Appendix
Is COI a Lower Bound to WTP?

It is generally recognized that the WTP approach is theoretically superior to the COI approach for measuring individual well-being. However, it is also often asserted that COI is less difficult to estimate than WTP. As a result, many health economists have attempted to establish a method for approximating WTP with COI measures. Many argue that COI is a lower bound to WTP and that, therefore, studies that use COI are conservative in their benefit estimates. This conclusion is usually incorrect.

Berger et al. (1994) developed a model of individual health investment that yields a general expression for the value of changes in risk to human health. This model includes health in three roles: as a variable in the utility function; as a determinant in the probability and quality of survival in the current period; and as part of the income constraint. Berger et al. use their health production model to solve for an individual's *ex ante* WTP for an improvement in health status and to derive the relationship between WTP measures, preventive expenditures, and COI measures.

In this appendix we present Berger et al.'s model along with an application to a food safety problem. Berger et al. detail the assumptions required to make WTP equal COI and to make COI a lower bound to WTP. An example of a food safety problem emphasizes the unreasonableness of these assumptions. The model shows that COI and WTP bear no relation to one another when health outcomes include death. Our example shows that practical estimation problems make the relation between COI and WTP uncertain even for analysis of morbidity.

The example we develop examines the measurement of benefits from reducing exposure to the bacteria *Vibrio vulnificus*. The bacteria naturally occurs in estuarine waters and is a normal flora in molluscan shellfish—mainly oysters and clams. Since 1979, *Vibrio vulnificus* has been known to cause food-related illnesses resulting in acute gastroenteritis and fulminating septicemia and death (ISSC, 1995). During 1988-1997, an annual average of 22 *V. vulnificus* septicemia cases and 11 associated deaths were reported to the Centers for Disease Control and Prevention. Almost all of these cases have been attributed to half-shell consumption of live oysters harvested from the Gulf of Mexico and tributary waters between April 1 and October 31.

The median incubation period from *V. vulnificus* is relatively short—18 hours after eating the contaminated food, and the median time from hospitalization to death is 2 days (Klontz et al., 1988). Epidemiologists have identified the at-risk population largely as raw-oyster consumers with existing medical risks including liver disease and immuno-compromising illnesses.

Federal regulators have examined a variety of programs to reduce the risk of infection. Proposed programs include information campaigns to make consumers aware of the potential health risk. Other programs include time-temperature controls limiting the time between harvest and refrigeration. Other possible programs include seasonal harvesting bans across the Gulf of Mexico (Kuchler, et al, forthcoming).

The Human Health Risk Reduction Benefit Model from Berger et al. (1994)

Variables:

C = consumption = goods, services, and time
q = vector of health characteristics
X = preventive expenditures
E = policy variable such as environmental quality or food safety
Z = cost of illness = medical expenditures and forgone earnings
M = money income

Definitions:

- Utility is a function of consumption and health characteristics:

$$U = U(C, q) \qquad (10)$$

- Probability of surviving depends on health:

$$p = p(q) \tag{11}$$

- Probability density function for health characteristics (q) defined over preventive expenditures (X) and the policy variable (E), e.g., environmental quality or food safety.

$$h(q; X, E) \tag{12}$$

In our example, time-temperature controls (E) may affect the number and severity of *V. vulnificus* infections. The same result might occur from preventive expenditures (X) if consumers substituted oysters harvested outside the Gulf of Mexico for the Gulf oysters they currently consume.

- Cost of illness depends on health characteristics:

$$Z = f(q) \tag{13}$$

- Income constraint requires that the sum of consumption, preventive expenditures, and cost of illness equals money income:

$$M = C + X + Z \tag{14}$$

The Problem

Individual chooses preventive expenditures X in order to maximize expected value of utility subject to income constraint:

$$\max E(U) = \int_{-\infty}^{\infty} U(C, q) p(q) h(q; X, E) dq \tag{15}$$

$$M = C + X + Z \tag{16}$$

where the first term in the expression, *U(C, q)*, is utility given the health state, and the second term, *p(q) h(q; X, E)* is the probability of a given health state, including death.

Express income constraint in terms of *C* and substitute into maximization problem:

$$\max E(U) = \int_{-\infty}^{\infty} U[M - X - f(q), q] p(q) h(q; X, E) dq \tag{17}$$

Suppose the health condition is dichotomous, measurable as a zero-one variable. Then, health is a matter only of the absence or presence of a deleterious condition and the function *h(q; X, E)* is discrete. Let *H(X, E)* be the probability of the absence of the condition.

$$\begin{aligned} h(q; X, E) &= H(X, E) && \text{if } q = 1 \\ h(q; X, E) &= 1 - H(X, E) && \text{if } q = 0 \end{aligned} \tag{18}$$

In our example, (18) implies that a person is either infected with *V. vulnificus* and is sick or is not infected and is not sick. The consumer's maximization problem reduces to:

$$\max E(U) = U_0 P_0 (1 - H) + U_1 P_1 H \tag{19}$$

where U_0 = *U(M - X, 0)* is utility if free of the disease; U_1 = *U(M - X - Z, 1)* is utility with the disease; P_0 = *p(0)* is the probability of survival if free of the disease; P_1 = *p(1)* is the probability of survival with the disease; and *H = H(X, E)* is the probability of contracting the disease.

Totally differentiating *E(U)*, holding *dE(U) = 0* yields an expression for willingness to pay for an exogenous change (such as environmental improvement or improved food safety) that reduces risk.

$$\begin{aligned} -\frac{dM}{dE} &= -[(U_0 P_0 - U_1 P_1)/m] H_E - \\ &\left\{1 + [(U_0 P_0 - U_1 P_1)/m] H_X\right\} \frac{dX}{dE} \\ &\textit{where } m = U_0' P_0 (1 - H) + U_1' P_1 H \end{aligned} \tag{20}$$

Berger et al. simplify this expression to the following.

$$-\frac{dM}{dE} = -[(U_0 P_0 - U_1 P_1)/m] \left(\frac{dH}{dE}\right) - \left(\frac{dX}{dE}\right) \tag{21}$$

Willingness to pay *(-dM/dE)* for an "environmental" improvement, like time-temperature controls, equals the sum of the utility value of the reduction in risk and the savings in preventive expenditures. The utility value of risk reduction is the dollar value of additional enjoyment a consumer receives because of a reduced threat of a *V. vulnificus* infection from raw oyster consumption. Reductions in defensive expenditures might include time saved by not having to search for oysters harvested outside the Gulf of Mexico or by not having to cook oysters. The *dM/dE* term is negative because to maintain expected utility at a constant level, improvement in the environment is balanced by a fall in income. So, *-dM/dE* indicates a positive WTP.

Is COI a Special Case of WTP?

There are no reasonable conditions under which COI = WTP when there is any possibility that an illness can lead to a fatality. Here, we show that the conditions that have to be imposed to make

$$WTP \equiv -\frac{dM}{dE} = -Z\frac{dH}{dE} \equiv COI$$

are unreasonable. Four assumptions are sufficient to force the equality.

1. Assume no defensive expenditures are possible, $dX/dE = 0$.

2. Assume health does not enter the utility function directly, namely utility is not enhanced by health. Instead, only consumption enters the utility function. Define $U = U(C)$. Then, marginal utilities do not depend on the health state. Assumptions 1 and 2 imply that $-dM/dE$ includes only the difference in utility between being sick and being well, and the difference in expected utilities only reflects reduced consumption when ill due to cost of illness incurred, Z.

$$-\frac{dM}{dE} = \frac{-[U(M-X)P_0 - U(M-X-Z)P_1]}{U'[P_0(1-H)+P_1H]}\frac{dH}{dE} \tag{22}$$

3. Assume away any possibility that the illness is fatal, $P_0 = P_1 = 1$.

$$-\frac{dM}{dE} = \frac{-[U(M-X)-U(M-X-Z)]}{U'}\frac{dH}{dE} \tag{23}$$

4. Assume the value of consumption is equal to the utility of the value of consumption.

$$Z = \frac{U(Z)}{U'} \tag{24}$$

Then, the equality of WTP and COI follow.

$$-\frac{dM}{dE} = -Z\frac{dH}{dE} \tag{25}$$

These assumptions are unreasonable and are especially unreasonable for foodborne illness.

Assumption 1, the assumption that there are no possible defensive expenditures, is usually wrong. Regardless of which, if any, regulatory program is instituted, consumers have a variety of preventive or defensive expenditures to employ. They can seek out non-Gulf of Mexico oysters. They can substitute cooked oysters for raw. They can substitute other foods for oysters. As the at-risk population is clearly identified, those individuals can request medical testing for liver function. Such tests may not prove that eating raw oysters is safe for an individual. But a finding of severely compromised function would certainly make a consumer aware of risks of eating raw oysters.

Assumption 2, that utility is a function of consumption alone, is a peculiar view of human behavior. It says that health is not desired because people like being healthy, rather the only reason for desiring a state of robust health is that it allows greater consumption than does a state of compromised health. If consumers value good health apart from the expanded consumption opportunities that come with it, and if consumers dislike the pain and fear associated with illness, the assumption is untenable. The assumption is especially peculiar for the *V. vulnificus* case. Although the lethality rate for a *V. vulnificus* infection is 50 percent, the illness is not long-lived, and thus for those who survive, it does not compromise much lifetime consumption. To define *U(C)* over health states including a possibility of *V. vulnificus* infection, forces attention on trivial changes in consumption and assumes the severe pain associated with the disease is of little consequence to utility.

Assumption 3, assuming away any possibility of fatalities, obviously restricts the usefulness of COI for analyses of foodborne illnesses. Clearly, *V. vulnificus* infections are fatal more frequently than almost any other foodborne illness. However, it would be unusual to find a public health problem that did not lead to at least one death. Consider for example a chemical residue that raised the lifetime probability of cancer for everyone by 1×10^{-8}. Such a risk is two orders of magnitude below conventional definitions of *de minimis* risk levels. But, when 260 million people are imagined to be exposed to the chemical, risk assessors might forecast 2.6 additional deaths.

Assumption 4, that the utility of value of consumption is equal to the value of consumption, contradicts basic economic theory. Berger et al. examine the relation between consumption expenditures and the value of the utility of consumption. They note that "conceptually it cannot be shown, strictly, what the empirical relationship should be" (p. 38). Their review of consumption theory, however, strongly suggests that the former should exceed the latter.

Clearly these four assumptions are untenable, particularly in the case of foodborne illness. WTP does not equal COI.

Can COI be a Lower Bound to WTP?

There are plausible conditions under which the theoretical COI is a lower bound to WTP. Assumption 3 leads to the conclusion that WTP exceeds COI. That is, WTP > COI if the health problem in question involves only morbidity ($P_0 = P_1 = 1$). In this case,

$$-\frac{dM}{dE_{P_0=P_1=1}} = \tag{26}$$

$$\frac{-[U(M-X,0)-U(M-X-Z,1)}{m^{**}}\left(\frac{dH}{dE}\right)-\left(\frac{dX}{dE}\right)$$

where $m^{**} = U_0\,(1 - H) + U_1 H$

If the marginal utilities in the two health states are similar, equation 26 reduces to

$$-(U_0-U_1)\left(\frac{dH}{dE}\right)-\left(\frac{dX}{dE}\right) \tag{27}$$

Here, utility does vary with health states. Two conditions imposed on (27) establish the inequality WTP > COI. Let $dH/dE < 0$ and $dX/dE < 0$. Health risks fall as the environment improves, and defensive expenditures and environmental improvements are substitutes in reducing health risks. The inequality is established because COI ignores savings in preventive expenditures; COI ignores that utility is enhanced by improved health, and the value of the utility of earnings should be greater than earnings.

However, practical problems in estimating COI intrude, making the inequality suspect. The inequality is based on COI estimates that are restricted to the costs that individuals privately incur. The value of COI used by Berger et al. in their derivations is entirely private costs. Recall $Z = f(q)$, or that the modeled COI depend only on the individual's health characteristics. If COI includes more than out-of-pocket costs incurred by individuals with health insurance, or if some medical procedures incorporated in direct costs include hospital subsidies, then calculated COI need have little relation to $-Zdh/dE$. Any costs above and beyond those incurred by individuals are ignored in the model. A COI estimate that includes social costs will include more costs than the theoretical individualized COI. Thus, an estimated COI value may exceed WTP.