Time for a change

The idea of equilibrium — as a natural state of rest or balance — is among the oldest of all scientific concepts. Aristotle put equilibrium at the centre of natural law, suggesting that all objects, unless otherwise disturbed, tend to approach a state of rest — a condition of timeless, unchanging perfection. Galileo may have replaced Aristotle's state of rest with one of uniform motion, but he didn't question the view that nature has an equilibrium condition, or that science should seek to describe it.

Even so, Galileo made a profound point by bringing motion — a concept decidedly involving change — into a framework based on the absence of change. Today we have gone a long way along the path suggested by Galileo's generalization, and notions of equilibrium often have rich dynamic connotations. Boltzmann, Maxwell and other physicists of the nineteenth century showed how unchanging regularities at the macroscopic level — fixed densities or pressures — could emerge from ongoing change and fluctuation at the molecular level. The mathematical theory of deterministic chaos brought even wildly erratic and unpredictable behaviour within the realm of equilibrium concepts (through the notion of a strange attractor). Likewise, the discovery of frustrated interactions in spin glasses and other condensed-matter systems also brought persisting change into equilibrium thinking: some systems possess dense nests of potential equilibrium states and wander perpetually among them.

But much of science, it seems, is digesting this richer view of equilibrium only slowly. "We would all be better off", Robert May once noted, referring to deterministic chaos, "if more people realized that simple nonlinear systems do not necessarily have simple dynamical properties." The same might be said for a more versatile idea of equilibrium — it doesn't have to mean that nothing changes.

About a decade ago, a realization of this kind helped to spur progress in theoretical ecology. Since the 1970s, theorists had been arguing over whether more complex ecosystems — those with richer networks of interacting species — should tend to be more stable than simpler ones. Most ecologists expected, intuitively, that complexity should probably enhance stability. A dense web of interacting species, after all, would have more ways to respond and adjust to environmental challenges.

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Yet simple dynamical models of randomly constructed webs of interacting species (studied, as it happens, by May and others) didn't work this way. After a perturbation, simple ecologies tended to return to equilibrium — a state of fixed populations — more frequently than did the more complex ones. Still, the weight of empirical evidence, especially from long-term studies of plant communities, suggested that more complex ecologies are generally more stable. Why the inconsistency?

The key, as a number of ecologists eventually realized, was a mathematically convenient but otherwise restrictive notion of equilibrium and stability used in the early models, which deemed a system to be stable only if it returned precisely to the fixed state it had been in before being perturbed. An ecosystem might well be considered perfectly stable if it is able to take a shock and go on persisting, in some more or less healthy condition, regardless of how much it has actually changed. Under this more realistic notion of stability, it turns out, many food-web models do indicate that more complex ecosystems tend to be more stable (McCann, K. *Nature* **405,** 228–233; 2000).

This simple realization has set theorists free, and ecologists in the past decade have begun to embrace population variability in space and time as natural to ecological function. A richer view of what might be involved in an equilibrium has led some to suggest that its not just complexity but variability that promotes ecosystem persistence in the face of challenges (McCann, K. & Rooney, N. *Phil. Trans. R. Soc. B* **364,** 1789–1801; 2009).

A similar appreciation for the richer possibilities of equilibrium might help elsewhere, especially in finance. Prevailing notions of equilibrium in economics typically emphasize unique and supposedly stable equilibrium states. That seems ill-suited to the understanding of abrupt transitions, such as the liquidity crisis of 2007–2008, which took form very quickly and has proven very resistant to reversal. Qualitatively, such a change looks less like an equilibrium than like a transition between two states, leading from one global phase to another.

Indeed, an enlightening study shows that the possibility of such transitions emerges naturally from a network picture of banks and other institutions interacting on the basis of potentially fragile bonds of trust. As Kartik Anand, Prasanna Gai and Matteo Marsili argue (http://arxiv.org/abs/0911.3099; 2009), trust lies at the heart of financial systems, which depend for their operation on dense networks of credit relationships. But trust can be eroded if 'bad news' enters the network, throwing doubt on the financial viability of some parties within it. Modelling such a network as a coordination game, as each party tries to profit, but also to protect itself, they find that collective trust can collapse abruptly, leading to credit crises.

As they note, each participant in such a network continually faces the decision of whether or not to call in some of the loans it has extended to others, as it grows concerned about those counterparties' financial health and ability to pay. A simple model shows that such a system can fall into two very different equilibrium states — a 'good' state in which a dense network of credit relations thrives, and a 'bad' state with a sparse credit network. In the latter, investors have doubts about others' ability to pay and hence may withdraw their credit relationships.

The transition between the two equilibria is sharp. Equally important, however, is a hysteresis effect — once the system 'tips' into the sparse state, the restoration of trust requires considerable effort, with model parameters needing to shift well beyond the turning point. This outcome looks very much like the state of the banking system over the past two years, in which banks have been loathe to lend even as governments have pumped them with cash infusions to re-establish healthy credit networks; re-establishing trust hasn't been so easy.

Thus, one might see the deeper cause of the recent crisis as the network dynamics that make it possible for some event — in this case, the losses on sub-prime mortgages — to trigger a rapid and far-reaching breakdown of trust between banks and between investors and banks. This is the kind of possibility that the simplest notions of markets in a static and unique equilibrium cannot describe, but less restrictive models make very evident. ❐

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