Self-Protection and Value of Statistical Life Estimation

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ABSTRACT. *Self-protection has been used to help define lower bounds on the value of statistical life (VSL). We show circumstances exist in which (1) the lower bounds are so low as to be more misleading than informative; and (2) the bound is an upper bound on the population's average VSL. The relationship between the bound and VSL depends on the degree and nature of individual heterogeneity, the fraction of the population buying self-protection, and the price and market setting for self-protection. Although some factors are observable, their impact is difficult to assess because they interact with unobservable population characteristics.* (JEL I18)

Despite the challenges, conventional wisdom says that under certain plausible conditions, market-based, self-protection expenditures provide a lower bound on the ex ante value people assign to reduced risks to life and limb. The self-protection (or averting behavior)[1] approach is aimed primarily at inferring the willingness to pay to avoid or reduce risk, which then can be used, if desired, to address policy-driven questions about the value of statistical life, or the VSL.[2] Recall self-protection are investments to reduce either the probability of a bad outcome or the severity of the bad outcome or both (Ehrlich and Becker 1972).[3] Viewing self-protection expenditures as a lower bound on the willingness to pay for self-protection makes intuitive sense because these expenditures reveal preferences. A person who spends $50 to purchase self-protection reveals a willingness to pay at least $50 for that protection.

If the task had been to put a lower bound on a newly spawned self-protector's willingness to pay (WTP), the case would be closed. But the goal of the research on so-called lower bounds is more ambitious; it wants a lower bound on the societal, or aggregate, willingness to pay for abatement of a particular risk.[4] This step from the individual self-protectors to the aggregate of everybody, both those who self-protect and those who do not, is not an easy step. The simple fact that not everybody self-protects makes this complicated. Added to that are problems caused by individual heterogeneity and by how the self-protection good or service is priced.

The step from the individual's lower bound to an aggregate lower bound is important. In cost-benefit calculations for risk-abatement measures it is convenient to have a lower bound for the total benefits—a lower bound on the aggregate willingness to pay for risk reduction. If such

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[1] Self-protection has also been called averting behavior, avoidance behavior, defensive action, and loss prevention.

[2] See Dickie (2003) for a most helpful review of averting behavior and self-protection. Also see for example Ribaudo and Hellerstein (1992), Chestnut et al. (1996), NRC (1997), Whitehead and Van Houtven (1997), Dharmaratne and Strand (1999), Hecht, Mian, and Rahman (1999), Kocagil et al. (1998), Van Houtven and Pattanayak (1999), USEPA (1999, 2000a), Davis, Krupnick, and Thurston (2000), McConnell and Rosado (2000), McDonald (2001), Dunford and Murdock (1997), Tiwari (2000), Roy (2001), Wu and Huang (2001), Stieb et al. (2002), Jenkins, Owens, and Wiggins (2002), and Um, Kwak, and Kim (2002).

[3] Actions to reduce the severity of a bad event once realized are also called self-insurance and loss reduction (Ehrlich and Becker 1972).

[4] Dickie and Gerking (2002) discuss the complications involved in the empirical literature trying to estimate the value of risk reduction given self-protection or averting behavior.

a lower bound is obtained, and the cost of the risk abatement happens to be less than this lower bound, one can make an unqualified policy recommendation—the risk abatement measure should be initiated.[5] As noted by Abrahams, Hubbell, and Jordan (2000, 427), these "lower-bound WTP estimates are useful because they provide decision-makers a minimum criterion for cost–benefit comparisons."

These bounds have also received attention from governmental agencies and policymakers. One prominent example is the "Guidelines for Preparing Economic Analyses" prepared by the EPA (U.S. Environmental Protection Agency 2000, 80). Here, they specifically mention such lower bounds as a valuation tool in their economic analyses. According to these guidelines, "One approach to estimation is to use observable expenditures on averting or mitigating activities to generate values that may be interpreted as a lower bound on WTP." The guidelines also mention the provisos in Cropper and Freeman (1991), Quiggin (1992), and Shogren and Crocker (1991). We show herein there are even further reasons to be cautious in the use of such bounds.

In the literature on bounds, Courant and Porter (1981), Harrington and Portney (1987), and Bartik (1988) were seminal by showing the possible use of self-protection expenditures as bounds on the WTP, where Bartik showed that these bounds can be both lower and upper bounds—something we consider in detail in our framework.[6] There is an extensive related literature both on the actual extent of averting behavior and on the use of the costs of this averting behavior as a basis for bounds on WTP, including the work of Abdalla, Roach, and Epp (1992), Bresnahan and Dickie (1995), Bresnahan, Dickie, and Gerking (1997), Harrington, Krupnick, and Spofford (1989), Jakus (1994), Jenkins, Owens, and Wiggins (2001), Lee and Moffitt (1993), Smith and Desvousges (1986), and Åkerman et al. (1991). Laughland et al. (1996, 111), for example, conclude their evaluation by noting "more theoretical work on the relationship between averting costs savings and willingness to pay may provide further illumination on appropriate theoretical relationships."

This all suggests that self-protection expenditures have received substantial attention in public policy and in the research literature. The reason for this is also clear—bounds based on self-protection expenditures may be a convenient and important tool in public policy making. But it is therefore important we correctly understand the properties of these bounds.

We show herein that several difficulties—in addition to those noted previously in the literature—arise in interpreting self-protection expenditures as a "lower bound." First, implicit within the standard view is that people are equally skilled in their personal ability to self-protect. But just as people have unique preferences toward risky events, they also have unique levels of skill to cope with risk (Shogren and Stamland 2002). Self-protectors are idiosyncratic. They are not equally skilled or equally tolerant to risk. Relative to consumers who do not purchase self-protection, a consumer who chooses self-protection reveals himself to be more averse to risk or to expect a higher risk reduction from self-protection or both. This means that the choice to self-protect is unlikely to reveal perfectly both personal characteristics (Stamland 1999, 2001)—this is of course the reason we attempt to obtain bounds on the WTP rather than estimating it directly. The problem is that this bound may not be informative either. How useful the bound is depends on the population's distribution of the hidden characteristics—which unfortunately sends us back

[5] It is probably for this reason that these lower bounds have received attention. As a casual search on Google or Yahoo reveals, researchers include these lower bounds in their lectures on environmental economics. The topic frequently arises in valuation discussions in policy meetings. We do not criticize this; we have lectured on these bounds as well.

[6] At least 66 papers have cited one or more of the following papers that discuss self-protection and the question of lower bounds: Abdalla, Roach, and Epp (1992), Bartik (1988), Courant and Porter (1981), and Harrington and Portney (1987). The details are available from the authors on request.

to square one; to know how much the bounds tell us about the WTP, we need to know other hidden characteristics that are just as difficult to directly observe as the WTP itself.

Second, and amplifying the first problem, difficulties are caused by the discreteness of the choice situation—a consumer purchases a specific type of self-protection or he does not. The choice between the two options—to buy or not to buy—reveals something about preferences, but unfortunately not much. It reveals that those who do not purchase self-protection are willing to pay less than the price. The cost of the self-protection is an upper bound on any non-purchaser's willingness to pay. This self-protection expenditure is therefore a lower bound on some people's willingness to pay, but an upper bound on others' willingness to pay (as noted before by Bartik 1988). With heterogeneous consumers, it is difficult to say in general how this number bears on the population's average willingness to pay. Herein we show that, the relationship between the "bound" and the population's average willingness to pay depends critically on the fraction of the population who purchases the self-protection, but in a way that depends on the distribution of the hidden characteristics. There does not appear to be any straightforward corrections for this effect. It is unclear whether a binary choice is sufficiently revealing to be useful for valuation.

Third, the price of the self-protection good is also a possible source of problems. It is unclear that market forces exist so the cost of self-protection bears a relationship to the average willingness to pay for self-protection. For instance, certain risks may be expensive to protect against given the current threat so the market for such self-protection is small or non-extant (e.g., the market for fallout shelters in homes). If estimates were based on these self-protection expenditures, one might obtain a "lower bound" that is indeed a lower bound for the few people who can afford this self-protection, but that may lie far above the average willingness to pay. Alternatively, other risks may be cheap to insure against, and the lower bound based on such self-protection may lie far below the average willingness to pay. A good estimate is based on a self-protection market that avoids both problems; but it is unclear that one can identify such a market without assuming that one knows the thing one wants to estimate, the population's average willingness to pay.

Fourth, price-setting in the market for the self-protection also plays a role. We show that the bounds' performance in a price-discriminating market differ from its performance in a competitive market.

We have identified at least four sources of problems for the interpretation of the so-called lower bounds on VSL in addition to those previously noted in the literature, and we do not claim to have completed the list of difficulties. We find that such "bounds" should be interpreted with great care, if they are useful at all. Åkerman et al. (1991), for instance, used a logit model that allowed households to be heterogeneous and estimated very low VSL estimates. This is consistent with our findings that controlling for heterogeneity may tend to lower the estimates. They say their estimated willingness to pay is a lower bound, but their argument is a little different and is due to underestimating risks or costs, or both. Given our results perhaps their estimate is low just due to them having corrected for heterogeneity while most studies do not.

I. MODEL

Consider consumers who differ in two *unobservable* respects to either an outside regulator or to each other: they are unequally skilled and they differ in their opportunity cost of mortality risk reduction. Different skill levels imply that different consumers do not face the same probability of a fatal accident from a given source of risk and that they obtain different risk reduction levels from purchasing self-protection or engaging in costly risk-averting behavior. Different risk preferences imply different trade-offs between the cost of purchasing a self-protection good and the risk of a fatal accident. A consumer's risk exposure depends on his endogenous choice of self-protection which in turn depends on his idiosyncratic, unobservable trade-off between the costs and benefits of risk reduction.

Assume there are T consumers (or consumer types); each has his own risk without the self-protection good, q_t, and risk with the self-protection good, p_t, where $q_t \geq p_t$ for all $t \in \{1,2,...,T\}$. A number $N \leq T$ of the consumers, enumerated $t \in \{1,2,...,N\}$, purchase the self-protection good whereas the rest do not. Denote the consumers' utility function by $u(t,P,C)$, where t denotes the consumers's type, $P \in \{p_t,q_t\}$ is the consumers's fatality risk, and C denotes the expenditure on self-protection. Assume the consumer obtains no added benefit from using more than one unit of the self-protection good. Let c denote the cost of one unit of self-protection. We have then that $C \in \{0,c\}$. Assume the utility function takes the form $u(t,P,C) = \overline{U}_t - P \cdot VOL_t - C$, where $\overline{U}_t$ is the monetary equivalent of the consumer's utility from all other goods and $VOL_t > 0$ is the monetary equivalent of type t's opportunity cost associated with premature death in the current period, i.e., VOL_t is type t's value of life.

Define $\delta_t \equiv q_t - p_t$, the *risk differential* between not using and using self-protection. We assume this risk differential is strictly positive and that the consumers maximize utility. Consumer t purchases the self-protection good if $u(t,p_t,c) \geq u(t,q_t,0)$, which is equivalent to $\text{VOL}_t \geq \frac{c}{\delta_t}\cdot$ Thus we obtain a well-known result; self-protection expenditures can provide a lower bound on the value of life (e.g., USEPA 2000a; also see Jenkins, Owens, and Wiggins 2001, who follow Freeman 1993). This inequality holds on the *individual* level for those who optimally choose to purchase self-protection. Some studies, however, employ this inequality on an *aggregate level* (e.g., Jenkins, Owens, and Wiggins 2001), a potentially problematic generalization due to heterogeneity across both risk preferences and skill to reduce risk.[7]

We now consider the use of self-protection expenditures as the basis for a lower bound on the VSL. We use the term (average) VSL loosely to refer to the average value of life (VOL) across a group of people. *For those who choose to buy the self-protection good*, we have

$$E_N[VOL_t] \geq E_N\left[\frac{c}{\delta_t}\right] \geq \frac{c}{E_N[\delta_t]}, \qquad [1]$$

where the last inequality follows since a fraction is a convex function of its denominator and where $E_N[\cdot]$ is the expectations operator conditional on $t \in \{1,2,...,N\}$, the consumers who optimally purchases self-protection. Denote lower bounds I and II by $LBI \equiv E_N\left[\frac{c}{\delta_t}\right]$ and $LBII \equiv \frac{c}{E_N[\delta_t]}$ where $LBII$ is the lower bound one obtains if, as in the literature, the cost of self-protection is divided by the average risk-reduction obtained by self-protection and LBI is an alternate lower bound that requires estimation of each individual's idiosyncratic risk reduction from self-protection. To our knowledge, LBI has not been employed empirically, which is understandable because it is difficult to implement. We examine LBI here to see if it provides a possible way out of the problems with $LBII$ that we find below. Since LBI corrects for heterogeneity to a degree, we might hope that it reduces the problems associated with $LBII$.

[7] Also see Blomquist (2001), who notes that "Jenkins, Owens, and Wiggins (2001) calculate the VSL implied by use of bicycle helmets and find it to be approximately \$4.1 million in 1998 dollars for adults who purchase and wear the helmets. They consider their estimate to be a lower bound because buyers and users find it worth at least as much as the cost to gain the added protection. Including time and disutility costs would increase the implied value and reinforce the claim that the estimate is a lower bound if only money costs are relevant to the use decision. However, their estimated VSL is an upper bound for bicyclists who are not buyers and users if time and disutility costs are zero. If potential time and disutility costs are important for all bicyclists and those costs are different for users and nonusers, then their estimate is not necessarily an upper bound for nonusers. It is not clear what the VSL is for the average bicyclist."

The inequalities in expression [1] supports the claim that *LBII* is a lower bound estimate of the *average* VOL for *self-protectors*. It is *not* a lower bound on the VOL of *all* those who self-protect as our examples below illustrates. This lower bound may be misleading for several reasons. First, although it is a lower bound for the people who self-protect, it is a potentially severely deflated lower bound. With heterogeneous consumers, and the discreteness of the choice situation, this VSL lower bound can be pushed far below the self-protectors' average VSL. Second, for the people who do not self-protect, self-protection might actually be an upper bound on VSL. The effect of this is that *LBII* may be far above the population's average VSL.

To see one reason why *LBII* is a deflated lower bound for the average VSL of the self-protectors, denote $f(\delta_t) \equiv \frac{c}{\delta_t}$, assume for the moment that the cost of the self-protection good is the same for all purchasers, and consider the second-order Taylor expansion of $f(\delta_t)$ around $\overline{\delta}_N \equiv E_N[\delta_t]$:

$$f(\delta_t) \approx f(\overline{\delta}_N) + f'(\overline{\delta}_N)(\delta_t - \overline{\delta}_N) + \tfrac{1}{2} f''(\overline{\delta}_N)(\delta_t - \overline{\delta}_N)^2$$

By taking conditional expectations and substituting in the expressions for $f(\delta_t)$ and its derivatives, we obtain:

$$E_N\left(\frac{c}{\delta_t}\right) \approx \frac{c}{\overline{\delta}_N}\left(1 + \frac{\sigma_\delta^2}{\overline{\delta}_N^2}\right) \equiv SOTA,$$

where σ_δ^2 is the variance of δ_t among those who purchase the self-protection good. Thus,

$$\frac{c}{\overline{\delta}_N} \approx \frac{E_N\left(\frac{c}{\delta_t}\right)}{\left(1 + \frac{\sigma_\delta^2}{\overline{\delta}_N^2}\right)}$$

Thus, *LBII* is deflated relative to *LBI* approximately by the factor $\left(1 + \frac{\sigma_\delta^2}{\overline{\delta}_N^2}\right)$. This effect could be pronounced in a very heterogeneous sample in which there is a large variation in the experienced risk reduction from a particular self-protection good. In our examples below, in which the heterogeneity is fairly low, this effect is relatively small.

For those who do not self-protect, self-protection expenditures may actually yield an upper bound on the VSL. For those who choose not to self-protect, we obtain $E_N(VOL_t) \leq E_N\left(\frac{c}{\delta_t}\right) \geq \frac{c}{\overline{\delta}_N}$. Here *LBI* is an *upper* bound on the VOL, whereas the relationship between *LBII* and the average VOL for those who do not purchase self-protection is indeterminate. It is unclear how *LBII* relates to the willingness to pay for mortality risk reduction among everyone in a population—both those who buy a particular self-protection good and those who do not.

Next, we look at examples that show there are at least two more factors that determine the usefulness of these bounds on the VSL—the proportion of the population that purchases the self-protection good and the price setting in the market for the self-protection good.

Example I. Price Competition

Table 1 describes the benchmark case in which there is one competitive price level, c, that all purchasers pay per unit of the self-protection good. This captures the case of self-protection sold in competitive markets like water filters, bottled water, sun-block lotion, bike helmets and so on. Jenkins, Owens, and Wiggins (2001) found that the use of bike helmets reduced the mortality risk by 4.41, 5.49, and 6.15 millionths on average in three different age-groups. Since the variation among individuals is likely to be significantly higher than among group averages, our variation in risk differentials—from 3 to 7 millionths—should be conservative. Also, Jenkins, Owens, and Wiggins (2001) found that their lower bounds for the VSL varied from 1.1 to 4.0 across their groups. By assuming these lower bounds are about half of the actual VSL, we obtain the variation between our VOL numbers—from 2 to 8 million dollars. Again, since our variations are across people rather than groups,

TABLE 1
PRICE COMPETITION (BENCHMARK)

(1) Type[a]	(2) VOL	(3) Risk Diff.[b]	(4) WTP for Self-Protection[c]	(5) True Lower Bound On VOL	(6) Lower Bound I	(7) Second-Order Taylor approx.	(8) Lower Bound II	(9) Average VOL of Self-Protectors	(10) Average VOL of Non-Self-Protectors
1	8	7	56	8	8.0	8.0	8.0	8.0	4.7
2	6	7	42	6	6.0	6.0	6.0	7.0	4.6
3	8	5	40	6	6.5	6.5	6.3	7.3	4.2
4	6	5	30	6	5.1	5.1	5.0	7.0	4.0
5	4	7	28	4	4.6	4.6	4.5	6.4	4.0
6	8	3	24	4	4.6	4.5	4.2	6.7	3.3
7	4	5	20	4	3.9	3.8	3.6	6.3	3.2
8	6	3	18	4	3.8	3.7	3.4	6.3	2.5
9	2	7	14	2	2.9	2.8	2.6	5.8	2.7
10	4	3	12	2	2.6	2.5	2.3	5.6	2.0
11	2	5	10	2	2.2	2.1	1.9	5.3	2.0
12	2	3	6	2	1.4	1.3	1.2	5.0	NA

Note: All numbers are in million dollars except:
[a] The types are ranked in order of decreasing WTP for self-protection.
[b] The risk differential is in millionths.
[c] The WTP for Self-Protection is in dollars.

this amount of variation is likely to be conservative. In our examples, we assume these two characteristics—an individual's VOL and idiosyncratic risk reduction—are uncorrelated in the total population. Although, as we will see, these characteristics need not be uncorrelated within the subgroups of those who self-protect and those who do not.

The WTP for self-protection is the product of the risk differential, corresponding to our parameter δ_t, and the VOL. This is the maximum price for self-protection at which the consumer's optimal choice is to protect. Our examples have 12 types, all with different VOL_t or δ_t or both. The types are numbered so that number 1 has the highest WTP for self-protection, type 2 has the second highest WTP, and so on. This implies that if type N buys self-protection, so do all types $t < N$. In our examples, we assume all types are equally likely (i.e., equally numerous).

We consider 12 different scenarios, corresponding to each of the possible 12 types being the marginal self-protector. In scenario N, the price of the self-protection good is equal to the WTP of type N, which means that types 1 through N buy self-protection. By setting the price at the marginal purchaser's WTP rather than below it, we minimize the deflation of the lower bounds relative to the average VSL of the self-protectors (since the lower bound is based on the price of the self-protection). Scenario N is depicted in the row corresponding to type N in Table 1. In this row, the number in the fifth column equals $\min_{t \le N} VOL_t$ which is the lowest VOL among *all* self-protectors in this scenario. The sixth column contains *LBI*, the seventh column contains the Taylor approximation of the lower bound, *SOTA*, and the eighth column contains *LBII*. The last two columns contain the average VOL (the VSL) of those who purchase self-protection and those who do not.

This example shows that *LBII* is *not* a lower bound on the VOL of *every* individual that purchases self-protection. In this example, either outcome is possible—the "lower bound" is as likely to be above the lowest VOL among the self-protectors as below it. Also, observe that *LBII* is not an upper bound on the average VSL of those who do not self-protect. Table 1 shows two instances in which *LBII* is less than the average VOL of the non-self-protectors. The magnitude of this reversal is small in this example.

LBII is, however, always a lower bound on the *average* VOL (the VSL) of those who buy self-protection. The problem is that this lower bound may be far below this average. This problem is particularly pronounced when *many* in the population purchase the self-protection good. On the other hand, this "lower" bound (*LBII*) may be above the population average VOL. This problem arises when *few* purchase self-protection. In this example, one or the other of these problems always emerges and, as we see below, it is unclear what constitutes *few* or *many* purchasers. Thus, we cannot directly tell which of the two problems prevails.

LBI and the second-order Taylor approximation, *SOTA*, given in columns six and seven in Table 1, perform somewhat better in this example. These bounds are somewhat higher than *LBII* so they are a closer bound on the average VSL of self-protectors and they always lie above the average VSL of non-protectors. But the magnitude of this improvement is small and probably not of practical significance.

Example II. Perfect Price Discrimination

In this section, we now establish a second benchmark of perfect price discrimination wherein each type pays his WTP for the self-protection good, that is, type t pays $c_t = \delta_t VOL_t$ for the self-protection good. This could occur if a seller of self-protection (e.g., a doctor) charged a rich client more than a poor one for preventive medical care; or if the seller charge different prices for an insured versus an uninsured client (see Tirole 1988, chap. 3). If both this price and type t's risk differential, δ_t, is observed for all t that purchase the self-protection, we calculate $LBI^* = E_N\left(\frac{c_t}{\delta_t}\right) = E_N[VOL_t]$. That is, if—under perfect price discrimination—one can observe each person's price and risk differential, one can obtain an exact estimate of the average value of life of those who purchase self-protection. But such direct observability and perfect price discrimination is unlikely.

With perfect price discrimination, the new lower-bound estimator based on group averages is $LBII^* = \frac{\bar{c}_N}{\bar{\delta}_N}$, where $\bar{c}_N \equiv E_N[\delta_t VOL_t]$ represents the average cost of self-protection when N consumers self-protect. Assume the self-protection good is sold to all type ts whom have a WTP higher than, or equal to, the marginal cost of producing one unit, c. In scenario N, we consider the situation in which $c_N \geq c > c_{N+1}$.

Table 2, depicting this example, contains the same columns as in Table 1, except we added column 3 to replace Table 1's columns 2 and 3. The new column 3 contains the average cost of self-protection in the various scenarios, $\bar{c}_N = E_N[\delta_t VOL_t]$. We do not report LBI^* since it is identically equal to the average VOL of those who purchase self-protection.

Observe that $LBII^*$ now becomes a tight lower bound on the average VOL of the self-protectors, giving a precise estimate of this number. But this lower bound is potentially far above the lowest VOL among the self-protectors. Perhaps worse, it is also always higher than the population average VOL unless the entire population buys self-protection. The same applies for *LBI* and *SOTA*.

Although perfect price discrimination improves the performance of *LBII* (or its correspondent $LBII^*$) in some respects, its performance relative to what we care the most about, namely the population average VSL is now worse. This bound is now an *upper bound* on the population average willingness to pay for mortality risk reduction, *not a lower bound.*

We can rewrite $LBII^*$ as

$$LBII^* = \frac{E_N[\delta_t VOL_t]}{E_N[\delta_t]} = E_N[VOL_t] + \frac{COV_N(\delta_t, VOL_t)}{E_N[\delta_t]},$$

where $COV_N(\delta_t, VOL_t)$ is the conditional

TABLE 2
PERFECT PRICE DISCRIMINATION

(1) Type[a]	(2) WTP for Self-Protection[b]	(3) Average Cost of Self-Protection	(4) True Lower Bound On VOL	(5) Second-Order Taylor approx.	(6) Lower Bound II	(7) Average VOL of Self-Protectors	(8) Average VOL of Non-Self-Protectors
1	56	56.0	8	8.0	8.0	8.0	4.7
2	42	49.0	6	7.0	7.0	7.0	4.6
3	40	46.0	6	7.4	7.3	7.3	4.2
4	30	42.0	6	7.2	7.0	7.0	4.0
5	28	39.2	4	6.5	6.3	6.4	4.0
6	24	36.7	4	6.9	6.5	6.7	3.3
7	20	34.3	4	6.5	6.2	6.3	3.2
8	18	32.3	4	6.7	6.1	6.3	2.5
9	14	30.2	2	6.0	5.6	5.8	2.7
10	12	28.4	2	6.0	5.5	5.6	2.0
11	10	26.7	2	5.6	5.2	5.3	2.0
12	6	25.0	2	5.5	5.0	5.0	NA

Note: All numbers are in million dollars except:
[a] The types are ranked in order of decreasing WTP for self-protection; and
[b] The WTP for Self-Protection is in dollars.

co-variance between δ_t and VOL_t given the consumer group $t \in \{1,2,...,N\}$. In the cases in which $LBII^* < E_N[VOL_t]$, we have $COV_N(\delta_t,VOL_t) < 0$. Similar to Shogren and Stamland (2002, 2005), we find the sorting of people into those who buy self-protection and those who do not (or those who take a risky job and those who do not in Shogren and Stamland (2002, 2005)) tends to induce a negative relationship between the two hidden characteristics. In Example II, however, this effect is small, so that *LBII* is a tight lower bound on the average VSL of the self-protectors. This result is perhaps more a problem than a blessing, since it is exactly this that makes *LBII* an upper bound on the average *VSL* in the population. This occurs because lower types tend to have higher *VOL*s, so that $E_N[VOL_t] > E_T[VOL_t]$, where T is the number of people in the population and $N < T$ is the number of people who purchase self-protection. Since *LBII* is close to $E_N[VOL_t]$, it is likely to be above $E_T[VOL_t]$. In Example II, they only coincide when $N = T$, so $E_N[VOL_t] = E_T[VOL_t]$. For the same reason, *LBI** and *SOTA* are also upper bounds on the population average *VSL*.

Example III. Correlated Hidden Characteristics

We have reason to suspect that a negative correlation exists between risk reduction obtained from buying a particular risk-reduction good and the VOL. The reason is that people with higher VOL are more likely to engage in additional risk-averting behavior than are those with lower VOL. For example, a high-VOL family has more incentive to buy a personal water filtration system, or to relocate into town with a safer water supply, than an otherwise identical household with a lower VOL. A higher VOL both increases the willingness to pay for the self-protection under consideration, and increases the demand for self-protection through other means. The marginal contribution to risk-reduction from the self-protection in question is likely to be less, since more risk has already been reduced. We saw in the previous example that endogenous self-protection tends to induce negative correlation between the hidden characteristics, which was also found in Shogren and Stamland (2002, 2005). Such correlation might well be the rule rather than the exception.

In Table 3, we consider a case of very strong negative correlation between the

TABLE 3
CORRELATED HIDDEN CHARACTERISTICS

(1) Type[a]	(2) VOL	(3) Risk Diff.[b]	(4) WTP for Self-Protection[c]	(5) True Lower Bound On VOL	(6) Lower Bound I	(7) Second-Order Taylor approx.	(8) Lower Bound II	(9) Average VOL of Self-Protectors	(10) Average VOL of Non-Self-Protectors
1	8	6.6	52.8	8	8.0	8.0	8.0	8.0	4.7
2	8	6.5	52.0	8	7.9	7.9	7.9	8.0	4.4
3	8	6.4	51.2	8	7.9	7.9	7.9	8.0	4.0
4	6	8.5	51.0	6	7.4	7.4	7.3	7.5	3.8
5	6	8.4	50.4	6	7.0	7.0	6.9	7.2	3.4
6	6	8.3	49.8	6	6.8	6.8	6.7	7.0	3.0
7	4	12.1	48.4	4	6.2	6.3	6.0	6.6	2.8
8	4	12.0	48.0	4	5.9	5.9	5.6	6.3	2.5
9	4	11.9	47.6	4	5.7	5.7	5.3	6.0	2.0
10	2	21.0	42.0	2	4.7	4.8	4.1	5.6	2.0
11	2	20.0	40.0	2	4.2	4.3	3.6	5.3	2.0
12	2	19.0	38.0	2	3.9	3.9	3.2	5.0	NA

Note: All numbers are in million dollars except:
[a] The types are ranked in order of decreasing WTP for self-protection;
[b] The risk differential is in millionths; and
[c] The WTP for Self-Protection is in dollars.

VOL and the risk differential (the correlation coefficient is –0.95). We revert back to the competitive market situation, which—as illustrated by Example I—is the best-case scenario for *LBII* as a *lower* bound. In this example, *LBII* is higher than the population average VSL if 75% of the consumers, or fewer, purchase self-protection. Here again it might be very misleading to think of *LBII* as a lower bound. Moreover, without explicitly assessing the heterogeneity in the population, we do not know if this is, or is not, the factual situation. To obtain a clear idea of the willingness to pay for mortality risk reduction, one should directly account for multi-dimensional heterogeneity in the estimation framework. Indirect attempts to handle heterogeneity, for instance, through the use of bounds, are not likely to be useful because there is no way of telling how close these bounds are to the object of main interest, the population average, VSL. To assess the usefulness of the bounds, the researcher needs detailed information about the distribution of the hidden characteristics, the idiosyncratic risk and VOL, of the consumers. But if this detailed information is obtainable, presumably there would be better uses of it than the calculation of imprecise bounds.

II. MODIFIED BOUNDS

As we have seen, the traditional lower bounds are problematic since they do not always lie below the VSL. It is desirable to search for modifications of the traditional lower-bound measures to find bounds that are guaranteed to lie below the VSL. The danger is, of course, that such bounds are so heavily biased downward that they do not contain sufficient information to make decisions. There still may be some circumstances, however, in which even a heavily downward-biased bound exceeds costs so that one with high confidence may adopt the risk-reduction measure.

A reviewer suggested the following bound: $MLB \equiv LB \times \Pr(Self\ Protect)$. This modified lower bound, *MLB*, takes some bound *LB*—for instance, one of *LBI*, *LBII*, *SOTA*, *LBI**, or *LBII** reported above—and multiplies it with the proportion of the population that self-protects, Pr(*Self Protect*), which equals the probability an arbitrarily chosen individual is a self-protector). The construction of *MLB* implies we use the bound *LB* only for those who self protect and then *zero* as the bound on those who do not self-protect. As long as *LB* is below the *VSL* of self-protectors, *MLB* lies below the population average *VSL*.[8] *MLB* may then form the basis of conservative estimates of the benefits of a policy initiative to reduce mortality risk. If this conservative measure of benefits exceeds cost, the policy implications should be beyond doubt.

In Table A2 in the Appendix, we report for all the examples the *MLB* (based on *LBII* or *LBII**, depending on the example in the same way as before) for the various scenarios studied in the examples above. The first thing to note is that *MLB* is below the population average, VSL (here pegged at $5 million), in all the scenarios in all examples, a fact that follows directly from *LBII* (or *LBII**) always is a lower bound on the VSL of self-protectors. Concern arises, however, that *MLB* may be far below the population average *VSL*. When few purchase self protection (in low-numbered scenarios), *MLB* is far below the VSL of $5 million. Also, increasing the fraction of self-protectors does not necessarily remove this problem. In example I, *MLB* peaks at $2.3 million—less than half the VSL.

As we noted for the case of price differentiation, *LBII** is a close lower bound on the self-protectors and thus it is natural the *MLB* also performs best in this case. Here, *MLB* approaches the population average *VSL* of $5 million as the fraction of self-protectors approaches one, but still *MLB* is no more than $3.2 million when as many as 50% purchase self-protection.

A subject for future research is to construct a more informative *MLB*. If one could find a market for self-protection in which a large fraction of the population participates, it is conceivable one might find a useful lower bound *MLB*. In this search, one should avoid sample-selection traps. For instance, in considering the use of biking helmets as self-protection, it is critical the population consists not just of all bicyclists, but of everyone. Biking may itself be considered a risk reduction measure and it is unclear that the VSL within this group is representative for the whole population.

In sum, the *MLB* may provide a useful tool in decision-making when considering inexpensive risk reduction, but such circumstances may already be clear cut. Conceivably, there may be a useful market to use for the construction of a more informative *MLB*, and that remains to be seen.

III. CONCLUDING COMMENTS

In a recent overview of the future of non-market valuation, Bishop (2003) argued that "we keep the defensive behavior [self-protection/averting] approach on the table in the hope that more research may succeed in broadening the cases where one can at least say whether defensive expenditures are a lower bound on true values. A biased (i.e., relatively invalid) value can still be useful if one is confident about the direction of the bias."

Herein we explore the direction of this bias given private information held by the self-protector. We find that the lower-bound estimator of the VSL is *not* in general a lower bound on the population average willingness to pay for mortality risk reduction. Situations arise in which these expenditures are an upper bound. Conversely, situations exist when this "lower bound" is not only a lower bound, but a severely deflated lower bound. These economic circumstances depend in part on things we can observe and correct for—the fraction who purchase self-protection, the price setting in the market for the self-protection, and the discreteness of the choice situation. But these results also depend on elements we cannot directly observe—the degree and nature of heterogeneity of both skill to cope with risk and risk preferences among people.

Unfortunately, the impacts of the observable factors are tangled with the impact of the unobservable factors. In Exam-

[8] Technically, there is also an assumption in using *zero* as a lower bound for those who do not self-protect.

ple I, *LBII* exceeds the population average when 25% of the people in the population, or fewer, buy self-protection. Table A1 in the Appendix provides an example (with uncorrelated hidden characteristics) in which *LBII* is above the population average if 50%, or fewer, purchases self-protection. Example III shows a scenario when *LBII* is above the population average when 75%, or fewer, purchase self-protection. Finally, Example II shows *LBII* is above the population average VSL if less than 100% purchase self-protection. Some hope exists that one may discern the 100% scenario by observing that the market perfectly price discriminates.

The three first scenarios—in which more than 25%, 50%, and 75% need to purchase self-protection before *LBII* is below the population average VSL—all occur in a competitive market. There does not appear to be a way to distinguish among the scenarios that solely rely on directly observable variables. To decide which scenario applies, one must look at the distribution of the hidden characteristics in the population. Using so-called lower bounds does not enable us to circumvent the problem of multi-dimensional heterogeneity. We believe it is necessary to estimate the hidden characteristics and to explicitly account for them in the estimation of the VSL. Shogren and Stamland (2003) explore such an approach using a General Method of Moments approach that poses formidable but hopefully surmountable challenges. More effort exploring the link between the valuation of risk and multi-dimensional heterogeneity in both skill to cope with risk and risk preferences seems worthwhile.

APPENDIX

TABLE A1

UNCORRELATED HIDDEN CHARACTERISTICS

(1) Type[a]	(2) VOL	(3) Risk Diff.[b]	(4) WTP for Self-Protection[c]	(5) True Lower Bound On VOL	(6) Lower Bound I	(7) Second-Order Taylor approx.	(8) Lower Bound II	(9) Average VOL of Self-Protectors	(10) Average VOL of Non-Self-Protectors
1	8	5.1	40.8	8	8.0	8.0	8.0	8.0	4.7
2	8	5	40	8	7.9	7.9	7.9	8.0	4.4
3	8	4.9	39.2	8	7.8	7.8	7.8	8.0	4.0
4	7	5.1	35.7	7	7.1	7.1	7.1	7.8	3.6
5	7	5	35	7	7.0	7.0	7.0	7.6	3.1
6	7	4.9	34.3	7	6.9	6.9	6.9	7.5	2.5
7	3	5.1	15.3	3	3.1	3.1	3.1	6.9	2.4
8	3	5	15	3	3.0	3.0	3.0	6.4	2.3
9	3	4.9	14.7	3	2.9	2.9	2.9	6.0	2.0
10	2	5.1	10.2	2	2.0	2.0	2.0	5.6	2.0
11	2	5	10	2	2.0	2.0	2.0	5.3	2.0
12	2	4.9	9.8	2	2.0	2.0	2.0	5.0	NA

Note: All numbers are in million dollars except:

[a] The types are ranked in order of decreasing WTP for self-protection;

[b] The risk differential is in millionths; and

[c] The WTP for Self-Protection is in dollars.

TABLE A2
MODIFIED LOWER BOUND (MLB)

(1) Scenario[a,b]	(2) *MLB Example I*	(3) *MLB Example II*	(4) *MLB Example III*	(5) *MLB Example AI*
1	0.7	0.7	0.7	0.7
2	1.0	1.2	1.3	1.3
3	1.6	1.8	2.0	2.0
4	1.7	2.3	2.4	2.4
5	1.9	2.6	2.9	2.9
6	2.1	3.2	3.3	3.4
7	2.1	3.6	3.5	1.8
8	2.3	4.1	3.7	2.0
9	1.9	4.2	4.0	2.2
10	1.9	4.6	3.4	1.7
11	1.8	4.7	3.3	1.8
12	1.2	5.0	3.2	2.0

Note: All numbers are in million dollars except:
[a] The scenarios are from 1–12, corresponding to the 12 types in each example. (The types differ across examples, but are within each example ranked in order of decreasing WTP for self-protection); and
[b] The population average VSL equals 5 ($5 million) throughout.

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