Decision Sciences

how the game is played

Early in its existence, NSF started to support research on game theory—the study of individuals' rational behavior in situations where their actions affect other individuals. Although the research had little practical value at the time, NSF continued to support it during the decades to follow, with substantial returns on the investment. Game theory and related areas of decision science supported by NSF have helped to solve practical problems once thought too complicated to analyze.

Game theory deals with the interactions of small numbers of individuals, such as buyers and sellers. For almost thirty years after its development during World War II, the theory remained an academic exercise, its dense mathematical proofs defying practical applications. Yet NSF stood by leading economists who painstakingly demonstrated how to use game theory to identify winning strategies in virtually any competitive situation. NSF also supported experimental economists who tested theoretical approaches under controlled laboratory conditions, and psychologists whose studies of individual decision making extended understanding of how economically rational individuals behave.

Persistence paid off. In 1994, John F. Nash, Reinhard Selten, and John C. Harsanyi, who first received NSF support in the 1960s, won the Nobel Prize in Economics for "their pioneering analysis of equilibria in non-cooperative games." The following year, game theory gave the Federal Communications Commission the logical structure for innovative auctions of the airwaves for new telecommunications services. The auctions raised over $7 billion for the U.S. Treasury, and marked a coming of age for this important analytic branch of economics.

In supporting this field, NSF's goal was to build the power of economics to elucidate and predict events in the real world. The support not only advanced the discipline, but also benefited all individuals in many aspects of daily life.

Decisions, Decisions

We all find ourselves in situations that call for strategic thinking. Business executives plan strategies to gain market share, to respond to their competitors' actions, to handle relations with employees, and to make career moves. Managers in government think strategically about the likely effects of regulations at home and of diplomatic initiatives abroad. Generals at war develop strategies to deploy troops and weaponry to defeat the enemy while minimizing their own losses. At a more individual level, buyers and sellers at flea markets apply strategies to their bargaining. And parents use strategy on their children, who—of course—behave strategically with their parents.

What is strategy? Essentially, it is anticipating the actions of another individual and acting in ways that advance one's self-interest. Since the other person also behaves strategically, strategy includes making assumptions about what that individual believes your strategy to be. We usually associate strategy with adversarial situations such as war, but that is much too narrow. In love, we use strategy, often unthinkingly, to win our loved one's heart without sacrificing our self-esteem or our bank account. Some strategists have objectives, such as racial harmony, that they feel serve everyone's interest. Probably the most common use of strategy occurs in basic economic transactions, such as buying and selling. However it is applied, the ultimate point of strategy is to achieve objectives.

That is precisely what players of games try to do. Similarities between games and strategic behavior in the economy formed the framework for *Theory of Games and Economic Behavior,* a book published in 1944 by mathematicians John von Neumann and Oskar Morgenstern. Their landmark work begins where classical economics leaves off.

The starting point for traditional economics is the equilibrium price, the point at which a seller's asking price equals the buyer's bid price. Classical economic theory goes on to analyze the price in terms of outside influences. Von Neumann and Morgenstern, however, went in another direction: They looked at the relationship between the participants.

Exactly how, they asked, do buyers and sellers get to the equilibrium price? In a world of perfect competition, containing so many buyers and sellers that any one individual's acts are insignificant, marketplace dynamics suffice. But what about economic transactions that involve only a few buyers and sellers? What happens when, for example, MCI offers potential customers a deal on long-distance service, and AT&T responds by offering the public its own new deal? The strategic moves in such economic decision making struck Morgenstern and von Neumann as mathematically indistinguishable from moves in chess, poker, and other games in which some strategies consistently win over others. Their book, a compendium of mathematical theorems embodying many different strategies for winning, was the first rigorously scientific approach to decision making.

Significant as it was, game theory took a long time to catch on. A small group of academics recognized its significance as a research tool. And some military applications appeared in the 1950s, when the Rand Corporation used game theory to anticipate responses of potential enemies to weaponry of various kinds. The world of business, however, regarded game theory as an arcane specialty with little practical potential.

NSF Lends Support

NSF took a different view, and began to support game theory mathematics in the 1950s. "The appeal of game theory always was the beauty of the mathematics and the elegance of the theorems," explains Daniel H. Newlon, senior program director for economics at NSF. "That was part of the appeal to a science agency."

A few years later, when NSF began to fund research in the social sciences, leading scholars urged the agency to continue its support for game theory. John Harsanyi of the University of California at Berkeley began receiving NSF grants in the 1960s, as did other major game theorists. "What kept NSF interested in game theory," says Newlon, "was the drive of people working in this field to understand how people interact, bargain, and make decisions, and to do it in a more rigorous, systematic fashion. For years, the problems were so difficult, given the state of computers and the mathematical tools at people's disposal, that you didn't see significant results. Yet NSF hung in there."

NSF went beyond supporting individual game theorists. It also sponsored conferences that gave game theorists the opportunity to gain visibility for their work. One such event was the annual Stanford Institute Conference in Theoretical Economics—run by game theorist Mordecai Kurtz—which NSF began to fund in the mid-1960s. Another NSF-funded meeting at the State University of New York had two goals: to use game theory to advance the frontiers of economic research and to improve the skills of graduate students and junior faculty in economics departments. From time to time, NSF invited proposals for workshops and awarded grants for computers and other needed equipment.

Into the Laboratory

Original work in game theory consisted entirely of models—simplified representations of the underlying logic in economic decision-making situations—which may have contributed to the business world's reluctance to accept its usefulness. A theory in physics or biochemistry can be tested in a controlled laboratory situation. In real-world decision making, however, conditions are constantly altered as a result of changes in technology, government interventions, organizational restructuring, and other factors. The business world and most economists found it hard to see how reading *Theory of Games and Economic Behavior* could actually help them win games or make money.

In the early 1960s, Charles R. Plott and his colleagues at the California Institute of Technology started to make game theory into an experimental pursuit. Supported by NSF, his group conducted a series of experiments that helped to answer questions about one facet of game theory: the ideal number of stages in an auction and their overall length. Experimentation, which Plott referred to as "debugging," became increasingly popular in economics as a complement to field research and theory.

The general idea was to study the operation of rules, such as auction rules, by creating a simple prototype of a process to be employed in a complex environment. To obtain reliable information about how test subjects would choose among various economic alternatives, researchers made the monetary rewards large enough to induce serious, purposeful behavior. Experiments with prototypes alerted planners to behavior that could cause a system to go awry. Having advance warning made it possible to change the rules, or the system for implementing the rules, while it was relatively inexpensive to do so.

Other economists refined and expanded game theory over the years to encompass more of the complex situations that exist in the real world. Finally, in the early 1980s, business schools and

The Fruits of Economic Research Are Everywhere

Starting in the 1960s, with support from NSF, Charles R. Plott of the California Institute of Technology made advances in game theory that paved the way for practical applications three decades later. Here, he outlines the practical relevance of NSF-supported economics research:

"The fruits of economic research are everywhere. Because NSF is the only dedicated source of funding in the United States for basic research in the economic sciences, its impact has been large. We see it in the successful application of game theory to the design of the FCC auctions of licenses for new telecommunications services.

"More broadly, we see the impact of NSF-supported work in some of the most important economic trends of our lifetimes, such as deregulation of airlines and other industries, nongovernmental approaches to environmental protection, and the liberalization of worldwide trade. The recent reexamination of the Consumer Price Index and how it should be measured relies heavily on NSF-sponsored basic research on price indices.

"In economics it is easy to find problems that are not solved, and perhaps are not solvable in any scientific sense. Yet measured in a cost-benefit sense, the achievements of economic research stand against those of any science."

—Charles R. Plott

Ph.D. programs in economics began to appreciate the power of game theory. By the 1990s, it had all but revolutionized the training of economists and was a standard analytical tool in business schools. In 1994, game theory received the ultimate recognition with the award of Nobel prizes to Nash, Selten, and Harsanyi—three pioneering researchers in the field.

Practical Payoffs

From a financial standpoint, the big payoff for NSF's long-standing support came in 1995. The Federal Communications Commission (FCC) established a system for using auctions to allocate bands of the electromagnetic spectrum for a new generation of wireless devices that included cellular phones, pagers, and hand-held computers with email capabilities.

Instead of the standard sealed-bid auction, Stanford University game theorist Paul Milgrom, an NSF grantee, recommended open bidding, which allows each bidder to see what the others are offering. Participants could also bid simultaneously on licenses in the fifty-one zones established by the FCC. Game theory's models of move and countermove predicted that open bidding would reassure bidders who, in trying to avoid the so-called winner's curse of overpaying, might be excessively cautious. Open bidding would also enable bidders to carry out economically advantageous strategies to consolidate holdings in adjacent territories, although FCC rules guaranteed that no one could obtain a monopoly in any zone. The intended outcome was an optimal solution for all parties. The bidders would get as many licenses as they were willing to pay for, while the U.S. Treasury would earn the maximum possible.

In the final accounting, the FCC's 1995 simultaneous multiple-round auctions raised over $7 billion, setting a new record for the sale of public property. Not only was the decision a landmark in the recovery of private compensation for use of a public resource, it also represented a victory for the field of game theory, whose leading scholars had applied what they knew about strategic decision making in recommending an auction design to the FCC.

Game theory has proved its worth in many other practical areas, among them management planning. Alvin E. Roth of the University of Pittsburgh applied game theory to analyze and recommend matching mechanisms for allocating thousands of medical interns among hundreds of hospitals in such a way as to give both the hospitals and the interns the matches they favor the most. He had the broader research aim of understanding how market institutions evolved to determine the distribution of doctors and lawyers.

Polls, Markets, and Allocations

Game theory represents one important facet of decision science. In fact, decision science deals with the entire subject of markets—for goods, services, and ideas, as well as labor. NSF-funded researcher Bob Forsythe, at the University of Iowa, provides one example of efforts in this area: His innovative Iowa Electronic Market, started in 1988, offered speculators a "real-money futures market." This type of market deals with abstract, but measurable, items. Participants bet on what the price of an abstract item, such as pork bellies, will be days, weeks, or months into the future. Between the time the bet is placed and the point at which it is paid off, the price of pork bellies will be influenced by a succession of economic and political events, including elections and the stock prices of firms in the pork industry.

Forsythe's "market" actually represented an effort to elicit more accurate information from voters than opinion polls provided. Instead of pork bellies, it focused on the electoral prospects of political candidates. "Market prices" summed up what players knew, or thought they knew, about a candidate's true chances of success in an election. Participants would win if the candidates on whom they bet were elected, and would lose if the candidates lost. Plainly, market participants could influence the result by their own votes; they would slightly improve the chances of the candidates they bet on by voting for those candidates, and slightly diminish those chances by voting for the opponents. Nevertheless, in its first ten years, the Iowa Electronic Market predicted election outcomes more accurately than did pollsters.

Recently, Forsythe and his colleagues received NSF funding to develop instructional materials that use the electronic market as a laboratory exercise to help undergraduates studying economics better understand market concepts

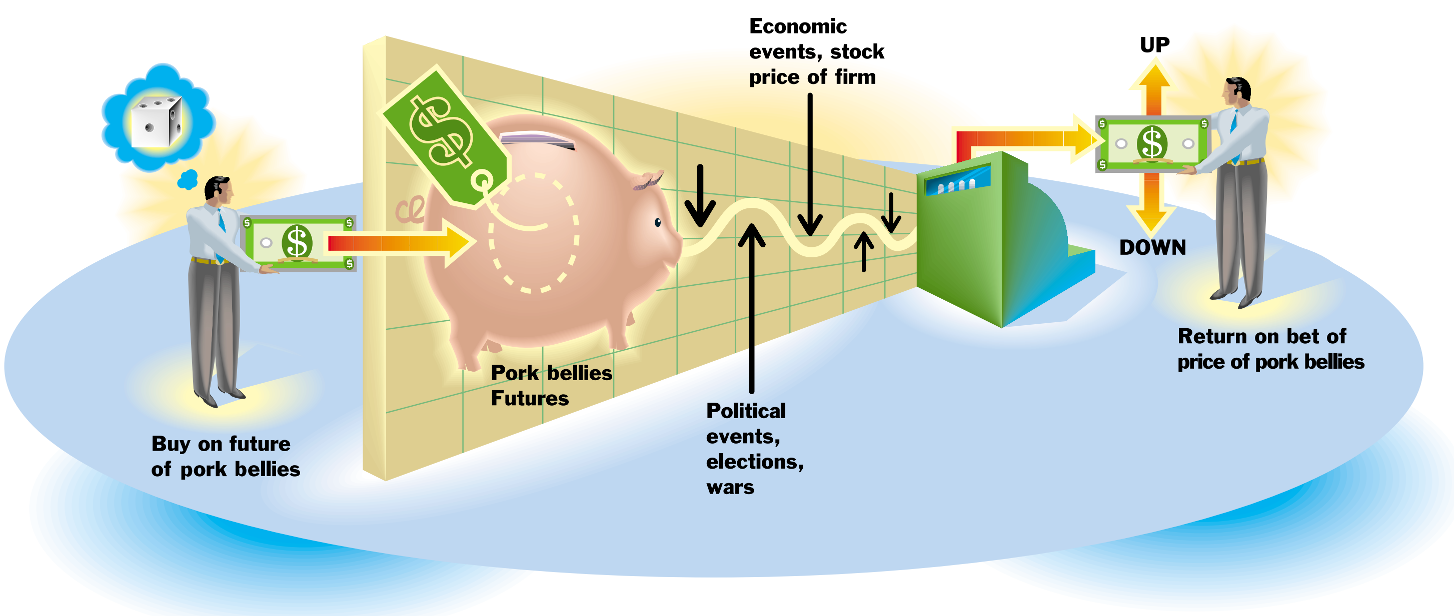
In another innovative area, called "smart markets," computers have become partners in the process of making allocation decisions, such as assignments of airport landing rights and management of gas pipelines and electric distribution systems. Computers process information, coordinate activities, and monitor allocation situations historically thought to be impossible to manage with anything other than a heavily bureaucratic administrative process. For example, the results of NSF-sponsored research have been used to shape a particular type of market that sets pollution limits and allows facilities that generate pollution to trade 'pollution permits' among themselves, so long as the overall limit is not exceeded.

Real-World Decision Making

These examples illustrate the common thread among the diverse projects of economists who build and test models: All of the projects are designed to explain more of what occurs in the real world.

Economic models work well when applied to markets and other institutions, in part because people gathered together in large numbers seem to behave as "rational" decision makers. But individual behaviors, and the behavior of small groups of individuals like the bidders in the FCC

Decision science has broad implications for all sectors of our society. It plays a role in understanding outcomes in financial markets and assessing the role of a centralized matching system in ensuring a stable supply of medical school graduates to hospital residency programs. Among the many questions that NSF-funded decision science researchers are attempting to answer: how people behave in economic environments, how information is distributed within economic institutions, and the influence of expectations and beliefs on decision making.



Gain Only

Gain and Loss

"A bird in hand is worth two in the bush" describes one action a person might take to minimize risk and maximize utility—the real or perceived ability of a product or service to satisfy a need or desire. Utility theory attempts to define the many factors that influence how people make decisions and to predict how an individual will behave when faced with difficult choices.

auctions, often seem inconsistent with rationality. NSF's Decision, Risk, and Management Science Program, within the Directorate for Social, Behavioral, and Economic Sciences, supports leading scholars in the decision sciences who look at these inconsistencies from another point of view. They try to determine the nature and origins of systematic errors in individual decision making, and use game theory to provide sets of strategies for anticipating and dealing with them.

Systematic errors abound in decisions that involve probability. Most people are not good at estimating the statistical likelihood of events, and their mistakes fall into distinct patterns. Reporting on these tendencies, Paul Slovic, Baruch Fischhoff, and Sarah Lichtenstein of Decision Research in Eugene, Oregon, wrote:

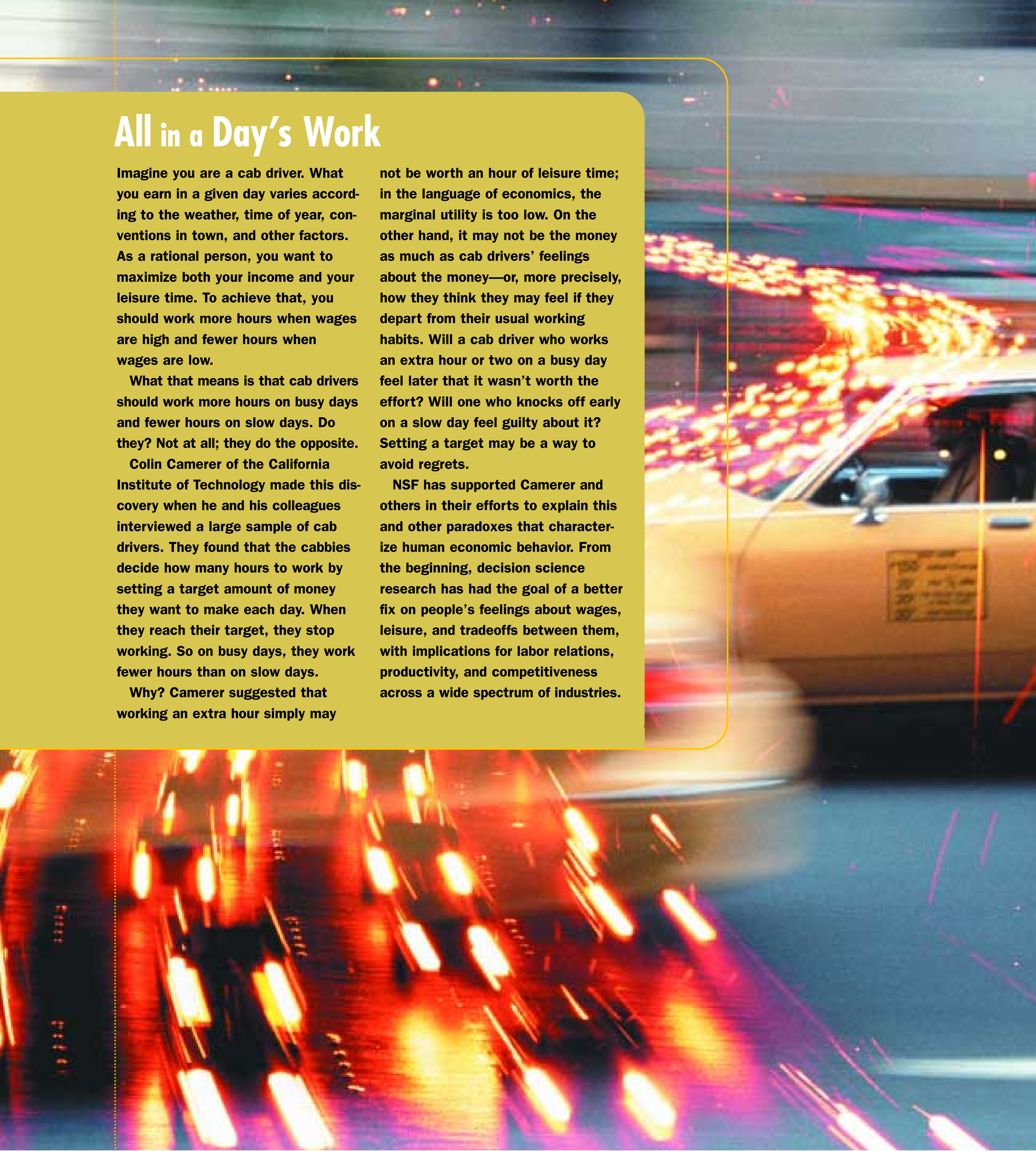
"People greatly overestimate the frequency of deaths from such dramatic, sensational causes as accidents, homicides, cancer, botulism, and tornadoes, and underestimate the frequency of death from unspectacular causes that claim one victim at a time and are common in nonfatal form—diabetes, stroke, tuberculosis, asthma, and emphysema . . . . The errors of estimation we found seemed to reflect the working of a mental shortcut or 'heuristic' that people commonly use when they judge the likelihood of risky events."

The authors explain that people judge an event as likely or frequent if instances of it are easy to imagine or recall. On the other hand, individuals often don't bother to consider information that is unavailable or incomplete. Every time we make decisions that involve probabilities, we confirm the reality of the phrase "out of sight, out of mind."

Another area where humans are systematically error-prone involves what economists call utility. We frequently face choices between doing the safe thing and taking a risk. One example is the choice between driving to work on secondary roads or taking the interstate, which usually saves several minutes but can occasionally take an extra half-hour or more because of back-ups. Another is the decision between investing in a safe money market account and taking a flier on a volatile stock.

No two people feel exactly the same about which risks are worth taking. The concept of utility combines several factors in decision making: the range of possible outcomes for a particular choice, the probability associated with each outcome, and an individual's subjective method of ranking the choices.

Imagine choosing between two tempting opportunities. One is a coin toss—heads you win $1,000, tails you win nothing. The other is a sure thing—an envelope with $500 inside. Do you choose the safe and sure $500 or the 50/50



All in a Day's Work

Imagine you are a cab driver. What you earn in a given day varies according to the weather, time of year, conventions in town, and other factors. As a rational person, you want to maximize both your income and your leisure time. To achieve that, you should work more hours when wages are high and fewer hours when wages are low.

What that means is that cab drivers should work more hours on busy days and fewer hours on slow days. Do they? Not at all; they do the opposite.

Colin Camerer of the California Institute of Technology made this discovery when he and his colleagues interviewed a large sample of cab drivers. They found that the cabbies decide how many hours to work by setting a target amount of money they want to make each day. When they reach their target, they stop working. So on busy days, they work fewer hours than on slow days.

Why? Camerer suggested that working an extra hour simply may not be worth an hour of leisure time; in the language of economics, the marginal utility is too low. On the other hand, it may not be the money as much as cab drivers' feelings about the money—or, more precisely, how they think they may feel if they depart from their usual working habits. Will a cab driver who works an extra hour or two on a busy day feel later that it wasn't worth the effort? Will one who knocks off early on a slow day feel guilty about it? Setting a target may be a way to avoid regrets.

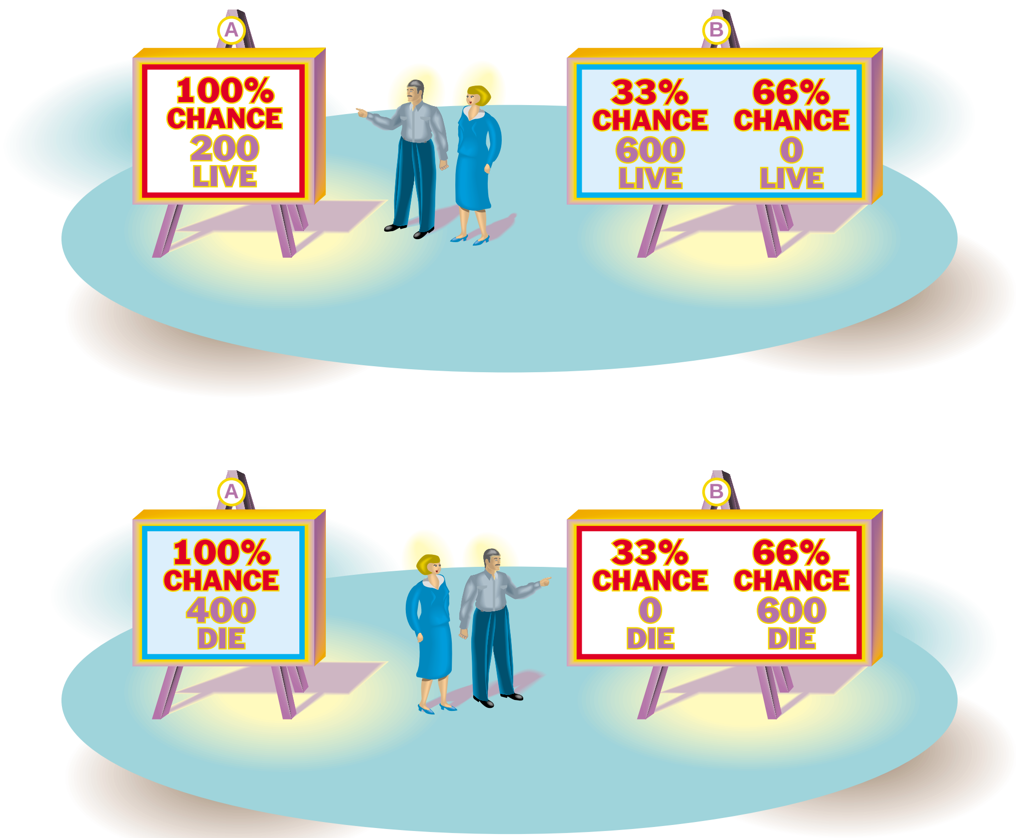
NSF has supported Camerer and others in their efforts to explain this and other paradoxes that characterize human economic behavior. From the beginning, decision science research has had the goal of a better fix on people's feelings about wages, leisure, and tradeoffs between them, with implications for labor relations, productivity, and competitiveness across a wide spectrum of industries.

chance to win $1,000? An economically rational person makes the choice that reflects the highest personal utility. The wealthier that individual is, for instance, and the more he or she likes to gamble, the higher is the utility of the risky 50/50 choice versus the sure thing.

Questioning Utility Theory

Utility theory postulates that it should not matter how alternatives are presented. Once we know what's at stake, and the risks involved, we should have enough awareness of ourselves to make the choice that serves us best.

In fact, psychologists Daniel Kahneman of Princeton and the late Amos Tversky of Stanford demonstrated that the way alternatives are framed can make quite a difference in our choices. In one of their most famous studies, they presented people with a choice between two programs that addressed a public health threat to the lives of 600 people. When the outcomes of the programs were described as (a) saving 200 lives for sure, or (b) a one-third chance to save 600 lives and a two-thirds chance to save no one, most respondents preferred the first option. But when the outcomes were presented as (a) 400 people dying for sure, or (b) a two-thirds chance of 600 people dying and a one-third chance that no one would die, most respondents preferred the second option. Of course, the two versions of the problem are the same, because the people who will be saved in one version are the same people who will not die in the other. What happens here is that people are generally risk-averse in choices between sure gains and favorable gambles, and generally risk-seeking in choices between sure losses and unfavorable gambles. "Some propensities," points out former NSF Program Director Jonathan Leland, "are so ingrained that the trick is to help people understand why their decisions are bad." No one, it seems, is immune to the power of the well-chosen word.



NSF-funded researchers Daniel Kahneman and the late Amos Tversky were instrumental in the development of rational choice theory. First used to explain and predict human behavior in the market, advocates of rational choice theory believe that it helps integrate and explain the widest range of human behavior—including who people vote for, what they buy at the grocery store, and how they will react when faced with a difficult decision about medical treatment.

Why We Make Foolish Decisions

Individuals frequently ensure poor decision making by failing to obtain even the most basic information necessary to make intelligent choices. Take, for example, the NSF-supported research of Howard Kunreuther of the University of Pennsylvania's Wharton School. He and his colleagues observed that most people living in areas subject to such natural disasters as floods, earthquakes, and hurricanes take no steps to protect themselves. Not only do they not take precautions proven to be cost-effective, such as strapping down their water heaters or bolting their houses to foundations; they also neglect to buy insurance, even when the federal government provides substantial subsidies.

What accounts for such apparently foolish decision making? Financial constraints play a role. But Kunreuther found the main reason to be a belief that the disaster "will not happen here." His research suggested "that people refuse to attend to or worry about events whose probability is below some threshold." The expected utility model, he added, "is an inadequate description of the choice process regarding insurance purchases."

Kunreuther next applied decision science to devising an alternative hypothesis for the behavior. First, he posited, individuals must perceive that a hazard poses a problem for them. Then they search for ways, including the purchase of insurance, to mitigate future losses. Finally, they decide whether to buy coverage. They usually base that decision on simple criteria, such as whether they know anyone with coverage. The research showed that, since people do not base their purchasing decisions on a cost-benefit analysis, premium subsidies alone did not provide the necessary impetus to persuade individuals to buy flood insurance.

Decision making within organizations is also riddled with systematic bias. One example is the familiar phenomenon of throwing good money after bad. Corporations frequently become trapped in a situation where, instead of abandoning a failing project, they continue to invest money and/or emotion in it, at the expense of alternative projects with higher expected payoffs. With NSF support, M.H. Bazerman of Northwestern University documented these stubborn tendencies in a variety of settings, and proposed corrective measures that organizations can take to counteract them.

Just as it supported game theory from the very early stages, NSF has funded research on the application of psychology to economic decision making from the field's infancy. That support yielded even faster dividends: Within a few years, the research had given rise to popular books advising managers and others on how to correct for error-prone tendencies and make better decisions. "We know that people bargain and interact, that information is imperfect, that there are coordination problems," NSF's Daniel Newlon explains. "NSF's long-term agenda is to understand these things. Even if they're too difficult to understand at a given time, you keep plugging away. That's science."

To Learn More

NSF Division of Social and Economic Sciences
Economics Program
www.nsf.gov/sbe/ses/econ/start.htm

NSF Decision, Risk, and Management Sciences Program
www.nsf.gov/sbe/ses/drms/start.htm

Consumer Price Index
http://stats.bls.gov/cpihome.htm

Decision Research
www.decisionresearch.org

Iowa Electronic Market
www.biz.uiowa.edu/iem/index.html

The Nobel Foundation
Nobel Prize in Economic Sciences
www.nobel.se/economics/laureates/1994/index.html

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Game Theory
http://plato.stanford.edu/entries/game-theory/

Stanford Institute for Theoretical Economics
www.stanford.edu/group/SITE/siteprog.html