# Indicators for Social and Economic Coping Capacity -

# Moving Toward a Working Definition of Adaptive Capacity

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**Abstract**

This paper offers a practically motivated method for evaluating systems' abilities to handle external stress. The method is designed to assess the potential contributions of various adaptation options to improving systems' coping capacities by focusing attention directly on the underlying determinants of adaptive capacity. The method should be sufficiently flexible to accommodate diverse applications whose contexts are location specific and path dependent without imposing the straightjacket constraints of a "one size fits all" cookbook approach. Nonetheless, the method should produce unitless indicators that can be employed to judge the relative vulnerabilities of diverse systems to multiple stresses and to their potential interactions. An artificial application is employed to describe the development of the method and to illustrate how it might be applied. Some empirical evidence is offered to underscore the significance of the determinants of adaptive capacity in determining vulnerability; these are the determinants upon which the method is constructed. The method is, finally, applied directly to expert judgements of six different adaptations that could reduce vulnerability in the Netherlands to increased flooding along the Rhine River.

Key Words

adaptive capacity, climate change

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## 1. Introduction

Adaptive capacity has worked its way, as an organizing concept, into the research structures of those who contemplate the potential harm that might be attributed to global climate change and other sources of external stress. As such, it holds the potential of being a point of departure for the construction of practical indices of vulnerability that could sustain comparable analyses of the relative vulnerabilities of different systems located across the globe and subject to a diverse set of stresses that lie beyond their control. This paper offers a practically motivated method for evaluating adaptive capacity by assessing the potential contributions of various adaptation options to improving systems' coping capacities. We expect that this method will be sufficiently flexible to accommodate diverse applications whose contexts are location specific and path dependent without imposing the straightjacket constraints of a "one size fits all" cookbook approach. It is designed to produce, nonetheless, unitless indicators that can be employed to judge the relative vulnerabilities of diverse systems to multiple stresses and to their potential interactions. It is designed, as well, to help practitioners distinguish productively between macro and micro scale factors that work to define the underlying determinants of coping capacity – a distinction that can bring critical scale differences into clear focus.

We begin in Section 2 with a brief review of the literature in which the notions of vulnerability, exposure, sensitivity and adaptive capacity have been developed. We focus particular attention on the determinants of adaptive capacity and their role in defining the boundaries of coping ranges – thresholds of relatively benign experience beyond which systems feel significant effects from change and/or variability in their environments. Section 2 also begins the presentation of the particulars of a specific artificial example that will be used throughout the paper to explain how our proposed method for computing coping capacity indicators might be developed and applied. Section 3 uses a more formal representation of vulnerability to show how overall coping capacity might be judged by contemplating the feasibility and efficacy of alternative adaptation options. Section 4 formally presents the adaptation-specific foundation of proposed methodology and chronicles its application to the artificial example. It will build on the determinants of adaptive capacity for each adaptation option, and it is designed ultimately to produce unitless and comparable indicators of coping capacity. Section 5 shows how the complications of adaptation interaction and multiple stresses can be accommodated for any adaptation before Section 6 offers brief application to the Rhine Delta in the Netherlands. Section 7 closes with a concise description of the methodology can be expanded to include multiple adaptations to multiple stresses and some concluding remarks about its strengths and likely applicability across diverse environments. An appendix presents some empirical justification for some of underlying correlations drawn from national data that support the purported roles of the determinants of adaptive capacity.

## 2. A Brief Literature Review.

The authors of Chapter 18 of the Report of Working Group II to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) focused considerable attention on the role of adaptation in judging the economic implications of climate change and climate variability [IPCC (2001)]. Even though they concentrated on climate-related stresses, their work can be applied by those who contemplate the potential for adaptation to diminish the costs (or to enlarge the benefits) of change in the mean or variability in any variable that defines a system's environment. Moreover, the care with which they assessed the broader adaptation literature in their approach to climate issues means that it is sufficient for present purposes simply to review their work with a careful eye toward converting their insights into workable and informative indicators of coping capacity.

We begin the process by recalling four major conclusions that the lead authors of Chapter 18 highlighted in their Executive Summary (IPCC, 2001):

1. The vulnerability of any system to an external stress (or collection of stresses) is a function of exposure, sensitivity, and adaptive capacity.

2. Human and natural systems tend to adapt autonomously to gradual change and to change in variability.

3. Human systems can also plan and implement adaptation strategies in an effort to reduce potential vulnerability or exploit emerging opportunities even further.

4. The economic cost of vulnerability to an external stress is the sum of the incremental cost of adaptation plus any residual damages that cannot be avoided.

Moreover, the authors of Chapter 18 emphasized that adaptive capacity varies significantly from system to system, sector to sector and region to region. Indeed, the determinants of adaptive capacity include a variety of system, sector, and location specific characteristics:

1. The range of available technological options for adaptation,

2. The availability of resources and their distribution across the population,

3. The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed,

4. The stock of human capital including education and personal security,

5. The stock of social capital including the definition of property rights,

6. The system's access to risk spreading processes,

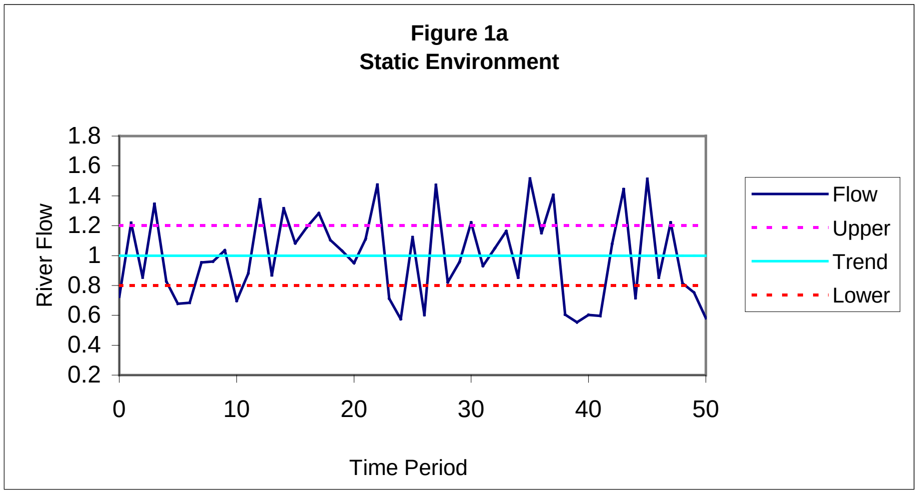
7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves, and

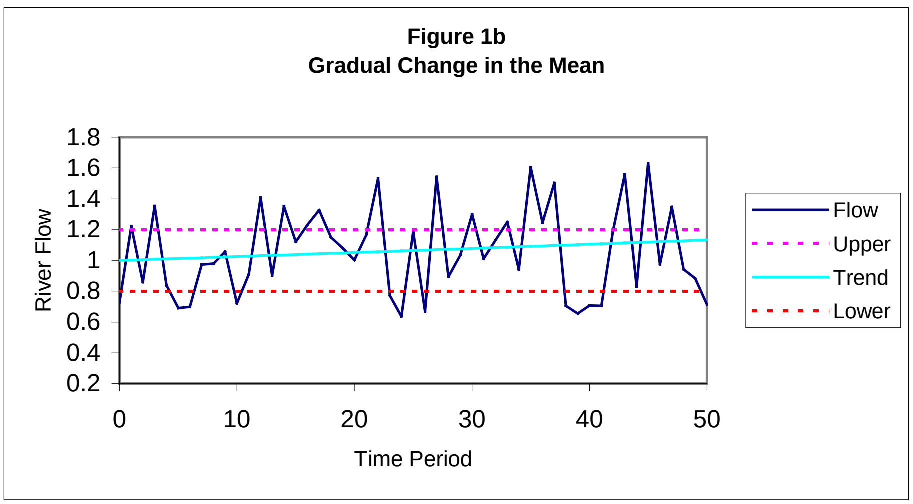
8. The public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

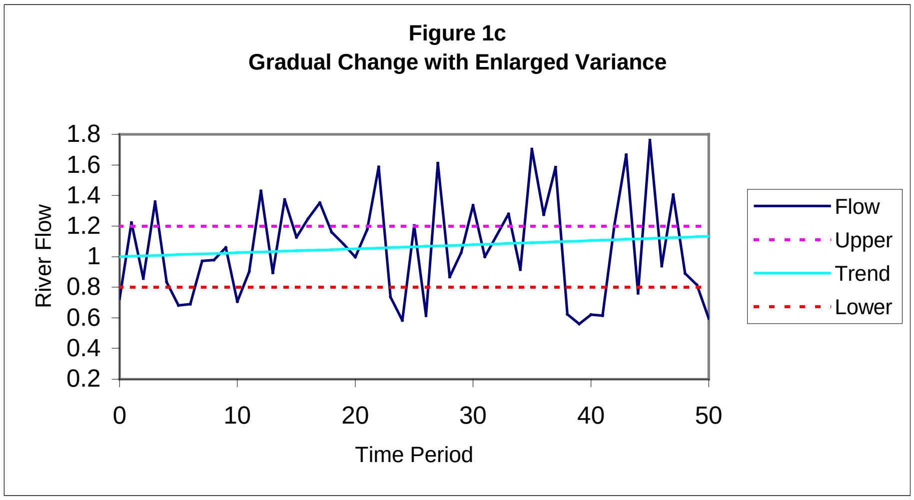
Finally, it is essential to note that exposure to variability and to extreme events is an important source of vulnerability. In fact, systems typically respond to variability and extreme events before they respond to gradual changes in the mean.

In summary, as noted in Chapter 18, the vulnerability *cum* adaptation literature recognizes explicitly that systems' environments are inherently variable from day to day, month to month, year to year, decade to decade, and so on [see Mearns, *et al.* (1997), Karl and Knight (1998) and Berz (1999)]. It follows that changes in the mean conditions that define those environments can actually be experienced most noticeably through changes in the nature and/or frequency of variable conditions that materialize across short time scales and that adaptation necessarily involves reaction to this sort of variability. This is the fundamental point in Hewitt and Burton (1971), Kane, *et al.* (1992), Yohe, *et al.* (1996), Downing (1996) and Yohe and Schlesinger (1998). Some researchers, like Smithers and Smit (1997), Smit, *et al.* (1999), and Downing et al (1997), use the concept of "hazard" to capture these sorts of stimuli, and claim that adaptation is warranted whenever either changes in mean conditions or changes in variability have significant consequences. For most systems, though, changes in mean conditions over short periods of time fall within a "coping range" – a range of circumstances within which, by virtue of the underlying resilience of the system, significant consequences are not observed [see Downing, et al (1997) or Pittock and Jones (2000)]. There are, however, limits to resilience for even the most robust of systems. As a result, it is important to understand the boundaries of systems' coping ranges – thresholds beyond which the consequences of experienced conditions become significant.

The various panels of Figure 1 illustrate this point graphically by portraying a time series of hypothetical and artificial river flows at a particular location. Figure 1a establishes an initial environment with a stable mean flow (indexed to unity) and a fixed variance in flow over prescribed periods of time. It also portrays upper and lower thresholds that define a current coping capacity for that location. The upper threshold has been set at 120% of the indexed mean flow might; it might indicate, for example, the flow level above which inhabited parts of the flood plain would be flooded. The lower threshold, meanwhile set at 80% of the indexed mean, might indicate the flow level below which operating an existing local power plant or subsistence fishing would be infeasible. Notice, as drawn, that this location would see 11 periods of flooding and 13 periods of power interruption over the 50 period series. Figure 1b portrays the same series with a gradually increasing mean – the result, perhaps, of upstream changes in climate or land use.  Even without any change in variation around the mean, the frequency of flooding climbs to 13 of 50 periods while the frequency of power plant suspensions falls to 11.  Figure 1c adds expanding variability from whatever source to the mix.  Its contribution increases the frequency of floods even more (to 16 of 50 periods), but it also increases the frequency of crossing the lower threshold back to 13 – the reflection of what would fundamentally be an ambiguous effect for power plant operations relative to the original stable environment.



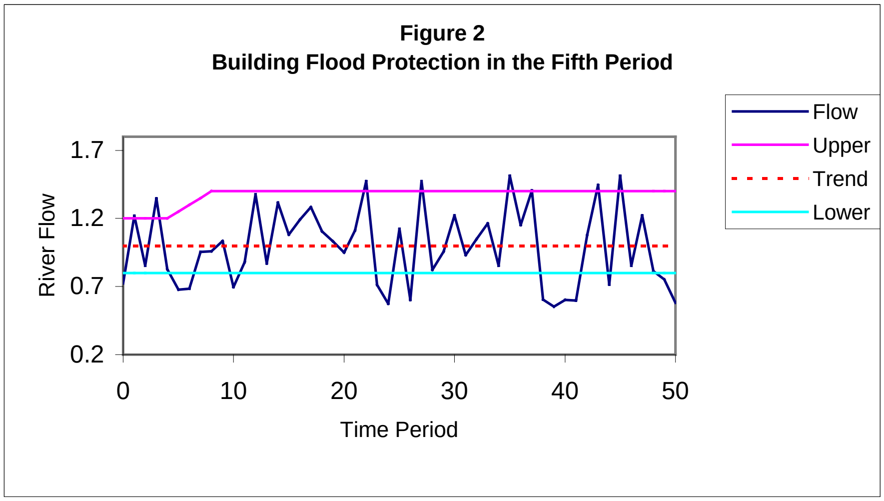






Coping ranges of the sort displayed in Figure 1 are not necessarily fixed over time, of course. Indeed, de Vries (1985), de Freitas (1989) and Smit, *et al.* (2000) all make it clear that judging adaptive capacity depends critically upon both defining a coping range *and* understanding how the efficacy of any coping strategy might be expanded by adopting new or modified adaptations. We will explore how by adding three different adaptation options to our river flow example.

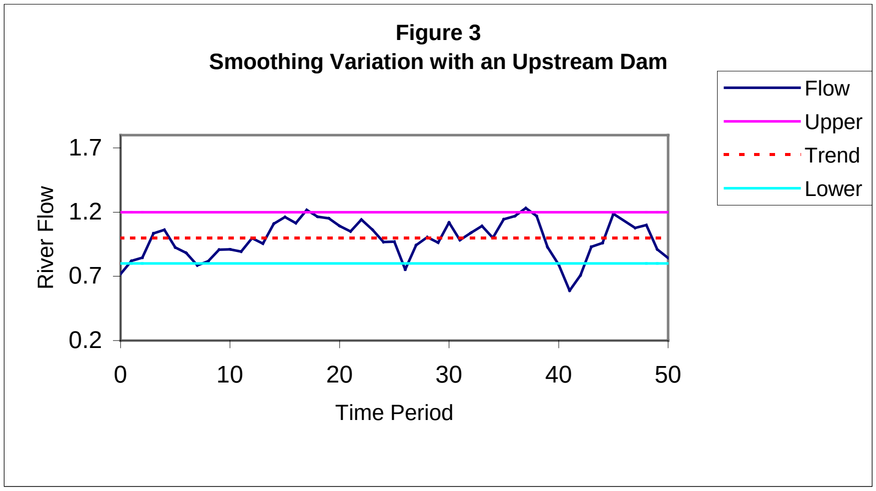
Option A: Construction of a series of protection levies.

Figure 2 portrays the effect of building protective levies by expanding the upper threshold of the coping range. The frequency of flooding is thereby reduced in all cases, but there is no change in exposure to flows that fall below the lower threshold. Flooding could be eliminated, at least for the static portrait, if the levies were large enough; but levies constructed to accommodate the static environment depicted in Figure 1a could still be overwhelmed if mean flow or variability rose unexpectedly over time. Construction and maintenance costs would be incurred, to be sure, but local environmental effects, local amenity costs, and increased flooding downstream could also be experienced.



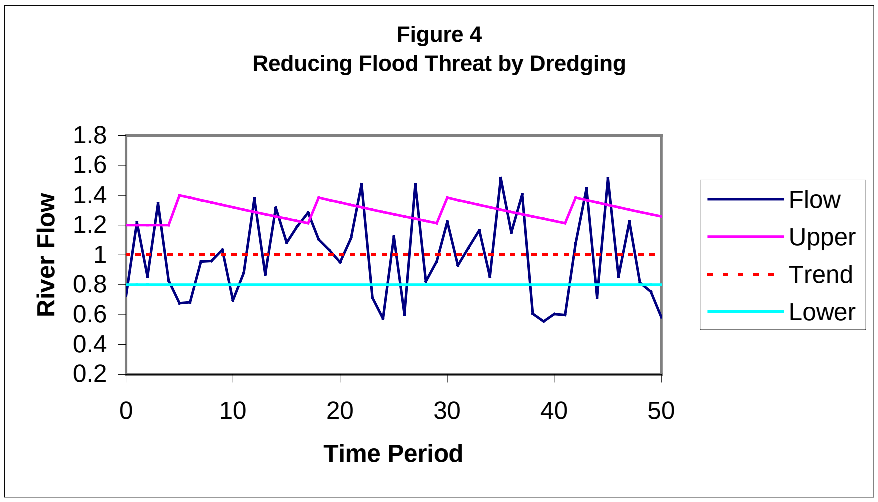

Option B: Building a dam upstream.

Figure 3 portrays the effect of building a dam upstream by reducing the variability in observed river flow at our location. This option would, in particular, allow managers to release water from the dam during low flow periods and hold water back during high flow periods so that the actual flow below the dam would be a moving average of current conditions. Figure 3, in fact, depicts observed flow as a 4 period moving average. Exposure could, with a dam of sufficient capacity, limit variability in actual flow to the size of the original coping range of Figure 1. This option therefore holds the potential of eliminating vulnerability to crossing either the high or low threshold, but it, too, could fail to accommodate an unexpected change in the underlying mean or variance. Construction and maintenance cost would again be incurred, as well as significant environmental impact upstream; but energy and recreational benefits could be created.




Option C: Periodically dredging the river.

Figure 4 portrays the effects of periodic dredging as a saw-toothed pattern for the upper threshold. Dredging would allow the river to accommodate more water and thereby increase the upper threshold, but this benefit would depreciate over time as silt re-deposits on the riverbed. To maintain long-term benefit, therefore, dredging would have to be repeated on a regular basis. This option also holds the potential of eliminating exposure to flooding, but only for short periods of time. On the other hand, opting for dredging regime could allow managers to accommodate unexpected changes in the underlying mean or variance by increasing or decreasing the frequency of dredging operations. The recurring cost of dredging plus some environmental damage could be expected as well as increased flooding risk downstream.




Implementing any one of these adaptations would clearly have a different effect on either the coping range of our river location or its exposure to the significant consequences of flow variability, but this diversity is a fact of life. Indeed, any useful indicator of coping capacity will have to handle this sort of diversity in a consistent and comparable way.

## 3. Adding Detail and Context to the Vulnerability Structure.

The broad relationship between vulnerability, sensitivity, and adaptive capacity illustrated in the river flow example can be expressed in its most general form with a little notation. Let **V** denote vulnerability, **E** denote exposure, **S** denote sensitivity, and A denote adaptive capacity, and let $\mathbf{D_i}$ index each of the eight determinants of adaptive capacity. Each of these variables except adaptive capacity is recorded in bold because each can be a vector. Vulnerability can be measured simultaneously along many different dimensions. A system can be exposed to many different stresses simultaneously. Many different sectors and many different people can feel sensitivity to any particular exposure at the same time. All of the determinants of adaptive capacity can, in principle, be depicted in multiple ways. Adaptive capacity is uniquely represented as a scalar, because we think that a scalar can be defined to serve as an aggregate measure of the potential to cope. Formally, then,

$$\mathbf{V} = \mathbf{F}\{\, \mathbf{E}(A);\ \mathbf{S}(A)\, \} \qquad \text{where} \qquad (1)$$

$$A = AC\{\, \mathbf{D_1};\ \dots\ ;\ \mathbf{D_8}\, \}. \qquad (2)$$

Both **F{--}** and AC**{--}** are multivariate and complex functions that are location specific and path dependent. It is reasonable to expect that vulnerability would, at least eventually, increase monotonically with exposure and sensitivity at increasing rates. It is also likely that exposure and sensitivity would fall at decreasing rates with higher adaptive capacity. The relationship between adaptive capacity and its determinants reflected in equation (2) would, however, be more difficult to characterize.

Functional representations of this sort are, of course, only useful if they offer ways of organizing thoughts and sifting through the complexity. Many of the variables cannot be quantified, and many of the component functions can only be qualitatively described. Still, working through their content from the bottom up can be useful in uncovering practical insights that can support the creation of indexes of coping capacity. Some of the determinants of adaptive capacity should, for example, operate on macro-scales in which national or regional factors play the most significant role, but other determinants should function on more micro scales that are precisely location specific. This will turn out to be a useful distinction. The set of available, applicable, and appropriate technological options (Determinant 1) for a given exposure at a particular location should, for example, be defined on a micro-scale, even though the complete set of possible remedies might have macro roots. Flood control options of the sort portrayed above are, for example, determined by the local conditions of the river bed and available engineering knowledge; and this knowledge may be restricted to indigenous knowledge on the one hand or informed by worldwide consultants on the other.

Determinants 2 through 6 should all have large macro components to them, but their micro-scale manifestations could vary from location to location or even from adaptation option to adaptation option. Resources (Determinant 2) could be distributed differently across specific locations, but adaptive capacity may be more sensitive to larger scale distributional issues across different locations. The essential questions here focus on whether sufficient funds are available to pay for adaptation and whether the people who control those funds are prepared to spend them on adaptation. The Appendix reports some empirical results from international comparisons; they show that these questions can be critical at the most fundamental level. We find, for example, that poorer people are more likely to fall victim of natural violence than are richer people. The relationship is highly significant. For every percent economic growth, vulnerability falls by a percent. We also find that more densely populated areas are more vulnerable. This is as expected, because the same disaster affects more people. Moreover, we find a positive relationship between income inequality and vulnerability; i.e., people in more egalitarian societies seem to be less likely to fall victim of natural violence than are people in a society with a highly skewed income distribution. This is expected, as well; and it is consistent with the negative correlation between income and vulnerability. It is that initial correlation that suggests that measures designed to highlight a skewed distribution would confirm the notion that the poorest communities within a country would face similar resource deficiencies when it comes to protecting themselves. Other explanatory variables are insignificant, but we should be aware that health care and education have a strong positive correlation with per capita income.

Macro-scale and even international institutions (Determinant 3) could certainly matter even at a micro level, especially in determining how decisions among various adaptation options might be made and who has access to the decision-making process. For example, the World Bank follows certain procedures in its investment decisions, and adaptation projects in countries seeking World Bank support must satisfy Bank criteria before even being considered. The European Union also has a framework (on procedures as well as consequences) into which all water management projects must fit, so macro-scale influences can be felt even in developed countries. On the other side of the coin, though, adaptation projects in other places can be decided and implemented completely according to local custom alone. The stock of human capital (Determinant 4) could be a local characteristic, as well, but its local manifestation would likely be driven in large measure by macro-scale forces, such as national education programs. The stock of social capital (Determinant 5) and efficacy of risk-spreading processes (Determinant 6) should be largely functions of macro-scale structures and rules; but they could again take different forms from location to location and option to option.

Risk can be spread through national markets for commercial insurance and the international reinsurance markets, but some companies refuse to sell flood insurance. Risk can also be spread through mutual obligations in the extended family, the strength of which varies between cultures and city and countryside. By way of contrast, determinants 7 (informational management) and 8 (attribution of signals of change) may have some general macro-scale foundations, but their primary import would be felt on a micro-scale. Indeed, decision-rules and public perceptions could take on forms that would be quite particular to the set of available options.

Taken in its most general form, the vulnerability model reflected in equations (1) and (2) can lead to the conclusion that everything is connected to everything else, but this is not a productive insight. A more practical approach would, instead, read carefully through the determinants of adaptive capacity to recognize

1. that the local implications of macro-scale determinants of adaptive capacity are their most critical characteristics,

2. that most if not all of the determinants of adaptive capacity can be seen working through specific adaptation options, and

3. that the potential of most if not all adaptation options to effect sensitivity or exposure might not be too difficult to assess.

Taking these more modest observations to heart, we will show that it is possible to build coping indicators directly from systematic evaluations of the feasibility of available adaptations, taken one at a time, and their relative efficacy in reducing either sensitivity or exposure. The next section will suggest how by working through the river flow illustration presented in Section 1.

## 4. Building an Indicator for Coping Capacity from the Determinants of Adaptive Capacity.

The construction of an index of the potential contribution of any adaptation (to be denoted by j) to an indicator of overall coping capacity (denoted by $PCC_j$ ) will begin with a step by step evaluation of feasibility factors – index numbers that are judged to reflect its strength or weakness *vis a vis* the last seven determinants of adaptive capacity. These factors will be subjective values assigned from a range bounded on the low side by 0 and on the high side by 5 according to systematic consideration of the degree to which each determinant would help or impede its adoption. Let these factors be denoted by $ff_j(k)$ for determinants k = 2, …, 8. We will argue that an overall feasibility factor for adaptation (j) should be reflected by the minimum feasibility factor assigned to any of these determinants; i.e.,

$$FF_j \equiv \min\{ff_j(2), \ldots\ ff_j(8)\} \qquad (3)$$

Each factor inserted in equation (3) would, in particular, suggest whether the local manifestations of each determinant of adaptive capacity would work to make it more or less likely that adaptation (j) might be adopted. A low feasibility factor near 0 for Determinant #k would, for example, indicate a shortcoming in the necessary preconditions for implementing adaptation (j), and this shortcoming would serve to reduce its feasibility. A high feasibility factor near 5 would indicate the opposite situation; assessors would, in this case, be reasonably secure in their judgement that the preconditions included in Determinant #k could and would be satisfied. Notice that the structure of equation (3) makes it clear that high feasibility factors for a limited number of determinants would not be sufficient to conclude that adaptation (j) could actually contribute to sustaining or improving an overall coping capacity. The overall feasibility of adaption (j) could still be limited by deficiencies in meeting the requirements of other determinants.

The ability of adaptation (j) to, in fact, influence a system's exposure or sensitivity to an external stress will meanwhile be reflected in an efficacy factor $EF_j$ – a subjective index number assigned from a range running from 0 to 1. Efficacy factors will reflect the likelihood that adaptation (j) will perform as expected to influence exposure and/or sensitivity compounded by the likelihood that actual experience would exceed critical thresholds if it were adopted. The potential contribution of any adaptation to a system's social and economic coping capacity can then, finally, be defined as the simple product of its overall feasibility factor and its efficacy factor; i.e.,

$$PCC_j \equiv \{EF_j\}\{FF_j\} \qquad (4)$$

The point of this section is to show how this structure might be applied by demonstrating how these factors might be assigned in the river flow example. Assume, to that end but only for the time being, that any of the options listed in Section 1 could work as displayed in Figures 2 through 4 to reduce the vulnerability of study location to variability and/or change in the river's flow.  Table 1 lists some assumptions that describe pertinent characteristics for each of the three options upon which hypothetical judgements about their feasibility factors might be based.

**Table 1**

Characteristics of the River Flow Adaptation Options

**Option A: Levies**

Cost:  Large initial investment; modest on-going expense; modest environmental impact; modest amenity cost; downstream flooding possible.

Benefit:  Reduction in the frequency of flooding in the study location.

Institutional Requirements:  Mechanisms to sustain modest land taking required

Risk:  Possibly vulnerable to change in flow regime over the medium term.

**Option B: An Upstream Dam**

Cost:  Largest initial investment; large on-going expense; large environmental impact.

Benefit:  Reduction in the frequency of flooding in the study location and downstream; increase power plant reliability, modest amenity gain; additional power capacity; recreational benefit.

Institutional Requirements:  Mechanisms to sustain significant land taking required.

Risk:  Possibly vulnerable to significant change in precipitation and run-off patterns over the long term.

**Option C: Dredging**

Cost:  Largest on-going expense distributed unevenly over time; modest environmental impact possible; downstream flooding possible.

Benefit:  Reduction in the frequency of flooding in the study location.

Institutional Requirements:  Management authority with the authority and responsibility to dredge as necessary.

Risk:  Amenable to "mid-course" adjustments in the frequency of dredging as conditions warrant.

In contemplating the potentially limiting role of resource availability (Determinant #2) for options A through C, differences in cost and their intertemporal distribution displayed in Table 1 would be critical.  If the threatened location were part of an economic/political/social system with modest resources, for example, assessors might find levies or dredging more attractive than building an upstream dam, and we could assign feasibility factors of 3 or 4 to those options and 0 or 1 to the dam.  If resources were limited by relatively certain over the foreseeable future, however, we might lower the factor assigned to levies to 0 or 1 but hold the dredging option at 3 or 4.  And if the system had access to significant resources we might give values of 4 or 5 to all three options. In any case, these feasibility factors would not represent the likelihood that any adaptation option might be implemented; they would simply reflect an assessment about whether or not requisite financing could be found.

Resource distribution could also play a role, here. A society may be too poor to dredge the river, but one of its superrich may decide that an upstream dam is a suitable monument to his or her stature in the community. Less prestigious adaptation options such as levies and dredging might then be assigned feasibility factors equal to 0 or 1 while an upstream dam could score 1 or 2 or perhaps higher. The key here is that there may many other potential monuments around and the investment decision would turn on personal stature and not necessarily social usefulness.

Determinant #3 speaks to institutional requirements for each adaptation option and the decision-making frameworks with which they will be evaluated. Both need to be considered, and both can be evaluated independently of resource availability. Table 1 notes that building levies would require some mechanism for modest takings of riverside property and that building the dam would require a mechanism that could sustain significant takings of upstream property. If no such mechanisms existed, low feasibility factors would have to be assigned. If a modestly robust mechanism existed, then levies might see a factor of 3 or 4, but the dam would suffer a 0 or 1 assessment. Meanwhile, the dredging option would require that an authority exist that both acknowledges the responsibility to maintain the river flow and has routine access to requisite funds; feasibility factors could be assigned accordingly. Assuming that these institutions and/or mechanisms existed, of course, different decision criteria might still be applied.

Table 1 also records broad outlines of the issues that would have to be considered if benefit-cost criteria would be applied in each case. The three options have different structures of direct and indirect costs; and they have different benefit profiles, as well. Assigning feasibility factors for each option in this regard would only reflect the likelihood that its internal rate of return would be greater than the applicable rate of interest plus some risk factor. The ability of the system to afford any option that would be judged worthy of consideration on the basis of the cost-benefit calculation is already reflected in the assessment of Determinant #2. Other decision criteria exist, of course; but the approach in evaluating feasibility with regard to Determinant #3 would be the same. In any case, though, the scope of authority, both thematic (flood management versus river management versus river-bed management) and geographic (river basin management versus management of political units) must be included in the calculus.

Human capital and social capital are the broad categories identified in Determinants #4 and #5. Both could play a role in this example in many ways by working through the definition of property rights and effective access to the decision-making process. We have already noted that constructing levies or the dam would require the taking of land that would either be used to support the levies or be inundated by the upstream lake created by the dam. The definition of property rights would, therefore, implicitly identify who would be hurt if either option were implemented. Levies could, though, benefit riverside property-owners. If that were perceived to be the case, then a high feasibility factor of 4 or 5 could be assigned to indicate the high likelihood that the people who would be harmed by their construction could be convinced that they would see a compensatory benefit. The people harmed by the construction of the dam would, by way of contrast, not necessarily benefit from downstream flood management; nor would they necessarily be compensated fully by associated recreational or energy benefits. If their access to the decision-making process gave them sufficient power to block the construction of the dam and if institutions did not exist that could compensate them fully for their losses, then this access could be reason to assign a low feasibility factor for the dam.

Determinant #6 speaks to systems' sensitivities to various exposures because it focuses attention on their ability to spread or reduce the risk. Suppose, in our example, that the broader community were "plugged into" a wide power grid so that it could compensate easily for power shortfalls from the local power plant. The macro-scale system would then be able to spread the risk of these shortfalls, and the feasibility factor assigned to any adaptation whose implementation would reduce vulnerability to low river flow, the dam in this case, should the decline irrespective of the decision rule applied in Determinant #2. By the same token, if sensitivity to flooding were fundamentally financial, then private or social insurance programs could spread risk, reduce the damage, and thereby diminish the feasibility of any of the specific options listed above. Notice, however, that both of these stories rely on structures and institutions that had not yet been introduced; and so the ability of these structures and institutions to accommodate additional stress needs to be evaluated. Indeed, the best approach in any case where access to risk spreading mechanisms might lead to assigning low feasibility factors to any specific adaptation would subject exploiting or enhancing these mechanisms to the very same feasibility assessment methodology.

Determinants #7 and #8 highlight informational needs, perceptions, and decision-making credibility. The significance of each depends upon decision-making structures drawn from macro sources that can have parallel effects on all three options. Perceptions about the sources of the vulnerability to flooding could have a significant effect on the derivative perception that any or all of the options would work. Perceptions about the significance of the vulnerability, independent of its source, could also have comparable and consistent effects on the likelihood that any option would be contemplated. Low confidence in attribution or low opinion of significance would make all of the options relatively less feasible because none of them would be subjected to serious evaluation; low feasibility factors should then be assigned. High confidence in attribution and widespread recognition of significant exposure would, of course, have the opposite effect. Some options, like the dredging option in this example, could add micro-scale dimensions to feasibility considerations in this category, as well. Since dredging would be repeated as needed as the future unfolds, its feasibility would additionally depend in part on the ability of river managers to collect information and to process it properly so that renewed dredging could be implemented in a timely fashion. Absent this ability, a low factor would be assigned to dredging.

Determinant #6 identified access to risk-spreading mechanisms, and so it highlighted the need to describe risk appropriately. The previous discussion highlighted the possibility that spreading risk might diminish a system's sensitivity to a given exposure, but there is another side of the risk equation that also needs to be evaluated. Will the adaptation options evaluated for their feasibility in terms of Determinants #2 through #8 actually work to reduce exposure or diminish sensitivity? This question leads directly to assessments of the second factor in equation (4) – assigning efficacy factors for each option.

To see how this might work, Table 1 finally offers a representative characteristic for each of the three options that expose each to its own peculiar vulnerability. The ability of levies adequately to protect property from flooding would, for example, depend upon changes in mean flow or variability of the sort displayed in Figures 1b and 1c. Assigning an efficacy factor in this case would therefore require some notion about the frequency of high-flow events (caused by change in the mean and/or variability) and the feasibility of building the levies with surplus capacity (or at least preserving the ability to add capacity as needed). This evaluation could direct attention back to earlier cost considerations that play directly into Determinant #2 because adding capacity would add expense, but a tradeoff between efficacy and feasibility could be explored explicitly in terms of the coping capacity indicator. In any case, a high efficacy index would indicate a low likelihood of significant change in the environment, a high degree of relatively inexpensive flexibility in the construction of the levies, or both. By way of contrast, a low efficacy index would indicate a high likelihood of significant change in river flow characteristics, relatively expensive accommodation of a need for higher levies, or both.

Building the dam could, meanwhile, expose the system to fixed and long term investment into physical capital that could, over the long term, be in located permanently in the wrong place if climate and precipitation patterns change. Assigning a low efficacy index to this option would then fundamentally be a judgment that there is a significant change that this might happen. Finally, the dredging option would be most amenable to "mid-course" correction if conditions change; and so it could receive high efficacy marks that could improve its contribution to coping capacity.

## 5. Broadening Context to Recognize Interactions Across Adaptation Options and Multiple Stresses.

The method that focuses attention on the feasibility and efficacy of adaptation options through equations (3) and (4) can be extended to handle the complication of interactions across multiple options designed to mitigate vulnerability to one source of stress and/or multiple sources of stress. The key here would involve simply keeping track of the degree to which options might serve to complement each other, to substitute for each other, or perhaps even to work at cross-purposes to each other. To show how, we return one last time to the river flow example. Table 2 indicates that levies and/or dredging might be considered substitutes to building a dam, in terms of flood control at least; but Table 2 also indicates that levies and dredging could actually complement each other if they were implemented together. If this complementarity could be exploited, then each option could perhaps be pursued less vigorously (smaller levies and/or less frequent dredging). The cost of achieving any degree of flood protection might thereby fall if the costs of either or both of the individual adaptation options increased with scope at an increasing rate. Binding resource constraints might thereby be relaxed so that the feasibility scores of either or both options might climb (if resources were the most binding determinant constraint). The efficacy factor for a combined approach could be higher, as well, so the overall indicator of potential coping capacity could increase significantly. Evaluating the feasibility a fourth adaptation option – a convex combination of Options A and C in this case – in terms of Determinants #2 through #8 would be an effective way to accommodate this complication.

**Table 2**

Interactions among the River Flow Adaptation Options

| | Option A<br>Levies | Option B<br>Upstream Dam | Option C<br>Dredging |
|---|---|---|---|
| Option A | …... | – | + |
| Option B | – | …… | – |
| Option C | + | – | …… |

Table 3 meanwhile offers insight into how the complication of the system's vulnerability to other stresses might also be incorporated into an evaluation of overall adaptive capacity. It shows how each of the original adaptation options identified in the river flow example as possible responses to threats from flooding and uncertain power generation might influence three other sources of potential social, political and/or economic vulnerability. Table 3 is built, in particular, on an assumption that the larger community might also feel vulnerable to anticipated shortfalls in energy supply, variable sources for irrigation required to accommodate planned switching to more profitable crops, and anticipated increases in the demand for river-borne transportation. It shows potential complementarity between building a dam for flood control and supplying energy; note that "++" is recorded in the first column of the second row. The dam would not only provide a new source of hydroelectric power, but also reduce the frequency of shortfalls from the existing power plant by reducing flow variability. In addition, the dam's reducing flow variability could provide complementary services for improved irrigation as well as increased reliability for in-river transportation ("+" is recorded across the rest of the second row). The dam could, however, also eliminate upstream navigation, so a "-" is also recorded as a possibility in the right column. Table 3 meanwhile shows no interaction between building levies and any other three sources of vulnerability; but it shows a possible negative correlation between dredging and irrigation. Indeed, the "-"

entry in the last row of the second column simply reflects the potential that harmful pollutants might be released from the river bottom by the dredging process.

**Table 3**

Interactions with other Sources of Vulnerability

| | Power Supply | Irrigation | River Transport |
|---|---|---|---|
| Option A | + | 0 | 0 |
| Option B | ++ | + | + or – |
| Option C | + | – | 0 |

The insights drawn from constructing tables of cross-vulnerability interactions can be employed to revise the original feasibility factors of each option. It is within the context of multiple stresses that the relative significance of their associated vulnerabilities would, for example, be assessed. Absent interactions of the sort illustrated in Table 3, rankings based on macro-based preferences could materialize and work through the perception Determinant (#8) to give options for adapting to some of the stresses high marks while assigning consistently low marks to options designed to reduce vulnerability to others. This ranking would surely assume more power if resources available for adaptation, broadly defined, were relatively more scarce; and this added complication should be reflected in evaluations of resource availability (Determinant #2). Complementarity across options of the sort reflected in Table 3 could, however, work to reduce either or both of these adjustments – increasing the feasibility factors assigned to specific adaptations for the resource and perception determinants (again, #2 and #8).

## 6. A Casual Application to the Rhine Delta.

Tol *et al.* (2001) reports on an extensive assessment of adaptation against increased risk of flooding in the Rhine Delta. Six options for the Netherlands were identified:

1. Store excess water in Germany.

2. Accept more frequent floods.

3. Build higher dikes.

4. Deepen and widen the river bed.

5. Dig a fourth river mouth.

6. Dig a bypass and create a northerly diversion.

Reviewing the supporting documentation, we can characterize the adaptive capacity of the Dutch through the determinants identified above. Taken in turn,

1. The range of available technological options for adaptation is fairly large; the six options listed above each have a number of variants, and can of course be combined. These options were identified by a major civil engineering consultancy as technically feasible.

Macro-scale forces tend to dominate in this setting, so evaluations of the strengths of each of the underlying determinants should be consistent. Qualitatively, then,

2. The availability of resources is substantial. The Netherlands is the 11th largest economy in the world (by PPP). The distribution of resources across the population is irrelevant, as flood protection is in the hands of the national government.

3. The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed may be more problematic. The main problem with institutions is the separation between water management and land use planning, increasing the pressure of the flood plain and limiting the options for water management. Managing a river in a crowded flood plain requires solving conflicts of interests between many stakeholders. Public works are increasingly decided upon by methods of direct participation, which typically leads to long postponements and hinders radical decisions. However, if needed, the government can be very autocratic, and the population tends to trust the government in that. The crucial decision criterion in Dutch flood management is a high level of safety, with little geographical variation. Adaptation is thus almost automatic (but see above), but not necessarily efficient.

4. The stock of human capital including education and personal security is very high in the Netherlands. Dutch water engineers are the best in the world.

5. The stock of social capital is also high. The Netherlands is a consensus-oriented society in which the collective need is an effective counterweight to individual interests. Property rights are clearly defined, and the judiciary is independent.

6. The system's access to risk spreading processes is limited. Flood insurance cannot be purchased. On the other hand, the government guarantees compensation for flood damage, and charity is strong.

7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers themselves are all high. Dutch bureaucrats are typically well-educated and supported by able consultancies. Water management is controlled by an "old-boys" network of professors, civil servants and consultants; however, this network is fairly large and open-minded (to ideas, not to other people's competence). Dutch water engineers are held in high regard, and civil servants are largely trusted by the population.

8. The public as well as the water managers are well aware of climate change and its implications for flood risk, as well as of the confounding influences.

Table 4 offers expert judgement into how these macro-scale observations might be translated into the micro-scale determinants of each option listed above. A multitude of factors lead to a low feasibility factor for storing water in large measure because of the international cooperation that would be required to implement and to manage such a scheme. Accepting floods, creating a fourth mouth for the river, and constructing a bypass score equally low marks, but their determinant deficiencies are far less ubiquitous. Specific determinants, like distributional ramifications and/or risk spreading are their downfalls; and the same determinants identify areas where concerted effort might increase coping capacity by increasing feasibility. Higher dikes and manipulating the river bed score higher feasibility scores, but neither is perfect. Indeed, manipulating the river bed would appear to be most feasible, but it is hampered by a relatively low efficacy factor; such a plan could not eliminate the risk of flooding. On the other hand, higher dikes face participation difficulties on the feasibility side, but could offer extremely effective flood protection. Of the six options, in summary, higher dikes and working the river bed display qualitatively larger potential coping indices; and raising the dikes seems most attractive.

**Table 4**
Quantifying the Details of Adaptation Options for the Lower Rhine Delta

| | **Options** | | | | | |
|---|---|---|---|---|---|---|
| **Determinant** | **Store water** | **Accept floods** | **Higher dikes** | **River bed** | **4th Mouth** | **Bypass** |
| **2. Resources** | | | | | | |
| Total costs | 3 | 5 | 4 | 4 | 1 | 2 |
| Distribution[a] | 1 | 3 | 4 | 5 | 1 | 1 |
| **3. Institutions** | | | | | | |
| Structure[b] | 1 | 4 | 5 | 4 | 2 | 3 |
| Participation[c] | 2 | 2 | 3 | 5 | 1 | 2 |
| Criteria[d] | 2 | 1 | 5 | 4 | 3 | 2 |
| **4. Human capital** | 1 | 2 | 5 | 4 | 4 | 3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **5. Social capital** | 1 | 3 | 4 | 5 | 2 | 2 |
| **6. Risk spreading** | 2 | 1 | 5 | 4 | 4 | 3 |
| **7. Information**<br>Management<br>Credibility | <br>1<br>1 | <br>3<br>2 | <br>5<br>4 | <br>4<br>5 | <br>2<br>3 | <br>2<br>3 |
| **8. Awareness** | 3 | 3 | 5 | 5 | 3 | 3 |
| **Feasibility Factor (FF)** [e] | 1 | 1 | 3 | 4 | 1 | 1 |
| **Efficacy Factor (EF)** | 0.8 | 1.0 | 1.0 | 0.6 | 0.8 | 0.6 |
| **Coping Index (PCC)** | 0.8 | 1.0 | 3 | 2.4 | 0.8 | 0.6 |

Notes:
[a] The distribution of the costs and benefits of implementing an option.
[b] The degree to which the current mandates of bureaucracies are inadequate for the problem, essentially, how much integration of land use and water management is needed for successful implementation.
[c] The degree to which the decision making process is likely to be hindered by “not in my backyard” phenomena.
[d] The degree to which the option fits in with current decision making criteria.
[e] Ranking (minimum of the weighted scores).

## 7. Concluding Comments - Gleaning General Insight from the Two Examples.

To be operational, a feasibility-based evaluation of an adaptation’s potential contribution to overall coping capacity must be informed by a compounding evaluation of feasibility and efficacy for each possible adaptation. The method described in equations (3) and (4) suggests one way in which this might be accomplished. Notice, in particular, than an adaptation option could receive a low coping capacity indicator for many reasons. It might, by virtue of shortcomings in meeting the determinants of adaptive capacity, receive a low overall feasibility index; and it is now clear that a macro-level assessment that it would address only a low-priority vulnerability would be picked up in this factor. An adaptation could, as well, receive a low indicator if it were relatively ineffective in reducing exposure and/or sensitivity or if the mechanism by which it could accomplish its tasks were uncertain. It remains only to describe the how the adaptation-based $PCC_j$ can be combined into an indicator of overall coping capacity.

Suppose, for the sake of argument, that m potential adaptations have been identified for a specific vulnerability and that they have been assigned potential coping capacity indicators $\{PCC_1, \ldots, PCC_m\}$. The spirit of equation (3) suggests that

$$CCI \equiv \max \{PCC_1, \ldots, PCC_m\} \qquad (5)$$

would be a consistent and workable indicator. It would make sense to order the adaptation options in terms of their $PCC_j$ so that CCI = $PCC_1$. That accomplished, in fact, the robustness, R, of overall coping capacity in the face of any vulnerability could ratio of the average of the $PCC_j$ of the next two highly rated alternatives and $PCC_1$:

$$R = \{ [ PCC_2 + PCC_2 ] / 2 PCC_1 \}. \qquad (6)$$

A high R ratio would indicate that several options of relatively comparable potential were available, but a low would indicate a lack of diversity that could prove harmful if the assessment of adaptation were flawed. Returning to the Rhine River example to see how these summary statistics might work, note from Table 4 that the overall coping capacity indicator for flooding along the Rhine would be derived from building higher dikes, with a score of 3. Moreover, the relatively high-scoring second ranked option would produce a robustness indicator of {3+2.4}/{6} = 0.9.

Focusing on the specific sources of the feasibility and efficacy of specific adaptation options allows judgement of their potential contribution to overall coping capacity based on a "weakest link" approach to the problem. That is to say, the potential contribution of any option would be constrained by its smallest feasibility attribute. This approach has three advantages. First of all, it can identify exactly where effort to expand coping capacity can have the greatest impact in improving the potential of the best adaptation or adding diversity to the suite of potentially effective alternatives. Simply focus attention on enhancing the most binding underlying micro-scale determinant for any specific option or on enhancing the macro-scale determinant that binds most severely across multiple options. Increasing the availability of resources could, for example, improve coping capacity by increasing the feasibility of one or more options, if Determinant #2 were uniformly the "weakest link", but equation (2) reveals that the advantage of making such an investment would not be unbounded. It would, instead, be limited by a variety of determinants across one or many adaptations whose constraints were the next most binding and by their relative efficacy factors.

Secondly, the corollary of this last observation teaches that releasing the constraint imposed by one determinant on one option or another need not increase its contribution to overall coping capacity. Such an effort would be ineffective if it were directed at an inferior option or accomplished without recognizing the limitations imposed by feasibility factors assigned to other determinants. Adding to the resource base may, for example, have no effect on coping capacity if institutional processes or decision-making structures would block the implementation of any adaptation option for other reasons.

It also follows that there might be many or few ways to build adaptive capacity, as reflected by coping capacity indicators that were built from the determinants of adaptive capacity. Working to improve specific coping capacities by working to enhance one or more of its underlying determinants can build adaptive capacity for reducing vulnerability to a specific stress. But highlighting efforts to enhance some of the more macro-scale determinants whose influences might extend across the adaptive capacities of multiple stresses can underwrite progress in many dimensions.

Finally, the methodological structure outlined here has the advantage of producing unitless indicators that can be compared across potential adaptations to multiple stresses in the same region and/or the same stresses across multiple regions. It could, as a result, play an important role in ranking the relative vulnerabilities of multiple regions to different stresses, regardless of their sources.

## Acknowledgements

The EU DG Research Environment and Climate Programme through the projects SIRCH (ENV4-CT97-0447) and DINAS-Coast (EVK2-CT2000-00084), the US National Science Foundation through the Center for Integrated Study of the Human Dimensions of Global Change (SBR-9521914) and the Michael Otto Foundation provided welcome financial support. Ina Theil helped with data collection. All errors and opinions are ours.

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# Appendix A

## Some Preliminary Empirical Results into the Determinants of Adaptive Capacity

The Centre for Research on the Epidemiology of Disasters (CRED), Catholic University of Louvain, collects information on the consequences of natural and man-made disasters. Their databases are made available through the US Office of Foreign Disaster Assistance (OFDA) at http://www.cred.be/emdat/. The database contains information of about 12,000 disasters, covering the entire world, a range of disasters and the period of 1990-2000. Indicators included are the time and place of disaster, its type, its strength, and the damage done, measured in the number of people killed, injured, made homeless or otherwise affected and the economic damage done. Sources include (re)insurance companies, development and disaster aid agencies (non-governmental, national or multilateral), and the press.

Based on these data, we calculated three vulnerability indices. First, we computed the number of people killed by natural disasters in the period 1990-2000 in each country, and normalized this with the size of the population in 1995, the middle of the decade. Second, we calculated the number of people affected (but not killed), normalized with population. Third, we computed material damage, measured in US dollars, normalized with Gross Domestic Product (GDP).

Population data were obtained from the World Bank Group Economic Growth Research (http://www.worldbank.org/research/growth). From the same source, we obtained information on GDP, income per capita, enrollment in education, life expectancy, and land area. We obtained indicators of political rights and civil liberties from Freedom House (http://www.freedomhouse.org). The Gini coefficient, measuring the distribution of income in a country, was obtained from the UNDP World Income Inequality Database from the United Nations University World Institute for Development Economics Research (http://wider.unu.edu/wiid/wiid.htm). All data are for 1995.

Figure A1a plots the chance of being affected by a natural disaster against per capita income. Figure A1b does the same for the chance of being killed. Figure A2 displays the annual economic damage as a percentage of GPD. The data should be interpreted with great caution. If no life loss is reported in a country like Denmark, one can be reasonably certain that indeed no one was killed. If no life loss is reported in, say, Zaire, this may be because deaths were overlooked. The problem of underreporting is more pronounced for economic damages, as the data collection in less developed countries is primarily done by health and humanitarian agencies, while data for developed countries comes primarily from (re)insurance companies. Note, however, that the number of reported disasters – either per head (Figure A3) or per square kilometer (Figure A4) – is not correlated to per capita income.

Setting aside data problems, we obtain the following results. Table A1 shows the regressing results for the chance of getting killed, Table A2 for being affected, and Table A3 for damage done. After some experimentation, we settled on the following functional form

$$R_c = \alpha_c I_{ci}^{\beta_{ci}} + \varepsilon_c \qquad \text{(A1)}$$

where $R$ is the risk, $I$ is an indicator of adaptive capacity (indexed by $i$), $c$ is the index for countries, $\alpha$ and $\beta$ are parameters and $\varepsilon$ is noise. The multiplicative form of the superindicator of adaptive capacity corresponds to the notion in the main text that the weaker links in the adaptive chain matter most. Equation (A1) is estimated as

$$\ln(R_c) = \ln\alpha_c + \sum_i \beta_{ci} \ln(I_{ci}) + \eta_c \qquad \text{(A2)}$$

The noise term $\eta$ is assumed to be Normally distributed. An additional complication is that, for a number of countries in the sample, we observe a zero risk. We interpret equation (A1) as if it would, for some countries, lead to a "negative risk", but that negative risks are observed as zero risks. In equation (A2), we interpret "zero" as "less than one in a thousand" or "-7". Equation (A2) can thus be estimated using censored regression. (As we do not observe zero economic damages, the damage equation is estimated using ordinary least squares.) The EViews 4.0 Professional statistical software package allows us to estimate (A2). The results are displayed in Tables A1-3.

The regressions for people killed and economic damage are not very informative. For economic damages, this probably reflects the data problems discussed above. In any case, we find a slight, barely significant positive relationship between income per capita and damage done. That is, richer people are prone to loose a higher share of their wealth to natural disaster than are poorer people. This may be because economic damages are unreported in less developed countries; it may also be because richer people accumulate more goods that can be destroyed if disaster strikes. Other explanatory variables are insignificant, and the explanatory power of the regression is very low.

For people killed, we find a negative, almost significant relationship between per capita income and risk. That is, poorer people are more likely to die of natural violence than are richer people. This is as we would expect. The fact that deaths are probably underreported in less developed countries can only make this relationship stronger. Other explanatory variables are insignificant, and the explanatory power of the regression is low. This may be partly due to the noisy link between a disaster occurring and people dying as a result.

We obtain more interesting results for the fraction of people affected by natural disasters. The data are more reliable, and the link between natural disaster, vulnerability, and observed effect is more straightforward. We again find that poorer people are more likely to fall victim of natural violence than are richer people. The relationship is highly significant. For every percent economic growth, vulnerability falls by a percent. We also find that more densely populated areas are more vulnerable. This is as expected, because the same disaster affects more people. We also find a positive relationship between income inequality measured by a Gini coefficient and vulnerability. As expected, people in more egalitarian societies are less likely to fall victim of natural violence than are people in a society with a highly skewed income distribution. This result is consistent with,the reported correlation with per capita income on a national level.[1] Alternative income inequality measures like top to bottom ratios or percentages of populations below certain thresholds could easily underscore this observation and bring into focus the notion that the poorest citizens of any country would find it difficult to devote sufficient resources to protect themselves from natural hazards.

Other explanatory variables are insignificant, but we should be aware that health care and education have a strong positive correlation with per capita income. The explanatory power of this regression is reasonable.

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1 Note that richer countries tend to be more egalitarian. Our conclusion is not influenced by this, and the reported parameters are not affected by this multicolinearity (results not shown).

## Table A1

Dependent Variable: LKILLED
Method: ML - Censored Normal (TOBIT) (Quadratic hill climbing)
Date: 04/18/01 Time: 09:54
Sample(adjusted): 3 157
Included observations: 130
Excluded observations: 25 after adjusting endpoints
Left censoring (value) series: -7
Convergence achieved after 6 iterations
Covariance matrix computed using second derivatives

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| C | 4.582106 | 3.524287 | 1.300151 | 0.1935 |
| VENEZUELA | 9.629357 | 5.471708 | 1.759845 | 0.0784 |
| LINCOME | -0.792378 | 0.443845 | -1.785260 | 0.0742 |
| | Error Distribution | | | |
| SCALE:C(4) | 5.432079 | 0.437607 | 12.41315 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.050079 | Mean dependent var | -0.769405 |
| Adjusted R-squared | 0.027462 | S.D. dependent var | 4.153803 |
| S.E. of regression | 4.096371 | Akaike info criterion | 5.117864 |
| Sum squared resid | 2114.312 | Schwarz criterion | 5.206096 |
| Log likelihood | -328.6612 | Hannan-Quinn criter. | 5.153716 |
| Avg. log likelihood | -2.528163 | | |
| Left censored obs | 37 | Right censored obs | 0 |
| Uncensored obs | 93 | Total obs | 130 |

## Table A2

Dependent Variable: LWET
Method: ML - Censored Normal (TOBIT) (Quadratic hill climbing)
Date: 04/17/01 Time: 20:02
Sample(adjusted): 3 192
Included observations: 108
Excluded observations: 82 after adjusting endpoints
Left censoring (value) series: -7
Convergence achieved after 4 iterations
Covariance matrix computed using second derivatives

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| C | -4.664855 | 3.695010 | -1.262474 | 0.2068 |
| LINCOME | -1.015810 | 0.177249 | -5.730975 | 0.0000 |
| LGINI | 2.208481 | 0.797376 | 2.769686 | 0.0056 |
| LPOPDENS | 0.237600 | 0.099353 | 2.391473 | 0.0168 |
| | Error Distribution | | | |
| SCALE:C(5) | 1.917059 | 0.139647 | 13.72785 | 0.0000 |

| | | | |
|---|---|---|---|
| R-squared | 0.349444 | Mean dependent var | -3.328380 |
| Adjusted R-squared | 0.324180 | S.D. dependent var | 2.223604 |
| S.E. of regression | 1.827987 | Akaike info criterion | 4.037268 |
| Sum squared resid | 344.1782 | Schwarz criterion | 4.161441 |
| Log likelihood | -213.0125 | Hannan-Quinn criter. | 4.087616 |
| Avg. log likelihood | -1.972338 | | |
| Left censored obs | 10 | Right censored obs | 0 |
| Uncensored obs | 98 | Total obs | 108 |

## Table A3

Dependent Variable: LDAMAGED
Method: Least Squares
Date: 04/18/01 Time: 09:49
Sample(adjusted): 3 192
Included observations: 99
Excluded observations: 91 after adjusting endpoints
White Heteroskedasticity-Consistent Standard Errors & Covariance

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| C | -3.828096 | 1.608029 | -2.380614 | 0.0192 |
| LINCOME | 0.200187 | 0.190578 | 1.050421 | 0.2961 |

| | | | |
|---|---|---|---|
| R-squared | 0.010567 | Mean dependent var | -2.212825 |
| Adjusted R-squared | 0.000367 | S.D. dependent var | 2.031805 |
| S.E. of regression | 2.031432 | Akaike info criterion | 4.275354 |
| Sum squared resid | 400.2915 | Schwarz criterion | 4.327781 |
| Log likelihood | -209.6300 | F-statistic | 1.035951 |
| Durbin-Watson stat | 1.858405 | Prob(F-statistic) | 0.311297 |

Vulnerability to Natural Disasters and Per Capita Income

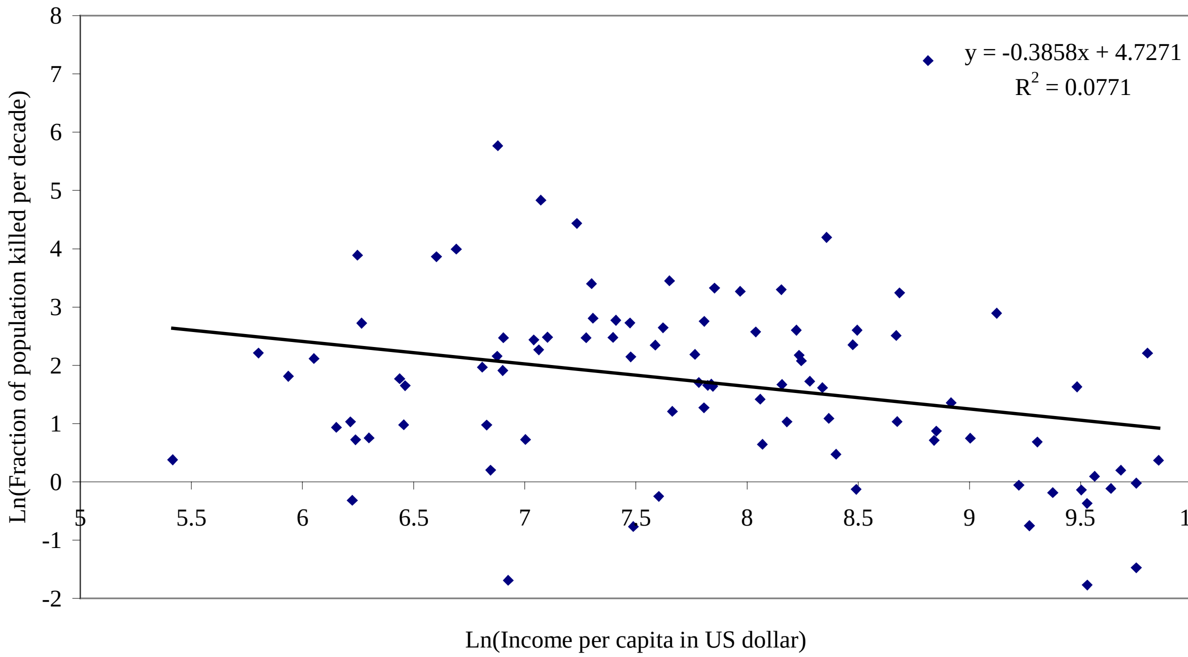


Figure A1b.

Vulnerability to Natural Disasters and Per Capita Income

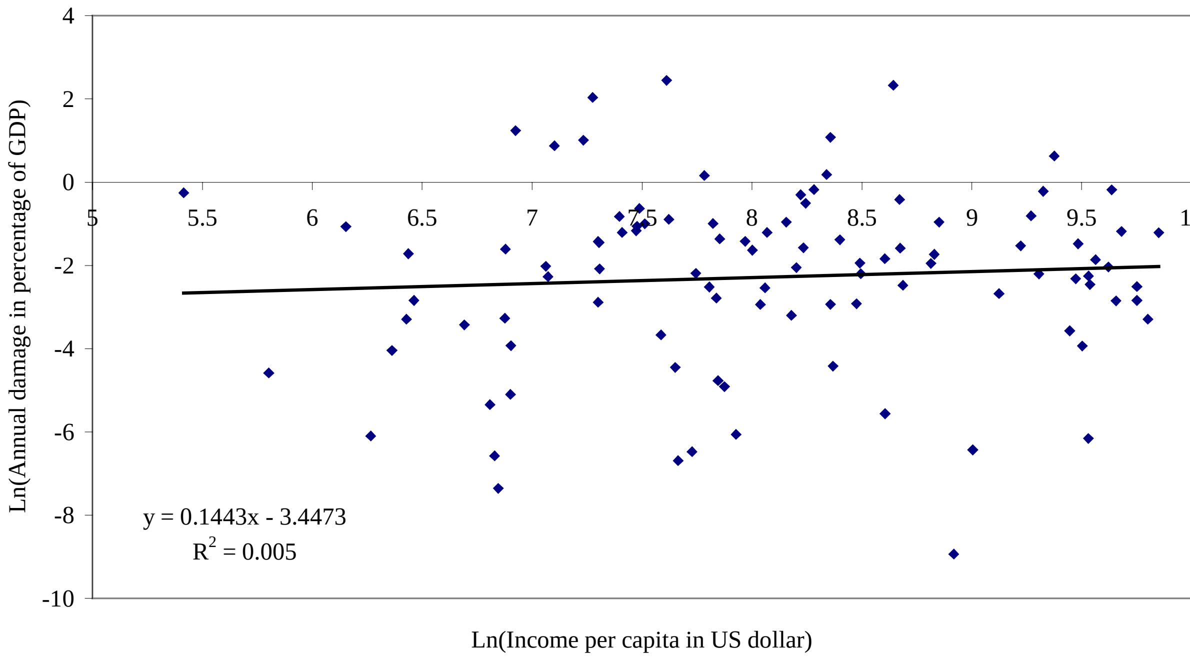


Figure A2.

Vulnerability to Natural Disasters and Per Capita Income

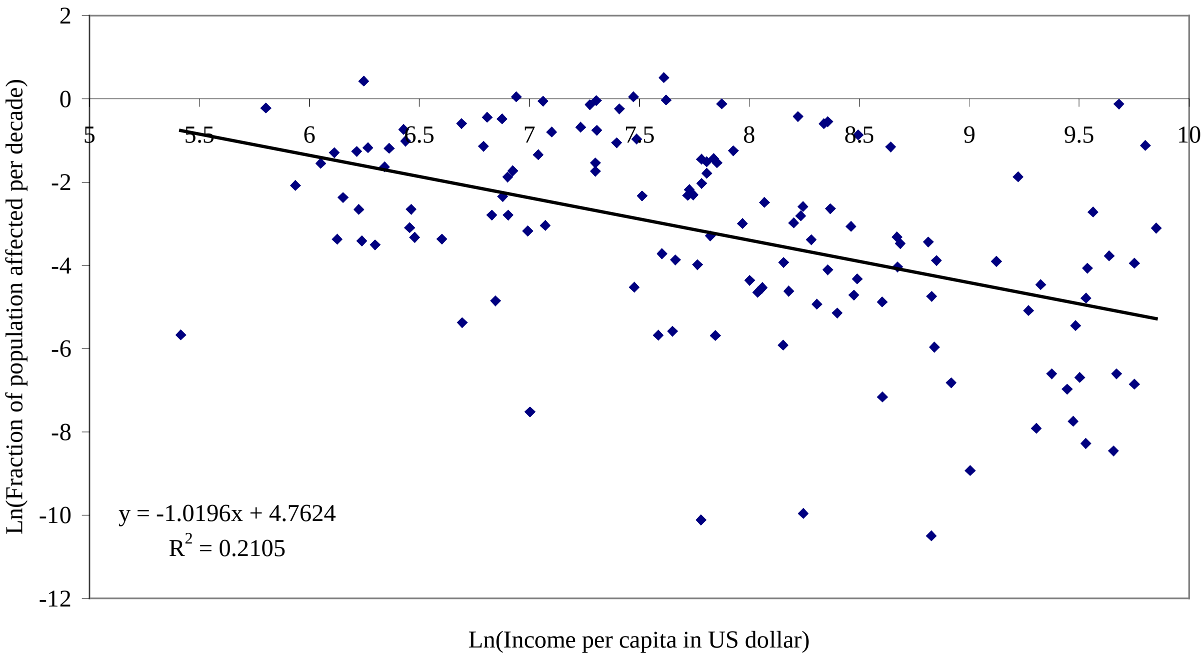


Figure A1a.

Number of Natural Disasters and Per Capita Income

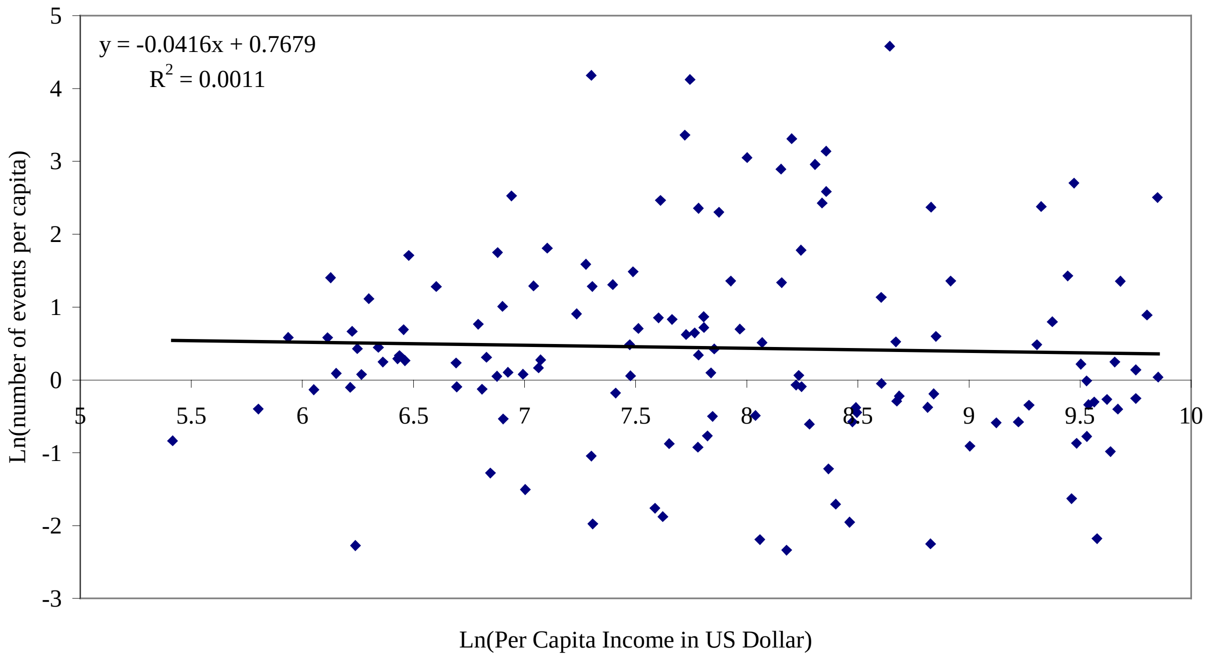


Figure A3.

Number of Natural Disasters and Per Capita Income

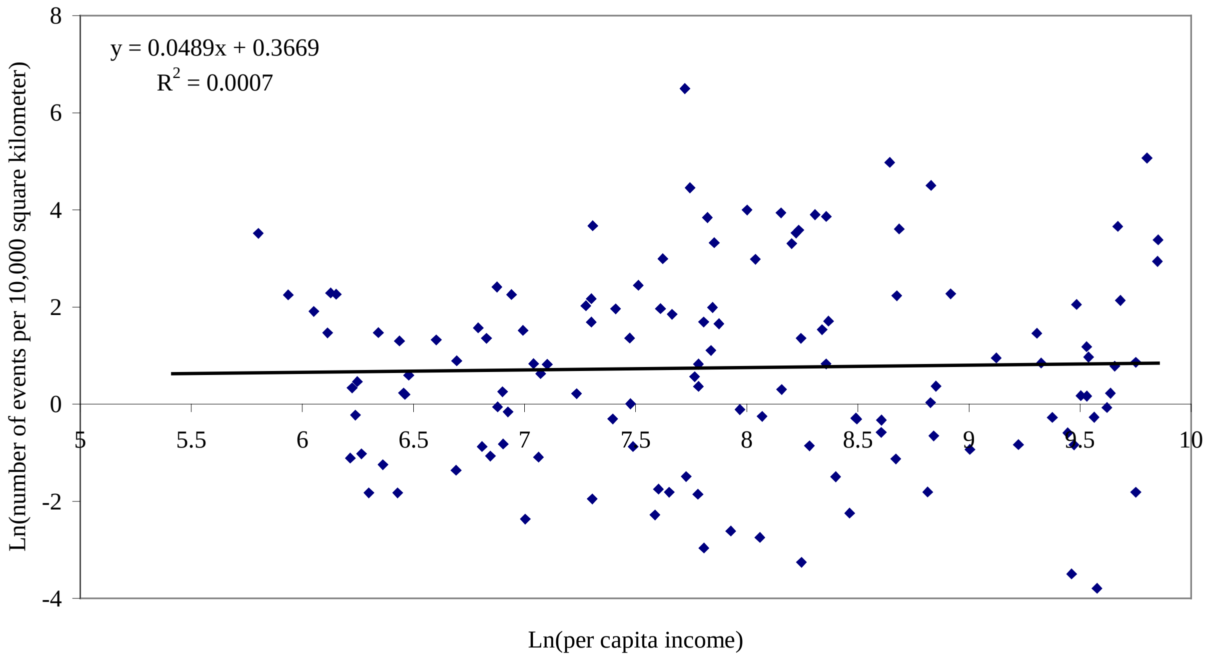


Figure A4.