Predicting Catastrophic Declines in Population Density: Measuring the *Critical Slowing Down* of Processes to Predict Catastrophe

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Abstract

This paper describes a recent study that uses catastrophe models, an approach that has been proven across multiple disciplines from physics to ecology, to describe tipping-point events in dynamical systems. If these models can be applied to human organizing, then lessons from these systems may also apply to innovation in social, political, and economic systems. In particular, when a biological system's dynamic state is described by a fold catastrophe model, a recent study identifies leading indicators that can signal the approach of a "tipping point" toward instability of that system. If analogous leading indicators can be identified within human activities, and if the relevant parameters can be identified and measured, then there is potential that early warning signals can be defined with regards potential disruptions to political and economic institutions. Such analysis would add analytical support to naysayers' warnings during times of crisis. Had such signals been known to exist in 2006 and 2007, it is possible that the financial crisis could have been averted, or at least its impact might have been mitigated through policy interventions.

Introduction

This briefing paper suggests the possibility that the internal behavior of a system as it responds to external events might offer clues that would predict an impending bifurcation event. It uses a recent study (Dai et al., 2012) to suggest that the use of fold catastrophe modeling might be a useful way to describe tipping-point events that indicate qualitative changes in the stability characteristics of dynamical systems. If indeed these models can be applied to human organizing, as has been suggested (Goldstein, Hazy & Silberstang, 2010), then lessons from biological systems like those described in the study may also apply to innovation and entrepreneurship in social, political, and economic systems.

The first indicator identified in the study (Dai et al., 2012) is an observed lessening the of organization's *resilience* when the system is shocked by an external event. This implies a decline in the probability that the system will recover to its prior stable state. The second seemingly related indicator is called *critical slowing down.* This means that the system begins to take longer to dampen fluctuations or perturbations that impact it, dynamics that can observed as increasing observable variance in populations.

Both of these indicators reflect the fact that informational differences about events in the organization are being retained as "options" within the system (at the fine-grained level), and that this information has not yet been incorporated into a (coarse-grained) structural "innovation" within the system, one that would make the organization's behavior more predictable *as a system*. After the Dai et al. (2012) study is described, each of these two potential indicators is discussed. This briefing paper concludes with a discussion of the implications of this approach.

Empirical results offer a new direction

In a recent article in *Science*, Dai et al. (2012) describe a detailed study that shows how the fold catastrophe model accurately describes the changing level where the population density of a yeast culture tends to stabilize depending upon the changing value of a well-defined and measureable parameter.

As shown in **Figure 1**, the parameter shown on the horizontal axis reflects the level of dilution to which the yeast culture is subjected on a daily basis. For low levels of the parameter, the culture tends to stabilize at a particular level of population density, a fixed point attractor. As the parameter increases, a certain bi-stability develops wherein some cultures stabilize at the expected density, and some die off (an alternative stable fixed point attractor). Beyond a certain dilution level, the only result is extinction; this is a catastrophic collapse.

Leading indicators of catastrophe

As the parameter on the horizontal axis increases, the tipping point approaches. Since the exact value of the parameter where this occurs is often unknown, it would be useful to be able to identify reliable signals that would indicate that something is about to change, that the possibility of radical change is in the offing. Although observers might feel this intuitively, a toolkit of analytical techniques is needed to explore what is happening.

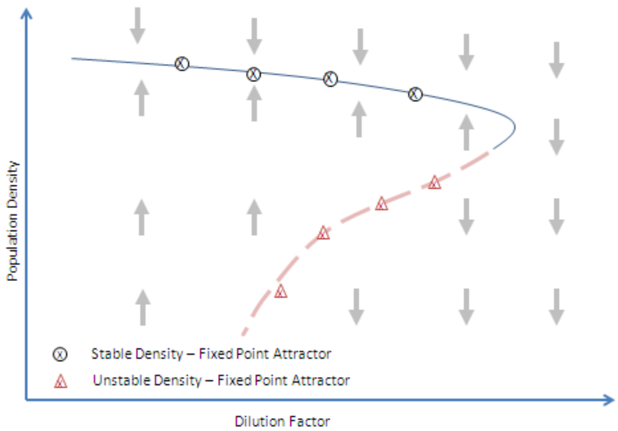

Figure 1. Illustration of how stable population densities and unstable ones act as attractors according to the prediction of the fold catastrophe model. (Based upon Dai et al., 2012).

Loss of resilience

The first indicator of an impending sudden drop in population density identified in the Dai et al. (2012) study was loss of *resilience* when the yeast culture was subjected to a salt shock. A lower value for the dilution factor parameter translated into a greater probability that the culture would survive after the shock. A higher value, above a threshold, indicated that there was a non-zero probability the system would not recover.

Thus, when a stable organization begins to take longer to recover from shocks, one might expect that a tipping point toward catastrophic collapse might be coming; this signals that there is reason for caution.

A critical slowing down

The second indicator involves what is called a *critical slowing down* in the dampening of fluctuations, experiments that arise within the system's functioning. When a variant process arises, it tends to remain active for a longer period, and thus the orbits of many fluctuations persist and can be observed. Dai et al. (2012) have identified empirical markers that signal the onset of *critical slowing down* as the tipping point is approached.

As the authors point out, this dynamic condition can be identified as an *increase in variance* across samples in the distribution of outcomes as well as an *increase in autocorrelations* within the sample. This latter result would indicate that organized deviations from normal functioning—or "experiments," as described by Goldstein, Hazy and Lichtenstein (2012)—are remaining active longer before they are dampened or eliminated by the system's internal stabilizing forces.

Implications for research in HID

The dynamics described here apply to a yeast culture, but they might offer a useful metaphor for certain aspects of human interaction dynamics. The same fold catastrophe (or the cusp with two parameters) may be a useful model for describing how externalities impact the stability of relevant aspects of social system functioning.

For this to happen, it is necessary to determine the internal variables and parameters that are relevant in the human situation, and then demonstrate the fold catastrophe model empirically. If this can be done, one would need to verify empirically the appropriate early warning signals like those described herein for yeast cultures. Possible ways to test this would be to study the collapse of financial institutions during the 2008 banking crisis, bankruptcies more generally, or even the collapse of project team collaboration in controlled settings.

With regards interventions, if these warning signals are identified and can be observed empirically to cross certain thresholds, then there is the potential that a bifurcation is likely if the parameter changes further in the destabilizing direction. In response to this information, interventions could be planned and implemented as predicted by the models.

References

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