ECONOMICS OF UNCERTAINTY AND INFORMATION

Giacomo Bonanno
Department of Economics, University of California, Davis, CA 95616-8578, USA

Keywords: adverse selection, asymmetric information, attitudes to risk, insurance, moral hazard, Pareto efficiency, principal-agent contracts, risk-sharing, signaling, uncertainty.

Contents

Summary

This chapter gives a non-technical overview of the main topics in the economics of uncertainty and information. We begin by distinguishing between uncertainty and risk and defining possible attitudes to risk. We then focus on risk-aversion and examine its role in insurance markets. The next topic is asymmetric information, that is, situations where two parties to a potential transaction do not have the same information; in particular, one of the two parties has valuable information that is not available to the other party. Three important phenomena that arise in situations of asymmetric information are adverse selection, signaling and screening. Each of these topics is analyzed in detail with the help of simple examples. We then turn to the issue of optimal risk-sharing in contracts between two parties, called Principal and Agent, when the outcome of the contractual relationship depends on external states that are not under the control of either party.

Finally we touch on the issues that arise when the Agent does have partial control over the outcome, through the level of effort that he chooses to exert. Such situations are referred to as moral hazard situations. Throughout the chapter we make use of simple illustrative examples and diagrams. A selected bibliography at the end provides suggestions to readers who wish to pursue some of the topics to a greater depth.

1. Introduction

While the analysis of markets and competition dates back to the late 1700s (the birth of economics as a separate discipline is generally associated with the publication, in 1776, of Adam Smith's book *An Inquiry into the nature and causes of the wealth of nations*), the economics of uncertainty and information is a more recent development: the main contributions appeared in the 1970s. The seminal work in this area was laid out most notably by three economists, George Akerlof, Michael Spence and Joseph Stiglitz who shared the 2001 Nobel Memorial Prize in Economic Sciences "for their analyses of markets with asymmetric information". Their work focused on the impact that informational asymmetries have on the functioning of markets. Before reviewing the main insights from this literature (Sections 5-10), we begin by introducing some general concepts and definitions (Sections 2 and 3), which are then applied to the analysis of insurance markets (Section 4).

2. Risk and Uncertainty

It is hard to think of decisions where the outcome can be predicted with certainty. For example, the decision to buy a house involves several elements of uncertainty: Will house prices increase or decrease in the near future? Will the house require expensive repairs? Will my job be stable enough that I will be able to live in this area for a sufficiently long time? Will I have a good relationship with the neighbors? And so on.

Whenever the outcome of a decision involves future states of the world, uncertainty is unavoidable. Thus one source of uncertainty lies in our inability to predict the future: at most we can formulate educated guesses. The price of a commodity one year from now is an example of this type of uncertainty: the relevant facts are not settled yet and thus cannot be known. Another type of uncertainty concerns facts whose truth is already settled but unknown to us. An example of this is the uncertainty whether a second-hand car we are considering buying was involved in a serious accident in the past. The seller is likely to know, but it will be in his interest to hide or misrepresent the truth. Situations where relevant information is available to only one side of a potential transaction are called situations of asymmetric information and will be discussed in Sections 5-8.

In his seminal book *Risk, uncertainty, and profit*, first published in 1921, Frank Knight established the distinction between situations involving risk and situations involving uncertainty. A common factor in both is the ability, in general, to list (at least some of) the possible outcomes associated with a particular decision. What distinguishes them is that in the case of risk one can associate "objective" probabilities to the possible outcomes, while in the case of uncertainty one cannot. An example of a decision involving risk is the decision of an insurance company to insure the owner of a car against theft. The insurance company can make use of statistical information about past car thefts in the particular area in which the customer lives to calculate the probability that the customer's car will be stolen within the period of time specified in the contract. An example of a decision involving uncertainty is the decision of an airline to purchase fuel on futures markets (a futures contract is a contract to buy specific quantities of a commodity at a specified price with delivery set at a specified time in the future; the price specified in the contract for delivery at some future date is called the futures price, while the market price of the commodity at that date is called the spot price). Since the future spot price of fuel will be affected by a variety of hard-to-predict factors (such as the political situation in the Middle East, the future demand for oil, etc.) it is impossible to assign an objective probability to the various future spot prices. In a situation of uncertainty the decision maker might still rely on probabilistic estimates, but such probabilities are called *subjective* since they are merely an expression of that particular decision maker's beliefs.

3. Attitudes to Risk

Suppose that a decision-maker has to choose one among several available actions $a_1, \dots, a_r$ $(r \geq 2)$. For example, the decision-maker could be a driver who has to decide whether to remain uninsured (action a_1) or purchase a particular collision-insurance contract (action a_2). With every action the decision-maker can associate a list of possible outcomes with corresponding probabilities (which could be objective or subjective probabilities). If the possible outcomes are denoted by $x_1, \dots, x_n$ and the corresponding probabilities by $q_1, \dots, q_n$ (thus, $q_i \geq 0$, for every $i = 1, \dots, n$, and $q_1 + ... + q_n = 1$), the list $\begin{pmatrix} x_1 & ... & x_n \\ q_1 & & q_n \end{pmatrix}$ is called the *lottery* corresponding to that action. Choosing among actions with uncertain outcomes can thus be viewed as choosing among lotteries. When the possible outcomes are numbers, typically representing sums of money, we will denote them by $m_1, \dots, m_n$ and call the lottery a *money-lottery*. With a money-lottery $L = \begin{pmatrix} m_1 & ... & m_n \\ q_1 & & q_n \end{pmatrix}$ one can associate the number $EV_L = q_1 m_1 + ... + q_n m_n$, called the *expected value* of L. For example, if $L = \begin{pmatrix} 5 & 2 & 4 \\ \frac{2}{8} & \frac{5}{8} & \frac{1}{8} \end{pmatrix}$ then $EV_L = \frac{2}{8}5 + \frac{5}{8}2 + \frac{1}{8}4 = 3$.

The expected value of a money lottery is the amount of money that one would get *on average* if one were to play the lottery a large number of times. For example, consider the lottery $L = \begin{pmatrix} \$5 & \$2 & \$4 \\ \frac{2}{8} & \frac{5}{8} & \frac{1}{8} \end{pmatrix}$ whose expected value is \$3. Suppose that this lottery is played N times. Let N_5 be the number of times that the outcome of the lottery turns out to be \$5 and similarly for N_2 and N_4 (thus $N_5 + N_2 + N_4 = N$). By the Law of Large Numbers in probability theory, if N is large then the frequency of the outcome \$5, that is, the ratio $\frac{N_5}{N}$ will be approximately equal to the probability of that outcome, namely $\frac{2}{8}$, and, similarly, $\frac{N_2}{N}$ will be approximately equal to $\frac{5}{8}$ and $\frac{N_4}{N}$ will be approximately equal to $\frac{1}{8}$. The total amount the individual will get is $5N_5 + 2N_2 + 4N_4$ and the average amount (that is, the amount per trial) will be $\frac{5N_5 + 2N_2 + 4N_4}{N} = \frac{N_5}{N}5 + \frac{N_2}{N}2 + \frac{N_4}{N}4$ which is approximately equal to $\frac{2}{8}5 + \frac{5}{8}2 + \frac{1}{8}4 = 3$, the expected value of L.

An individual is defined to be *risk-averse* if, when given a choice between a money-lottery $L = \begin{pmatrix} m_1 & \dots & m_n \\ q_1 & & q_n \end{pmatrix}$ and its expected value for sure [that is, the (trivial) lottery $\begin{pmatrix} EV_L \\ 1 \end{pmatrix}$], she would strictly prefer the latter. If the individual is indifferent between the lottery and its expected value, she is said to be *risk-neutral* and if she prefers the lottery to the expected value she is said to be *risk-loving.* For example, given a choice between being given \$50 for sure and tossing a fair coin and being given \$100 if the coin lands Heads and nothing if the coin lands Tails, a risk-averse person would choose \$50 for sure, a risk-loving person would choose to toss the coin and a risk-neutral person would be indifferent between the two options.

Most individuals display risk aversion when faced with important decisions, that is, decisions that involve substantial sums of money. In the next section we show that risk-aversion is what makes insurance markets profitable.

4. Risk Aversion and Insurance

When individuals are risk averse, there is room for a profitable insurance industry. We shall illustrate this for the simple case where the insurance industry is a monopoly (that is, it consists of a single firm) and all individuals are identical, in the sense that they have the same initial wealth (denoted by W) and face the same potential loss (denoted by ℓ, with $0 < \ell < W$) and the same probability of loss (denoted by q). Suppose that the potential loss ℓ is incurred if there is a fire. Thus there are two possible future "states of the world": the good state, where there is no fire, and the bad state, where there is a fire. Suppose that the probability that there will be a fire within the period under consideration (say, a year) is q (with $0 < q < 1$). Each individual has the option of remaining uninsured, which corresponds to the lottery $\begin{pmatrix} W & W - \ell \\ 1-q & q \end{pmatrix}$. Insurance contracts are normally specified in terms of two quantities: the *premium* (denoted by *p*) and the *deductible* (denoted by d). The premium is the price of the contract, that is, the amount of money that the insured person pays to the insurance company, irrespective of whether there is a fire or not. If a fire does not occur, then the insured receives no payment from the insurance company. If there is a fire then the insurance company reimburses the insured for an amount equal to the loss minus the deductible, that is, the insured receives a payment from the insurance company in the amount of $\ell - d$. Thus the decision to purchase contract (p, d) corresponds to the lottery

$\begin{pmatrix} W-p & W-p-d \\ 1-q & q \end{pmatrix}$. If d = 0 the contract is called a *full-insurance* contract, while if d > 0 the contract is called a *partial-insurance* contract. Let L_{NI} denote the lottery corresponding to the decision not to insure (*NI* stands for 'No Insurance'); thus $L_{NI} = \begin{pmatrix} W & W-\ell \\ 1-q & q \end{pmatrix}$. The expected value of this lottery is $W - q\ell$, that is, initial wealth minus expected loss. Given our assumption that the individual is risk-averse, she will prefer $W - q\ell$ for sure to the lottery L_{NI}, that is, she would be better off (relative to not insuring) if she purchased a full-insurance contract with premium $p = q\ell$. Since such a contract makes her strictly better off, she will also be willing to buy a full-insurance contract with a slightly larger premium $\bar{p} > q\ell$. If the insurance company sells a large number of such contracts, its average profit, that is, its profit per contract, will be $\bar{p} - q\ell > 0$ (as explained above, by the Law of Large Numbers, the fraction of insured customers who would suffer a loss and submit a reimbursement claim would be approximately q and thus total profit would be approximately $\bar{p}N - qN\ell$ - where N is the number of insured customers - so that the profit per customer would be $\frac{\bar{p}N - qN\ell}{N} = \bar{p} - q\ell$). Hence the sale of insurance contracts would yield positive profits. Would a profit-maximizing monopolist want to offer a full insurance contract or a partial insurance contract to its customers? A simple argument shows that the monopolist would in fact want to offer full insurance. Consider any partial insurance contract (p_0, d_0) with premium p_0 and deductible $d_0 > 0$. Denote by π_0 the profit per customer given this contract: $\pi_0 = p_0 - q(\ell - d_0) = p_0 + qd_0 - q\ell$. Consider the alternative full-insurance contract with premium $\hat{p} = p_0 + qd_0$. The profit per customer from the sale of this contract would be $\hat{\pi} = \hat{p} - q\ell = p_0 + qd_0 - q\ell$. Thus $\hat{\pi} = \pi_0$, so that the insurance company is indifferent between these two contracts. The customers, however, would strictly prefer the full-insurance contract with premium $\hat{p} = p_0 + qd_0$. In fact, purchasing contract (p_0, d_0) can be viewed as playing the lottery $\begin{pmatrix} W-p_0 & W-p_0-d_0 \\ 1-q & q \end{pmatrix}$ whose expected value is $W - p_0 - qd_0 = W - \hat{p}$; the full insurance contract guarantees this amount for sure and thus, by the assumed risk-aversion of the customer, makes her strictly better off. Hence the customer would be willing to purchase a full-insurance contract with a slightly higher premium $\tilde{p} > \hat{p}$; such a contract would yield a profit per customer of $\tilde{\pi} = \tilde{p} - q\ell > \hat{p} - q\ell = \hat{\pi} = \pi_0$. Hence contract (p_0, d_0) cannot be profit-maximizing.

In the above analysis it was assumed that the probability of loss q remained the same, no matter whether the individual was insured or not and no matter what insurance contract she bought. It is often the case, however, that the individual's behavior has an effect on the chances that a loss will occur, in which case a situation of *moral hazard* is said to arise. Moral hazard refers to situations where the individual, by exerting some effort or incurring some expenses, has some control over either the probability or magnitude of the loss, but these preventive measures are not observed by the insurer and hence the premium cannot be made a function of them. For example, the chances that a bicycle is stolen are lower if the owner is very careful and always locks the bicycle when she leaves it unattended. If the bicycle is not insured, the owner might be more conscientious about locking it, while if it is covered by full insurance she might at times not bother to lock it (after all, if the bicycle is stolen the insurance company will pay for a replacement). When the individual stands to lose if the loss occurs (e.g. if she is uninsured or if she incurs a high deductible) then she will have an incentive to try to reduce the chances of a loss. Hence in situations where moral hazard is present, the insurance company will prefer to offer *partial* insurance rather than full insurance.

So far we have focused on the case where the two parties to the insurance contract have the same information. Often, however, potential customers have more information than the insurance company, in which case we say that information is asymmetric. In the next three sections we turn to several issues that arise when there is asymmetric information and in Section 8 we return to insurance markets by examining strategies that insurance companies can employ to remedy the informational asymmetry.

5. Asymmetric Information

The expression 'asymmetric information' refers to situations where two parties to a potential transaction do not have the same information; in particular, one of the two parties has valuable information that is not available to the other party. Examples abound. The owner of a used durable good has had enough experience through use to know the true quality of the good he wants to sell; the potential buyer, on the other hand, cannot help but wondering if the seller is merely trying to get rid of a low-quality item he regretted buying. A loan applicant knows whether her intentions are to do her best to repay the loan and what the chances are that she will be able to repay it; the lender, on the other hand, will worry about the possibility that the borrower will simply "take the money and run". The owner of a house has more information than the prospective buyer about matters that are important to the latter, such as the quality of the house (e.g. how many repairs were needed in the past), the neighborhood (e.g. whether the neighbors are noisy), the upkeep of the house, etc.

In such situations the uninformed party cannot simply rely on verbal assurances by the informed party, since the latter will have an incentive to lie or misrepresent the truth: after all, talk is cheap! For example, if the seller of the house tells the prospective buyer that the neighbors are quiet and amicable, he may be lying in an attempt to get rid of a place where he hates to live. Sometimes the law makes the disclosure of important information compulsory (e.g. in some countries when you sell your house you have to make a written disclosure to the buyer of any problems you are aware of). However, some information may be unverifiable or it may be hard to prove that the owner knew about a particular fact.

Thus, in situations of asymmetric information, the uninformed party will need to try to infer the relevant information from the actions of the other party or from other observable characteristics. This often leads to market failures where society gets stuck in a *Pareto inefficient* situation. A situation X is defined to be Pareto inefficient if there is an alternative situation *Y* which is feasible and such that everybody is at least as well off in situation *Y* as in situation *X* and some individuals strictly prefer *Y* to *X*. This notion of efficiency is named after the Italian sociologist, economist and philosopher Vilfredo Pareto (1848–1923) who introduced it.

In the next two sections we discuss two important phenomena associated with asymmetric information: adverse selection and signaling. Both phenomena can give rise to Pareto inefficiencies.

6. Adverse Selection

George Akerlof's seminal paper (1970) pointed out what is now known as the phenomenon of *adverse selection* (also called *hidden information*). Akerlof considers markets where buyers are unable to ascertain the quality of the good they intend to purchase, while sellers know the quality. He shows that this asymmetry of information may lead to the breakdown of the market. He illustrates this possibility by focusing on the market for used cars where buyers' inability to determine the quality of the car they are considering buying makes them worried that they might end up with a 'lemon' (the American term for 'bad car'). Since buyers cannot distinguish a good car from a bad car, all cars must sell at the same price. This fact would not create a problem if the average quality of cars in the market were given exogenously. However, because of the sellers' knowledge, the average quality will in fact depend on the market price. The lower the price, the smaller the number of cars offered for sale and the lower the average quality. Realizing this, buyers will be willing to pay lower and lower prices, leading to a situation where only the lowest-quality cars are offered for sale: the bad quality cars drive the good quality cars out of the market. We will illustrate this with a simple example.

Suppose that there are two groups of individuals: the owners of cars and the potential buyers. The quality of each car is known to the seller (he used the car for a sufficiently long time) but cannot be ascertained by a potential buyer (a buyer will discover the true quality of a car only after owning it for a while). Denote the possible qualities by *A*, *B*¸ … *F* where *A* represents the best quality, *B* represents the second best quality and so on (thus *F* is the lowest quality). Quality could be measured in terms of durability or fuel efficiency or other characteristics that all consumers rank in the same way. Suppose that, for each quality level, the corresponding car is valued less by its owner than by a potential buyer. Thus, in the absence of asymmetric information, all cars would be traded (assuming a sufficiently large number of potential buyers). Suppose also that some general information is available to everybody (e.g. through consumer magazines) giving, for each quality, the proportion of all cars produced that are of that quality. All this is shown in Table 1, which we take to be common knowledge among sellers and potential buyers.

Quality	***A***	***B***	***C***	***D***	***E***	***F***
Value to potential	\$6,000	\$5,000	\$4,000	\$3,000	\$2,000	\$1,000

buyers						
Value to current owners	\$5,400	\$4,500	\$3,600	\$2,700	\$1,800	\$900
Proportion	$p_A = \frac{1}{12}$	$p_B = \frac{2}{12}$	$p_C = \frac{1}{12}$	$p_D = \frac{4}{12}$	$p_E = \frac{3}{12}$	$p_F = \frac{1}{12}$

Table 1 Information which is common knowledge among sellers and potential buyers.

According to Table 1, for each possible quality, the seller's valuation of the car is 10% less than a potential buyer's valuation. Since buyers cannot determine the quality of any particular car prior to purchase, all cars must sell for the same price, denoted it by *P*. For what values of *P* can there be trade in this market? Suppose that all potential buyers are risk-neutral, so that they view a money lottery as equivalent to its expected value. A potential buyer might reason as follows: "buying a car can be viewed as playing the following lottery

$$\left(\begin{array}{c|cccccc} \textit{net gain} & 6,000-P & 5,000-P & 4,000-P & 3,000-P & 2,000-P & 1,000-P \\ \textit{probability} & \frac{1}{12} & \frac{2}{12} & \frac{1}{12} & \frac{4}{12} & \frac{3}{12} & \frac{1}{12} \end{array}\right)$$

whose expected value is

$\frac{1}{12}(6,000-P)+\frac{2}{12}(5,000-P)+...+\frac{1}{12}(1,000-P)=3,250-P$; thus, as long as $P <$ \$3,250 I would gain from buying a second-hand car." This reasoning, however, is naïve in that it assumes that the average quality of the cars *offered for sale* is independent of *P*. A sophisticated buyer, on the other hand would realize that if, say, *P* = \$3,100 then buying a car would *not* yield an expected gain of \$150 (= 3,250 – 3,100), because only the owners of cars of qualities *D*, *E* and *F* would be willing to sell at that price: the higher qualities *A*, *B* and *C* would not be offered for sale.

-
-
-

Bibliography

Akerlof, George A., The market for ‘lemons’: quality uncertainty and the market mechanism, *Quarterly Journal of Economics*, 1970, 84: 488-500. [This is the seminal paper that started the literature on adverse selection.]

Diamond, Peter and Michael Rothschild (Editors), *Uncertainty in economics*, Academic Press, New York, 1978. [This is a collection of 30 original articles on various areas of the economics of uncertainty and information. Each article is preceded by a brief introduction by the editors. Notes and exercises are also provided.]

Dionne, Georges and Scott E. Harrington (Editors), *Foundations of insurance economics.* Kluwer Academic Publishers, Boston, 1991. [This is a collection of 34 papers on the economics of uncertainty with a focus on insurance markets.]

Hey, John, *Uncertainty in microeconomics*, Martin Robertson, Oxford, 1981. [This textbook focuses on how uncertainty affects the actions and decisions of economic agents. The focus is on consumer theory, theories of the firm and market models. It is suitable for use at all levels.]

Laffont, Jean-Jacques, *The economics of uncertainty and information*, MIT Press, Cambridge, 1990. [This is a book designed for advanced undergraduate and graduate students. It makes heavy use of mathematics, in particular, calculus. It offers an extensive analysis of a variety of topics in the area of information economics.]

McKenna, C.J., *The economics of uncertainty*, Oxford University Press, New York, 1986. [This is a concise and not too technical introduction to the main topics in the economics of uncertainty and information. It is suitable for use at all levels.]

Molho, Ian, *The economics of information*: *lying and cheating in markets and organizations*, Blackwell, Oxford, 1997. [This is a textbook suitable for use at all levels. The discussion is not too technical and covers the main topics in the economics of uncertainty and information. It also provides a useful account of the experimental and empirical literature on the various topics.]

Phlips, Louis, *The economics of imperfect information*, Cambridge University Press, Cambridge, 1988. [This is a textbook at the advanced undergraduate and graduate level. It is an extensive analysis of the implications of informational asymmetries for microeconomic theory. The book is divided into two parts: Part I deals with static models and Part II with dynamic models.]

Rothschild, Michael and Joseph Stiglitz, Equilibrium in competitive insurance markets: An essay on the economics of imperfect information, *Quarterly Journal of Economics*, 1976, 90: 629-650. [This is a seminal paper examining the notions of screening and separating equilibrium within the context of insurance markets.]

Spence, Michael, *Market signaling: informational transfer in hiring and related screening processes*, Harvard University Press, Cambridge, 1974. [This is the seminal contribution to the theory of signaling. It is easy to read and non-technical.]

Stiglitz, Joseph and Andrew Weiss, Credit rationing in markets with imperfect information, *American Economic Review*, 1981, 71: 393-410. [This is one of the important contributions to the theory of asymmetric information and adverse selection.]

Biographical Sketch

Giacomo Bonanno is professor of economics at the University of California, Davis, where he has been since 1987. He obtained his PhD from the London School of Economics in 1985 and was Research Fellow at Nuffield College, Oxford, from 1985 to 1987. He was editor of the journal *Economics and Philosophy* from 2005 to 2010 and is a member of the editorial board of several journals. He is the author of more than 70 research articles and editor of a dozen books and special issues of journals. He has organized nine editions of the interdisciplinary LOFT conference as well as other conferences. His web page is at h t t p : / / w w w . econ . ucdavis . edu / faculty / bonanno /