CHAPTER 8

Option Price and Option Value

In the actual practice of CBA in circumstances involving significant risks, analysts almost always apply the Kaldor-Hicks criterion to expected net benefits. They typically estimate changes in social surplus conditional on particular contingencies occurring, and then they compute an expected value over the contingencies as demonstrated in Chapter 7. Economists, however, now generally consider *option price*, the amount that individuals are willing to pay for policies prior to the realization of contingencies, to be the theoretically correct measure of willingness to pay in circumstances of uncertainty. Whereas social surplus can be thought of as an *ex post* measure of welfare change in the sense that individuals value policies as if contingencies have already occurred, option price is an *ex ante* welfare measure in the sense that consumers value policies without knowing which contingency will actually occur. These measures generally differ from one another. In this chapter, we consider the implications of the common use of expected social surplus, rather than option price, as the method for measuring benefits.

The central concern of this chapter is the conceptually correct measure of willingness to pay in circumstances in which individuals face uncertainty. Individuals may face uncertainties about their demand for a good, the supply of a good, or both. With respect to demand, one may be uncertain about one's future income, utility function (tastes), and the prices of other goods. For example, one's utility from skiing may depend on the sturdiness of one's knees, a physical condition that cannot be predicted with certainty. With respect to supply, one may be uncertain about the future quantity, quality, or price of a good. For example, the increase in the quality of fishing that will result from restocking a lake with game fish depends on such circumstances as weather and spills of toxic chemicals, and thus is uncertain to some degree.

In contrast to Chapter 7, we limit our attention to uncertainties of direct relevance to individuals. We ignore uncertainties that are not of direct individual relevance, but instead arise because analysts must make predictions about the future to estimate measures of WTP. In the context of the CBA of the vaccination program discussed in Chapter 7, for example, the probability of epidemic, the probability an unvaccinated individual will be infected, the probability a vaccinated individual will be infected, and the probability a vaccinated individual will suffer a side effect are exactly the types of uncertainties considered in this chapter. The analyst's uncertainties about the magnitude of these probabilities, the appropriate shadow price of time, or the number of people who will choose to be vaccinated were adequately addressed in the discussion of sensitivity analysis presented in Chapter 7. Although these analytical uncertainties are usually of greatest practical concern in CBA, we seek here to provide the conceptual foundation required for understanding the appropriate measure of costs and benefits when individuals face significant uncertainties. We are especially interested in how to assess government policies that increase or reduce the uncertainties that individuals face.

This chapter has three major sections. The first introduces option price and clarifies its relationship to expected surplus. The second section introduces the concept of *option value,* the difference between option price and expected surplus, and reviews the theoretical literature that attempts to determine its sign. Although sometimes thought of as a conceptually distinct category of benefits, option value is actually an adjustment to measured benefits to account for the fact that they are usually measured in terms of expected surplus rather than in terms of option prices. The third section provides a general assessment of the appropriateness of the use of expected surplus as a proxy for option price.

EX ANTE WTP: OPTION PRICE[1]

Viewing benefits (or costs) in terms of the willingness of individuals to pay to obtain desirable (or avoid undesirable) policy impacts provides a clear perspective on the appropriateness of treating expected net benefits as if they were certain amounts. By identifying the conceptually correct method for valuing uncertain costs and benefits, we can better understand the circumstances under which the use of expected net benefits is more or less appropriate.

There is now a near consensus among economists that the conceptually correct way to value the benefits of a policy in circumstances involving risk is to sum the *ex ante* amounts that the individuals affected by the policy would be willing to pay to obtain it.[2] To see this, imagine that each person, knowing the probabilities of each of the contingencies that would occur under the policy, would give a truthful answer to the following question: *Prior to knowing which contingency will actually occur, what is the maximum amount that you would be willing to pay to obtain the policy?* Each individual's answer to this question is what economists call the person's *option price* for the policy. If we think of the policy as a lottery having probabilities of various payoffs to the person, then the individual's option price is a *certainty equivalent* of the lottery—that is, an amount the person would pay for a ticket without knowing the payoff (or contingency) that is actually realized. (It is called a certainty equivalent because the amount paid for a lottery ticket is certain even if the payoff is not.)

By summing the option prices of all persons, we obtain the aggregate benefits of the policy, which can then be compared to its opportunity cost in the usual way. If the opportunity cost is not dependent on which contingency actually occurs, then we have fully taken account of risk by comparing the aggregate WTP, which is independent of the contingency that actually occurs, with the certain opportunity cost.

Illustrations of Option Price

To illustrate the concept of option price, return to the asteroid defense policies set out in Table 7-1 in the previous chapter. Assume that the United Nations wishes to evaluate forward-based asteroid defense from the perspective of humankind. Analysts might employ a contingent valuation survey of the sort described in

Chapter 15. It would require surveyors to explain to each person (or more likely to a representative of each household) the possible contingencies (exposure to collision with an asteroid larger than one kilometer diameter, exposure to collision with an asteroid between 20 meters and one kilometer in diameter, and no exposure to collision with an asteroid larger than 20 meters in diameter), the probabilities of each contingency, and the consequences to the Earth under each contingency with and without forward-based asteroid defense. Each person would then be asked questions to elicit the maximum amount that he or she would be willing to pay to have forward-based asteroid defense. These amounts would be summed over all earthlings to arrive at the social benefits of forward-based asteroid defense. As this sum represents aggregate WTP before people know which contingency occurs, and therefore is the WTP irrespective of which one actually occurs, it can be thought of as a certainty equivalent. Let us assume that the social net benefits, the sum of individual option prices, equaled $100 billion. The net benefits of forward-based asteroid defense would then be calculated as this amount minus the certain program costs of $60 billion, or $40 billion.

Recall that in actual CBA, analysts more commonly measure benefits by first estimating the social surplus under each contingency and then taking the expected value of these amounts using the probabilities of the contingencies. For example, the information in Table 7-1 indicates that the expected benefits of forward-based asteroid defense relative to no program to be −$15 billion. (The expected value of net costs of no program, $54 billion, minus the expected value of net costs of forward-based asteroid defense, $69 billion.) Thus, in this example, the expected surplus would underestimate net benefits by $55 billion ($40 billion minus −$15 billion). This difference between option price and expected surplus is the option value of forward-based asteroid defense. In this case, the option value can be thought of as an additional "insurance benefit" of the program. It is the maximum amount beyond expected benefits that individuals are willing to pay to have the defense program available to reduce the risk of the catastrophic consequences that would result from an undefended collision with a large asteroid.

In general, how does this expected surplus measure compare to the option price? Assuming that individuals are risk averse, *expected surplus can either underestimate or overestimate option price depending on the sources of risk*. For an individual who is risk averse and whose utility function depends only on income, expected surplus will underestimate option price for policies that reduce income risk and overestimate option price for policies that increase income risk. In order to understand how these possibilities can arise, it is necessary to look more carefully at the relationship between option price and expected surplus from the perspective of an individual consumer. The following diagrammatic expositions illustrate cases where option price exceeds expected surplus (a temporary dam) and expected surplus exceeds option price (a bridge).

Table 8-1 shows the contingent payoffs for building a temporary dam that provides water for irrigation. With or without the dam, the farmer can be viewed as facing two contingencies: It rains a lot or it does not rain very much. If it is wet, then he will always produce more crops than if it is dry. Without the dam, the farmer would receive an income of $100 if it rains a lot and only $50 if it does not rain very much. As a result of the dam, his income will increase by $50 if it is dry but by only $10 if it is wet. These $50 and $10 figures are the surplus that the farmer receives from the dam under each

TABLE 8-1 Example of a Risk-Reducing Project

	Policy		
Contingency	*Dam*	*No Dam*	*Probability of Contingency*
Wet	110	100	.5
Dry	100	50	.5
Expected value	105	75	
Variance	25	625	

Surplus point:	$U(110 - S_w) = U(100)$ implies $S_w = 10$ $U(100 - S_d) = U(50)$ implies $S_d = 50$
Expected surplus:	$E(S) = .5S_w + .5S_d = 30$
Expected utility of no dam:	$EU = .5U(100) + .5U(50)$
Willingness-to-pay locus:	(s_w, s_d) such that $.5U(110 - s_w) + .5U(100 - s_d) = EU$
Option price:	$.5U(110 - OP) + .5U(100 - OP) = EU$ $EU = 4.26$ and $OP = 34.2$ for $U(c) = \ln(c)$, where c is net income
Comparison:	$OP > E(S)$

contingency. In expected value terms, assuming that the dry and wet contingencies are equally likely, this surplus equals \$30. This \$30 expected surplus figure corresponds to the measure of benefits that is used in CBA when option price is not estimated.[3]

Notice that this example assumes that the dam will store water that can be used for irrigation purposes if it is dry. Consequently, the dam will do more for the farmer if it turns out to be dry than if it turns out to be wet. As a result, his income depends much less on which contingency actually occurs once the dam is built than it did without the dam. In other words, the dam reduces the income risk faced by the farmer by reducing the variation in his income. A useful summary measure of this reduction in income risk is provided by the effect of the dam on the variance of the farmer's income, which is \$625 without the dam but only \$25 with the dam.[4]

To determine the farmer's benefits from the dam, we first calculate his expected utility, *EU*, without the dam. We then find his option price, which is the maximum amount he would be willing to pay for the dam or, equivalently, the amount that gives him the same expected utility as he would have without the dam. To compute these amounts, we need to know the farmer's utility function. Normally, we would not have this information, which is why, in practice, expected surplus rather than option price is normally used to determine net benefits. For purposes of our illustration, however, we assume that the farmer's utility is given by the natural log of his income as shown in Table 8-1.

The curved line in Figure 8-1 shows this utility function. In the absence of a dam, the farmer realizes income of \$50 dollars if it is dry and \$100 if it is wet. Because the probabilities of wet and dry are each one-half, the expected utility without the dam can be found as the point midway between the utilities of these no-dam

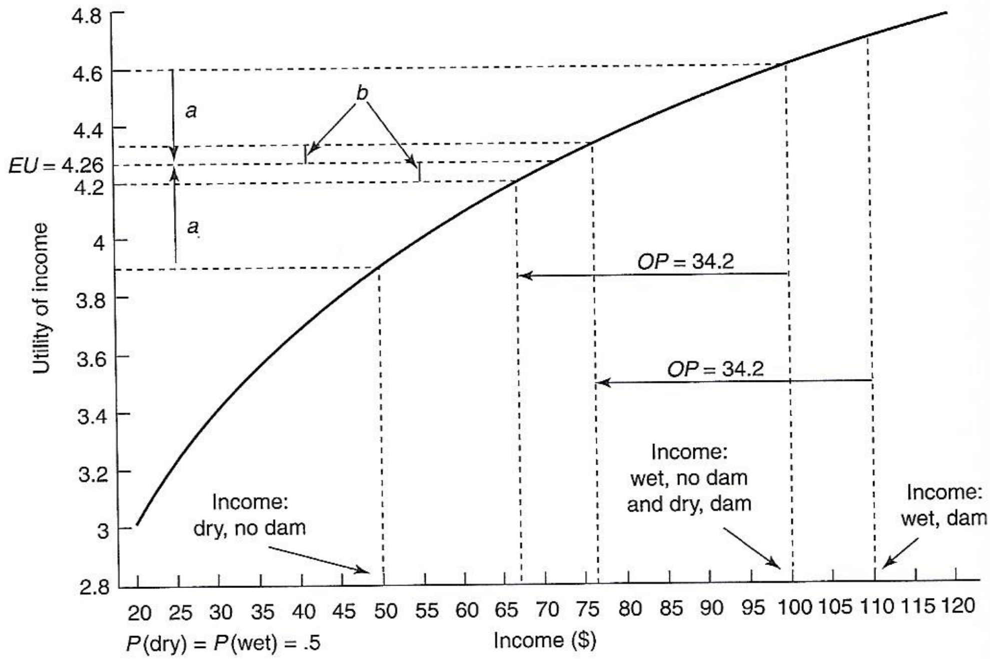

FIGURE 8-1 Utility Function and Option Price for Risk-Decreasing Project

incomes. The point on the vertical axis labeled $EU = 4.26$ is exactly a units of utility away from each of the contingent utilities. As it is midway between them, it equals the expected utility. If the dam is built, then the farmer receives an income of \$100 if it is dry and \$110 if it is wet. The option price for the dam is the maximum amount of income the farmer would be willing to give up to have the dam—in other words, the amount that would allow him to obtain the same expected utility with the dam as he would obtain without it. The arrows marked $OP = 34.2$ shift the contingent incomes with the dam by subtracting \$34.20 from each so that the net contingent incomes are \$65.80 and \$75.80. The utilities of these net incomes are each b units of utility away from 4.26 so that their expected utility equals the expected utility of no dam. Thus, either no dam or a dam with a certain payment of \$34.20 gives the farmer the same expected utility.

The farmer's option price for the dam of \$34.20 exceeds his expected surplus of \$30. Thus, if the opportunity cost of the project were \$32 and the farmer were the only beneficiary, then the common practice of using expected surplus would result in rejecting building the dam when, in fact, the option price indicates that building the dam would increase the farmer's utility.

Figure 8-2 provides an alternative graphical representation of the relationship between expected surplus and option price for the farmer. The vertical axis indicates the farmer's willingness-to-pay amounts if it is dry; the horizontal axis represents his willingness-to-pay amounts if it is wet. Thus, point A represents his surplus under each contingency.

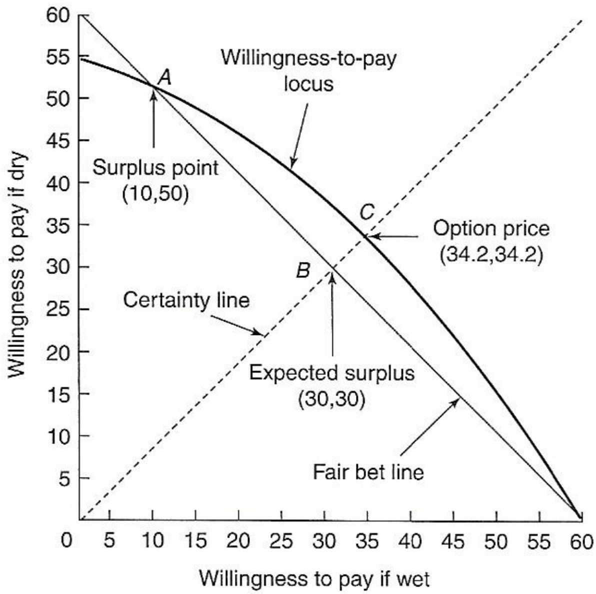

FIGURE 8-2 Risk-Reducing Project: Expected Surplus and Option Price

There is a slightly different way to view point *A*. Imagine that before the government will build the dam the farmer would be required to sign a contract, Contract *A*, that stipulates that he will pay the government an amount equal to $\$X_w$ if it turns out to be wet and an amount equal to $\$X_d$ if it turns out to be dry. This is called a *contingent contract* because its terms depend on events that will not be known until sometime in the future. Although the government is unlikely to require a contingent contract in practice, it is a useful device for thinking about how much the farmer values the dam or, in other words, his benefits from the dam. These benefits correspond to the maximum value that the government could assign to $\$X_w$ and $\$X_d$ and still get the farmer to sign Contract *A*, $10 and $50, respectively. The farmer would be willing to sign at these amounts because he would be exactly back to the situation he faced without the dam, when his income equaled $100 if it rained and $50 if it was dry. In other words, $10 and $50 are his maximum WTP under Contract *A*.

Notice that because the $10 payment if it is wet and the $50 payment if it is dry put the farmer back to where he would be without the dam, they measure the surplus he receives but not the utility he receives because the dam reduces the income risk he faces. If the farmer makes these payments, then his income variability would be exactly what it was without the dam. To examine the change in income risk resulting from the dam, imagine now that the government is also willing to let the farmer choose an alternative contract, Contract *B*, that allows him to pay the same amount, $30, regardless of which contingency actually occurs. If the government does this, then the expected value of the payment it will receive would be equal under the two contracts. However, Contract *B* would place the farmer on a line that bisects the origin of Figure 8-2. This line is called the *certainty line* because payment amounts along it are the same regardless of which contingency actually occurs. Thus, any point along this line, including *B*, represents a certainty equivalent.

The certainty line intersects another line. This one passes through the surplus point, but every point along it has the same expected value. For example, in the case of our illustration, the expected value would always be equal to \$30 along this line. This line is called the *fair bet line*. To see why, imagine flipping a coin. A payoff of \$10 if you get heads and \$50 if you get tails would have exactly the same expected value as \$20 if you get heads and \$40 if you get tails. Thus, the slope of the fair bet line, −1, is equal to the negative of the ratio of the probabilities of the contingencies. As one moves along the fair bet line toward the certainty line, the expected value always remains the same, but the variation in income decreases. Finally, at point *B* on the certainty line, the payoff is equal regardless of which contingency, heads or tails, actually occurs.[5] In our example, this payoff is \$30.

We now return to our farmer and the dam and ask whether he would be indifferent between signing Contract *A*, under which he must pay \$10 if it is wet and \$50 if it is dry, and Contract *B*, under which he must pay \$30 regardless of whether it is wet or dry, noting that the expected value of his income would be equal under the two contracts. To answer this, we look at what his income would be under the two contracts:

Contingency	*Probability*	*Income under Contract A*	*Income under Contract B*
Wet	.5	\$100	\$80
Dry	.5	\$50	\$70
EV		\$75	\$75

Although the expected value of income under the two contracts would be identical, the variation in income between the two contingencies is obviously much less under Contract *B*. Thus, by comparing Contracts *A* and *B*, we can examine the effect of the dam on the risk facing the farmer, while holding the expected value of his income constant. If the farmer is risk averse and, hence, would prefer a more stable to a less stable income from year to year, then he will not be indifferent between the two contracts but will prefer *B* to *A* because he will face less risk with *B* than with *A*.

Now, recall that at point *A* in Figure 8-2 the farmer was willing to sign a contract that would require him to pay \$10 if it is wet and \$50 if it is dry and that the expected value of these payments was \$30. Because the farmer prefers point *B* to point *A*, this suggests that in order to reach the certainty line, the farmer would be willing to sign a contract requiring him to pay a certainty equivalent greater than \$30. The maximum such amount that he would pay is represented by point *C* in Figure 8-2, a point that is farther northeast along the certainty line than point *B*. Point *C* represents the farmer's option price, the maximum amount that he would be willing to pay for *both* the increase in expected income and the reduction in income risk resulting from the dam. In other words, it incorporates the full value of the dam to the farmer. Conceptually, it is the correct measure of benefits that the farmer would receive from the dam. But in CBAs, it is point *B*, the expected value of the surpluses resulting from the dam, that is typically predicted. While point *B* captures the effect of the dam on expected income, it does not incorporate the effect of the dam on income variability or risk.

TABLE 8-2 Example of a Risk-Increasing Project

	Policy		
Contingency	***Bridge***	***No Bridge***	***Probability of Contingency***
No earthquake	200	100	.8
Earthquake	100	80	.2
Expected value	180	96	
Variance	1600	64	

Surplus point:	$U(200 - S_n) = U(100)$ so $S_n = 100$ $U(100 - S_e) = U(80)$ so $S_e = 20$
Expected surplus:	$E(S) = .8S_n + .2S_e = 84$
Expected utility of no bridge:	$EU = .8U(100) + .2U(80)$
Willingness-to-pay locus:	(s_n, s_e) such that $.8U(200 - s_n) + .2U(100 - s_e) = EU$
Option price:	$.8U(200 - OP) + .2U(100 - OP) = EU$ $EU = 4.56$ and $OP = 71.1$ for $U(c) = \ln(c)$, where c is net income
Comparison:	$OP < E(S)$

Although the farmer would prefer point *B* to point *A*, he would be indifferent between points *A* and *C*. Indeed, a curve drawn between these points is very similar to an indifference curve. This curve, the *willingness-to-pay locus,*[6] shows all of the combinations of contingent payments for the dam that give the farmer the same expected utility with the dam as without it.[7] It is based on knowledge of the probabilities of the contingencies prior to knowing which one will actually occur.

If the option price lies farther to the northeast along the certainty line than does the certain project cost, then the project would increase the farmer's welfare.

Table 8-2 describes a policy involving constructing a bridge in an area where the probability of an earthquake is 20 percent. The bridge would increase the expected value of income that the individual described in the table receives, but at the same time, it would make her income more dependent on whether or not a quake actually occurs. In other words, the bridge increases the income risk facing the individual. Consequently, as shown in the table, the expected surplus of $84 exceeds the option price of $71.10. Thus, if the opportunity cost of the bridge were a certain $75 and the person were the only beneficiary, then the option price indicates that building it would reduce her expected utility if she actually had to pay the opportunity cost of its construction. Hence, the bridge should not be built, even though the expected surplus from building it is positive.

This situation is illustrated in Figure 8-3. The bridge can be viewed as initially placing the individual at point *D*. Once again, we can imagine the government requiring the individual to sign a contingent contract, Contract *D*. In this case, the individual would

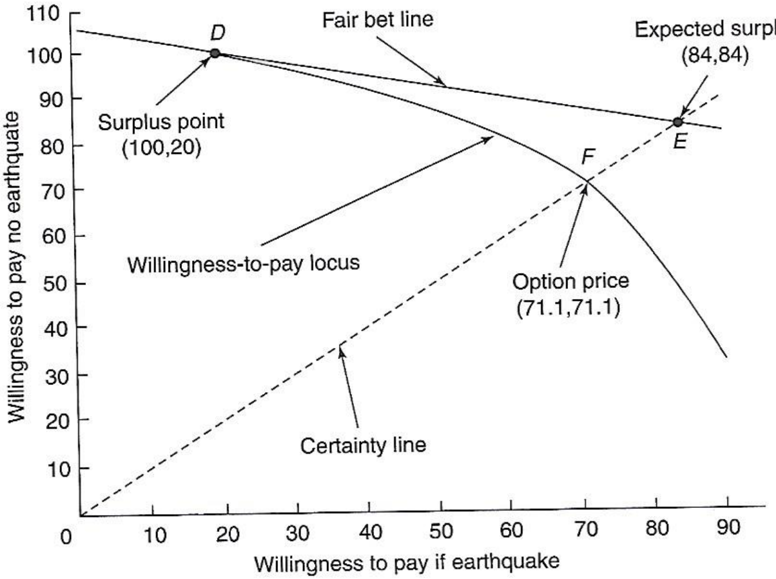

FIGURE 8-3 Risk-Increasing Project: Expected Surplus and Option Price

be willing to pay up to $100 in the event that there is not a quake but only $20 if there is a quake. By signing such a contract, she would be no worse off than she was without the bridge.

We have taken account of the fact that the bridge would increase expected surplus but not the fact that it would also affect income risk. Thus, as before, we imagine that the government is also willing to sign a different contract, Contract *E,* as long as the expected value of the payments continues to equal $84, their expected value under Contract *D*.

Which contract would she prefer? If she is risk averse, she would prefer Contract *D* to Contract *E* because, in the following table even though the expected value of her income is identical under the two contracts, her income would be subject to less risk:

	Income under	***Income under***	
Contingency	***Probability***	***Contract D***	***Contract E***
No quake	.8	$100	$116
Quake	.2	$80	$16
EV		$96	$96

Because a risk-averse individual would prefer Contract *D* to Contract *E,* her willingness to pay locus for the bridge would be below her fair bet line. Consequently, her option price, which is represented by point *F,* is less than $84. As in the previous illustration, the individual would be indifferent between points *D* and *F,* but not between points *D* and *E*.

Is Option Price the Best Measure of Benefits?

The illustrations previously described demonstrate that, in general, option price does not equal expected surplus in circumstances of uncertainty. In the first illustration, option price was larger than the expected value; in the second illustration, it was smaller. We have implicitly taken option price to be the correct benefit measure. Is this generally the case? The answer to this question requires a clearer specification of the institutional environment of policy choice.

The key consideration concerns the availability of insurance against the risks in question. *If complete and actuarially fair insurance is unavailable against the relevant risks, then option price is the conceptually correct measure of benefits.* Insurance is complete if individuals can purchase sufficient coverage to eliminate their risks entirely. It is actuarially fair if its price depends only on the true probabilities of the relevant contingencies. In the case of two contingencies, with the probability of contingency 1 equal to p and the probability of contingency 2 equal to $1 - p$, actuarially fair insurance would allow the individual to trade contingent income in contingency 1 for contingent income in contingency 2 at a price of $p/(1 - p)$. For example, if p equals .2, then the price of insurance equals .25 (.2/.8), so that to increase income in contingency 1 by \$100, the individual would have to give up \$25 in contingency 2. Graphically, the availability of actuarially fair insurance means that individuals could move along the fair bet lines toward the certainty lines shown in Figures 8-2 and 8-3 through purchases of insurance.

Complete and actuarially fair insurance is rarely available in the real world.[8] The problem of *moral hazard,* the changes in risk-related behavior of insurees induced by insurance coverage, encourages profit-maximizing insurers to limit coverage through copayments.[9] Insurers may be unwilling to provide full insurance against losses to unique assets that cannot be easily valued in markets.[10] *Adverse selection* occurs when insurees have better information about their true risks than do insurers. Adverse selection may result in either the combining of low- and high-risk persons in the same price pool or the limiting of the extent of coverage to induce high risks to reveal themselves.[11] The pooling of high- and low-risk persons implies that at least one of the groups receives an actuarially unfair price; limiting available coverage to high-risk persons means that complete insurance is unavailable. Routine administrative costs, as well as efforts to control moral hazard and adverse selection, inflate prices above the actuarially fair levels. Limited pools of insurees or uncertainty about the magnitudes of risks may require a further increment in prices to reduce the risk of bankruptcy.[12] Finally, some risks are so highly correlated across individuals that risk pooling does not sufficiently reduce aggregate risk to allow actuarially fair prices.[13] In order to manage the risk of going bankrupt, insurers facing correlated risks must charge an amount above the actuarially fair price to build a financial cushion or buy reinsurance to guard against the possibility of having to pay off on many losses at the same time.

Imagine that, despite these practical limitations, complete and actuarially fair insurance were available for the risk in question. It would then be possible for the sponsor of the project to trade the contingent surplus amounts for a certain payment by purchasing sufficient insurance to move along the fair bet line, which represents actuarially fair insurance, to the certainty line. In this way, a certain payment corresponding to the expected surplus could be achieved. For example, returning to Figure 8-3, the project sponsor could guarantee a certain payment of \$84, which is larger than the option price of \$71.10. Notice, however, that if the option price exceeds the expected surplus (the situation illustrated in Figure 8-2), then the latter will understate the conceptually correct measure of project benefits, even if complete and actuarially fair insurance can be purchased. In general, therefore, *if complete and actuarially fair insurance is available, then the larger of option price or expected surplus is the appropriate measure of benefits.*

This generalization ignores one additional institutional constraint: It is not practical to specify contingency-specific payments that would move an individual from his or her contingent surplus point to other points on his or her willingness-to-pay locus. The impracticality may arise from a lack of either information about the shape of the entire willingness-to-pay locus or the administrative capacity to write and execute contingent contracts through taxes and subsidies whose magnitudes depend on the occurrence of events. Yet, if such contracts were administratively feasible *and* the analyst knew the entire willingness-to-pay locus, then the policy could be designed with optimal contingent payments so that the person's postpayment contingent surpluses would have the greatest expected value, which could then be realized with certainty through insurance purchases.

Figure 8-4 illustrates this possibility. In the absence of payments, the person realizes either S_1 or S_2 depending on which contingency occurs. If, in addition to the direct

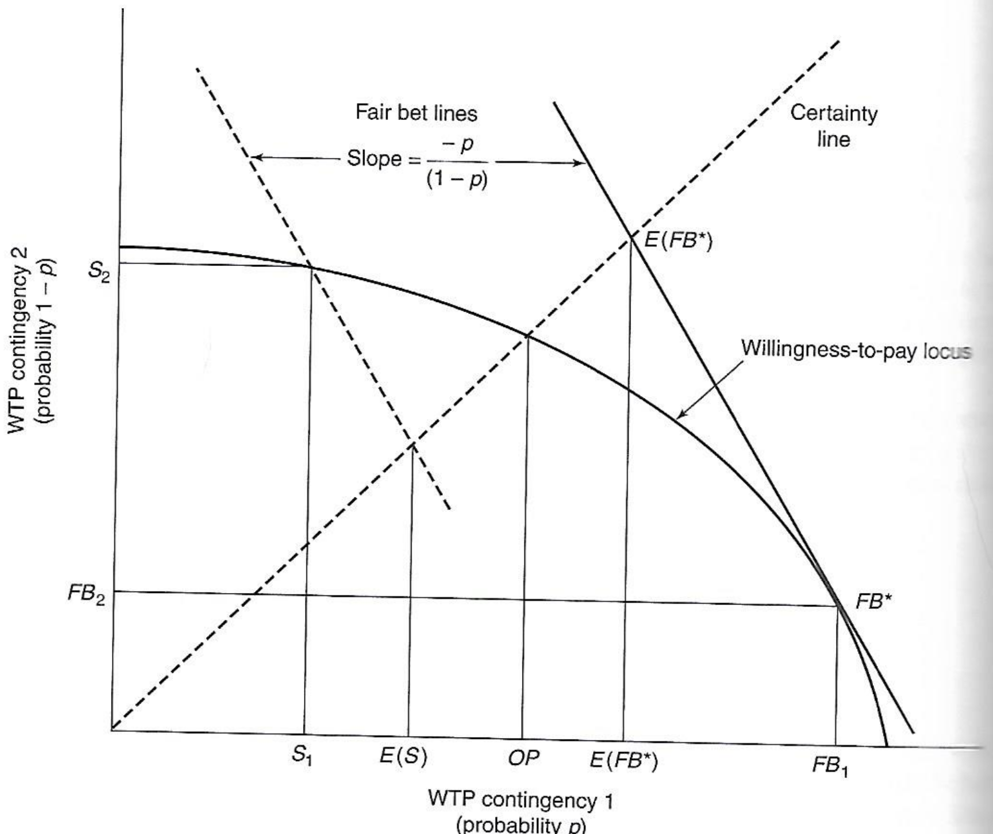

FIGURE 8-4 Option Price and the Maximum Expected Value of Willingness to Pay

effects of the policy, the person were given a payment equal to $FB_1 - S_1$ if contingency 1 occurred or paid a fee of $S_2 - FB_2$ if contingency 2 occurred, then the person's post-payment contingent surpluses would be given by point FB^*. Because FB^* is the point of tangency between the willingness-to-pay locus and a fair bet line, it has the largest expected value of any point on the willingness-to-pay locus. Starting at this point, complete and actuarially fair insurance would allow the policy sponsors to move along the fair bet line to the certainty line. The resulting certain payment, $E(FB^*)$ would be the maximum certain amount of benefit produced by the payment-adjusted policy.[14]

Thus, *in the exceedingly unlikely circumstance that optimal contingent payments are feasible* ***and*** *complete and actuarially fair insurance is available, the expected value of the point on the willingness-to-pay locus that is just tangent to the fair bet line is the appropriate measure of benefits.*

In summary, if the policy under consideration involves costs that are certain and complete and actuarially fair insurance is unavailable, then option price is the appropriate measure of benefits because it allows us to compare certain willingness-to-pay amounts with certain costs. In practice, however, option prices are difficult to measure. Indeed, as will be evident from the discussion of option values in the next section, very specific assumptions about the nature of risks must be made to be able to determine whether option price is larger or smaller than the commonly measured expected surplus.

DETERMINING THE BIAS IN EXPECTED SURPLUS: SIGNING OPTION VALUE

Early attempts to apply CBA to recreational resources such as national parks raised uneasiness about the appropriateness of expected surplus as a benefit measure. In a seminal article dealing with the issue, Burton Weisbrod pointed out that estimates of the benefits of preserving a national park based solely on the benefits accruing to actual visitors do not capture its value to those who anticipate visiting it sometime in the future but actually never do.[15] He argued that these nonvisitors would be willing to pay something to preserve the option of visiting. He called this amount *option value*, which has been interpreted by many as a separate benefit category of relevance to valuing assets, such as natural resources, that offer opportunities for future consumption.

CBA requires a more precise definition of option value, however.[16] The key to formulating it lies in the recognition that option price fully measures a person's *ex ante* willingness to pay for a policy in the presence of uncertainty about the benefits that will accrue *ex post*. The uncertainty may arise from a variety of sources, including not only uncertainty about the demand the person will actually have for the goods produced by the policy if it is implemented (Weisbrod's point), but also uncertainty about the quantities, qualities, and prices of the goods, as well as the prices of other goods. Because, even with such uncertainties, it is a full measure of willingness to pay, option price includes option value.

It is now standard to define *option value* as the difference between option price and expected surplus:

$$OV \equiv OP - E[S] \quad \textbf{(8.1)}$$

where *OV* is option value, *OP* is the option price, and *E*[*S*] is expected surplus. For example, the option value for the dam presented in Table 8-1 is $4.20, the option price of $34.20 minus the expected surplus of $30. The option value of the bridge presented in Table 8-2 is −$12.90, the option price of $71.10 minus the expected surplus of $84.

Rearranging the equation defining option value gives the practical interpretation of option value as an adjustment to expected surplus required to make it equal to option price:

$$OP = E[S] + OV \qquad (8.2)$$

where the left-hand side is the certain amount a person is willing to pay, the conceptually correct measure of benefits, and the right-hand side consists of expected surplus, which is what is typically measurable, and option value, which is the amount that would have to be added to expected surplus to make it equal to option price. Though it may seem natural to interpret option value as a distinct benefit category, it is probably better to interpret it as the bias in estimated benefits resulting from measurement by expected surplus rather than option price. Unfortunately, either interpretation requires caution because the sign, let alone the magnitude, of option value is often difficult to determine.

Determining the Sign of Option Value

The sign of option value may be positive or negative, depending on a variety of assumptions concerning the source and nature of risk, the characteristics of the policy being analyzed, and the underlying structure of individual utility. With only a few exceptions, the sign of option value has proven to be theoretically ambiguous. This raises the issue of the usefulness of the concept of option value for even determining the direction of bias when expected surplus is used as an approximation of option price.

The earliest studies (see Appendix 8A) attempted to determine the sign of option price when the change in the price or quantity of the good being valued is certain but the demand for the good is uncertain. For example, in the earliest effort to sign option value, Charles J. Cicchetti and A. Myrick Freeman III assumed that there is some probability that a person will have positive demand for the good.[17] Their conclusion that option price is always positive when demand is uncertain was later contradicted by Richard Schmalensee, who showed that the sign was ambiguous under general assumptions.[18]

Subsequent efforts to sign option value without making specific assumptions about individuals' utility functions have produced an unequivocal result only with respect to uncertainty in income. Specifically, in valuing a certain change in the price or quantity of a normal good (quantity demanded increases with increases in income), option value will be negative for a risk-averse person with uncertain income because the change in price or quantity of the good accentuates the income uncertainty. Conversely, in valuing a certain change in the price or quantity of an inferior good (quantity demanded decreases with increases in income), option value will be positive for a risk-averse person. As CBA typically involves valuing normal goods, this general result cautions against the tendency to think of option value as a positive adjustment to expected surplus.

EXHIBIT 8-1

In 1980 Richard G. Walsh, John B. Loomis, and Richard A. Gillman combined survey and recreational use data in an effort to estimate the willingness of Colorado households to pay for increments of land designated for wilderness. They estimated that residents of the state were willing to pay a total of $41.6 million annually for 2.6 million acres. Approximately $6.0 million, or almost 15 percent, of this total was option value.

Source: Adapted from Richard G. Walsh, John B. Loomis, and Richard A. Gillman, "Valuing Option, Existence, and Bequest Demands for Wilderness," *Land Economics* 60(1) 1984, 14–29.

On the other hand, with the imposition of a variety of different restrictive assumptions, it appears that for risk-averse persons, uncertainty about the quantity, quality, or price of a normal good (supply-side uncertainty) will usually result in a positive option value. For example, Douglas M. Larson and Paul R. Flacco show that if the demand for a normal (inferior) good is linear, semilog, or loglinear in price, then option price is positive (negative) for uncertainty in the price or quality of the good being valued.[19] They also show that uncertainty about the prices of other goods and tastes—demand-side uncertainty—similarly yields positive (negative) option values for normal (inferior) goods for these demand functions.[20]

Overall, the theoretical studies of option value suggest the following general heuristic: *With risk-averse individuals and normal (inferior) goods, treat option value as negative (positive) for income uncertainty, positive (negative) for other demand-side uncertainties, and generally positive (negative) for supply-side uncertainties*. Of course, the assumed sign of option value should be consistent with the specific assumptions employed. So, for example, if the empirically estimated demand for a normal good employs a loglinear functional form with a positive income elasticity, then option value would be negative for income uncertainty, positive for other demand-side uncertainties, and positive for supply-side uncertainties.

It should not be surprising that in view of the difficulty in establishing the sign of option value, even less progress has been made in putting bounds on its size relative to expected surplus. Calculations by V. Kerry Smith suggest that the size of option value relative to expected surplus is likely to be greater for assets that have less perfect substitutes.[21] Larson and Flacco derived expressions for option value for the specific demand functions that they investigated, but the implementation of these expressions is computationally very difficult.[22] Consequently, it is generally not possible to quantify option value using the information from which estimates of expected surplus are typically made.

RATIONALES FOR EXPECTED SURPLUS AS A PRACTICAL BENEFIT MEASURE

Although option price is generally the conceptually correct measure of benefits in circumstances of uncertainty, analysts most often estimate benefits in terms of expected surpluses. As indicated in the preceding discussion of option value, determining even