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THE TRIUMPH (AND FAILURE) OF JOHN NASH'S GAME THEORY

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The mathematician John Nash, in Beijing, China, in 2011. Photograph by ChinaFotoPress/Getty

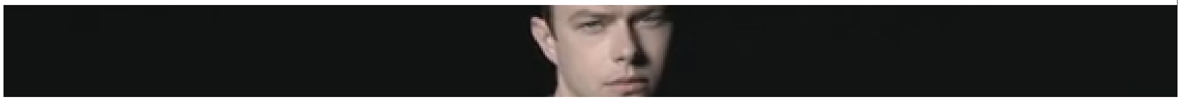
Thanks to the sterling efforts of Sylvia Nasar, Ron Howard, and Russell Crowe, many people are aware that John Nash, the Princeton mathematician who was killed over the weekend in a car crash on the New Jersey Turnpike, lived a remarkable life. It included early academic stardom, decades of struggling with schizophrenia, and, in 1994, a shared Nobel Memorial Prize in Economic Sciences. But outside the field of economics, Nash's contribution to game theory, for which he was awarded the Nobel, remains rather less well understood.

Although it is often used in economics, game theory can be applied to any venue where people, or other decision makers, interact strategically and follow rules-based behavior. The setting could be nuclear negotiations, such as the ones currently taking place between Iran and the great powers. It could be a product market, in which a number of firms compete for business. Or it could be a political campaign, in which various candidates try to outdo each other. The word "strategically" is important, because the various players, in choosing from a variety of possible moves, take account of one another's actions, or likely actions. And the phrase "rules-based" means that the players are acting purposefully and seeking to maximize their own advantages, rather than behaving passively, or randomly.

On one level, Nash's contribution to game theory was highly mathematical, and, ultimately, somewhat trivial. That is how his intellectual rival at Princeton, John von Neumann, reputedly described it back in 1949, anyway, and he had a point. In co-authoring the 1944 magnum opus "Theory of Games and Economic Behavior," von Neumann had virtually invented a new subject, complete with its own language. Nash, in diverting from his studies in pure mathematics to this nascent field, showed that in a certain class of games a certain set of outcomes exists: those outcomes are now called "Nash equilibria."

Many of Nash's fellow mathematicians were more impressed by his work in algebraic geometry. Over time, though, the game-theoretical methods he pioneered became widely used in the social sciences, and especially in economics. Indeed, in a 2004 article for the National Academy of Sciences that reviewed the genesis and development of Nash-based game theory, the economists Charles Holt and Alvin Roth noted, "Students in economics classes today probably hear John Nash's name as much as or more than that of any economist."

To understand why that is, you need to know a bit about the history of economics. Before game theory was invented, economists had a workable account of the dynamics of competitive markets with many buyers and sellers, such as the markets for grain and other commodities. This was the theory of supply and demand, which Alfred Marshall and others developed. Economists also had a workable theory of how the economy as a whole operates: Keynesian economics. But in studying the dynamics of industries where a handful of businesses compete against one another, or how corporations respond to regulation, or how bidders in an auction decide how much to bid, they hadn't made much progress.



Enter von Neumann and his co-author, Oskar Morgenstern, who provided an intellectual framework for analyzing such situations: game theory. But despite the monumental nature of their achievement, von Neumann and Morgenstern succeeded in showing that definitive solutions, or "equilibria," existed for only a fairly narrow category of interactions: so-called zero-sum games, in which one person's gain is another person's loss. (Poker is a zero-sum game; so is coin tossing.) Often in real-world situations, though, such as how to divide a market among a few competitors, there is a positive economic surplus to be divided: the question is who gets what, and that depends on which actions (or "strategies") are adopted.

This is where Nash came in. He started out by defining a particular solution to games—one marked by the fact that each player is making out the best he or she (or it) possibly can, given the strategies being employed by all of the other players. Then, applying a deep-mathematical theory that had been developed earlier by the Dutch mathematician L. E. J. Brouwer, Nash demonstrated that such an equilibrium exists in *any* game with a finite number of players and a finite number of moves to choose from.

It was this derivation that von Neumann dismissed as trivial: analytically, Brouwer's "fixed point theorem" did much of the work for Nash. But the lasting importance of Nash's contribution wasn't the existence proof, it was the idea of a "Nash equilibrium," or, as it is sometimes called, a best-response equilibrium. Over time, this concept would become almost as familiar in economics textbooks as supply-and-demand curves.

The reason is its broad applicability, which extends well beyond economics. Take, for example, the problem of deciding which side of the road to drive on—a question that clearly involves trying to figure out what everybody else will do. If you are living in the United States, where custom and law dictate using the right lane, sticking to that lane is a Nash equilibrium: it gives you the best chance of getting to your destination in one piece. And since the same logic applies to everybody else, the "stay on the right" solution is pretty stable.

Like the intersection of a supply curve and a demand curve, the concept of a Nash equilibrium appeared to pick out a distinct point where things would inevitably end up.

Indeed, once you grasped the idea, it was hard to see how an outcome that wasn't a Nash equilibrium could be sustained for very long in the absence of coercion or misinformation. If there were a better response available, such as driving down the median or zigzagging from left to right, at least some of the players would eventually adopt it. And that would mean that the original solution wasn't a stable solution at all.

In the nineteen-sixties, seventies, and eighties, economic theorists worked on extending Nash's approach. At the same time, however, it became clear that his concept of equilibrium has some serious drawbacks that limit its usefulness. To start with, there is often more than one best-response equilibrium, and, in some cases, there is a very large (or even infinite) number of them. For a methodology that is designed to pick out particular solutions, this non-uniqueness property is a serious problem, especially since there is usually no obvious way of deciding which Nash equilibrium will end up being selected.

To return to the driving example, a moment's reflection should persuade you that driving on the left can also be a best-response equilibrium. In the United Kingdom and many other countries, it's the one that has been adopted and enshrined into law. But why do Americans drive on the right and Brits on the left? And if we were starting out from scratch, which convention would be adopted: left or right? Nash, and the many economists who have followed in his footsteps over the past sixty-five years, can't necessarily provide an answer.

This is just one of the drawbacks of Nash's approach. Another problem is that game theory is mentally taxing. In many games, including some that initially seem pretty simple, finding the Nash equilibria can be very difficult, at least for ordinary mortals. And when the rules of the game aren't clear, or when some information is hidden, or when the passage of time is introduced into the analysis, even seasoned game theorists sometimes have a hard time figuring things out. To be sure, various refinements of the Nash equilibrium can be called upon to deal with some of these complications, and there are also refinements of the refinements—but they are even more complicated.

The long and the short of it is that if the purpose of economic theories is to predict which of many possible outcomes will occur, Nash's methodology often isn't much help—a point acknowledged by David Kreps, an economic theorist at Stanford, back in 1990. But asking any theory in the social sciences to correctly predict the future is a very demanding requirement. And asking that it accomplish this task across a wide range of areas, such as the ones to which Nash's approach has been applied, is surely too much.

That's partly because Nash-influenced game theory isn't actually a testable scientific theory at all. It is an intellectual tool—a way of organizing our thoughts systematically, applying them in a consistent manner, and ruling out errors. Like Marshallian supply-and-demand analysis or Bayesian statistics, it can be applied to many different problems, and its utility depends on the particular context. But while appealing to the Nash criteria doesn't necessarily give the correct answer, it often rules out a lot of implausible ones, and it usually helps pin down the logic of the situation.

For these reasons, studying game theory, and learning how to recognize a Nash equilibrium, are highly worthwhile exercises. Once you learn the basics, it is amazing how broadly they can be applied. (Much of the advanced stuff can be safely skipped.) For example, in writing a book about the economics of the financial crisis and trying to figure out why so many people on Wall Street and elsewhere did things that ultimately blew up in their faces, I relied heavily on the Prisoner's Dilemma, a simple game involving a particular type of Nash equilibrium that shows how certain incentive schemes can promote self-destructive behavior.

My experience wasn't out of the ordinary. These days, political scientists, evolutionary biologists, and even government regulators are obliged to grasp best-response equilibria and other aspects of game theory. Whenever a government agency is considering a new rule—a set of capital requirements for banks, say, or an environmental regulation—one of the first questions it needs to ask is whether obeying the rules leads to a Nash equilibrium. If it doesn't, the new policy measure is likely to prove a failure, because those affected will seek a way around it.

John Nash, in writing his seminal 1951 article, "Non-Cooperative Games," which was published in *The Annals of Mathematics*, surely didn't predict any of this. He was then a brilliant young mathematician who saw some interesting theoretical problems in a new field and solved them. But one thing led to another, and it was he, rather than von Neumann, who ended up as an intellectual celebrity, the subject of a Hollywood movie. Life, as Nash discovered in tragic fashion, often involves the unexpected. Thanks to his work, though, we know it is possible to impose at least some order on the chaos.

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