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1. A place in the history of social thought

My goal is to reexamine Nash's contributions to noncooperative game theory as a major watershed event in the development of social theory, and as one of the most important intellectual advances in the 20th century.

But there are good current books history of economic theory (Jurg Niehans 1990) that fail to allocate even one full page to Nash's work.

To understand the importance of Nash's work, and how it could have been so undervalued, we should begin with the definition of economics itself.

Smith (1776): "Political oeconomy, considered as a branch of the science of a statesman or legislator, proposes two objects: first to provide a plentiful revenue or subsistence for the people, ... and secondly, to supply the state or commonwealth with a revenue sufficient for the public services. It proposes to enrich both the people and the sovereign."

Samuelson (1992): "Economics is the study of how societies use scarce resources to produce valuable commodities and distribute them among different people."

If we think economics is mainly about resource allocation then perhaps game theory could be viewed as a peripheral topic in economics.

Cournot (1838): "From a standpoint of mere etymology, whatever appertains to the organization of society belongs to the field of Political Economy; but it has become customary to use this last term in a sense more restricted ... being occupied principally with the material wants of mankind..."

Indeed, if we read Xenophon (author of first Oikonomikos) and other philosophers of ancient Greece, we find a passion to understand the institutions of society, but no separate academic specialization in the study of markets for material goods.

I want to argue that the effect of Nash's breakthrough was to stimulate a change in the scope of modern economics and a reorganization of social science, so that the analysis of incentives in any social institution is of interest to economists today.

Questions: What exactly was the breakthrough?

Why was it so important? And why was it so hard to see before Nash?

2. Niehans's outline of the History of Economic Theory
Niehans divides History of Economic Theory into the Classical Era (1630-1830),
Marginalist Era (1830-1930), and Era of Economic Models (since about 1930).

Among the problems of social organization, the production and distribution of
material goods are more amenable to quantitative analysis, because flows of money
and goods are measurable, and because systems of exchange can be characterized
by tractable linear equations (flow-balance equations, no-arbitrage equations).
So in Niehans's Classical Era, economic theory first achieved a higher level of
analytical rigor in social science by focusing on questions about the flows of goods
and money among interdependent sectors of the economy.

During the Marginalist Era beginning with Cournot, economic theorists worked to
develop a deeper theory of the determinants of supply and demand for goods based
on an assumption of rational decision-making by producers and consumers, using
differential calculus to characterize optimal production and consumption plans.

Niehans does not suggest any distinctive intellectual thrust in our Model Era other
than the increasing analytical sophistication ["Classical economists had written for
the general public. The marginalists wrote mainly for untrained undergraduate
students. The leading economists in the model-building era, thanks to the growth in
their numbers, could afford to write for their peers." p317].
But we can see a distinctive direction for this era compared to the previous two:
In this "Era of Models", the principles of rational-choice analysis that the
Marginalists used to explain supply and demand for goods have been extended to
characterize decisions by individuals in more complex competitive situations, which
may involve more than just production and exchange of goods.

Such extension of rational-choice analysis requires a more general theoretical
framework than Walrasian general equilibrium, the great Marginalist creation.
This search for such a general framework for rational-choice analysis was
undertaken by the early game theorists.
Nash's theory of noncooperative games was the critical breakthrough in this process
of extending rational-choice analysis to general competitive situations.

3. Rational-choice analysis and the study of institutions
So to understand the importance of noncooperative game theory, we need to appreciate why rational-choice analysis should be so important in economics. Perfect rationality is certainly an imperfect description of real people's behavior. But our goal is not just to predict human behavior, but to analyze social institutions and evaluate proposals for institutional reform.

To look for potential flaws in an institution, it can be helpful to analyze the institution under the assumption that the individuals in it are not themselves flawed, because otherwise arguments for institutional reform become confused with arguments for reeducation of individuals.

To be able to handle normative questions of institutional reform, we need some way to measure human welfare, and we need some assumption about human behavior that is constant across institutions.

If individuals are not motivated to maximize their own welfare (as measured in our model) or if they do not understand their environment (as predicted in our analysis) then any loss of welfare that is predicted in our analysis may be blamed on such dysfunctional or misinformed individual behavior, rather than on the structure of social institutions.

So applied social theorists should find it useful to scrutinize proposed institutions under the assumption that every member of society will act, within his domain of control, to maximize his own welfare, given the predicted behavior of others.

The concept of Nash equilibrium is the general formulation of this assumption. A Nash equilibrium is a complete prediction of how all individuals would behave such that no individual could expect to improve his own welfare by behaving differently when this prediction is believed to be correct for all others.

If not, someone is making a mistake or misunderstands, or it's incomplete or wrong!

Questions of how to improve the education of individuals may be identified as the domain of psychologists, who naturally find such individual-perfection assumptions to be much less useful.

So from this perspective, a principle subdivision of social science may be between scholarship that is motivated by questions of institutional design (economics etc), and scholarship motivated by questions of educational reform (psychology etc).

4. Understanding of equilibrium after Cournot

Given that Nash equilibrium can be a useful solution concept for the analysis of any social institution, and given the apparent logical simplicity of Nash equilibrium, it may seem surprising that this solution concept was not articulated much earlier. The first clear application of Nash equilibrium in a precise mathematical model is in the brilliant pathbreaking analysis of Cournot (1838), who began the work of identifying rational-choice determinants of supply, and who analyzed two models of competition among profit-maximizing firms by finding Nash (Cournot) equilibria.

But neither he (a philosopher of science) nor his readers recognized its generality. Cournot: "*Each of them independently* will seek to make this income as large as possible. ...We say *each independently*, and this restriction is very essential" [because if they can come to an agreement then it would be like a monopoly]. Readers from Bertrand (1883) to Fellner (1949) saw a theoretical error in Cournot's assumption that firm 1 ignores the fact that firm 2's optimal choice would depend on what 1 chooses.
Fisher (1898): "No business man assumes that his rival's output or price will remain constant any more than a chess player assumes that his opponent will not interfere with his effort to capture a knight. ... The whole study is a 'dynamic' one, and far more complex than Cournot makes it out to be."
Fellner (1949): "[In the Cournot model] each *assumes* that his rival follows a policy of fixed output while *in reality* each follows a policy of adjusting his own output to the requirements of profit maximization, on the assumption that the other follows a policy of fixed output."

To us today, they seem to be confusing the question of how to analyze games with the question of what game model should represent competition among producers. What they did not understand in reading Cournot before Nash, is how the concept of <u>strategy</u> can allow us to normalize extensive form games and assume independence of strategic decisions.

5. Early advances in game theory: Borel and von Neumann

What Fisher and Fellner did not understand (but we do) is how the concept of strategy can allow us to normalize extensive form games and assume independence of strategic decisions.

This crucial insight begins with a remark at the end of the first paragraph of Borel (1921): "A method of play [*méthode de jeu*]... is a code that determines, for every possible circumstance, exactly what the person should do. In most ordinary games, the number of methods is extremely large but nonetheless always finite."

Von Neumann (1928) in his section 1 (General Simplifications) developed this idea more fully and defined: (1) extensive games where moves occur over time, (2) strategies as complete plans for each player in the game, and (3) normal form as a list of each player's expected payoff from each combination of strategies. Because strategies are complete plans, each player could choose his strategy before observing any events in the game, and could leave its implementation to an umpire. Thus, von Neumann argued, we can analyze games in normal form under the assumption that "each player must make his decision without being informed about the choices of the other participants."

Did von Neuman (1928) learn this from Borel's remark? He mentioned only Borel (1927) where this idea is not discussed, but his term for strategy is *Spielmethode*.

But when he began to study of games with more than 2 players, in section 4 of this 1928 paper, he assumed that they could act jointly in coalitions!

Also, by emphasizing on max-min values, von Neumann implicitly evaluated strategies as if the opponent could plan an offensive response after observing them. So the idea of strategic independence was buried until Nash developed it as a solution concept in 1950 and made it central to all game-theoretic analysis in 1951.

Von Neumann also imposed two other unnecessary restrictions on players' payoffs in his games: zero-sum, transferable utility. (Originally motivated by making payoff monetary to avoid measurement problems ... which he solved with utility theory!)

6. Nash's central contributions in noncooperative game theory
(1) Definition of equilibrium as optimality of each player's strategy (1950a),
(2) Proof of existence of randomized equilibria for all finite games (1950a),
(3) Assertion that Nash equilibrium is a general solution concept (1951):
"This writer has developed a 'dynamical' approach to the study of cooperative games based on reduction to non-cooperative form. One procedes by constructing a model of the larger pre-play negotiation so that the steps of negotiation become moves in a larger noncooperative game... describing the total situation."
Nash's existence argument clearly builds on earlier work of Borel (randomization) and von Neumann (fixed-point thm, justification of expected utility).

Nash (1950b) also developed a cooperative theory of two-person bargaining without vN's assumption of transferable utility, based on elegant axioms about symmetric treatment of players and invariance under transformation of utility scales.
In 1953 Nash offered a noncooperative justification of his cooperative bargaining solution, based on a simple bargaining game of simultaneous demands. This game has many equilibria, but Nash defined a natural class of perturbations of this game such that his solution is the only limit of equilibria from all perturbations, anticipating methods of the later literature on refinements of Nash equilibrium.

To see the effect of Nash's reformulation, look at the early reviews of vN&M's book. Stone's & Hurwicz's reviews actually mention Counot-type analysis and credit vN&M with helping us to gain wider appreciation of coalitional possibilities.
But the best economic application they could find was a simple game of one seller and two buyers that vN&M consider after p564(!). As Stone described this game, one of the buyers has greater willingness to pay for this object, but the other has more information about the prices of such objects, which (from the perspective of modern information economics) sounds like an interesting example of asymmetric information. But to follow vN&M, Stone then did a coalitional analysis in which all informational questions disappeared, as they must in a world where people first choose their friends before getting any information and thereafter act only as a perfectly coordinated union with their friends.

Nash taught us to keep our eyes on individual decision-making even in negotiations to collude, where we may find problems of dishonesty and distrust among colluding buyers. So Nash's program opened the door to questions of information economics, while von Neumann's program led away from it.

7. *Development of noncooperative game analysis after Nash*

The acceptance of Nash's reconstruction of game theory spread slowly. Luce&Raiffa (1957) were skeptical of Nash equilibrium because, in the 100-fold repeated Prisoners' dilemma game, the unique equilibrium is to always "defect". Here L&R would advocate building a relationship: cooperating until the other defects, or until sometime in the final 5 or 10 rounds.

But before Nash equilibrium could become a practical tool of applied social theory, some methodological advances were needed. The biggest steps were:

(1)   Kuhn (1953) reformulated randomization in dynamic extensive-form games.

(2)   Schelling (1960) showed how to interpret games with multiple equilibria, in terms of the potentially decisive <u>focal-point effect</u> of minor publicly-observed factors....

(3)   Harsanyi (1967) developed the <u>Bayesian</u> model for games with incomplete information, where players have different information at the beginning of the game.

(4)   Harsanyi (1973) showed how to interpret randomized equilibria, in terms of the potentially decisive effect of minor factors privately observed by various players.

(5)   Aumann (1974) defined <u>correlated equilibrium</u> for analyzing noncooperative games with preplay communication, which gave us our first linear incentive constraints and a precursor to the revelation principle for Bayesian games.

(6)   Selten (1975) showed that some equilibria in normal form may be irrational when viewed in the extensive form, because they are not <u>sequentially rational</u> after some zero-probability events. Our standard formulation of sequential equilibrium was introduced by Kreps and Wilson (1982). An early application was to the repeated prisoners' dilemma, showing how sequential equilibria give Luce&Raiffa's answer in a perturbed version of the game with incomplete information.

Notice (1) and (6) here are about a return to the dynamic analysis in extensive form, which also turns out to be necessary for games with communication in (5). So vN's reduction to normal form, which was essential to see the right approach in the first place, had to be set aside to build a usable theory of games.

So today we model games in normal form, in Bayesian form, and in extensive form. We analyze games by computing Nash equilibria, sequential equilibria, and correlated equilibria. The theory of noncooperative games that Nash founded has developed into a practical calculus of incentives that can help us to better understand the problems of competition in virtually any social institution.

7.5 More on the role of Thomas Schelling

Schelling's <u>Strategy of Conflict</u> (1960) was really the first turning point.

His criticism of Harsanyi here stimulated Harsanyi to turn to noncooperative theory, and Harsanyi led the other game theorists (including me) in this direction thereafter.

Schelling's initial concerns were applied problems international bargaining, and theoretical questions of about the role of <u>commitment</u> in social systems.

He developed a concept of a <u>boundary equilibrium</u> in which antagonists can use each other's hostility as a commitment device: "if I let you cross this line, then you'd expect me to let you push me out of everything; so I'm better fighting here."

Where the line goes is arbitrary, as long as both understand it is there.

More generally, he argued, whereever there are multiple equilibria, anything that focuses the players' attention on any one equilibrium may make them all expect and hence fulfill it, as a self-fulfilling prophecy.

Any successful society must provide mechanisms (cultural traditions, arbitrative authorities, accepted procedures for focal manipulation) to coordinate individuals in situations of multiple equilibrium.

So the focal-point effect puts a bound on economic determinism in social theory, but also sets new directions for study of culture from a rational-choice perspective.

The determination of focal equilibria by considerations of equity and effcency for players' welfare offer foundations for a post-Nash cooperative game theory.

The other pioneers here (Harsanyi, Selten, Aumann) collaborated in an arms-control research project in the 1960s, which stimulated much of this work, but ironically took little or no inspiration from Schelling, who really had expertise in this area.

Schelling did not join in the pursuit of general solution concepts for games, but he studied and criticized these pursuits in a way that was essential to stimulating the development of a noncooperative game theory that can address problems of coordination, information, communication, dynamics, and commitment.

The absence of Nash was felt throughout this period.

8. Conclusions

Scholars in any academic discipline always need a methodology to give a framework to inquiry and debate, to see connections that untrained laymen miss. But we also are aware that our expertise is diminished beyond the scope of our methodology, and we learn to stay within its boundaries.

Before Nash, price theory provided a general analytical methodology for economists, and its power enabled economists to serve as highly valued guides in practical policy-making, to a degree that was not approached by scholars in any other area of social science. But even within the traditional scope of economics, price theory has serious limits (bargaining among people who have different information, the internal organization of a firm, the defects of a nonprice command economy, crime and corruption that undermine property rights, etc).
The broader analytical perspective of Nash's noncooperative game theory has freed practical economic analysis from these methodological restrictions.

Of course Nash's noncooperative game theory is an abstract mathematical framework for economic analysis; it is not the economic analysis itself.
The real work for economic theorists has been to identify the models that yield the most useful insights into economic problems. We are continually building a canon of games and models, so that a student who has worked through the analysis of these canonical examples should be better prepared to understand the subtleties of competitive forces in the widest variety of real social situations.

But by accepting noncooperative game theory as a core analytical methodology alongside price theory, economic analysis has moved from a focus on material goods to a broader concern with analysis of incentives in any social institution, and thus we have regained some of the breadth of vision that characterized the ancient Greek social philosophers who first gave economics its name.