

## John Nash – Founder of Modern Game Theory

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If economists are ranked according to the value of their contribution per paper they wrote, then John Nash will have an excellent claim for the top spot, with the possible exception of Frank Ramsey. In a short but brilliant career, he wrote just half a dozen papers that liberated noncooperative game theory from the two-person and zero-sum confines of von Neumann and Morgenstern, greatly improved upon their solution for an important class of cooperative games, and laid the foundations of the approach that has come to dominate thinking and modeling in economics, politics, business studies, and other disciplines as well.

John Nash burst upon the economics scene in 1950 with two papers that have defined the subsequent direction of economic applications of game theory in both its cooperative and noncooperative modes. The latter line was launched by his simple and elegant general proof of the existence of a noncooperative equilibrium in  $n$ -person games. In Nash's framework each player takes the others' strategies as given and chooses his own strategy; equilibrium is where all these choices are mutually consistent. In the standard Marshallian or Walrasian theory of competitive markets, each individual consumer or firm takes the market prices as given and makes or her own purchase and sale decisions; the equilibrium price is where all these choices are mutually consistent. Therefore Nash's approach is a natural extension to strategic situations of the familiar economic framework of choice and equilibrium. What is more, Nash's theorem works for any number of players, and with arbitrary mixtures of common interests and conflicts of interest; this is needed in economics where many people interact, and there are potential mutual gains from trade as well as distributive conflicts. All this makes Nash equilibrium such an appropriate way to model interactions of rational individuals that it has taken over the field of economics and spread to many other fields. Writers using this theory no longer feel the need to cite Nash's paper explicitly, but merely say "Nash equilibrium". If Nash got a dollar for every time someone wrote or said "Nash equilibrium", he would be a rich man.

Some of the best ideas in science are simple, even obvious, once someone has thought of them. These are the papers that cause you to smack your forehead and say "Why didn't I think of that?" With Nash's paper I am spared that personal chagrin because I was only five years old at the time, but I am surprised that others including the legendary von Neumann did not think of it. In my view it makes Nash's contribution that much more valuable.

Nash's contribution to the theory of bargaining was equally pathbreaking. Before him, economists thought that the outcome of bilateral bargaining was indeterminate, dependent on some vaguely defined "bargaining powers" of the participants about which economics could say little. The more formal cooperative game-theoretic approach of von Neumann and Morgenstern was equally indeterminate; it offered as the solution the whole set of Pareto efficient allocations. Nash took the cooperative approach, and laid down a set of properties such that there would be a unique solution satisfying them for each bargaining problem in a large class of such problems. The solution had some features of fair arbitration to divide up the players' gains from the deal, but this was not central to Nash's aim. He thought of the outcome as resulting from some unspecified process of negotiation or strategizing by the individual bargainers each acting in his own interests; the cooperative solution was intended as a device to cut through the complex details of this process and be useful for predictive purposes. The idea of elaborating this connection, so that "steps of negotiation become moves in a larger non-cooperative game", has become known as the "Nash program". The best known and most influential contribution to this line of research is Ariel Rubinstein's work on the bargaining problem. But even before that appeared, many applications in labor economics and international trade had used Nash's axiomatic and cooperative solution with great success for the predictive purpose he intended.

Laboratory experiments have become an important method of testing theories of behavior and interaction, and Nash was a pioneer here too. In the early 1950s at RAND, in collaboration with Kalisch, Milnor and Nering, he carried out experiments involving games of bargaining and coalition formation. Equally foresighted was his incisive criticism of others' experiments on the prisoners' dilemma, where a pair of players played the game many times, and were found to cooperate a great deal: "The flaw in the experiment as a test of equilibrium point theory is that the experiment really amounts to having the players play one large multi-move game. One

cannot just as well think of the thing as a sequence of independent games as one can in zero-sum cases." This could be the first glimpse of the possibility of tacit collusion in repeated games, which has become such an important topic in economic and political applications.

I have limited myself to discussions of Nash's work in economics, because I lack the expertise to discuss his contributions to mathematics – embedding of Riemannian manifolds, existence of solutions for parabolic and elliptic partial differential equations – which many mathematicians regard as even more important than his Nobel-winning work in economics, and which made him a leading candidate for a Fields Medal.

Nash accomplished so much in so few papers that one wonders what would have happened if his academic career had continued in the normal way after 1960. Would he have continued to produce equally startling papers at the same rate? Alas, we will never know. 'Ον οί τεοι φιλουσι αποθνεσκει νεος. (He whom the gods love dies young.) That is what happened to Frank Ramsey. In John Nash's case, gods must have loved his mind so much that they took it away from us for almost thirty years. But gods are not heartless; they must have heard the prayers of John's many dedicated friends and even more numerous admirers, and have at last restored his mind to us. He is actively engaged in research that continues the Nash program he laid down almost half a century ago, and is developing an approach to many-player bargaining that replaces the cooperative coalitional formation by a noncooperative process of election of designated negotiating agents. We await the results eagerly.