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Risk and Probability Premiums for CARA Utility Functions

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The risk premium and the probability premium are used to determine appropriate coefficients of absolute risk aversion under CARA utility. A defensible range of risk-aversion coefficients is defined by the coefficients that correspond to risk premiums falling between 1 and 99% of the amount at risk or to probability premiums falling between .005 and .49 for a lottery that pays or loses a given sum. The consequences of ignoring risk premiums when selecting risk-aversion coefficients for representative decision makers are illustrated by calculation of the implied risk premium associated with the levels of absolute risk aversion assumed in six selected studies.

Key words: CARA utility, probability premiums, risk-aversion coefficients, risk premiums.

Introduction

The use of absolute risk aversion (ARA) levels to determine the effects of risk aversion on the decisions of firms is common. Typically, a range of ARA is used to show how increases in risk aversion alter decisions (e.g., Collender and Zilberman; Holt and Brandt; Freund; and King and Lybecker). The assumed, elicited, or estimated values of ARA for risk-averse agents in empirical studies differ widely. For example, Love and Buccola estimate a maximum value of .538 while Collender and Zilberman use a minimum value of .000000921.

Constant absolute risk aversion (CARA), or negative exponential utility functions, with an assumed value of ARA often is used to analyze farm decisions under risk (e.g., Antle and Goodger; Buccola; Chalfant, Collender, and Subramanian; and Yassour, Zilberman, and Rausser). For CARA utility functions, an ARA value is sufficient to determine an individual's preference over alternative decisions. For a given ARA level, one can determine how preferences change as risk aversion increases. However, an ARA value does not convey sufficient information to indicate whether the implied level of risk aversion is "reasonable." One typically cannot tell from knowledge of the assumed ARA level if, for example, the preference of policy *A* over policy *B* is held by slightly, moderately, or strongly risk-averse individuals or by those with unreasonably high levels of risk aversion.

Knowledge of the risk premium as a proportion of the amount of wealth at risk, however, conveys much more information than does the ARA level. For example, if an individual would be willing to pay 98% of the potential loss in a gamble to eliminate that gamble, then the individual could be characterized as extremely risk averse. The purpose of this

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article is to use the risk premium and the probability premium to select ranges of ARA appropriate for determining the effects of risk aversion on individuals with CARA utility functions. The appropriate ARA ranges are determined by calculating risk-aversion coefficients for various gamble sizes when individuals have risk premiums falling between 1 and 99% of the gamble size and probability premiums falling between .005 and .49 for a lottery that pays or loses a given sum. The advantage of the proposed approach is that two interpretable quantities—the risk premium, expressed as a percentage of gamble size, and the probability premium—are used as the determinants of the degree of risk aversion.

Risk Premiums Under CARA

Consider an individual with certain income w and random income z. Let $z = [h, -h; .5, .5]$ be a bet to gain or lose a fixed amount $h \in (0, w]$ with equal chances. The risk premium, expressed as a fraction θ of the gamble h, is implicitly defined by the equation

$$(1) \qquad \frac{1}{2}u(w + h) + \frac{1}{2}u(w - h) = u(w - \theta h),$$

where $u(\cdot)$ is an increasing von Neumann–Morgenstern utility function and where $0 \leq \theta \leq 1$. If utility is linear in income, then θ equals zero. If $u(\cdot)$ is strictly concave in income, then θ is positive, but less than unity.

When θ and h are given, the exact ARA value can be obtained for CARA utility functions $u(w) = 1 - e^{-Aw}$. Note that this utility function is increasing in income if and only if $A > 0$, and hence the risk-neutral case ($A = 0$) is ruled out. With CARA utility, (1) becomes

$$(2) \qquad \frac{1}{2}[1 - e^{-A(w+h)}] + \frac{1}{2}[1 - e^{-A(w-h)}] = 1 - e^{-A(w-\theta h)}.$$

After some manipulation, we obtain

$$(3) \qquad x^{-1} + x = 2x^{\theta},$$

where $x = e^{Ah}$. Because x depends on both A and h, equation (3) indicates that θ will be affected by the degree of risk aversion and the gamble size h, but that it is independent of w. The relation can be written explicitly as

$$(4) \qquad \theta(A, h) = \frac{\ln[.5(e^{-Ah} + e^{Ah})]}{Ah}.$$

In view of the relation between θ and A, information about θ for a given value of $h > 0$ is sufficient to ascertain the exact value of A.

Probability Premiums Under CARA

Now suppose that the individual faces a choice between status quo w and random income $w + z$, where z is a random variable. Using a binary gamble, Arrow derived a general measure of risk aversion from the probability premium. When a gamble of winning or losing a given amount is fair, the probability premium measures the increase in probability above 1/2 that an individual requires to maintain a constant level of utility equal to the utility of status quo w.

Let $z = [h, -h; p, 1 - p]$ be a bet to gain or to lose a fixed amount $h \in (0, w]$ with probability p and $(1 - p)$, respectively. Let $\hat{p}$ be the probability such that the individual is indifferent between the status quo, w, and the risky income, $\hat{w} = [w + h, w - h; \hat{p}, 1 - \hat{p}]$. The value of $\hat{p}$ is defined implicitly by the equation

$$(5) \qquad \hat{p}u(w + h) + (1 - \hat{p})u(w - h) = u(w).$$

If $u(\cdot)$ is linear in income, then $\hat{p}$ is equal to the actuarially fair value, 1/2. Let $\rho \equiv \hat{p} - 1/2$ be the probability premium. If $u(\cdot)$ is strictly concave in income, then $0 < \rho < 1/2$.

For the CARA utility function, the probability premium can be used to determine the exact value of A. Using CARA in (5) we obtain

$$\hat{p}[1 - e^{-A(w+h)}] + (1 - \hat{p})[1 - e^{-A(w-h)}] = 1 - e^{-Aw}. \quad (6)$$

After some manipulation and after we substitute $x = e^{Ah}$, (6) can be written in quadratic form:

$$(1 - \hat{p})x^2 - x + \hat{p} = 0. \quad (7)$$

Two solutions to (7) are $x = \{1 \pm [1 - 4(1 - \hat{p})\hat{p}]^{1/2}\}/2(1 - \hat{p})$. Using $\hat{p} = 1/2 + \rho$, we obtain $x = (1 \pm 2\rho)/(1 - 2\rho)$. Ruling out the solution $x = 1$, we choose $x = (1 + 2\rho)/(1 - 2\rho)$. Substituting $Ah = \ln(x)$ yields

$$A(\rho, h) = \frac{\ln[(1 + 2\rho)/(1 - 2\rho)]}{h}. \quad (8)$$

Equation (8) expresses ARA as a function of the probability premium and of the gamble size. The risk premium in (4) is a function of A. Substituting (8) into (4), we obtain

$$\theta(\rho) = \frac{\ln[(1 + 4\rho^2)/(1 - 4\rho^2)]}{\ln[(1 + 2\rho)/(1 - 2\rho)]}. \quad (9)$$

Thus, for a given gamble size h, equation (9) shows the relation between the probability premium and the risk premium.

Equation (4) shows that θ is a function of A and h. A is, in turn, a function of the probability premium and h by (8). Therefore, the relation between θ and ρ seems a function of both A and h. But, (9) indicates that for CARA utility functions the relation between θ and ρ is independent of the gamble size, i.e., there exists a function ϕ such that $\theta = \phi(\rho) = \theta[A(\rho, h), h]$.

Values of ARA in the Literature

Empirical studies of firms often use either a level of ARA with stochastic dominance or a CARA utility function to demonstrate the effects of risk aversion on firm decisions. In these typical simulation studies, the choice of the appropriate level of risk aversion is critical. If an implausibly high level is chosen, the firm will act "too risk averse" in the sense that the firm could not remain competitive because excessive expected returns would be traded for risk reductions. On the other hand, if too small a level of risk-aversion coefficient is chosen, the decisions will not differ appreciably from the decisions of a risk-neutral firm. In the latter instance, one may as well use the risk-neutral model and ignore the effects of risk aversion altogether.

Most studies recognize this problem and attempt to present results over a range of risk-aversion coefficients. It is often difficult, however, for readers to gain an intuitive understanding of the degree of risk aversion simply by looking at assumed risk-aversion coefficients. As demonstrated by equations (4) and (8), the size of the gamble greatly influences reasonable interpretations of a given risk-aversion coefficient. For example, if the gamble size is \$10,000, a person with a risk-aversion coefficient of .0001 would have a risk premium of 43% of the gamble. A risk premium of this amount suggests a relatively high level of risk aversion. The same coefficient with a gamble of \$1,000 implies a risk premium of only 5%, suggesting a relatively low level of risk aversion. This example demonstrates why it is desirable to present levels of risk aversion in terms of the implied certainty equivalent or risk premium of the decision maker. A good example of this approach is given in Chalfant, Collender, and Subramanian.

Table 1 illustrates the importance of calculating implied risk premiums during selection

Table 1. Risk-Aversion Levels, Gamble Size, and Implied Risk Premiums from Six Selected Studies

Study	Risk-Aversion Level[a]	Gamble Size[b] ($)	Risk Premium[c]
Babcock, Chalfant, and Collender	.00003	5,172[d]	.077
	.0029	4,272	.51
	.0005	4,204	.68
Kramer and Pope	.00125	27,427[e]	.98
	.03	27,427	1.00
Love and Buccola	.017	39[f]	.31
	.538	39	.97
McSweeny and Kramer	.0001	22,607[g]	.70
	.0006	4,870	.92
Rister, Skees, and Black	.00001	12,473[h]	.062
	.00008	12,473	.44
Zacharias and Grube	.000092	47,593[i]	.84
	.0035	47,593	.996

[a] Some of the cited studies allowed for risk-loving behavior. When this occurred, the lowest positive risk-aversion coefficient was used as the lower range of risk aversion.
[b] The size of gamble is taken as the standard deviation of net returns.
[c] The risk premium is expressed as the fraction of the gamble size.
[d] Calculated at the optimal solutions assuming no correlation between the yields of corn and oats.
[e] Calculated under the 1979 program features scenario.
[f] Calculated for Linn County, Iowa, at the mean levels of nutrients, a corn price of $1.40/bushel, and one acre of land.
[g] Taken directly from the presentation of results.
[h] For the scenario of selling half the crop in July and half in October.
[i] For the continuous corn with varied herbicide treatment scenario.

of appropriate risk-aversion coefficients. The six studies presented in table 1 were selected because they provide sufficient detail to allow the calculation of an approximate gamble size facing their representative decision makers. None of the six studies report risk premiums or certainty equivalents as functions of the size of the gambles, although Babcock, Chalfant, and Collender report the increase in certainty equivalents across risk-aversion levels. The results of the six studies cannot be compared directly because they involve different distributions of net returns. And, none of the six studies assumes a two-state gamble as was assumed to calculate the risk premiums in this study. However, an approximately equivalent two-state gamble can be obtained by converting the gambles in the six studies into a two-state gamble. We take the standard deviation of net returns as an approximation for the gamble size in the six selected studies in table 1. For normally distributed net returns, the approximate risk premiums in table 1 converge to the true risk premiums as risk aversion decreases.[1] It can be shown that for high risk-aversion levels and for normally distributed returns, the approximate risk premiums reported in table 1 are smaller than the true risk premiums.

The selected risk-aversion levels in table 1 range from .00001 in Rister, Skees, and Black to .538 in Love and Buccola. This wide range may be appropriate because the approximate gamble size ranges from a high of $47,593 in Zacharias and Grube to $39 in Love and Buccola. Given the approximate gamble size and the studies' risk-aversion coefficients, the implied risk premiums are calculated from equation (4), which assumes that the representative individuals in the studies exhibit CARA across all gamble sizes and alternative distributions. These calculated values range from .062 in Rister, Skees, and Black to 1.00 in Kramer and Pope. Thus, taken together, these studies seem to portray a wide range of risk aversion.

In some of the studies, however, the decisions of risk-averse firms do not differ from those of risk-neutral firms unless the risk premium is a large fraction of the gamble size. For example, Kramer and Pope, in their study of alternative commodity programs, find that risk-averse firms rank program alternatives in the same manner as risk-neutral firms if the risk-aversion level is less than .00125. This level corresponds to a risk premium greater than 98% of the gamble. McSweeny and Kramer and Zacharias and Grube also find that, unless the risk premium is quite large, the decisions of risk-averse firms are consistent with risk neutrality. Rister, Skees, and Black seem to cover the lower range of risk-averse individuals, perhaps because they calculate the implied certainty equivalent of their assumed level of risk aversion as a guide in selecting risk-aversion coefficients. Love and Buccola's risk-aversion levels are estimated from observed variable input decisions. Their estimate of $A = .017$ seems reasonable if it assumed that only one acre of corn is grown. Their estimate of .538 seems extreme even under this assumption. The estimates of Babcock, Chalfant, and Collender cover the range from slightly risk averse to levels of risk aversion that seem quite high for current commercial farmers. A risk premium of .68, which corresponds to $A = .0005$, used by Babcock, Chalfant, and Collender, implies a probability premium of approximately .39. In a binary gamble, such a producer requires an 89% chance of winning a given amount before the expected utility of the gamble equals the utility without the gamble. Babcock, Chalfant, and Collender used Binswanger's classifications of slight, moderate, and intermediate levels of risk aversion to select appropriate risk-aversion coefficients.

Inspection of table 1 leads one to conclude that care should be taken in selecting risk-aversion coefficients to demonstrate the effects of risk aversion on decisions. Rather than selecting levels that give desired quantitative results, one should select levels that represent plausible degrees of risk aversion, as represented by plausible levels of risk or probability premiums. The consequences of selecting implausible levels can be critical. Suppose, for example, policymakers used the results of Zacharias and Grube to determine the preferences of risk-averse producers over alternative herbicide policies. Whose preferences would they be taking into consideration? Probably those of producers who are too risk averse to farm.

Numerical Analysis

Table 2 shows the values of A and ρ corresponding to values of θ ranging from .02 to .98 for three levels of h: $h = \$10{,}000$, $h = \$1{,}000$, and $h = \$100$. The ρ values were calculated numerically from the implicit relation given by equation (9). The probability premium is approximately half the value of θ for $\theta < .3$, at which point ρ increases more slowly, reaching a plateau for $\rho > 90\%$.

Consider a gamble size of \$10,000. From the third column in table 2, we see that the value of A corresponding to $\theta = .02$ is .000004, and that the corresponding probability premium is approximately .01. Intuitively, an individual with a risk premium of \$200 (2% of \$10,000) on a fair lottery with a payoff of either \$10,000 or −\$10,000 would demand a probability of winning of $\hat{p} = .51$ to be indifferent between the lottery and the status quo w, if and only if that individual's constant absolute risk-aversion coefficient were .000004. Similarly, if the risk premium is \$1,000 ($\theta = .1$), then the individual's constant absolute risk-aversion coefficient is .000020, and the probability premium would be approximately .05.

Next, consider the value of A for which the risk premium is 50% of the gamble. At $\theta = .5$, $A = .000122$, and the individual is willing to pay \$5,000 to avoid a gamble to win or lose \$10,000 with even chances. This individual would demand a probability of winning of approximately .77 to be indifferent between a lottery to win or lose \$10,000 and the status quo.

Now consider the effects of decreasing the gamble size. Recall from equation (9) that the relation between the risk premium and the probability premium is unaffected by gamble size for CARA utility functions. As (4) indicates, however, the risk premium is

Table 2. Risk Premiums, Probability Premiums, and Absolute Risk-Aversion Coefficients

Risk Premium	Probability Premium	Absolute Risk Aversion		
		h = \$10,000	h = \$1,000	h = \$100
.02	.010001	.000004	.000040	.000401
.04	.020011	.000008	.000080	.000803
.06	.030036	.000012	.000120	.001212
.08	.040086	.000016	.000161	.001622
.10	.050167	.000020	.000201	.002023
.12	.060289	.000024	.000242	.002424
.14	.070460	.000028	.000284	.002847
.16	.080687	.000033	.000326	.003278
.18	.090980	.000037	.000368	.003698
.20	.101347	.000041	.000411	.004130
.22	.111797	.000046	.000455	.004567
.24	.122338	.000050	.000500	.004999
.26	.132980	.000055	.000545	.005472
.28	.143731	.000059	.000592	.005930
.30	.154601	.000064	.000639	.006427
.32	.165599	.000069	.000688	.006895
.34	.176735	.000074	.000739	.007398
.36	.188017	.000079	.000791	.007937
.38	.199456	.000084	.000845	.008515
.40	.211060	.000090	.000901	.009045
.42	.222837	.000096	.000959	.009607
.44	.234798	.000102	.001019	.010204
.46	.246948	.000108	.001082	.010827
.48	.259295	.000115	.001149	.011489
.50	.271844	.000122	.001219	.012191
.52	.284599	.000129	.001293	.012987
.54	.297559	.000137	.001371	.013795
.56	.310723	.000146	.001455	.014652
.58	.324082	.000154	.001544	.015563
.60	.337622	.000164	.001641	.016530
.62	.351322	.000175	.001745	.017452
.64	.365149	.000186	.001859	.018593
.66	.379055	.000198	.001984	.020008
.68	.392977	.000212	.002122	.021230
.70	.406826	.000227	.002276	.022755
.72	.420486	.000245	.002449	.024710
.74	.433806	.000265	.002647	.026484
.76	.446590	.000287	.002875	.029021
.78	.458600	.000314	.003142	.031450
.80	.469552	.000346	.003461	.034636
.82	.479129	.000385	.003848	.038484
.84	.487018	.000433	.004331	.043311
.86	.492971	.000495	.004951	.049507
.88	.496909	.000578	.005776	.057762
.90	.499024	.000693	.006932	.069315
.92	.499827	.000866	.008664	.086643
.94	.499990	.001155	.011553	.115525
.96	.500000	.001733	.017329	.173287
.98	.500000	.003466	.034657	.346574

determined jointly by A and h. As shown in table 2, for a given θ, decreasing the gamble size by approximately a factor of 10 also decreases the corresponding risk-aversion coefficient by a factor of 10. This result illustrates the importance of considering gamble size when trying to interpret risk-aversion coefficients.[2] Most would agree, for example, that a risk-aversion coefficient of .0004 implies a small degree of risk aversion for a gamble size of \$100 ($\theta = .02$; $\rho = .01$). But at a gamble size of \$10,000, a risk-aversion coefficient of .0004 implies a much greater amount of risk aversion (with $\theta > .82$; $\rho > .48$). It is clear from the calculations presented in table 2 that more insight about an individual's degree of risk aversion can be gained by considering the risk or probability premium than can be gained by simply considering a value of the risk-aversion coefficient.

Such an insight, however, still may lead to somewhat subjective and arbitrary classifications of the amount of risk aversion present. For example, does a risk premium of 50% of a gamble of \$1,000 imply moderate or strong risk aversion? For the purpose of selecting ARA levels for use in simulation studies, one should choose risk-aversion levels corresponding to risk premiums greater than 1% and less than 99% of a gamble h. Observe that for the binary gamble considered here, h also is the standard deviation of the gamble. If an individual's risk premium is less than or equal to 1%, then the individual behaves essentially as risk neutral, and the constant absolute risk aversion is less than or equal to .000002 for a gamble size of \$10,000.

It also is difficult to argue against the conclusion that an individual who has a probability premium in excess of .49 ($\hat{p}$ = .99) on a fair gamble of winning or losing h exhibits extreme risk aversion. For a \$10,000 gamble, the associated value of A is .000462, and the risk premium is 85% of the gamble. An individual with an ARA index in excess of .000462 would demand a probability of winning in excess of 99% for h = \$10,000; hence, .000462 provides a reasonable *practical upper bound* for the risk-aversion coefficient for use in applied empirical analyses of the firm under CARA with a gamble size of \$10,000. A risk-aversion coefficient greater than .000462 is unlikely in most circumstances because it would imply an individual who prefers the status quo to a 99% chance of winning \$10,000 and a 1% chance of losing \$10,000.

ARA Ranges

To ascertain the plausible ranges of ARA, it is necessary to make some assumptions concerning an individual's risk or probability premium, the size of the relevant gamble, and the situation that one is attempting to model. Suppose that one is interested in determining the response of a representative farmer to yield risk if the farmer has a CARA utility function. Because the response of a typical farmer is of interest, one should not use values of the risk-aversion coefficient that imply implausibly high levels of risk aversion. As shown in table 2, the upper range of risk aversion (the most contentious boundary) should be determined by the probability premium, because selecting a risk premium value greater than .90 implies an implausibly high probability premium. If $\hat{p} \in [.505, .99]$ for h = \$10,000, the implied absolute risk aversion A lies between .000002 and .000462. For h = \$1,000 and for $\hat{p} \in [.505, .99]$, an appropriate range for A is .00002 to .00462. And for h = \$100, the range of A is .0002 to .046204.

The large effects of gamble size on the appropriate range of the risk-aversion coefficient indicate that one should take care in assuming that the CARA utility function is appropriate if the gamble size differs greatly across choices. For example, if the gamble size varies from \$100 to \$10,000 and $\hat{p} \in [.505, .99]$ for all gambles, then the only plausible range of risk-aversion coefficients for the CARA utility function is .0002 to .000462, which is the intersection of the three ranges given above. Empirical studies based on CARA utility functions could choose ARA values in this relevant range. But such a choice might lead to implausible results. For example, assuming CARA implies that an individual in this range of risk aversion has a risk premium between \$6,600 and \$8,500 for the \$10,000 gamble, between \$100 and \$218 for the \$1,000 gamble, and between \$1 and \$2.30 for the \$100 gamble. If these levels are atypical of a representative producer for gambles between \$100 and \$10,000, then CARA is an inappropriate utility function to use for modeling producer behavior under risk.

Concluding Remarks

Empirical analyses of the effects of risk aversion on the decisions of firms often specify a range of assumed levels of absolute risk aversion to take into account the different risk attitudes among producers. Often, however, insufficient attention is paid to the behavioral implications of the assumed values of risk aversion. This article shows that assuming appropriate levels of either risk premiums or probability premiums can aid in the selection of reasonable ARA levels for use in simulation studies using CARA utility functions. Specifically, if risk premiums are between 1 and 85% of the gamble size in a binary gamble (implying a probability premium between 1/2 and 49%), then the appropriate ARA ranges are: .000002 to .000462 for gamble sizes of $10,000, .00002 to .00462 for gamble sizes of $1,000, and .0002 to .046204 for gamble sizes of $100.

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Notes

[1] The implied probability premiums are not reported in table 1, though they can be calculated from equation (9).

[2] Grube also notes the importance of gamble size in selection of appropriate risk-aversion coefficients. He shows that Kramer and Pope's selected coefficients would be more appropriate for gambles ranging up to $100 rather than the much larger gambles actually considered.

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