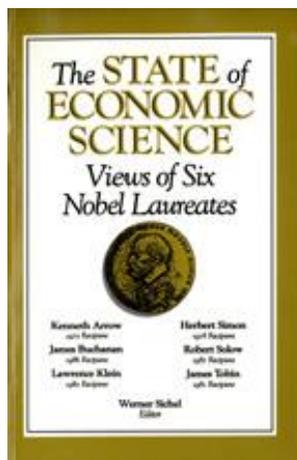

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Kenneth Joseph Arrow
Stanford University



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KENNETH J. ARROW is Consultant to the Rand Corporation and Senior Fellow by Courtesy of the Hoover Institution at Stanford University. During the past thirty-five years he has focused on and made major contributions to the theories of individual and social choice and of general economic equilibrium.

Professor Arrow earned a B.S. degree in Social Science from City University of New York and M.A. and Ph.D. degrees from Columbia University. He has been awarded more than a dozen honorary degrees from U.S. and foreign universities including Harvard, Chicago, Columbia, Yale, Pennsylvania, City University of New York, Hebrew University, and Cambridge. Professor Arrow taught for one year at the University of Chicago before accepting an appointment at Stanford University. Later, he taught for eleven years at Harvard University before returning to Stanford. He has also served as a visiting professor at MIT, Cambridge University, the Institute for Advanced Study in Vienna, and the European University Institute.

Dr. Arrow is a past president of the American Economic Association, the Econometric Society, the Institute of Management Sciences, the Western Economic Association, the International Economic Association and the International Society for Inventory Research. In 1957, he was awarded the John Bates Clark Medal by the American Economic Association. He is a member of the National Academy of Sciences, the American Philosophical Society, and the Institute of Medicine. He is also a Fellow of the American Academy of Arts and Sciences, the Institute of Mathematical Statistics, the American Statistical Association, and the American Association for the Advancement of Science. He recently received the von Neumann Prize of the Institute of Management Sciences and the Operations Research Society of America.

Professor Arrow is the author of about 20 books and over 165 articles in scholarly journals and books. Titles of Dr. Arrow's books that are indicative of his work include: *Social Choice and Individual Values*, *Studies in Linear and Non-Linear Programming*, *Aspects of the Theory of Risk-Bearing*, *General Competitive Analysis*, *The Limits of Organization*, and *Social Choice and Multicriterion Decision Making*. In addition, Harvard University Press has published six volumes of *Collected Papers of Kenneth J. Arrow*.



Dr. Kenneth J. Arrow

**Joan Kenney Professor of Economics
and Professor of Operations Research
Stanford University**

Recipient of the 1972 Nobel Prize in Economics

In the context of a modern economy, economic science tries to explain what and how much all of us buy and sell, what prices we pay and receive, and the effects of taxes and expenditures by the government. These few words contain a tremendous variety of activities and phenomena. We humans buy and sell not only chickens, which yield immediate satisfaction, but also factories and machines, which yield outputs and revenues in the future. We buy and sell such sophisticated commodities as securities, i.e., bonds and stocks. These are obligations to pay and receive amounts of money (itself a stage removed from goods in a simple sense) at points in the future and, in the case of stocks, the amounts are not even prescribed but depend on future events and decisions not completely predictable at the time of the securities transfer. The prices we receive or pay include such abstractions as a rate of interest.

This is a very incomplete survey of the subject matter that economics seeks to explain. Economics is the attempt to systematize all these phenomena, to find underlying regularities and patterns in the relations among the prices and quantities it studies. It seeks to understand the basic motives that guide the economic agents in their decisions, and it tries to draw the implications of these motives for the evolution of prices and quantities. It is fair to say that economics was given its

present orientation by Adam Smith, whose book, *An Enquiry Concerning the Wealth of Nations*, was published in 1776—a date otherwise of considerable significance. It was his great insight that there is a mutual interaction between the workings of the economic system and the actions of every individual. The overall magnitudes, totals sold and bought, prices paid and received, are the result of the actions of individuals, but in turn the system magnitudes control the actions of individuals. Even though everyone is trying to act to his or her own benefit, the results may correspond to no one's intent. For example, a firm will seek to maximize its profits (that is, make them as large as possible) taking as given the prices it pays for inputs and receives for outputs. But competition among many firms, each maximizing profits, results in minimum profits. The elaboration of the interconnectedness of the economy and the reciprocity between the system and the individual has been a fine example of international scientific intercourse over more than two centuries, as what the Scotsman Smith introduced was further developed by the Frenchman, Leon Walras, and the Italian, Vilfredo Pareto.

The economic system performs several functions, but the one that is most stressed by modern economists is the allocation of resources. Goods flow from place to place. They start from farm or mine through various stages of transformation to end in the hands of their ultimate consumers. Where and to whom they go and what processes are performed are the result of myriad individual economic decisions all profoundly influenced by the conditions of the market. Goods will not be produced if the prices received do not cover the costs of production or if there is no one who will buy them.

What is remarkable about the process by which the market system allocates resources is that it requires surprisingly little knowledge of the entire system by any one individual. The seller need only know there is a buyer willing to pay a suitable price and does not need to know (and usually does not know) why the buyer wants the product, whether to resell or to use in further production. This economy of vision is not merely the product of a modern complex society. In Athens of the 5th century B.C., Herodotus, the "Father of History" and certainly an unusually well-informed man of his day, did not know the ultimate source

of the tin which the Greeks imported to make bronze. All he knew was that the Greek settlers in what is now Marseilles bought tin from merchants who brought it down the Rhone. We know now that it ultimately came from Britain, a land whose very existence had only legendary meaning to Herodotus.

As economists see it, the chief coordinating instruments are prices. A price is an incentive to sellers or producers and a penalty to buyers. If there is a serious imbalance between supply and demand, prices rise or fall to bring the two into balance. Thus, if there is more supply than demand at a given price, competition among sellers brings prices down, both reducing supply and increasing demand. An *equilibrium* is a set of prices for which the corresponding inducements to sellers and buyers lead to equality of supply and demand on each market. The price system explains the limited need for knowledge by any one participant; it is necessary to know only the prices of the commodities in which he or she deals.

Economists differ as to the degree to which equilibria are actually attained. Some argue that the economy is very nearly in equilibrium all of the time; others, like myself, point to recurrent unemployment and to the nonexistence of markets for future sale and delivery as serious deficiencies in the equilibrium account of the economic world. But all agree that the tendencies toward equilibrium are real and important.

With this sketch of what economics is all about, let me turn to what I regard as the most significant and indeed dramatic developments of the last 50 years: the fuller and deeper exploration of the time dimension in economic behavior, the importance of uncertainty, and the recognition of information and knowledge as significant economic variables. These are interrelated developments, as we shall see.

Exchange and transformation of goods are the key economic phenomena, as has been emphasized. But these can occur not only over space or across industries but also over time. Individuals live for extended periods of time. They have concern, not only for their own futures but for their children and others beyond their own lifetime. Production takes time. The farmer plants first and harvests only after a period of time. Factory production also takes time. The production of a given commodity is not only a time-consuming process but also requires the

use of instruments, whether machines or buildings, which wear out only gradually and over very long periods of time. Inventories are essential for the smooth running of production and have to be held for some period of time, though usually brief. Wine must be held for several years to achieve its full potential, and the greater the wine the more it will improve with age. Electric power generating plants have effective lifetimes of 30 years and more; dams for power or for irrigation may be useful for a century.

The choices of the amounts and durabilities of investment projects are based on two values. One is the individual desire to protect oneself for the future, that is, to save; the other is the usefulness of investment in creating new valuable products in the more or less distant future. The saver will use the money not expended on current consumption to purchase bonds or stocks, whose sale finances investment. More fundamentally, we can see that for the economy as a whole the resources diverted from consumption by the individuals' desire to save are made available for investment.

How are these desires on the parts of different sectors of the economy coordinated or, in technical language, brought into equilibrium? There are now two periods in which transactions must take place, in the present and in the future, when the product resulting from the investment becomes available. Today we have current markets for bonds or securities or other instruments of saving, and these operate like other markets. There are prices for these securities; in the case of bonds, the price effectively determines the rate of interest. But in the future, there is no such simple step. The product to be produced has to find a market. But there is not today any market for future sales and purchases of goods, with some few exceptions, and therefore no prices for them.

The profitability of an investment, therefore, can never be calculated from market data at the time of investment. Future prices are "expected" or "anticipated." We move from the concrete world of markets and market prices to a less solid realm of expectation. Now forming expectations and acting on them are surely among the most characteristic of human actions. Shakespeare put this observation in the mouth of that most reflective character Hamlet: "Sure, he that made us with such large discourse,/ Looking *before* and after, gave us not/ That capabili-

ty and god-like reason/ To fust in us unused.” (*Hamlet*, Act IV, Scene 4). It is not only future prices that one must look “before”; more generally, the future conditions under which production and consumption will take place must be anticipated, for they are not currently known. Family size, market conditions, innovations whether to facilitate one’s productivity or to create competitors, and weather conditions are among the innumerable conditions which will shape our decisions tomorrow and which therefore affect today’s decisions to save or to invest.

The image or expectation of the future, therefore, shapes the present. What we expect for the future will affect the amount we wish to save and how we distribute that amount among alternative ways of saving. What we expect for the future will also determine the directions in which we plan investments and therefore take at least the first steps to embody our plans in concrete and metal. But these decisions have concrete effects today. A high willingness to save reduces current consumption. It may cause workers, therefore, to shift from consumption goods industries to investment goods industries, from garments to construction. Workers may have to shift geographically to implement the interindustrial shift. A different set of expectations about the future leads to a different present world.

To digress for a minute, the principle here goes beyond economics. Images of future peace or war determine our present armaments and military preparations and may indeed lead to war or peace now. Expectations of good or bad future lives can influence our present attitude towards life, towards having children, towards developing or not developing social and cultural skills.

The elaboration of this picture of the economic world, in which the anticipations of the future affect the present and, of course, our present actions in investment and savings, help to determine the future, which I take to be perhaps the leading development in economic theory and analysis in the last 50 or 60 years. Let me mention by name the great pioneers of the 1930s, Ragnar Frisch, of Norway, and John R. Hicks, who died at the time these words were being written. These names are not household words like John Maynard Keynes, yet I would hold that their works are even today more influential in the practice of economics. Subsequent elaboration has resulted in an increasingly sophisticated set

of models of economic action over time, followed by empirical implementation of at least certain aspects, most noticeably in the securities markets, to which I will return a bit later.

I have emphasized the future, but the future always brings uncertainty. Perhaps the greatest intellectual step of all in our understanding of the role of time in economics has been the explicit recognition of uncertainty as an economic fact and as a factor recognized by individuals in their market behavior. Investors and savers alike are aware of the universality of uncertainty. They are uncertain about future prices, about future technology, about future preferences for goods.

Yet it is only after 1947 that economists and decision analysts developed explicit methods for assisting individuals, firms and governments in making decisions under uncertainty and to study the equilibrium configuration of the economy when agents are uncertain about the future and know they are uncertain. The study of this topic has transformed the content of economics, more perhaps than might be expected on first consideration.

The study of human behavior under uncertainty deepened and intensified our understanding of one of the basic and most enduring themes in economic analysis, the notion of rationality. Implicitly in Adam Smith, explicitly in the economic theorists of the last quarter of the nineteenth century who in many ways set the basic structure of modern economics, the actors in the economy are considered to be rational beings in their choices.

First of all, firms are supposed to be rational in the sense that they seek, successfully, to maximize their profits under the conditions they face. This implies, for example, that each firm chooses methods of production that make as small as possible the cost of production of whatever amount is produced and produces that quantity which will yield the largest profit possible, that is, the excess of revenue over cost is maximized. Rationality is identified with maximization; a rational firm will not rest content with one level of profits if by changing either its methods of production or its quantity produced it can make higher profits. Second, each consumer or household is assumed to choose the quantities of the different goods consumed (and amount of labor supplied) so as

to maximize some measure of the satisfaction the consumer receives, given the prices the household faces and the income it has.

These have been the traditional criteria for economic rationality. Under conditions of uncertainty, however, the concept of rationality becomes stronger, that is, says more about the behavior of economic actors. It is required that there be consistency among choices made under different conditions of uncertainty. To state in detail these criteria and their justification would take more space than is deserved here; but they can be made very persuasive indeed. They lead to the following standard formulation: We do not know which of several different possible outcomes will occur, but we can assign probabilities to each possible outcome. The actions taken by firms and households are like bets, in that the outcome of any such action (investment, act of saving) depends both on the action taken and the outcome in fact realized (e.g., which horse will win in a racetrack bet, what future product prices will be). In this language, I give one example of a rationality assumption: If you are willing to bet on an event, and the odds change in your favor, you are still willing to make the bet.

Earlier, when discussing the way resources are allocated over time, I stressed the importance of expectations of future prices. When uncertainty is recognized, the concept of expectations is broadened. There is no single price expected; the investor or saver is uncertain about future prices and knows he or she is uncertain. Economic actors hold probability distributions of future prices for each commodity and each time period in the future. Put a slightly different way, there is a set of *contingent* prices, one for each commodity in each time period under each of the possible states of affairs that may prevail between now and the time in question. For example, we might have a price for wheat next year contingent on the weather that prevails in the intervening period. Actually, in fuller detail, we should have a price for wheat next year contingent on the weather, demand conditions here and in foreign countries, technological innovations in the milling industry, new information about the health implications of bread and of rival commodities, and so forth. Each contingent price is a well-defined number, but the contingencies themselves are uncertain. Each actor in the economy assigns probabilities to the alternative possible contingencies.

Let us suppose that these contingent prices and the probabilities attached to the contingencies are rationally developed by the participants in the economy. Then, if all the relevant information is publicly known, all individuals will have the same probability judgments. This theory may seem very general, but in fact it has striking implications for the pricing of securities. Namely, on the best available information, the average change will be zero (corrected for dividend payments). That is, the price of the security tomorrow is not known today. All investors assign the same probabilities to the different possible values of tomorrow's price. Then the average of these different possible values, calculated using these probabilities, must be today's price. The reason for this conclusion is that if it were not so, if there were some predictable tendency for the price to rise from today to tomorrow on the average, then buyers would bid up the price of the stock today and so remove the profit opportunity.

This exposition contains in a nutshell what has come to be known as the "rational expectations" theory of the movement of prices and quantities over time. No doubt there is a slightly absurd aspect in assigning complete rationality and complete foresight within the limits of ineliminable uncertainty, a point illustrated by a parable widely repeated among economists: Two economists are walking down the street. One says, "Look, there's a \$20 bill lying on the street," to which the other replies, "There can't be; if there were, someone else would have already picked it up." Nevertheless, the hypothesis that securities price changes are unpredictable from current prices has been subject to a good deal of empirical test. Many studies have confirmed the hypothesis very well; others have found minor variations.

Recognizing the importance of uncertainty in forward-looking economic behavior has led to another crucial extension of our perspectives, understanding information as an economic variable. Information can be looked at broadly as any observation which *changes* one's probability judgments. Up to this point, I have made explicitly the assumption that all information is public, that it is freely available to all individuals equally. In fact, of course, different agents have different information. Certainly, each firm, for example, knows its own production possibilities better than other firms and better than possible investors;

similarly, consumers know their own future needs better than others and particularly better than potential lenders to them. In a complex world with much more knowledge than any one individual can have, knowledge is specialized. Indeed, increasingly what workers of all kinds are selling is knowledge of a kind that others do not have; physicians, lawyers, and professors are no doubt extreme examples of what is, however, a very widespread characteristic. But such a world is one in which differences in information not only exist but are the very reason for the existence of economic transactions.

There are many implications of this new viewpoint. One is that prices, particularly of securities or other assets, themselves convey information, for they reveal something of what other people know. If one investor sees a rise in the price of a security for no reason known to him, it might at first be concluded that he or she will sell. In fact, the investor might be better off to infer that someone else has received favorable news and acted on that and therefore to conclude that the security is worth more than originally thought.

There are many other implications of differing information among economic agents. In a transaction between a less and a more informed person, the former cannot be sure the latter is using the information available in the former's interest. This leads to provisions in contracts and in the nature of industrial organization which depart considerably from the simple model of buying and selling services and goods at fixed prices. The new analysis has explained the many complex systems of rewards and long-term contractual relations as responses to the possibility of exploitation of special informational inequalities.

I have given to this point a fairly glowing picture of the success of economic theory in grasping more realistically many aspects of the economic relations among individuals: transactions over time, the presence of uncertainty, and the existence of private and uncommunicated information. I must add a sense of caution and limits to the accomplishments, not only about the state of theory but even at the level of fully understanding what the questions are.

It has in fact been a long-standing complaint against standard economic theory that it depends too much on the assumption of rationality. The complaint was raised by Thorstein Veblen, a famous dissenting

economist at the turn of the century, against a theory of rational behavior in circumstances much less complex than those now studied, a world of certainty and predictability. Economic agents do not and indeed cannot perform all the calculations demanded by the theory. To anticipate prices rationally, they have in effect to understand a correct model of the economy and use it to project future prices or, more precisely, what future prices would be under a great variety of possible contingencies. The impossibility of carrying out such calculations is manifest from everyday observation and confirmed by the inability of economists using our theory and our computing power to make good forecasts (even good contingent forecasts). The theory of computation shows that the necessary computations have a high degree of complexity.

In recent years, cognitive psychologists have studied the abilities of humans to make rational choices and form probability judgments rationally in experimental situations far less complex than the real economy. Not only are the assumptions of rational behavior strongly contradicted, but systematic kinds of bias are found. Two are of special interest because of their potential implications for economics. One is a tendency to overconfidence. People usually rate their own abilities above average; obviously, this cannot be true of half of them. Thus, the buyer of a security is not so likely to ask himself or herself what the seller knows that motivates the sale; the buyer simply assumes his or her superiority of understanding. A second is that choices that are objectively the same are looked at differently according to the context, a phenomenon known as “framing.” The same outcome can usually be thought of as a loss or a gain, depending on what the outcome is being compared to. For example, a profit on the sale of a stock could be thought of as a gain compared to the purchase price and a loss compared with what was expected or what could have been made in an alternative investment. Rational behavior implies that these comparisons are irrelevant to a decision to sell the stock. But a considerable body of both experimental and field evidence in psychology implies that action does indeed depend on framing the decision as a gain or a loss.

There are many phenomena observed in the market which can be interpreted to confirm lack of rationality. These are best drawn from the securities markets, not so much because they are central to the economy

but because they can be far better observed than other economic phenomena, such as investments in plant and equipment. There is considerable evidence that stock and bond prices fluctuate far more than is consistent with rational behavior on the part of the participants. The theory would imply that the current price of a security is the present value of its future returns averaged over all contingencies. Then the price should change only as the probabilities of different contingencies change in response to new information. But important new information is rare. The price of a given stock frequently changes by 5 percent in a single day with no significant news about its prospects. This undue response to small changes conforms to some generalizations found experimentally by cognitive psychologists.

Another observation is the large volume of transactions on organized markets. The assumptions of rational behavior, including rationality in deducing changes in the information of others from changes in market prices, would imply that no transactions would take place simply because of some change in the private information of some individual, although the price would alter. Transactions would be motivated by hedging or changes in other circumstances of the individual (aging or other changes in wealth or need prospects). For example, on the foreign exchange markets, a purchase or sale would be rational as an accompaniment to a sale or purchase abroad, to hedge against changes in the value of the payment. Hence the volume of transactions would be at most equal to the volume of foreign trade. In fact, the transaction volume is hundreds of times greater.

What can we conclude? The image of the future, cloudy though it be, powerfully influences the current state of the economic world (and indeed the social and political world). The formation of this image owes something indeed to our individual and collective efforts to use our experience and our preconceptions to that end. We are not without sense and reason, but we are subject to the necessity of oversimplification and to biases built into us. We can effectively use only part of the knowledge that is or could be available to us. But even if we used all we could, our prevision would be deficient because so much can happen that will necessarily be a total surprise.

An important task of economic analysis today, in conjunction with recent work in psychology and in computer science, is to know better how we come to acquire knowledge and form beliefs and how we act and can act on that knowledge.