t,t+1)}$$

Assuming $Mult(t) \prec 1$, $ICOR'(t+1) \succ ICOR(t+1)$, in other words, achieving a given growth target requires additional resources.

Alternative model closures and the role of foreign savings

RMSM can be solved in two basic model closures.[2] Depending on which closure is used, the distribution of impacts of the catastrophic shock among agents in the economy will be different. The relevant question is "When capital is damaged by natural catastrophe, which variable must adjust to meet the investment expenditure requirement determined by ICOR and the assumed rate of GDP growth?"

Public Closure. In Public Closure, private investment is set exogenously as a proportion of GDP and private consumption is set exogenously as a proportion of private disposable income (essentially, GDP minus taxes). The resource balance $E(t)-M(t)$ is dictated by assumptions on GDP growth, the real exchange rate, and the assumed elasticities of imports and exports. Therefore, the variable calculated as a residual is public consumption expenditure $G(t)$. When ICOR rises to take replacement investment into account, $G(t)$ is reduced to free up the required resources.

Private Closure. In Private Closure, government consumption and government investment are set exogenously as proportions of GDP and, again, the resource balance is predetermined. Private investment is calculated as required total investment minus government investment and the residual variable in the national income identity is private consumption, $C(t)$. When ICOR is adjusted upward to reflect replacement investment, $C(t)$ is reduced.

Hybrid closures and the role of prices. It is probably unrealistic to assume that the entire brunt of adjustment to a natural catastrophe falls either on public or private consumption, and that there are no degrees of freedom for allocating adjustment between the two, or for substituting foreign for domestic savings by running a lower trade surplus.

One possible modification is to start from Public Closure, but to raise taxes and offset the required reduction in government consumption expenditure. The result is lower private consumption as higher taxes reduce disposable income. In this way, the adjustment burden can be shared out between public and private consumption. Another approach is to start from Private Closure but adjust government consumption down in order to reduce the required compression of private consumption. A third possible modification is to adjust upward the assumed elasticities of imports with respect to GDP and investment expenditure. Instead of foregoing consumption of domestic product in order to mobilize resources for replacement investment, resources are imported from abroad, at the expense of added foreign debt.

Finally, we have dealt entirely with the real side of the economy, whereas in reality, it is likely that many responses to catastrophic losses (especially large ones) are mediated through relative prices. However, the purpose of price shifts in this context is to mobilize real resources, so the type of analysis we are presenting here is still relevant.

Example 1: a large deterministic shock

In this section, we work through the example of a very large deterministic shock under the Private Closure. The country studied is Argentina, and we work with the baseline RMSM solution provided by the World Bank's Buenos Aires office. The base year is 1998, the simulation period is 1999-2005, and we apply the shock, amounting to the destruction of 1

[2] A third standard closure, the Policy Closure, endogenizes GDP growth, as a result of which we do not consider it here.

percent of the capital stock, in 2000. Assuming a capital-output ratio of 3, the adjusted ICOR for 2001 is

$$ICOR'(2001) = ICOR(2001) + 0.5\left[\frac{(0.99)\,(3.0)}{g(2000,2001)}\right]$$

In Tables 1-5, we work through some of the adjustments described above. Table 1, the baseline case, shows the case in which there is no catastrophic loss. Table 2, labeled "no offset," displays results when the capital stock is shocked downward by 1 percent in 2000 and there is no compensating adjustment of either government consumption or imports. The impact of the catastrophe is to raise the ICOR, 5.0 in the baseline scenario, to 5.64 for the year 2001.[3] The required replacement investment expenditure is calculated to be 10,388 million Local Currency Units (LCU) or 12.8 percent of baseline investment expenditure. Under the Private Closure, the resources necessary for replacement investment will come entirely from the compression of private consumption, which is reduced (on a baseline *versus* alternative basis during 2000) by LCU 9,317 million or 3.5 percent.

Why is the reduction in private consumption not identically equal to the required increment to investment? The difference arises because the elasticity of capital-goods imports with respect to gross domestic investment (GDI), assumed to be 1.6, is higher than the elasticity of other types of imports with respect to GDP, assumed to be 1.0. When investment increases as a share of GDP, so do imports. The resulting decline in the resource balance, which occurs entirely on the import side, is LCU 1,070 million (corresponding to imports which are 2.9 percent higher in the alternative scenario than in the baseline) during 2000. The positive increment to imports plus the absolute value of the negative increment to private consumption is (up to rounding error) the LCU 10,388 million necessary to replace damaged infrastructure.

The impact on foreign indebtedness is modest but significant, with foreign debt rising by 0.4 percent of GDP in 2000 (36.5 percent as against 36.1 percent in the baseline) and then gradually returning to its baseline level. Over the five year period 2000-2005, average total debt service (interest payments plus amortization) is higher by 0.4 percent of export revenues.

In Table 3, labeled "government consumption offset," it is assumed that government consumption is reduced by 25 percent of the direct damages to the capital stock. Because import demand is unaffected by the public-private consumption split, the only impact of this offset is to spread the adjustment costs of replacement investment more evenly between public and private consumption.

In Table 4, labeled "import offset", it is assumed that imports of capital goods associated with replacement investment is more elastic with respect to gross domestic investment (GDI) than are imports of "normal" capital goods. In particular, the import elasticity of capital goods with respect to GDI is determined as follows:

[3] It is also possible to distribute the increase in ICOR over several years to capture the lagged nature of response to catastrophic damage. Since our main purpose here is to describe how impacts are diffused through the model, we stick to the simplest single-year adjustment process.

Table 1
Baseline: No catastrophic loss

	1998	1999	2000	2001	2002	2003	2004	2005
Growth Rate of GDP		**-1.5%**	**4.0%**	**4.7%**	**4.7%**	**4.7%**	**4.7%**	**5.2%**
ICOR		5.0	5.0	5.0	5.0	5.0	5.0	5.0
Catastropic loss (percent of K)		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Catastrophic loss (mill. LCU)		0	0	0	0	0	0	0
Adjusted ICOR		5.00	5.00	5.00	5.00	5.00	5.00	5.00
Total Investment (mill. LCU)	74302	66589	81371	85196	89200	93392	108184	124753
Government	3767	2664	3116	3988	4555	5166	5409	5690
of which Replacement Investment	0	0	0	0	0	0	0	0
Private Investment	70535	63925	78255	81208	84645	88226	102775	119062
Total consumption (mill. LCU)	271847	272314	272672	284651	296421	308557	312547	317921
Government	9350	8989	9695	10151	10628	11128	11651	12256
Private	262497	263325	262976	274500	285793	297429	300896	305664
Resource balance	-8135.9	-5960.2	-7782.6	-7312.4	-6047.3	-4535.6	-4638.8	-4944.4
Imports	38205.8	34790.8	37334.8	38780.6	40325.3	41974.5	45476.1	49627.9
Exports	30069.9	28830.6	29552.2	31468.2	34278.0	37438.9	40837.4	44683.4
Saving-investment balances								
(percent of GDP)								
Investment	22.0%	20.0%	23.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Private	20.9%	19.2%	22.6%	22.4%	22.3%	22.3%	24.8%	27.3%
Public	1.1%	0.8%	0.9%	1.1%	1.2%	1.3%	1.3%	1.3%
GDFI	22.0%	20.0%	23.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Changes in stocks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gross Domestic Savings	19.6%	17.8%	20.8%	21.1%	21.4%	21.8%	24.3%	26.8%
Total Savings	22.0%	20.0%	23.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Foreign Savings	4.4%	4.0%	4.6%	4.5%	4.2%	4.0%	4.0%	4.2%
Gross National Savings	17.6%	16.0%	18.9%	19.1%	19.3%	19.6%	22.0%	24.4%
Monetary Savings	0.7%	1.0%	1.0%	0.9%	0.9%	0.9%	0.9%	0.9%
Government Savings	-0.2%	-0.7%	-0.1%	-0.4%	-0.3%	-0.2%	-0.2%	0.0%
Private Savings	17.1%	15.7%	18.0%	18.5%	18.7%	18.9%	21.3%	23.5%
Debt and Debt Service (LT+ST+IMF):								
Total DOD (US$M)	109051.0	116367.5	126824.1	137319.8	147745.4	158492.8	171772.1	187575.2
Total Debt/GDP	32.3%	34.8%	36.1%	36.8%	37.2%	37.6%	37.9%	38.3%
Debt Service (US$M)	22079.3	20198.8	20044.6	19816.8	22605.6	24177.3	29201.3	28276.3
Debt Service / Total Exports	65.8%	65.4%	62.5%	56.7%	58.3%	56.1%	61.1%	53.1%
Debt Service / GDP	6.5%	6.0%	5.7%	5.3%	5.7%	5.7%	6.4%	5.8%
Interest Burden (LT+ST+IMF):								
Interest Paid (US$M)	7209.3	7150.8	7960.0	8571.2	9483.4	10528.3	11433.4	12675.3
Interest Due (US$M)	7209.3	7150.8	7960.0	8571.2	9483.4	10528.3	11433.4	12675.3
Interest / Total Exports	21.5%	23.1%	24.8%	24.5%	24.5%	24.4%	23.9%	23.8%
Interest / GDP	2.1%	2.1%	2.3%	2.3%	2.4%	2.5%	2.5%	2.6%

Table 2

Alternative 1: catastrophic loss in 2000, no offset

	1998	1999	2000	2001	2002	2003	2004	2005
Growth Rate of GDP		**-1.5%**	**4.0%**	**4.7%**	**4.7%**	**4.7%**	**4.7%**	**5.2%**
ICOR		5.0	5.0	5.0	5.0	5.0	5.0	5.0
Catastropic loss (percent of K)		0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Catastrophic loss (mill. LCU)		0	10388	0	0	0	0	0
Adjusted ICOR		5.00	5.00	5.64	5.00	5.00	5.00	5.00
Total Investment (mill. LCU)	74302	66589	91759	85196	89200	93392	108184	124753
Government	3767	2664	13504	3988	4555	5166	5409	5690
of which Replacement Investment	0	0	10388	0	0	0	0	0
Private Investment	70535	63925	78255	81208	84645	88226	102775	119062
Total consumption (mill. LCU)	271847	272314	263354	284488	296247	308372	312315	317631
Government	9350	8989	9695	10151	10628	11128	11651	12256
Private	262497	263325	253659	274337	285619	297244	300664	305375
Resource balance	-8135.9	-5960.2	-8853.1	-7148.9	-5873.4	-4350.6	-4406.5	-4654.8
Imports	38205.8	34790.8	38405.3	38617.1	40151.5	41789.5	45243.9	49338.2
Exports	30069.9	28830.6	29552.2	31468.2	34278.0	37438.9	40837.4	44683.4
Saving-investment balances								
(percent of GDP)								
Investment	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Private	20.9%	19.2%	22.6%	22.4%	22.3%	22.3%	24.8%	27.3%
Public	1.1%	0.8%	3.9%	1.1%	1.2%	1.3%	1.3%	1.3%
GDFI	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Changes in stocks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gross Domestic Savings	19.6%	17.8%	23.5%	21.1%	21.5%	21.9%	24.4%	26.8%
Total Savings	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Foreign Savings	4.4%	4.0%	4.9%	4.4%	4.2%	3.9%	4.0%	4.1%
Gross National Savings	17.6%	16.0%	21.6%	19.1%	19.3%	19.6%	22.1%	24.4%
Monetary Savings	0.7%	1.0%	1.0%	0.9%	0.9%	0.9%	0.9%	0.9%
Government Savings	-0.2%	-0.7%	0.0%	-0.5%	-0.5%	-0.4%	-0.4%	-0.2%
Private Savings	17.1%	15.7%	20.7%	18.7%	18.9%	19.1%	21.5%	23.7%
Debt and Debt Service (LT+ST+IMF):								
Total DOD (US$M)	109051.0	116367.5	128404.1	138331.4	148624.7	159234.0	172286.9	187763.7
Total Debt/GDP	32.3%	34.8%	36.5%	37.0%	37.4%	37.7%	38.0%	38.3%
Debt Service (US$M)	22079.3	20198.8	20044.6	20117.0	22808.6	24367.5	29377.5	28421.9
Debt Service / Total Exports	65.8%	65.4%	62.5%	57.5%	58.8%	56.6%	61.4%	53.4%
Debt Service / GDP	6.5%	6.0%	5.7%	5.4%	5.7%	5.8%	6.5%	5.8%
Interest Burden (LT+ST+IMF):								
Interest Paid (US$M)	7209.3	7150.8	7960.0	8713.4	9569.4	10603.1	11496.4	12719.1
Interest Due (US$M)	7209.3	7150.8	7960.0	8713.4	9569.4	10603.1	11496.4	12719.1
Interest / Total Exports	21.5%	23.1%	24.8%	24.9%	24.7%	24.6%	24.0%	23.9%
Interest / GDP	2.1%	2.1%	2.3%	2.3%	2.4%	2.5%	2.5%	2.6%

Table 3

Alternative 2: catastrophic loss in 2000, government consumption offset

	1998	1999	2000	2001	2002	2003	2004	2005
Growth Rate of GDP		**-1.5%**	**4.0%**	**4.7%**	**4.7%**	**4.7%**	**4.7%**	**5.2%**
ICOR		5.0	5.0	5.0	5.0	5.0	5.0	5.0
Catastropic loss (percent of K)		0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Catastrophic loss (mill. LCU)		0	10388	0	0	0	0	0
Adjusted ICOR		5.00	5.00	5.64	5.00	5.00	5.00	5.00
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GDFI	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
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Foreign Savings	4.4%	4.0%	4.9%	4.4%	4.2%	3.9%	4.0%	4.1%
Gross National Savings	17.6%	16.0%	21.6%	19.1%	19.3%	19.6%	22.1%	24.4%
Monetary Savings	0.7%	1.0%	1.0%	0.9%	0.9%	0.9%	0.9%	0.9%
Government Savings	-0.2%	-0.7%	0.7%	-0.5%	-0.5%	-0.3%	-0.3%	-0.1%
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Debt Service / Total Exports	65.8%	65.4%	62.5%	57.5%	58.8%	56.6%	61.4%	53.4%
Debt Service / GDP	6.5%	6.0%	5.7%	5.4%	5.7%	5.8%	6.5%	5.8%
Interest Burden (LT+ST+IMF):								
Interest Paid (US$M)	7209.3	7150.8	7960.0	8713.4	9569.4	10603.1	11496.4	12719.1
Interest Due (US$M)	7209.3	7150.8	7960.0	8713.4	9569.4	10603.1	11496.4	12719.1
Interest / Total Exports	21.5%	23.1%	24.8%	24.9%	24.7%	24.6%	24.0%	23.9%
Interest / GDP	2.1%	2.1%	2.3%	2.3%	2.4%	2.5%	2.5%	2.6%

Table 4

Alternative 3: catastrophic loss in 2000, imports offset

	1998	1999	2000	2001	2002	2003	2004	2005
Growth Rate of GDP		**-1.5%**	**4.0%**	**4.7%**	**4.7%**	**4.7%**	**4.7%**	**5.2%**
ICOR		5.0	5.0	5.0	5.0	5.0	5.0	5.0
Catastropic loss (percent of K)		0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Catastrophic loss (mill. LCU)		0	10388	0	0	0	0	0
Adjusted ICOR		5.00	5.00	5.64	5.00	5.00	5.00	5.00
Total Investment (mill. LCU)	74302	66589	91759	85196	89200	93392	108184	124753
Government	3767	2664	13504	3988	4555	5166	5409	5690
of which Replacement Investment	0	0	10388	0	0	0	0	0
Private Investment	70535	63925	78255	81208	84645	88226	102775	119062
Total consumption (mill. LCU)	271847	272314	263978	285034	296828	308990	313090	318598
Government	9350	8989	9695	10151	10628	11128	11651	12256
Private	262497	263325	254283	274883	286200	297862	301440	306342
Resource balance	-8135.9	-5960.2	-9477.1	-7694.7	-6453.9	-4968.4	-5182.0	-5621.9
Imports	38205.8	34790.8	39029.3	39162.9	40731.9	42407.3	46019.4	50305.3
Exports	30069.9	28830.6	29552.2	31468.2	34278.0	37438.9	40837.4	44683.4
Saving-investment balances								
(percent of GDP)								
Investment	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Private	20.9%	19.2%	22.6%	22.4%	22.3%	22.3%	24.8%	27.3%
Public	1.1%	0.8%	3.9%	1.1%	1.2%	1.3%	1.3%	1.3%
GDFI	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Changes in stocks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gross Domestic Savings	19.6%	17.8%	23.3%	21.0%	21.3%	21.7%	24.2%	26.6%
Total Savings	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Foreign Savings	4.4%	4.0%	5.1%	4.6%	4.4%	4.1%	4.2%	4.4%
Gross National Savings	17.6%	16.0%	21.4%	18.9%	19.2%	19.4%	21.8%	24.1%
Monetary Savings	0.7%	1.0%	1.0%	0.9%	0.9%	0.9%	0.9%	0.9%
Government Savings	-0.2%	-0.7%	0.0%	-0.5%	-0.5%	-0.4%	-0.4%	-0.1%
Private Savings	17.1%	15.7%	20.5%	18.5%	18.7%	18.9%	21.3%	23.4%
Debt and Debt Service (LT+ST+IMF):								
Total DOD (US$M)	109051.0	116367.5	129325.0	139897.7	150971.8	162491.7	176791.9	193891.7
Total Debt/GDP	32.3%	34.8%	36.8%	37.5%	38.0%	38.5%	39.0%	39.6%
Debt Service (US$M)	22079.3	20198.8	20044.6	20292.0	23107.5	24827.5	30032.0	29344.9
Debt Service / Total Exports	65.8%	65.4%	62.5%	57.9%	59.6%	57.6%	62.8%	55.1%
Debt Service / GDP	6.5%	6.0%	5.7%	5.4%	5.8%	5.9%	6.6%	6.0%
Interest Burden (LT+ST+IMF):								
Interest Paid (US$M)	7209.3	7150.8	7960.0	8796.3	9702.6	10802.6	11773.3	13102.0
Interest Due (US$M)	7209.3	7150.8	7960.0	8796.3	9702.6	10802.6	11773.3	13102.0
Interest / Total Exports	21.5%	23.1%	24.8%	25.1%	25.0%	25.1%	24.6%	24.6%
Interest / GDP	2.1%	2.1%	2.3%	2.4%	2.4%	2.6%	2.6%	2.7%

Table 5

Alternative 4: catastrophic loss in 2000, imports and government consumption offset

	1998	1999	2000	2001	2002	2003	2004	2005
Growth Rate of GDP		**-1.5%**	**4.0%**	**4.7%**	**4.7%**	**4.7%**	**4.7%**	**5.2%**
ICOR		5.0	5.0	5.0	5.0	5.0	5.0	5.0
Catastropic loss (percent of K)		0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Catastrophic loss (mill. LCU)		0	10388	0	0	0	0	0
Adjusted ICOR		5.00	5.00	5.64	5.00	5.00	5.00	5.00
Total Investment (mill. LCU)	74302	66589	91759	85196	89200	93392	108184	124753
Government	3767	2664	13504	3988	4555	5166	5409	5690
of which Replacement Investment	0	0	10388	0	0	0	0	0
Private Investment	70535	63925	78255	81208	84645	88226	102775	119062
Total consumption (mill. LCU)	271847	272314	263978	285034	296828	308990	313090	318598
Government	9350	8989	7137	10151	10628	11128	11651	12256
Private	262497	263325	256842	274883	286200	297862	301440	306342
Resource balance	-8135.9	-5960.2	-9477.1	-7694.7	-6453.9	-4968.4	-5182.0	-5621.9
Imports	38205.8	34790.8	39029.3	39162.9	40731.9	42407.3	46019.4	50305.3
Exports	30069.9	28830.6	29552.2	31468.2	34278.0	37438.9	40837.4	44683.4
Saving-investment balances								
(percent of GDP)								
Investment	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Private	20.9%	19.2%	22.6%	22.4%	22.3%	22.3%	24.8%	27.3%
Public	1.1%	0.8%	3.9%	1.1%	1.2%	1.3%	1.3%	1.3%
GDFI	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Changes in stocks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gross Domestic Savings	19.6%	17.8%	23.3%	21.0%	21.3%	21.7%	24.2%	26.6%
Total Savings	22.0%	20.0%	26.5%	23.5%	23.5%	23.6%	26.1%	28.6%
Foreign Savings	4.4%	4.0%	5.1%	4.6%	4.4%	4.1%	4.2%	4.4%
Gross National Savings	17.6%	16.0%	21.4%	18.9%	19.2%	19.4%	21.8%	24.1%
Monetary Savings	0.7%	1.0%	1.0%	0.9%	0.9%	0.9%	0.9%	0.9%
Government Savings	-0.2%	-0.7%	0.7%	-0.5%	-0.4%	-0.3%	-0.3%	-0.1%
Private Savings	17.1%	15.7%	19.7%	18.4%	18.7%	18.8%	21.2%	23.4%
Debt and Debt Service (LT+ST+IMF):								
Total DOD (US$M)	109051.0	116367.5	129325.0	139898.4	150972.6	162492.8	176793.3	193893.6
Total Debt/GDP	32.3%	34.8%	36.8%	37.5%	38.0%	38.5%	39.0%	39.6%
Debt Service (US$M)	22079.3	20198.8	20044.6	20292.0	23107.7	24827.6	30032.2	29345.2
Debt Service / Total Exports	65.8%	65.4%	62.5%	57.9%	59.6%	57.6%	62.8%	55.1%
Debt Service / GDP	6.5%	6.0%	5.7%	5.4%	5.8%	5.9%	6.6%	6.0%
Interest Burden (LT+ST+IMF):								
Interest Paid (US$M)	7209.3	7150.8	7960.0	8796.3	9702.6	10802.6	11773.4	13102.1
Interest Due (US$M)	7209.3	7150.8	7960.0	8796.3	9702.6	10802.6	11773.4	13102.1
Interest / Total Exports	21.5%	23.1%	24.8%	25.1%	25.0%	25.1%	24.6%	24.6%
Interest / GDP	2.1%	2.1%	2.3%	2.4%	2.4%	2.6%	2.6%	2.7%

$$e = 5.0\,\frac{I_R(t)}{I(t)} + 1.6\,\frac{I(t) - I_R(t)}{\mathrm{I(t)}}$$

where $I_R(t)=Cat(t)$ is replacement investment. In other words, where the elasticity of "normal" capital goods with respect to "normal" GDI is assumed to be 1.6, the corresponding elasticity of imports corresponding to replacement investment is assumed to be 5. According to calculations carried out within the model, a catastrophe that destroys 1 percent of the capital stock increases the weighted-average elasticity of total capital imports with respect to GDI to 2.98 in 2000, returning again to 1.6 in 2001. The procedure is purely *ad hoc*, but succeeds in linking the elasticity of imports to the extent of catastrophic damages and replacement investment.

Comparing Table 4 to Table 2 (the no-offset case), the resource balance is lower, and private consumption is higher, by LCU 624 million. Foreign debt, already 0.4 percentage points higher as a share of GDP in Alternative 1 (the no-offset case) than in the baseline, is increased by another 0.3 percent of GDP. The difference between the debt-GDP ratios in Alternative 3 and Alternative 1 widens to 1.3 percentage points by the end of the simulation period.

This increasing difference reflects the fact that the import offset has a modest lagged effect over the simulation period. This is due to persistence of the upward ratchet in capital goods imports in the year of the catastrophic loss. GDP and exports are identical in the baseline and alternative scenarios, and investment and government consumption return to baseline levels following the catastrophe. Therefore, *via* the national income accounting identity, higher imports translate into higher private consumption.

Finally, in Table 5, the government consumption and import offsets are combined. The resulting compression in 2000 of private consumption (*vis à vis* the no-catastrophe baseline case) is LCU 6,134 million, or 2.3 percent. Again, the import offset gives rise to a weak persistent increase in private consumption in the years 2001-05.

Example 2: a Monte Carlo simulation

In our previous paper, we used the following flood loss distribution for Argentina:

- In any year, there is a 20 percent chance of a catastrophic event destroying 0.2 percent of the capital stock,
- a 5 percent chance of an event which destroys 0.4 percent of the capital stock, and
- a 1 percent chance of an event occuring which destroys 6 percent of the capital stock.

These data were estimated by matching flood loss time series for 1960-present prepared for the Office of Foreign Disaster Assistance of the U.S. Agency for International Development (Labat-Anderson Incorporated n.d.) with capital stock data from the Summers-Heston Penn World Tables.

The software package RISK is designed to facilitate Monte Carlo applications of Excel spreadsheets such as RMSM. We have solved the RMSM model 500 times in RISK, the solution period being 1999-2005 as above. In each solution run, for each of the years 2000-2005, a draw was made from the stochastic loss distribution above and the ICOR was shocked as described. Each year is assumed to represent an independent experiment, that is, the probability of catastrophic losses in a given year is independent of catastrophic losses in

previous years. Both the government consumption offset and import offset as described above were assumed to be operative.

In Figure 1, we display the distribution of cumulative capital losses relative to total capital stock due to natural catastrophic events over the simulation period 2000-05. This cumulative loss measure is, in a given solution run,

$$\sum_{t=2000}^{2005} \frac{Cat(t)}{K(t)} = \sum_{t=2000}^{2005} [1 - Mult(t)]$$

The expected value of the loss distribution above in any given year is 0.0012, so over a six-year period, we would expect cumulative losses to sum to 0.0072, in other words, about 0.7 percent.

Means can be misleading, however, because they fail to express variability and the likelihood of extreme outcomes. The interpretation of Figure 1 is as follows. Along the x-axis, the cumulative loss measure above is sorted into bins. The columns of the histogram give number of runs in which a loss measure in the corresponding range was observed. For example, in approximately 250 runs (the sum of the two bars at the left of the diagram), total loss to the capital stock was between 0 and 0.0062, that is, approximately 0.6 percent. In a small but significant number of cases in the right-hand tail of the distribution cumulative capital losses in excess of 6 percent of capital stock were observed.

The dotted line is the cumulative distribution function (CDF) derived from the Monte Carlo simulation. The dot over the second bar from the left corresponds to 0.5 on the right-hand axis, telling us that in half of all runs, total losses to the capital stock over the six-year period were less than 0.6 percent of the capital stock. In almost 95 percent of all cases, losses were approximately 1 percent or less of the capital stock.

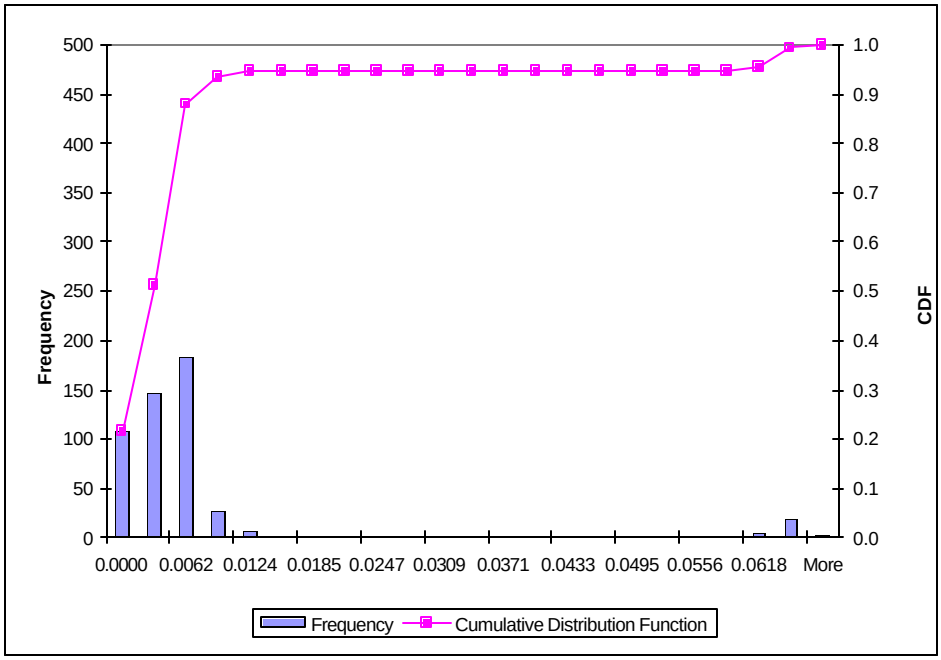

Figure 1. Cumulative Losses due to Natural Catastrophes, 2000-05 (proportion of capital stock)

The presence of the government consumption and import offsets makes these variables, as well as variables linked to them through the RMSM model structure, stochastic. In Figure 2, we display average annual public consumption foregone as a result of catastrophic losses relative to public consumption in the baseline (no-catastrophe) case. The index is

$$\frac{\sum_{t=2000}^{2005}[G'(t)-G(t)]}{\sum_{t=2000}^{2005}G(t)}$$

where the prime denotes government consumption in the alternative (catastrophic shock) scenario and the absence of a prime denotes the variable in the baseline (no catastrophic shock) scenario.

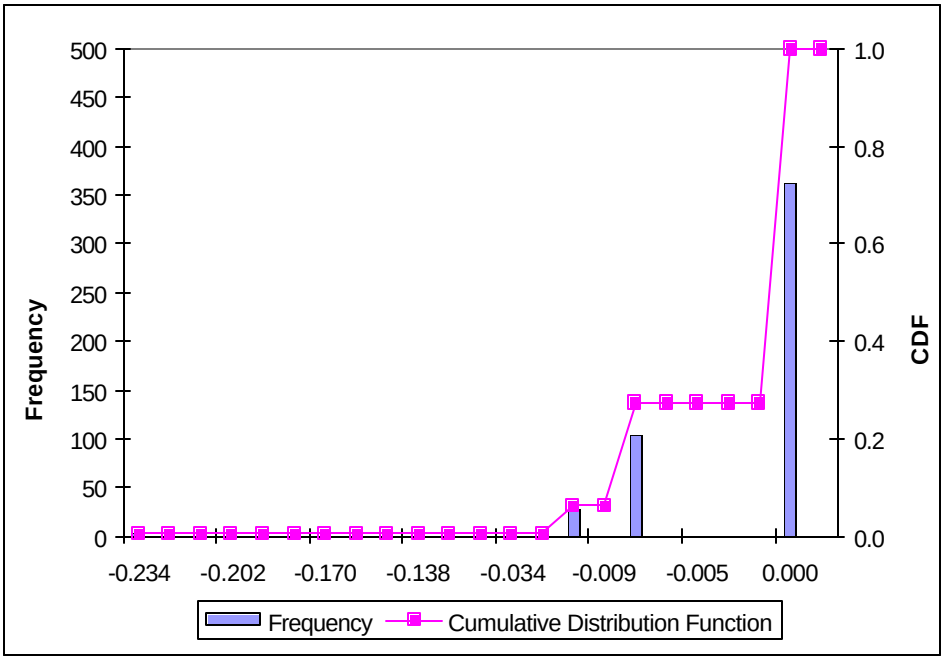

Figure 2. Foregone Public Consumption, 2000-05 (proportion of the baseline).

Note, first, that as opposed to the cumulative loss index in Figure 1, this index measures loss in an average year calculated on the basis of 500 six-year model solution runs. Second, the diagram is reversed: in Figure 1, model runs in the left-hand side of the diagram correspond to modest catastrophic loss impacts; in Figure 2, events in the left-hand side of the diagram correspond to large impacts. In about 75 percent of all cases, corresponding to the tall bar at the right, public consumption is reduced on average by only a small fraction of a percentage point. In about 20 percent of all runs, the loss averages between 0.5 and 0.9 percent of baseline public consumption. In a handful of cases not visible in the diagram, however, heavy losses are observed.

Figure 3 displays the same index of impacts on private consumption:

$$\frac{\sum_{t=2000}^{2005}[C'(t)-C(t)]}{\sum_{t=2000}^{2005}C(t)}$$

In about three-quarters of all runs, the average-year impact was either zero or a slight increase via the import offset described above. In small number of cases shown in the left-hand side of the diagram, catastrophic losses leads to very large declines in private consumption.

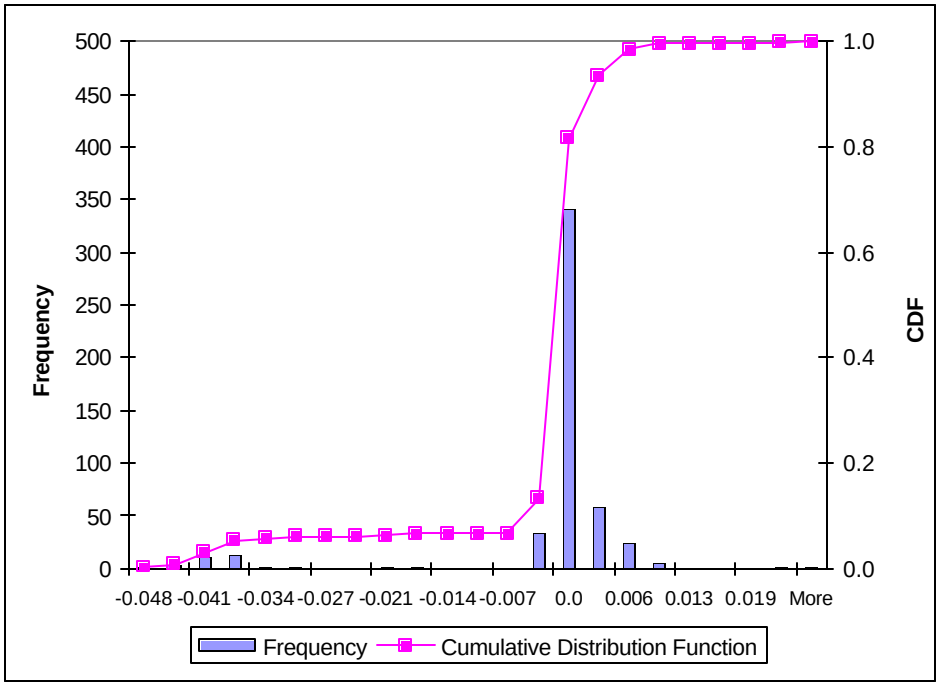

Figure 3. Foregone Private Consumption, 2000-05 (proportion of baseline)

Finally, Figure 4 displays added debt service (interest payments and amortization) as a share of baseline exports:

$$\frac{1}{6}\sum_{t=2000}^{2005}[DebtServiceRatio'(t)-DebtServiceRatio(t)]$$

where the prime is as above. Here, runs in the left-hand side of the diagram represent modest catastrophic loss impacts whereas runs in the right-hand side represent serious impacts. In about 75 percent of all model runs, corresponding to the two tall bars at the left of the diagram, the impact of catastrophic losses (more specifically, the associated import offset)

was to raise debt-service costs relative to export earnings by an average of 0-1.6 percentage points per year over the no-catastrophe baseline case.

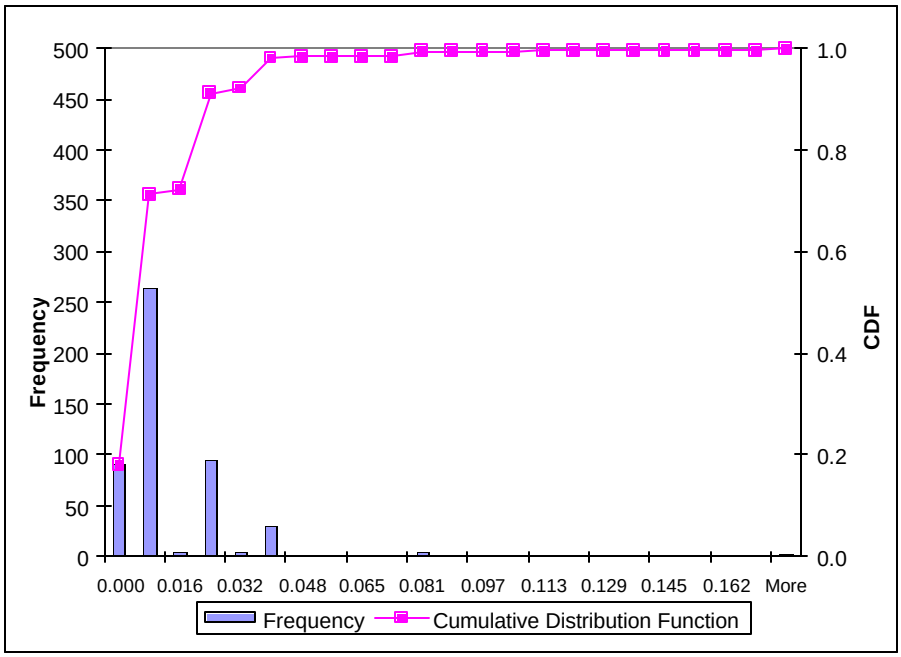

Figure 4. Average ratio of debt service to total exports.

Directions for further work

In this paper, we applied a widely used economic / financial programming model to perform an illustrative assessment of the macroeconomic impacts of natural catastrophic losses in a developing economy. The assumption that motivated the exercise was that policy makers wish to know the resource implications of catastrophic losses given an exogenous target path for GDP. Higher investment demand associated with replacement investment can be met only by reducing domestic consumption (public or private) or importing resources from abroad. Both strategies reduce welfare, immediately in the first case, and eventually when debt must be serviced and repaid in the second.

Several conclusions, as well as several directions for future work, emerge from this exercise. The conclusions relate to the feasibility of studies in this area. We have seen that so long as the model used is in spreadsheet form, software and computer programming resources need not be an issue. There is no reason why an analysis much deeper than the one presented here cannot be done on a laptop computer during the course of a technical advisory mission. We have also seen that even crude catastrophic loss data can provide a basis for meaningful macroeconomic analysis of natural disasters. Improving the accuracy and comprehensiveness of these data will, however, extend the range and reliability of economic analysis.

What, in addition to improving catastrophic loss data, are the indicated directions for future work? As befits a model designed for a range of applications in many countries, the basic RMSM is an accounting model with a minimum of behavioral detail. This parsimony arises for at least two reasons. First, the greater the behavioral richness, the greater the economic data requirements are likely to be. Second, the higher the ratio of behavior to accounting, the greater is the likelihood that the model will be judged inappropriate for any

given country application. Thus, RMSM is best regarded as an elaborate flexible accounting shell (including a state-of-the-art international financial module) into which special-purpose behavioral equations may be inserted.

The heart of simulations such as that presented here is the aggregate production function. In RMSM, a Harrod-Domar function is inverted to solve for investment requirements given an exogenous GDP growth path. The next stage of research should design and estimate a production function that breaks out infrastructure from other forms of capital. During this process, it is likely that it will be desirable to disaggregate infrastructure into components having varying impacts on economic growth as well as varying vulnerabilities to catastrophic events. However, a premium should be placed on flexibility and portability; that is, the equation should be designed with multiple country applications in mind.

As we have seen in this paper, RMSM permits incorporation of reaction mechanisms such as reductions in government consumption and increases in imports. At the current stage of research, these mechanisms are incorporated in an entirely *ad hoc* fashion, but at least the underlying assumptions are made explicit. The next stage of research should identify and econometrically investigate how natural catastrophic losses are likely to affect the major macroeconomic demand functions (consumption, investment, money, and imports). Linkages involving the credit market and prices (including the exchange rate) may be especially worth investigating. Finally, and especially in view of the detailed financial module in RMSM, the next stage of research should investigate the impact of natural catastrophes on countries' costs of borrowing in international capital markets. These costs might be direct, in the form of a risk premium reflecting catastrophe-related risks of default, or indirect, if natural catastrophes increase foreign indebtedness relative to GDP and drive up risk premia in consequence.

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