RALF'S RAMBLING RESILIENCE NUMBER
OR HOW BIG IS YOUR TAU TODAY?

Carl Walters

July 1975 WP-75-85

RALF'S RAMBLING RESILIENCE NUMBER
OR HOW BIG IS YOUR TAU TODAY?

Carl Walters
July 23, 1975

It strikes me that resilience indicators and measures ought to be defined in relation to the policy environment for the system in question. It may be that natural systems flip about among a series of stability regions under the influence of natural perturbations, but we would only be concerned about the resilience of such systems if we could see that some policy might change the boundary locations or introduce new perturbations: resilience is a comparative concept.

Policy Environments

My intent in this note is to develop a resilience indicator that explicitly takes policy issues into account. In arriving at the indicator, I have assumed that any policy environment has four basic features:

(1) there is a nominal or baseline policy that would be followed if no one were concerned about resilience.

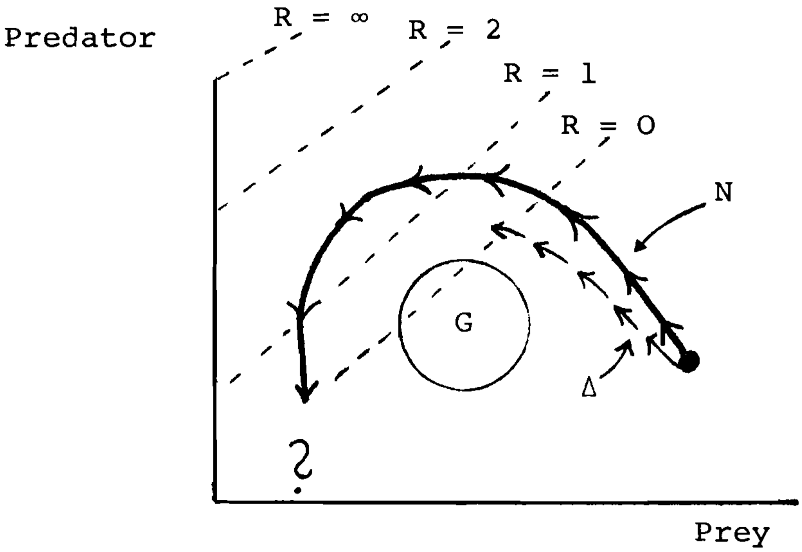
(2) policy changes are limited to an incremental domain set by political and economic conditions and by the perceived level of risk associated with continuing the nominal policy.

(3) there is some goal structure that can be mapped as a satisficing region or utility structure on the system state space.

(4) the locations of stability boundaries, catastrophe folds, and the like are not known; subjective assessments about these locations take the form of a risk mapping on the state space.

These elements can be shown graphically in our inevitable predator-prey phase space as:

Figure 1



G ≡ goal region (may have internal dynamic features like catastrophe folds, etc.)

N ≡ nominal trajectory implied if current policy is followed for a long time.

R ≡ contours of increasing risk that system recovery will be impossibly costly within a reasonable time scale.

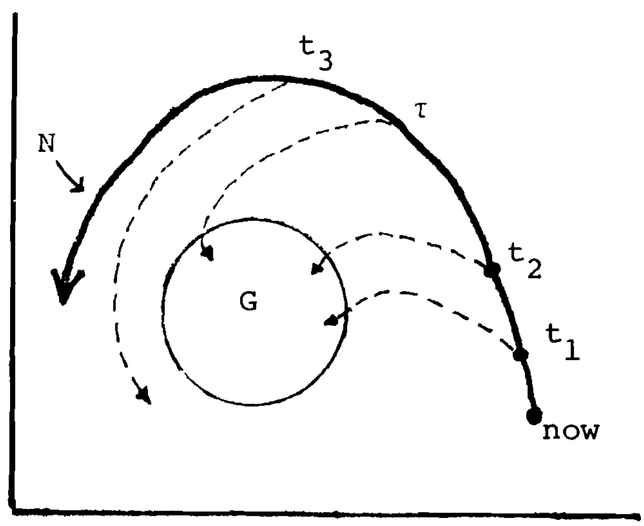
Δ ≡ deviation from nominal trajectory that would result by applying the largest policy change that is believed to be possible.

I believe that it is also necessary to assume some "management time-scale" or time horizon within which we would want to be sure to reach the desired region G (resilience issues are meaningless otherwise - all nautral systems will eventually go extinct or be destroyed). A critical feature of the policy environment is that it is defined by a series of subjective factors: every decision maker will perceive a different set of constraints, possible actions, and risks. Thus any resilience measure that derives from analysis of this environment is also a subjective measure - different decision makers will assess different values for it.

The Tau Indicator

Referring to the definitions above, let me now define the resilience index τ as the maximum amount of time that the nominal policy N could be safely followed and still allow the system to be brought into the goal region G by application of incremental policy changes (Δ) after time τ has elapsed. Graphically, τ has the interpretation:

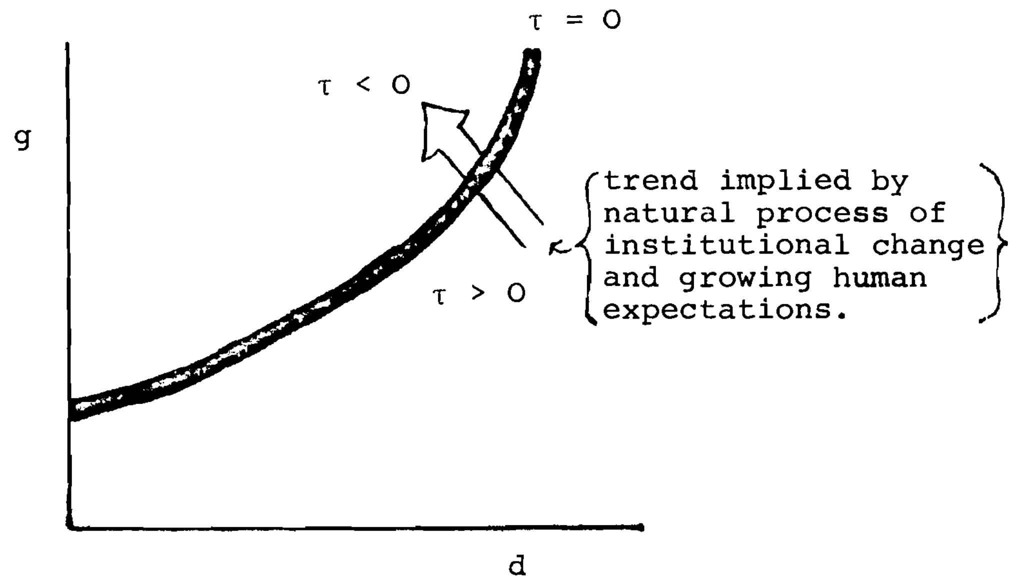
Figure 2



In this example, the nominal policy can be followed up to times t_1, t_2, or τ, and the goal region can be reached afterward by policy changes. On the other hand, changes beginning at time t_3 and afterward are not successful, at least within whatever arbitrary management time scale is defined by the plotted trajectories. Intuitively, τ measures the amount of time that the manager can safely wait before he must institute some possibly painful policy change. A key word in the definition is "safely": every policy-influenced trajectory traces a path through the risk contours of Figure 1 and as such courts at least some probability and magnitude of disaster. Values of τ less than 0 imply that no feasable policy changes (as perceived by the manager who establishes Δ) will be sufficient to reach the goal region.

Suppose next that: (1) we can calculate some measure g that reflects how badly the nominal trajectory will miss the goal region, and (2) we can measure incremental policy changes on a quantitative scale d. Then we can represent the effect of changing goals and increasing flexibility ($\Delta \sim d$) to make incremental policy changes on the system's resilience as measured by τ:

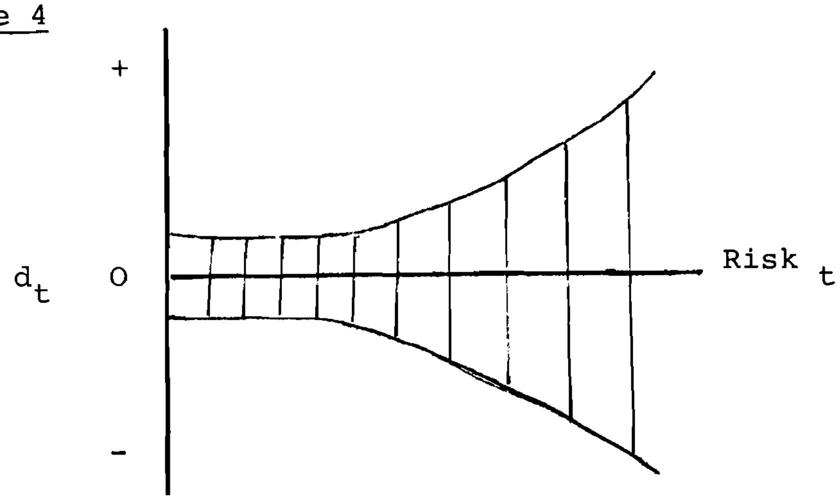
Figure 3



This graph simply asserts that for a given "policy flexibility" d, goals that are more disparate from the nominal trajectory are more likely to be unreachable ($\tau < 0$). Likewise for any disparity g, larger policy flexibility d is needed to insure that $\tau \geq 0$. Thus in an inverse objective function sense, τ measures either the variety of alternative goals that could be reached with a given flexibility d, or the amount of flexibility d that could be lost while still permitting the achievement of those goals represented by any fixed deviation g.

A major complicating factor is that the permissable policy changes (d) are likely to be related to risk levels along the trajectory:

Figure 4



Thus larger policy changes may be possible after the nominal or altered trajectory has entered a high risk region of the phase space.

Perhaps I can clarify some aspects of the τ notion by reference to related concepts. News magazines recently have carried many stories on the financial plight of New York city, with its political tradition of "brinksmanship": the Big

Apple government seems always to wait until disaster is imminent before instituting changes in financial policy. In short, they wait until τ approaches 0 and gamble on a pattern like Figure 4 to give them enough flexibility to save the day. In cybernetics, we worry about Ashby's Law of Requisite Variety: how much flexibility (Δ or d) is necessary in order to control a complex system? In my option foreclosure discussions, I argued that managerial flexibility (options available) often decreases over time - thus pushing τ toward negative values. Sergio Rinaldi tells me that control theorists would view the computation of τ as a problem in "constrained controllability".

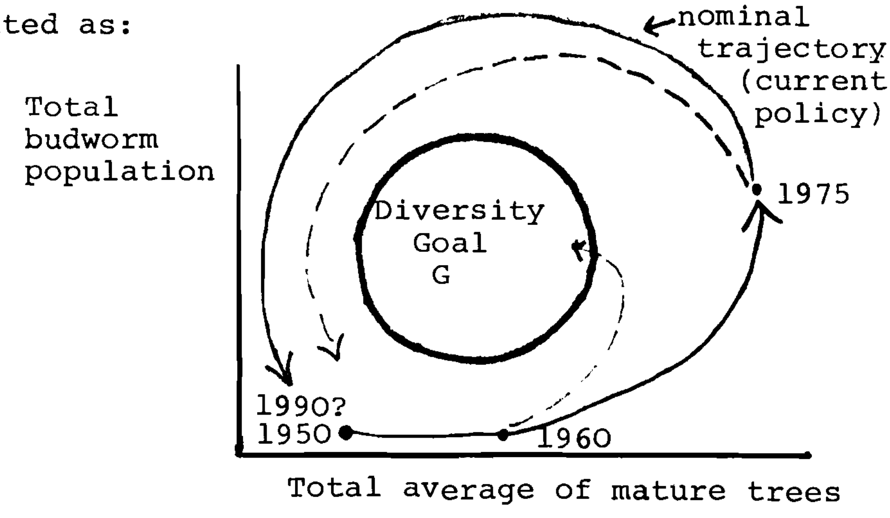
<u>Examples from IIASA Case Studies</u>

There is a strong possibility that we will be able to calculate τ indicators for the IIASA case systems now being used for resilience comparisons. The following section attempts to give more precise definitions through case examples for the fuzzy concepts outlined in the previous section.

1. <u>The Budworm</u>

Much of the resilience and stability analysis in the budworm study has been in relation to single "sites", or 6 x 9 mile grid areas. Budworm dynamics over New Brunswick as a whole can be represented as:

<u>Figure 5</u>

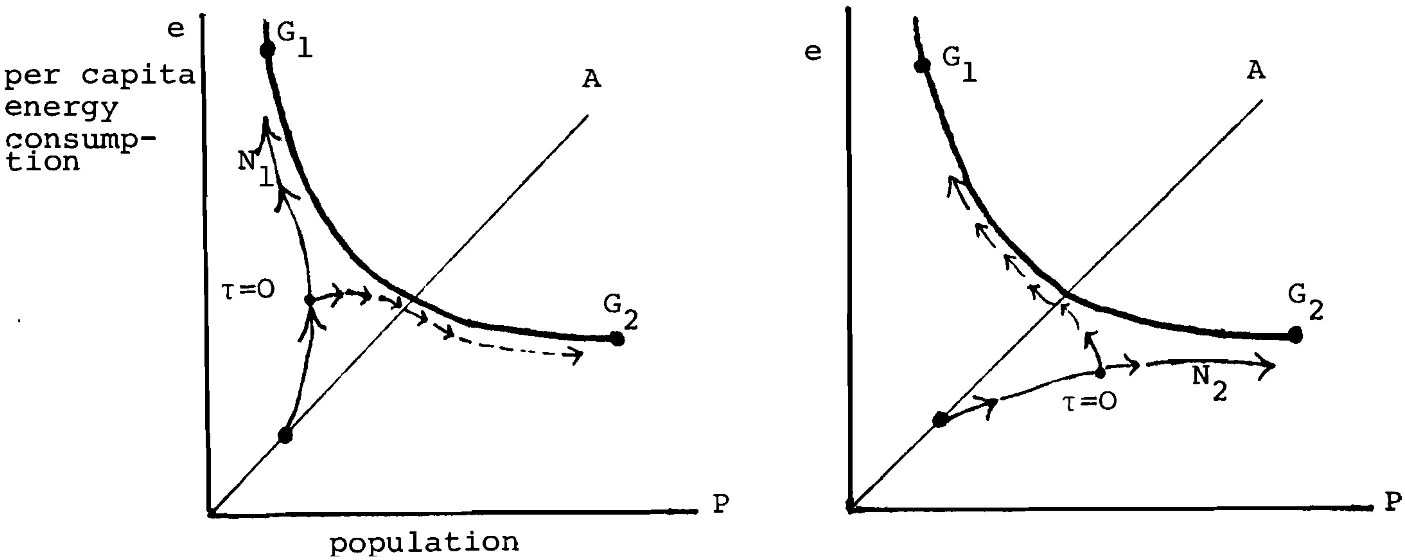


Budworm policies are defined in terms of total areas and locations of tree cutting and insecticide spraying. For economic and political reasons, these controls can only be changed rather slowly; it may be that no real control will ever be possible over the location of forest cutting. It appears that the best long run goal would be to generate and maintain a spatially diverse (mixed age) forest with small budworm outbreaks going on all the time. We do not yet know if there is a feasable policy for reaching and maintaining this goal given present constraints on cutting and sparying. My guess is that such a policy does exist, but that it would have been necessary to implement it at least 15 years ago in order to reach the goal state by around the year 2000 (a reasonable time horizon?). Thus my guess is that $\tau = -15$. Note that the nominal policy, based on myopic local decisions for cutting and spraying, would never achieve the goal.

2. Haefele Societal Equations

The societal equations for energy development pose another kind of problem, in which there are at least two alternative goal regions and high uncertainty about which region is best. Graphically, there are two alternatives for nominal policy trajectories:

Figure 6



In the left-hand case, goal G_1 is considered best at first, and $\tau = 0$ represents the last point along the nominal policy trajectory N_1 for which it is possible to implement policy changes so as to recross the separatrix A and head toward the alternative goal G_2. In the right-hand case, G_2 is considered best and $\tau = 0$ represents the last point along policy trajectory N_2 for which it is possible to move back across the separatrix A. The two graphs can be combined to define a "resilience region" of alternative state combinations for which it remains possible to change the ultimate goal:

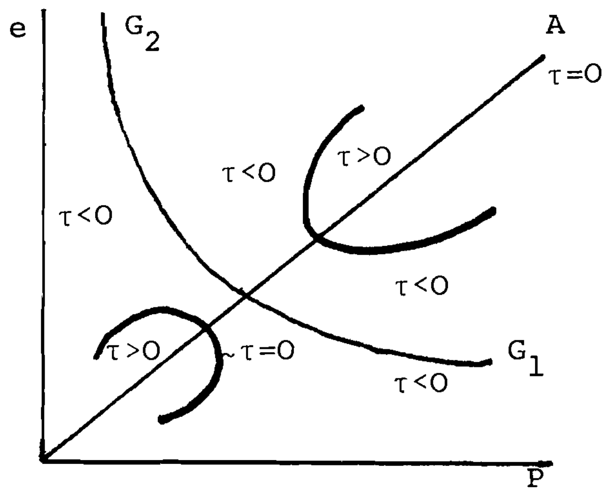


Figure 7

In this case, incremental policy changes are related to rates of investment in new energy sources and to changes in public acceptance of risks. We could consider the nominal trajectories N_1 and N_2 as the "pure market cases", in which market penetration of alternative energy sources is not affected by public policy. Then modified trajectories represent various degrees of public investment and control: in this example, the concept of limited policy changes due to political and economic constraints becomes quite clear.

In essence it appears that many arguments about ecological doom are based on the implicit notion that we are already too far along trajectory N_2, so that $\tau < 0$ now. This is not saying that basic resources will be exhausted soon, but rather that we are no longer capable of corrective policy responses if unexpected limits do appear - a most frightening possibility indeed.

3. Fisheries development

Virtually all of the world's fisheries are operated as "open-entry" predator-prey systems, with no control on the dynamics of fishing fleet (predator) development. Most international fishing agreements specify very precisely that only the catches should be controlled, through quotas that are periodically adjusted. The experience has been that quotas are quite difficult to change in the face of economic pressures, and fishing investment increases until the quota is distributed across such a large fleet that profits (incentives for further investment) disappear. There is a possibility to control the predators through license limitation schemes and through subsidy-taxation policies that modify the investment dynamics; but such policies could only be implemented and changed very slowly without causing excessive economic and social hardship.

Fishery development can be represented in a predator-prey phase space:

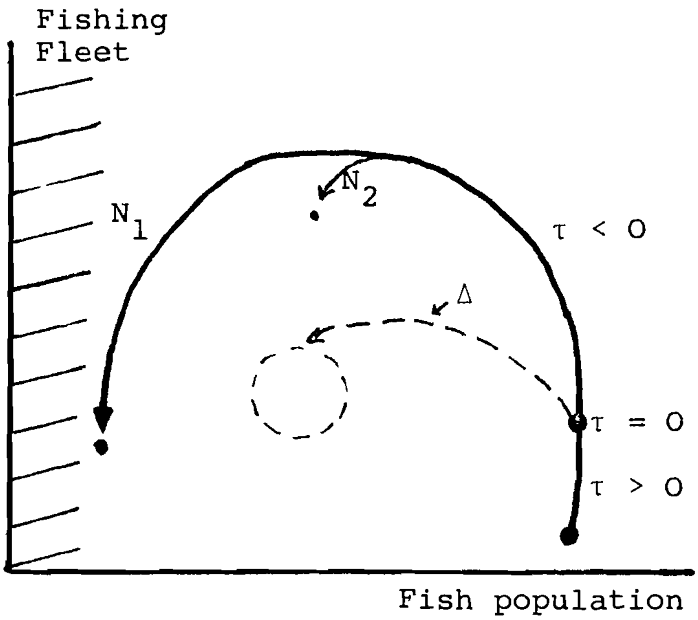


Figure 8

N_1 ≡ nominal policy with no catch quotas (no management at all)

N_2 ≡ nominal policy with quotas for population protection but no economic control

Δ ≡ policy with some quota and economic control

G ≡ goal region with productive population and reasonable fishing profits

Quota management (policies like N_2 above), has developed under the very explicit recognition that low populations (shaded area above) may cross some boundary after which extinction is inevitable.

For the fishing example it is simple to give a quantitative interpretation to the concept that incremental policy changes are strongly constrained:

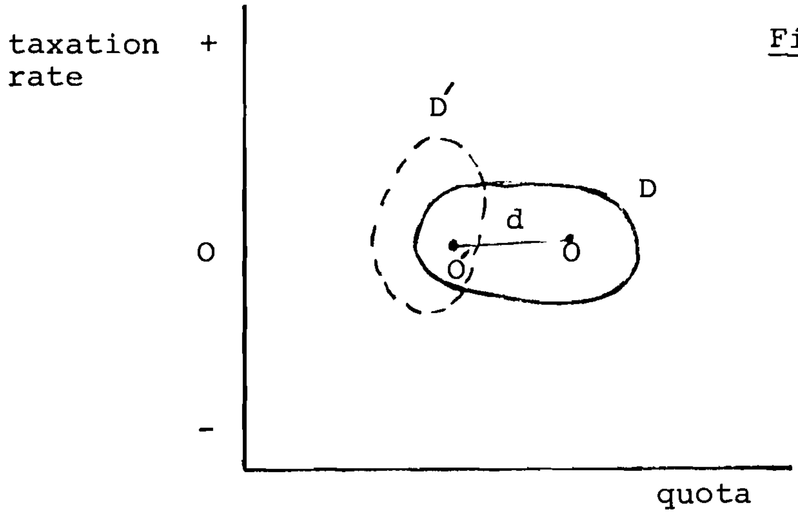


Figure 9

O - current policy

D - domain of possible policies after one time step into the future (usually one year in fisheries)

d - a particular incremental policy change (to policy O′)

D′ - domain of possible policies at time t + 2, given that policy O′ is followed at time t + 1.

In this example the domain D is drawn to illustrate a special problem: once policy change has been initiated (e.g. some tax rate has been applied and accepted), larger policy changes (wider range of taxation rates) may afterwards be possible.

4. Obergurgl Growth

We have argued that this alpine village is facing economic disaster through overdevelopment for tourism. The village economy is now in very good shape, but there is a large cohort of young people (10-15 years old) who will soon be demanding opportunities to enter the tourist industry by building their own hotels. The land available for building is very small and in its natural state (meadows and pastures) is of major aesthetic value and economic importance (ski slopes, appearance to tourists). The situation has developed:

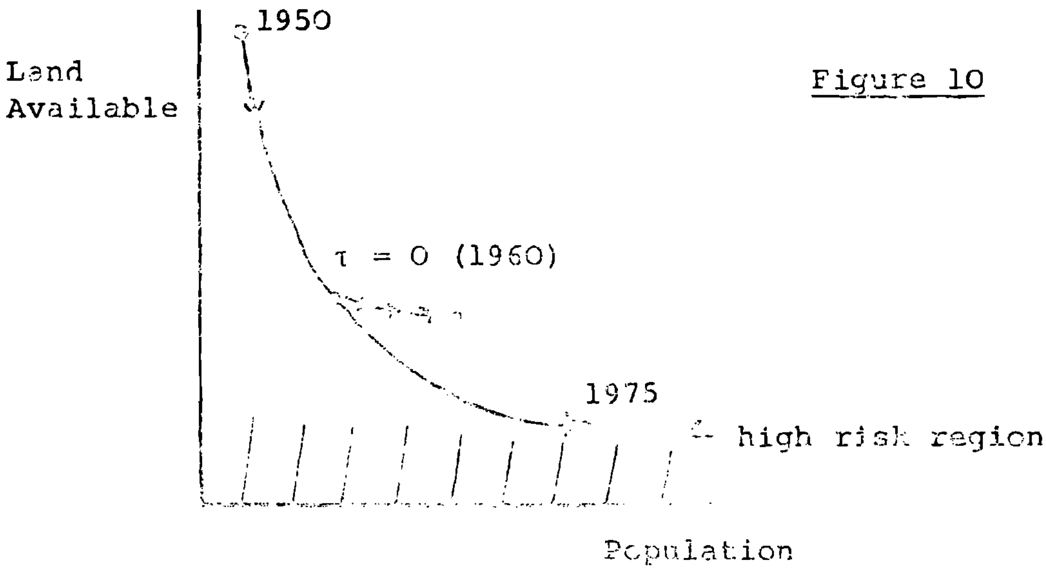


Figure 10

To prevent the system from entering a high risk region, it would have been necessary to begin controlling population growth (birth rates) at least 15 years ago ($\tau = -15$). The sad thing is that such a policy change might actually have been feasable in 1960; the Obergurglers take great pride in pointing out that during the 1800's their forefathers instituted a 30 year moratorium on marriages in order to prevent population growth that they perceived would lead to starvation in their limited agricultural economy.

Conclusions

Much work is needed to clarify the definition of τ and to make precise the policy and system assumptions that must be made in order to calculate it for particular systems. The potential payoffs are considerable, especially for the policy maker who seeks some quantitative justification for policy change or some indication of how urgent it is to implement some recommended change. As an object for intellectual study, τ involves painful ambiguities since it can only be defined in relation to highly subjective assessments about limits on policy change; in a sense this makes it an especially challenging problem. As an object for evaluation in our workshops involving scientists and policy makers, τ might form a very useful focus for discussions leading to clearer statements of policy objectives and constraints.