Path BREAKER

Janet Stotsky **profiles Kenneth J. Arrow, a Nobel Prize–winning theorist who has done pioneering work in many areas of economics**

KENNETH J. ARROW'S path-breaking contributions to economic theory in the years after World War II are the cornerstones of the work of successive generations of theoretical and applied scholars across the economics profession.

The late economic theorist Frank Hahn, alluding to Shakespeare's description of Julius Caesar, once said that his colleague Arrow "'bestrides the world like a colossus' . . . . There is hardly any area of our subject which he has not illuminated and often profoundly changed," demonstrated perhaps by the disparate economic concepts with his name attached—such as the Arrow-Debreu model, the Arrow impossibility theorem, and Arrow securities.

Although Arrow's first love was mathematics and mathematical statistics, he ended up an economist for a very economic reason. He ran out of money while a graduate student in mathematical statistics at Columbia University just before World War II, and the economics department offered him financial aid.

The highest bidder

Harold Hotelling, an economist, taught some of the statistics courses and "gave a course in mathematical economics" that Arrow said he took "out of curiosity." But because it began to hook him on economics, when his cash ran down Arrow approached Hotelling. The economist told Arrow that he had no influ-ence over the math department's financial awards, but he could help him if he switched to economics. "So I switched to econom-ics. People get very shocked by this. I said, 'You're all economists—why shouldn't I go to the highest bidder?'" he recalled in a recent interview in his office at Stanford University, where he spent most of his professional life.

That move to the economics department started a career during which he would share a Nobel Prize for economics in 1972—at 51, the youngest economist ever to win one. The Nobel committee cited the work of Arrow and British economist John Hicks in two areas: *general equilibrium theory*, which seeks to explain how prices are set across an economy, and *welfare theory*, which analyzes the optimal allocation of goods and services in an economy. But the Nobel committee also noted that both econo-mists had made important contributions in other areas.

That is clearly true of Arrow, who has stud-ied what happens when one side in a transac-tion knows more than the other, showed how technical change can arise from economic activity, and introduced the idea of risk and uncertainty to equilibrium analysis. He has also made contributions to the economic analysis of racial discrimination and health care. Moreover, in his first major foray into economic analysis, his doctoral dissertation, Arrow essentially invented the field of *social*

choice theory, which looks at how individual preferences are aggregated into social choice decisions, such as in voting.

In nearly all his endeavors Arrow introduced mathematical rigor and was a major influence in making economic theory as mathematically oriented as it is today.

The son of immigrants from Romania, Arrow was born in New York City in 1921. Like many in his generation, he was strongly affected by the dislocations of growing up during the Great Depression. His father's comfortable living as a banker was upended and the family moved frequently as his father's income rose and fell. "I wound up going to school in a lot of different places," he recalled. But the family finally settled back in New York, where he attended Townsend Harris, a three-year public high school ("you did that by staying an extra hour a day in class"). There the mathematics bug bit him. When he graduated from high school in 1936, "we were still very poor . . . so the only real chance of going to college" was the tuition-free City College of New York (CCNY).

Like many young people who experienced the ravages of the Depression, "I was concerned about getting a job . . . . The question was, where could I get a secure job? And there was one obvious one—being a high school teacher of mathematics." As a result he majored in math and education, although he found education courses "not very inspiring."

No jobs teaching math

And, as would happen several years later at Columbia, mathematics did not come through for Arrow. There was such a backlog of applicants who had passed the exam for math teachers in 1933 that New York hadn't held an examination since. As a result, Arrow said, he decided that he'd "better not bet everything on this job. So I learned to do something called statistics, and I got interested in it . . . . It happened that Columbia fortunately was the place to study." After he graduated from CCNY in 1940, his father borrowed money to pay his tuition at Columbia, and "I easily enrolled in the math department. . . . But I realized, as I've learned through the rest of my life, mathematicians look down on statistics."

That's when Hotelling stepped in to entice Arrow to study economics. After receiving a master's degree in mathematics, Arrow pushed hard to learn economics. He took all his qualifying courses and passed his oral exam for a doctorate by the end of 1941. But World War II intervened, putting a temporary halt to his studies. "It was clear I was going in the Army." So instead of waiting to be drafted, he decided to find something that would interest him. "The closest thing I could find was weather forecasting," a crucial activity for the Air Force, which was then part of the U.S. Army.

He studied meteorology at New York University, then was assigned to a research center, where part of what he did "was verifying how good weather forecasts are." But he also identified "a real problem: How do you use wind forecasts to guide the plane so the plane could take advantage of the winds?" It wasn't important for getting planes more quickly to Europe from North America, but it was important for conserving fuel. Arrow said he worked out a method to reduce fuel consumption by 20 percent. He never persuaded the military to use his technique, but "I think it's been used commercially since then." Moreover, his research was the basis for a paper, "On the Optimal Use of Winds for Flight Planning," which appeared in 1949. The first published paper by the future Nobel Prize winner in economics was in the *Journal of Meteorology*.

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When the war ended, Arrow returned to Columbia, with a good fellowship that had been held for him while he was in the service and a belief that "I had to do something very important. . . . I felt I was a very good student, but without having an original idea."

In 1947, still casting about for a dissertation topic, he joined the Cowles Commission for Research in Economics at the University of Chicago as a researcher with a faculty appointment. The commission, founded in 1932 by businessman Alfred Cowles, studied the link between economic theory and mathematics and statistics. At Cowles he met Selma Schweitzer, who was studying there. Not only did he marry her that year, but she introduced him to statistician M.A. Girschik, who invited Arrow to spend the next summer at the RAND Corporation, a global policy think tank. "That summer, 1948, was the year I took off."

In conversations at RAND with German philosopher and futurologist Olaf Helmer, Arrow was inspired to write his dissertation on social choice theory. The concept was so new that his dissertation adviser, Albert Hart, knew nothing of what Arrow was exploring. "But he had a lot of confidence in me . . . . He said, 'Well, I don't know what it's all about, but I will trust you,'" Arrow said.

In the dissertation and a book, *Social Choice and Individual Values,* which was published in 1951, the year he received his doctorate, Arrow laid the foundations for the field of social choice theory, which examines mathematically such issues as how well individual voters' different views about candidates and issues are reflected in an election outcome. In what is now called the Arrow impossibility (or possibility) theorem, he postulated that when certain reasonable conditions of fairness are imposed, it is impossible for a voting system to accurately reflect societal preferences. Mainstream economists tend to model individuals as rational. One implication is that preferences are transitive—meaning, for example, that voters who prefer candidate Smith to Jones and Jones to Williams will prefer Smith to Williams. Arrow's theorem shows that when only four reasonable conditions are imposed on three or more choices, it is impossible to aggregate rational individual preferences into social preferences that maintain transitivity of decision making. That is, there is no method to ensure that social preferences (winners of elections, say) will be accurately reached from individual preferences. Social choice theory is used to help understand group decision making and to design voting rules.

Unblocked

Completing his dissertation was the key to his success. "Once I got that dissertation out of the way on social choice, it unblocked me somehow."

Arrow applied advanced mathematics to the theory of general equilibrium, an idea that went back to economist Léon Walras in 1874 and was, in a sense, a demonstration that Adam Smith was right. Myriad economic actors seeking to further their own ends do not create chaos but are guided by an "invisible hand" that results in relatively orderly economy-wide production of goods, services, and jobs.

In economics, market equilibrium refers to a set of prices for which demand equals supply for all goods. Partial equilibrium analysis looks at the demand for (or supply of) a good as a function of its price, holding other prices fixed. General equilibrium analysis looks at all prices as variable and for equality of demand and supply in all markets. For example, the demand for natural gas in global markets may depend not only on its price but also on those of oil and other fossil fuels and of goods and services that may have a less immediate relationship to energy markets—and also on wages and interest rates.

In 1954, Arrow, working with French economist Gérard Debreu, developed general conditions for prices at which overall supply equals overall demand for every item in an economy (now known as the Arrow-Debreu model of general equilibrium). Working independently, Lionel McKenzie arrived at a similar result in a somewhat different manner. Arrow and Debreu (who won a Nobel in 1983) drew on ideas John Nash had developed in game theory—then a new field of study in mathematics that analyzes strategies for competition in which the outcome of one participant's actions depends on actions of others and for which Nash won a 1994 Nobel Prize.

In later work, including that written with Leonid Hurwicz, Arrow looked at the stability of markets and how prices adjust to equilibrate supply and demand.

General equilibrium thinking led to the development of theoretical and empirical models that explicitly incorporate interactions between parts of the economy—such as those that tie together the consumption and production sides.

Such general equilibrium models are used in many areas of economics. In public finance and international trade, these models might assess whether countries are better or worse off because of tax and tariff changes. In the early 1970s, John Shoven, a longtime Stanford colleague of Arrow, and British economist John Whalley devised the first applied general equilibrium model of the U.S. economy to assess tax changes. When applied to economic development, such models might assess how a growing export sector affects wages.

General equilibrium analysis has also greatly influenced modern thought about the macro, or overall, economy. Economists sought to find in microeco-

nomics, which studies the behavior of individual markets, the foundations of the macroeconomy. New classical macroeconomic theory draws on general equilibrium as the basis for its view of the economy as fundamentally in equilibrium, with flexible prices and wages in individual markets. Deviations from equilibrium quickly clear (resolve themselves). The Keynesian or neo-Keynesian schools (See "What Is Keynesian Economics?" in this issue of *F&D*) also draw on general equilibrium ideas, but reject the idea that markets always or quickly clear. Prices and wages tend to be slow to change, they argue, allowing economies to be out of equilibrium for long periods—and providing a rationale for activist fiscal and monetary policies. *Dynamic stochastic general equilibrium models* try to capture the inherently changing and uncertain nature of macroeconomic developments. Arrow believes that macroeconomic models must address the tendency of markets to remain out of equilibrium, as they did with prolonged unemployment during the Great Depression.

Welfare breakthrough

In 1951, just after introducing social choice theory, Arrow applied advanced mathematics to the area of welfare economics that is concerned with so-called Pareto optimality, a situation in which it is impossible to make one person better off without making someone else worse off. Pareto optimality is one criterion to measure whether an economy is functioning well. The first theorem of welfare economics describes the conditions under which a competitive general equilibrium results in a Pareto optimal allocation of resources; the second theorem describes the conditions under which every Pareto optimal outcome for an economy can be achieved with a competitive equilibrium and some redistribution of resources. Arrow's treatment generalized these theorems so that they apply when some goods or services are not demanded or supplied, which happens often and is what economists refer to as a "corner solution."

General equilibrium theory initially contained no element of uncertainty or risk. Building on the difficulty of insuring against risk in markets, Arrow introduced the notion of a "contingent" commodity, one that combines a commodity's physical characteristics with what is going on in the world into which it is delivered (wheat produced during a drought is different from wheat produced in a year of abundance). He then postulated a financial security whose payout depends on the state of the world. This so-called Arrow security is at the foundation of modern finance theory. It allows market participants to economize on the number of commodities they need to trade. For instance, farmers can enter into contracts to sell their wheat in the future at a specific price to insure against the risk of the price falling too much. These futures contracts can then be traded in a market where participants have different expectations about prices.
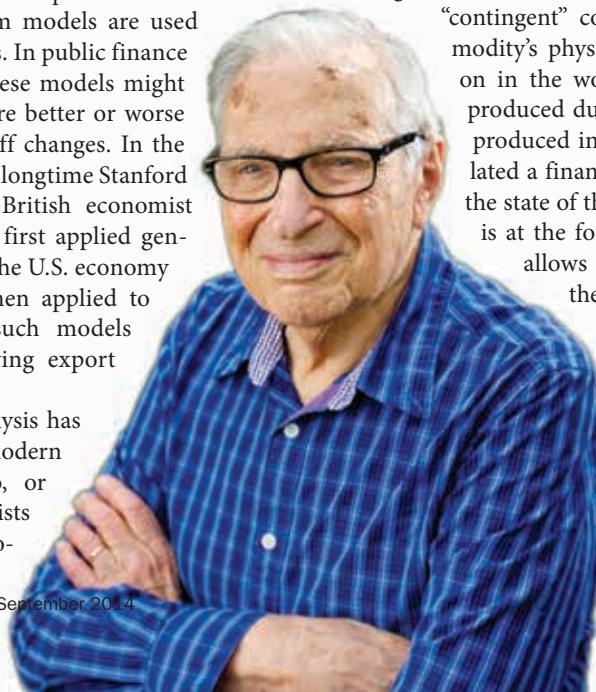
A crucial tool of economic analysis is the production function, which describes how inputs such as labor and capital combine to produce final output. Theories of growth had assumed that technical change, an important driver of productivity growth (using fewer inputs to produce a particular output), was not the result of economic activity but came from outside, even though common sense suggested that

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many technical improvements were the result of economic activity. Arrow's 1962 paper on learning by doing developed the idea that through experience, workers and businesses improve their productivity and that some of this knowledge generates benefits for the economy as a whole. This idea helps explain certain realities, such as the persistently large differences in productivity across countries.

Arrow's 1963 paper on uncertainty and the welfare economics of medical care explained the difficulties in designing a well-functioning market for medical care both because some participants know more than others—for example, the gap in medical knowledge between doctors and their patients—and because there is an absence of price competition in this market. He demonstrated the central importance of moral hazard in the medical marketplace—for example, greater demand for medical care by patients with insurance. A committee of leading economists said the article was one of the 20 most influential in the first century of the *American Economic Review*, the flagship publication of the American Economic Association.

Branching out

In other important efforts, Arrow, with Mordecai Kurz, set out an approach to optimizing public investments. Arrow also looked at some of the economic and noneconomic explanations for the persistence of racial discrimination in and outside the workplace.

Arrow's concern for the practical problems of economics and social and political issues has taken him from work on climate change to work on subsidizing medicine in developing economies. He was one of the first contributors to the intergovernmental panel on climate change, which provides authoritative estimates on its impact.

Much of his work on climate change has focused on the way individuals evaluate what might happen in the future. In a recent article in the journal *Nature*, Arrow and his coauthors argue that the U.S. government underestimated the cost of carbon, which the Obama administration is using as the basis for its plan to limit carbon emissions from power plants.

In recent years he chaired an Institute of Medicine committee that lent weight to the idea of subsidizing antimalarial treatments to make them more affordable in low-income countries. He is also a founding trustee of Economists for

Peace and Security, which is committed to supporting non-military solutions to world challenges.

Except for 11 years at Harvard from 1968 to 1979, Arrow spent his career at Stanford. Arriving in 1949, he quickly became Professor of Economics, Statistics, and Operations Research and helped Stanford become a center for the study of economic theory, econometrics, and applied mathematics.

He counts four Nobel Prize winners among his Stanford and Harvard students: John Harsanyi in 1994, Michael Spence in 2001, and Eric Maskin and Roger Myerson in 2007. Spence recalled, in his Nobel autobiography, the awe in which Arrow's students held him. "Describing Ken Arrow's contributions to economics in the second half of the 20th century would come quite close to just describing the evolution of economics during that period." Former Stanford student Ross Starr, who extended general equilibrium theory, recalls the affection he inspired. In a phone interview Starr said that "Arrow's students absolutely loved him. He shared brilliance and insight with us."

Arrow is also a member of a prominent academic family. His sister, Anita Summers, is a retired professor at the University of Pennsylvania, where her late husband, Robert, was an economics professor. Arrow's nephew, Lawrence Summers, is a well-known economist at, and former president of, Harvard University. The late Paul Samuelson, who in 1970 was the first U.S. citizen to win a Nobel Prize in economics, was the brother of Robert Summers.

Colleagues and students remember Arrow's distinctive presence in departmental seminars. Early in a seminar, for example, he might appear distracted, even seeming to nap. But suddenly he would turn his attention to the blackboard, contemplate for a few minutes what the speaker had been writing, and then politely point out a fatal flaw in the line of reasoning. Arrow, who continues to advise students but stopped teaching after his retirement in 1991, downplays his classroom skills. Some former students remember him putting up so many ideas almost simultaneously on the blackboard, all the while tossing chalk up and down without dropping it, that it was a challenge to keep up.

Until recent years Arrow would bike to campus, and former students recall him arriving at class, bike helmet on head, with a pump jutting from his backpack.

Arrow, 93, said he has always been more stimulated by working out problems and that once he works them out "I must say I kind of lose interest." That's why even though he received a Nobel Prize for his work on general equilibrium theory, he is prouder of his work on social choice theory.

Several other researchers, such as the late Lionel McKenzie, were working on the same problems in general equilibrium theory at the time Arrow and Debreu formulated their model. "In some respects . . . if I weren't there, it wouldn't have made that much difference."

But no one else was asking the social choice questions. "So that I am proud of." ∎

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