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ABSTRACT

This paper develops and applies an integrated model of human mortality and morbidity valuation that is consistent with principles of welfare economics. The standard expected utility model of one person facing two health states (alive and dead) is extended to a setting in which two family members (a parent and a child) face three health states (healthy, sick, and dead). A key finding is that total health benefits of public programs equate to the sum of willingness to pay for reduced mortality risk plus a fraction of the willingness to pay for reduced morbidity risk. Implications of the integrated model are tested using two field data sets from the U.S. on skin cancer and leukemia risk reductions. Results obtained show how the integrated model can be used to increase the accuracy of health benefit estimation for benefit-cost analyses as well as for the design of public hazard reduction programs.

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1. *Introduction*

Valuation of improvements in human health is a central feature in benefit-cost analyses

of public programs to reduce environmental hazards such as air pollution (e.g., U.S.

Environmental Protection Agency 2011). Benefit-cost studies generally divide human health

improvements into two categories, reduced mortality and reduced morbidity. Valuation of

reduced mortality is achieved using an estimate of the value of a statistical life (VSL) that is

assumed to be applicable across many types of mortality risk.[1] Total health benefits then are

obtained by adding the value of reduced mortality to independently estimated, disease-specific

values of reduced morbidity. A recent white paper released by the U.S. Environmental

Protection Agency's National Center for Environmental Economics (2010, p. 8) concludes that

this procedure is deficient because mortality risks and morbidity risks are intertwined; thus

benefits of reduction in each would ideally be based on an integrated model. Developing such a

model, however, was considered to be beyond the scope of the white paper and near the frontier

of the empirical valuation literature.

This paper: (1) develops an integrated model of human mortality and morbidity valuation

that is consistent with principles of welfare economics and (2) demonstrates how this model can

be empirically implemented. In particular, the standard one-person/two-health state (alive and

dead) expected utility model used to support estimation of the VSL is extended in two directions.

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[1] Cameron (2010) discusses alternative ways to scale reductions in mortality risk to avoid misconceptions associated with the term "value of a statistical life." The units in which mortality risk is measured, however, do not materially affect the results presented here. In any case, this paper retains the more traditional terminology used in benefit-cost studies of environmental hazards that affect human health.

First, to develop a theoretical link between mortality and morbidity valuation, the model proposed envisions three possible health states (healthy, sick, and dead).[2] Inclusion of the "sick" health state allows an illness to leave a person alive, but with a lower level of utility than would be enjoyed in the healthy state. Second, to allow for the possibility that parents value risks to their children's health differently than they value risks to their own health, the model is developed in a setting with two family members, a decision-making parent and a child.[3] This framework then is applied to obtain morbidity and mortality values both for parents and their children using two data sets on cancer risk reduction in the U.S.

The theoretical model yields two main insights. The first turns on the possibility that the risk of getting sick (S), referred to as "illness likelihood risk", and the conditional risk of death given sickness (D), referred to as "conditional mortality risk", are perfect substitutes. As the term is used in this paper, perfect substitution means indifference between alternative combinations of S and D that leave unconditional mortality risk $(r = S \cdot D)$ unchanged. In the special case in which illness likelihood risk and conditional mortality risk are perfect substitutes, total health benefits are entirely captured by the willingness to pay to reduce unconditional mortality risk obtained from the standard two-health state model (i.e, the monetized difference between utility if alive and utility if dead).

In the more general case in which illness likelihood risk and conditional mortality risk are not perfect substitutes, total health benefits are equal to the willingness to pay for reduced

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[2] In policy oriented studies, the value of reduced morbidity often is established from an *ex post* perspective using medical costs and lost work time incurred by those suffering from particular diseases. Alberini and Krupnick (2002, p. 234) point out that this approach is not consistent with principles of welfare economics. This paper, in contrast, takes an *ex ante* view in which the value of reduced morbidity rests on the monetized difference between utility if healthy and utility if sick.

[3] Recent empirical studies (e.g., Dickie and Messman (2004); Hammitt and Haininger (2010)) have estimated that parents are willing to pay more to reduce hazards to their children than they are to reduce the same hazards to themselves.

unconditional mortality risk (r) plus a fraction of the willingness to pay for reduced morbidity risk (q), where morbidity risk is defined as the risk of getting sick given that death does not occur.[4] An important additional nuance in this calculation is that willingness to pay to reduce unconditional mortality risk accounts for the risk of getting sick and willingness to pay to reduce morbidity risk accounts for the risk of death. Thus, in the model developed, willingness to pay to reduce these two types of risk differs from the corresponding values that would be obtained by making independent estimates of each.

A second result from the model is that a parent's willingness to pay to reduce a given health risk to herself will not generally equal her willingness to pay to reduce this same risk to her child. She may be willing to pay a higher or lower amount to protect herself as compared to the amount that she would pay to protect her child depending on the utility levels that she would experience in various health states, together with the relative likelihood of these possible occurrences. This result highlights the difficulties inherent in the practice sometimes followed by policy-makers either in implicitly or explicitly transferring to children prior estimates of the VSL obtained for adults.

The theoretical model also is used to: (1) motivate empirical estimation of parents' willingness to pay to reduce both illness likelihood risk and conditional mortality risk, (2) convert these estimates into values of willingness to pay to reduce unconditional mortality risk and morbidity risk, and (3) test whether illness likelihood risk and conditional mortality risk are perfect substitutes. In the extensive literature on the VSL, the implicit assumption of perfect substitution has never been tested.

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[4] In line with recent empirical studies (Cameron, DeShazo, and Stifler 2010; Evans and Shaur 2010), the approach taken here allows for heterogeneity in the willingness to pay for reduced mortality that depends on illness characteristics.

Empirical estimates are based on stated preference data obtained in two field studies of skin cancer and leukemia risks to parents and their children. Use of stated preference data is controversial partly because respondents are often thought to overstate their purchase intentions when they do not actually have to pay. Econometric methods applied here, however, confine any systematic tendency to misstate willingness to pay in a regression constant term that plays no role in the analysis.

Estimates obtained suggest that for skin cancer, parents view illness likelihood risk and conditional mortality risk as perfect substitutes both for themselves and for their children. This outcome means that for this disease: (1) parents are willing to pay the same amount of money for X% reductions in illness likelihood risk, conditional mortality risk, and unconditional mortality risk and (2) parents' willingness to pay to reduce morbidity risk is equal to zero. Estimates obtained for leukemia also, and perhaps surprisingly, suggest that parents view illness likelihood risk and conditional mortality risk as perfect substitutes for their children, but for themselves, they view utility if sick as the same as utility if dead. In this case, total willingness to pay to reduce unconditional mortality risk and morbidity risk turns out to be a multiple of the willingness to pay to reduce illness likelihood risk.

2. *Model*

A. *Overview*

The model extends the standard von Neumann-Morgenstern expected utility model to consider a "family" consisting of one parent and one child. The family behaves as if maximizing a single expected utility function subject to a single budget constraint and household choices can be described as if made by a single individual (a parent). This perspective is adopted for two reasons. First, the field data focus on health risk tradeoffs facing one parent and her child.

Second, the model developed can be closely linked to the expected utility framework traditionally used to support estimation of the VSL.[5]

The model envisions that both the parent (assumed to be the mother) and the child are initially healthy and that each face three prospective health states, healthy (H), sick (S), and dead (D). The parent's expected utility (EU) is the probability weighted sum of utility levels that she would experience in each of nine possible health states. These probabilities and thus expected utility can be expressed in two equivalent ways. Both formulations of the model are described because each is useful in the analysis later on.

One way to write the model would be to let S_p denote the parent's perception of her own illness likelihood risk (i.e., the probability that she will become sick), S_k denote the parent's perception of her child's illness likelihood risk, D_p denote the parent's perception of her own conditional mortality risk (i.e., the probability that the parent will die if she becomes sick), and D_k denote the parent's perception of her child's conditional mortality risk. In this case, EU can be expressed as

$$
\begin{aligned}
EU = {} & (1-S_k)(1-S_p)U_{HH} + (1-S_k)S_p(1-D_p)U_{HS} + (1-S_k)S_p D_p U_{HD} \\
& + S_k(1-D_k)(1-S_p)U_{SH} + S_k(1-D_k)S_p(1-D_p)U_{SS} + S_k(1-D_k)S_p D_p U_{SD} \\
& + S_k D_k(1-S_p)U_{DH} + S_k D_k S_p(1-D_p)U_{DS} + S_k D_k S_p D_p U_{DD}
\end{aligned}
\tag{1}
$$

where, U_{ij} refers to the parent's utility in health state ij where i refers to the child's health state ($i = H, S, D$), and j refers to the parent's health state ($j = H, S, D$).[6] For example, U_{HS} denotes

the parent's utility if the child is healthy and the parent is sick. Equation (1) can be written more compactly as

$$EU = (1 - S_k)EU_{H\square} + S_k(1 - D_k)EU_{S\square} + D_k S_k EU_{D\square}. \tag{2}$$

Here $EU_{H\square}$, $EU_{S\square}$, and $EU_{D\square}$ respectively denote the parent's expected utility given that the child is healthy, sick, or dead $(EU_{i\square} = (1 - S_p)U_{iH} + S_p(1 - D_p)U_{iS} + D_p S_p U_{iD}, \ i = H, S, D)$.

Equation (2) focuses explicitly on risks faced by the child, but could be alternatively expressed to focus on risks to the parent.[7]

A second and equivalent way of expressing the model is to denote the unconditional mortality risk to either the parent or child as $r_z = S_z \cdot D_z$, $z = p, k$ and define morbidity risk (i.e., the conditional risk of illness given that death does not occur) as $q_z = (S_z - r_z)/(1 - r_z)$. In this case, and again focusing on risks to the child, the parent's expected utility is

$$EU = (1 - r_k)(1 - q_k)EU_{H\square} + q_k(1 - r_k)EU_{S\square} + r_k EU_{D\square} \tag{3}$$

where $EU_{i\square} = (1 - r_p)(1 - q_p)U_{iH} + q_p(1 - r_p)U_{iS} + r_p U_{iD}, \ i = H, S, D$.[8]

Regardless of whether expected utility is expressed as equation (2) or equation (3), six assumptions are adopted to simplify the analysis. First, $U_{ij} = U_{ij}(I)$; where I denotes the parent's income when she and her child are healthy. Of course, the parent may not have the same amount of income in other health states. If she is sick or her child is sick, for example, her capacity to

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[7] To focus on risks to the parent EU can be written as $EU = (1 - S_p)EU_{\square H} + S_p(1 - D_p)EU_{\square S} + D_p S_p EU_{\square D}$ where $EU_{\square j} = (1 - S_k)U_{Hj} + S_k(1 - D_k)U_{Sj} + D_k S_k U_{Dj}, \ j = H, S, D$.

[8] To focus on risks faced by the parent, EU can be written as $EU = (1 - r_p)(1 - q_p)EU_{\square H} + q_p(1 - r_p)EU_{\square S} + r_p EU_{\square D}$ where $EU_{\square j} = (1 - r_k)(1 - q_k)U_{Hj} + q_k(1 - r_k)U_{Sj} + r_k U_{Dj}, \ j = H, S, D$.

earn income may be lower than if both are healthy. Nonetheless, income differences between health states are subsumed into the various health state utility functions.

Second, the model assumes that decision making occurs in a one-period, rather than in a multi-period, framework. This approach rules out the possibility that a person might be sick for a period of time and then die later on. Because exposure to environmental hazards may result in a long illness leading to death, extension to a multi-period framework may be a useful direction in future research. Nonetheless, factors important in the one-period analysis presented here may also emerge in a multi-period setting.

Third, the expected utility model abstracts from treatment of illness. For instance, if the parent becomes sick, she either can remain sick or die. She cannot return to the healthy state or take action to increase her utility if she becomes ill. Thus, utility in the sick health state in this model is interpreted as net of any treatment received and can be thought of as a situation in which the parent has lower income than in the healthy state or has a reduced capacity to enjoy a given amount of income available in both health states.

Fourth, the possibility that the parent might purchase insurance to transfer income between health states is not considered. Fifth, the expected utility that the parent derives from bequests may depend on the health state of the child. Sixth, the parent's marginal expected utility of income generally obeys $EU'_{H\square} \geq EU'_{S\square} \geq EU'_{D\square} \geq 0$ and $EU'_{\square H} \geq EU'_{\square S} \geq EU'_{\square D} \geq 0$, where the prime notation denotes the derivative of expected utility with respect to income. An exception could occur in the case where an illness is considered a "fate worse than death" in which case utility if dead exceeds utility if sick and it is possible that $EU'_{D\square} \geq EU'_{S\square}$ and $EU'_{\square D} \geq EU'_{\square S}$. The condition $EU'_{H\square} \geq EU'_{D\square} \geq 0$ reflects a common assumption in related literature.

B.   *Willingness to pay to reduce mortality and morbidity risks (r_z and q_z)*

In this sub-section, the parent's willingness to pay to reduce unconditional mortality risk r_k and morbidity risk q_k is treated explicitly for the case of the child. Her willingness to pay to reduce the corresponding risks to herself takes a similar form and is therefore not treated in detail. In computing the expressions for willingness to pay, the (small) reduction in r_z (q_z) considered is just large enough to save the life of one person (prevent one person from becoming sick given that death does not occur) in a large population of identical persons.

Using equation (3), the parent's *ex ante* willingness to pay to reduce unconditional mortality risk to the child is

$$\frac{\partial I}{\partial r_k} = \frac{(EU_{H\square} - EU_{D\square}) - q_k(EU_{H\square} - EU_{S\square})}{(EU'_{H\square} - r_k(EU'_{H\square} - EU'_{D\square}) - q_k(1 - r_k)(EU'_{H\square} - EU'_{S\square})} \tag{4}$$

In equation (4), the numerator denotes the difference in the parent's expected utility when the child is alive rather than dead, recognizing that the child will be healthy with probability $(1 - q_k)$ and sick with probability q_k. The denominator is interpreted as the marginal expected utility of income (assumed to be positive) hereinafter denoted MEU_I. The value of $\partial I / \partial r_k$ differs from that derived from the two-health state (alive and dead) model in which $EU_{H\square}$ and $EU_{S\square}$ are implicitly assumed to be equal. In equation (4), if $q_k > 0$, departures of $EU_{S\square}$ from $EU_{H\square}$ make both the numerator and denominator smaller. Thus, the resulting value of $\partial I / \partial r_k$: (1) either may be larger or smaller than in the two-health state case and (2) will vary with the illness considered (i.e., with the magnitude of $(EU_{H\square} - EU_{S\square})$).

Equation (3) also can be used to find the willingness to pay for a reduction in morbidity risk q_k.

$$\frac{\partial I}{\partial q_k} = \frac{(1 - r_k)(EU_{H\square} - EU_{S\square})}{MEU_I} \tag{5}$$

Thus, the parent's willingness to pay for a reduction in q_k is the monetized difference in expected utility between the state in which the child is healthy and the state in which the child is sick, multiplied by the probability that death does not occur $(1 - r_k)$. Notice that $\partial I / \partial q_k$ accounts for utility in the death state through the marginal expected utility of income (see equation (4)). If the marginal expected utility of income if sick declines with declines in expected utility if sick, then larger values of $(EU_{H\square} - EU_{S\square})$ indicate smaller values of MEU_I and therefore larger values for willingness to pay to reduce morbidity risk by a given amount. In any event, the value of $\partial I / \partial q_k$ will vary according to the illness considered.

Benefit-cost studies of changes in environmental policy sometimes calculate a value for total health benefits by adding an estimate of the value of a statistical life that is assumed to be applicable to many types of unconditional mortality risks, to disease-specific values of reduced morbidity risk. In the context of the model developed here (neglecting the scale factor for population size), the correct calculation would be obtained by adding equation (4) to equation (5).

$$\frac{\partial I}{\partial r_k} + \frac{\partial I}{\partial q_k} = \frac{(EU_{H\square} - EU_{D\square}) + (1 - r_k - q_k)(EU_{H\square} - EU_{S\square})}{MEU_I} \tag{6}$$

Equation (6) shows that a parent's total willingness to pay for reductions in unconditional mortality risk and in morbidity risk equates to the sum of willingness to pay to avoid mortality $((EU_{H\square} - EU_{D\square}) / MEU_I)$ plus a fraction $(1 - r_k - q_k)$ of the willingness to pay to avoid an illness

given that it is not fatal $(EU_{H\square} - EU_{S\square})/MEU_I$.[9] An advantage of the integrated model described here is that both utility differences are monetized using a common value for the marginal expected utility of income. In any case, failure to account for the fraction $(1 - r_k - q_k)$ when adding the illness avoidance value to the death avoidance value will lead to an overestimate of total health benefits.

C. *Willingness to pay to reduce children's mortality risk (r_k)*

To illustrate how a parent's willingness to pay to reduce her child's unconditional mortality risk $\partial I / \partial r_k$ might depend on the nature of the illness examined, consider two situations that arise when the parent's expected utility given that the child is sick is: (1) less than her expected utility when the child is healthy and (2) equal to her expected utility when the child is healthy.

Illness reduces expected utility. Values of willingness to pay for reductions in r_k, q_k, S_k, and D_k can be compared for alternative values of $(EU_{S\square} - EU_{D\square})$ and $(EU_{H\square} - EU_{S\square})$ using equations (4) and (5) together with equation (2). It is convenient to begin by considering willingness to pay for percentage reductions in S_k and D_k. Relationships developed turn out to be useful in interpreting empirical results presented in Section 4.

Willingness to pay for percentage reductions in D_k and S_k are

$$\frac{\partial I}{\partial D_k / D_k} = \frac{r_k(EU_{S\square} - EU_{D\square})}{MEU_I} \tag{7}$$

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[9] Notice that it is possible that $r_k + q_k$ could exceed unity, nonetheless if mortality and morbidity risks are "small" then $(1 - r_k - q_k) > 0$.

$$\frac{\partial I}{\partial S_k / S_k} = \frac{S_k (EU_{H\square} - EU_{S\square})}{MEU_I} + \frac{\partial I}{\partial D_k / D_k} \tag{8}$$

If $(EU_{S\square} - EU_{D\square}) > 0$, indicating that sickness is preferred to death, then as shown in equations (7) and (8), willingness to pay for an X% reduction in S_k will exceed willingness to pay for an X% reduction in D_k. In this situation, the parent has more to gain from a given percentage reduction in one component of r_k (illness likelihood risk) than a reduction in the other component (conditional mortality risk) by that same percentage.

If instead $(EU_{S\square} - EU_{D\square}) = 0$, indicating that the illness is as bad as death, then $\partial I / \partial D_k = 0$ and using equations (4) and (5), $\partial I / \partial r_k = (1 - q_k)(\partial I / \partial S_k)$ and $\partial I / \partial q_k = (1 - r_k)(\partial I / \partial S_k)$. Total health benefits in this case, obtained by summing $\partial I / \partial r_k + \partial I / \partial q_k$ as shown in equation (6), can be expressed as a multiple $(2 - r_k - q_k)$ of $\partial I / \partial S_k$. If $(EU_{S\square} - EU_{D\square}) < 0$, then the illness is viewed as a fate worse than death. In this situation, because the individual would prefer death to illness, $\partial I / \partial D_k < 0$. Nonetheless, $\partial I / \partial q_k > 0$, $\partial I / \partial S_k > 0$, and $\partial I / \partial r_k > 0$.[10]

Finally, using equation (4) it is straightforward to show that $\partial^2 I / \partial r_k \partial r_k \geq 0$. Thus, willingness to pay to save the lives of two children cannot be greater than twice the willingness to pay to save the life of just one.

Illness has no effect on expected utility. Next consider the special case in which the parent's expected utility is the same whether the child is healthy or sick $(EU_{H\square} = EU_{S\square})$. In this situation, perhaps the child's illness is so minor that the parent does not suffer a utility reduction,

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[10] These results assume that $MEU_I > 0$ even if $EU_{D\square} > EU_{S\square}$

or perhaps the parent simply does not care about the child's health. As shown in equation (5), the value of reduced morbidity risk is zero. Thus, total health benefits are fully captured by the willingness to pay for a reduction in unconditional mortality risk. This willingness to pay value is equal to

$$\frac{\partial I}{\partial r_k} = \frac{(EU_{H\square} - EU_{D\square})}{(1 - r_k)(EU'_{H\square}) + r_k(EU'_{D\square})} \tag{9}$$

where the denominator of equation (9) is just MEU_I when $(EU_{H\square} = EU_{S\square})$ at all income levels.

Additional calculations using equations (7) and (8) show that if $(EU_{H\square} = EU_{S\square})$ S_k and D_k are perfect substitutes in the sense that the parent is willing to pay the same amount of money for an X% reduction in S_k as for an X% reduction in D_k (i.e., the marginal rate of substitution between equal percentage changes in S_k and D_k equates to -1). Thus, in this case, the parent will sacrifice the same amount of money for an equal percentage reduction in r_k as in either S_k or D_k.

D. *Marginal rate of substitution between children's and parents' mortality risk*

Is the parent willing to pay more to protect her child from unconditional mortality risk than she is to protect herself? The parent's willingness to pay to protect her child from unconditional mortality risk is given in equation (4) and her willingness to pay to protect herself is given below in equation (10).

$$\frac{\partial I}{\partial r_p} = \frac{(EU_{\square H} - EU_{\square D}) - q_p(EU_{\square H} - EU_{\square S})}{MEU_I} \tag{10}$$

Equations (4) and (10) can be more easily compared using the marginal rate of substitution between r_p and r_k.

$$\frac{\partial r_p}{\partial r_k} = -\frac{(EU_{H\square} - EU_{D\square}) - q_k(EU_{H\square} - EU_{S\square})}{(EU_{\square H} - EU_{\square D}) - q_p(EU_{\square H} - EU_{\square S})} \tag{11}$$

Equation (11) demonstrates that the parent's willingness to pay to reduce her child's unconditional mortality risk $\partial I / \partial r_k$ either may be larger or smaller than the parent's willingness to pay to reduce unconditional mortality risk to herself $\partial I / \partial r_p$.[11] Even in the perfect substitution case in which $(EU_{H\square} = EU_{S\square})$ and $(EU_{\square H} = EU_{\square S})$ the marginal rate of substitution between r_p and r_k will equate to -1 only in the unlikely event that the parent's expected utility loss from her child's death is equal to her expected utility loss from her own death $((EU_{H\square} - EU_{D\square}) = (EU_{\square H} - EU_{\square D}))$. This outcome suggests that adult VSL values may be a questionable guide to corresponding VSL values for children.

3. Data

Section 4 presents empirical estimates of parents' willingness to pay to reduce mortality and morbidity risks to their children and to themselves (i.e., $\partial I / \partial r_i$ and $\partial I / \partial q_i$) for two diseases that have been associated with exposure to environmental hazards, skin cancer and leukemia. Two similarly structured instruments, one for each disease, were used to collect the data. The skin cancer data set, collected in Hattiesburg MS in 2002, is fully described in Dickie and Gerking (2007). In consequence, discussion in this section presents only a few details about the skin cancer data and focuses mainly on the leukemia data.[12]

A. Overview of leukemia data

Data on leukemia risk perceptions were collected in a field study conducted in Orlando, FL between December 2008 and February 2009. Parent respondents were drawn from a list of more than 20,000 residents of the Orlando area maintained by the market research firm Insight Orlando, Inc. Parents were contacted by dialing randomly selected telephone numbers from this

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[11] A similar result easily can be developed for the marginal rate of substitution between parent morbidity risk and child morbidity risk.
[12] Further details about the leukemia data set may be found in Dickie and Gerking (2009).

list and were asked whether they had children living at home between the ages of 1 and 16 years. If so, they were asked to participate in a federally-funded, computer-assisted survey dealing with health risks to parents and their children. Prospective participants were told that they would receive $40 for completing the survey instrument. Prior to administering the instrument, a preliminary version was tested in two focus groups consisting of a total of 24 parents in May 2008. The instrument was revised in light of focus group input and pretested with 68 subjects in early December 2008.

The sample analyzed below consisted of 815 parents.[13] Questions focused on the parent and one child aged 1-16 years. Among the parents, 68.5% were white, 14.2% were African-American, 15% were Hispanic, and 21% were under the age of 40. Most of the parents were female (77.9%), employed full-time (56%), and mean household income was $76,000. Most parents indicated that they were aware of leukemia; 90% said that they had heard of the disease, 43% knew someone personally who had had it, 25% had thought about the possibility that they themselves might get it, and 28% had thought about the possibility that one of their children might get it. For the 68% of parents with two or more children living at home, one child was randomly selected and designated as the sample child. Roughly half (52.8%) of the sample children were male and the average age of sample children was 10 years.

B.   *Leukemia questionnaire design and data description*

The leukemia questionnaire was divided into four segments that elicited: (1) initial perceptions of the likelihood of getting leukemia, (2) revised perceptions of the likelihood of getting leukemia, (3) perceptions of conditional mortality risk from leukemia defined as the

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[13] A total of 839 parents participated in the survey. Responses from 24 parents were disregarded: 3 parents did not answer the question about the number of children in their family, 10 parents were ineligible because they responded that no children lived with them, and 11 parents failed to answer key questions about their perceptions of leukemia risks.

conditional probability of dying within five years given a diagnosis of this disease, and (4)

willingness to pay to reduce leukemia likelihood risk and conditional mortality risk.

Initial perceptions of leukemia likelihood risk (S_k and S_p). Parents made an initial

estimate of the lifetime risk of contracting this disease (illness likelihood risk) using an

interactive scale similar to that used by Krupnick *et al.* (2002) and Corso, Hammitt, and Graham

(2001). The scale depicted 1000 squares in 25 rows and 40 columns. Squares were numbered

from 1 to 1000 and all initially were colored blue. Parents re-colored squares from blue to red to

represent amounts of risk. For example, a parent could use the computer mouse to indicate a risk

level of 200 in 1000 by selecting the square numbered 200 in the scale, causing all the squares

from 1 to 200 to turn red. Beneath the scale, the level of risk was indicated by displaying both

the number and the percentage of the 1000 squares that were colored red. Parents could make as

many changes to the scale as desired before pressing the "Continue" button to record the final

answer.

Parents practiced using the risk scale before making estimates of the risk of getting

leukemia. First, they were shown four examples of scales representing risk levels of 25%, 50%,

75% and 100% and were told the relationship between these percentages and "chances in 1000."

Second, parents were asked to identify which of two hypothetical people had the smallest chance

of getting into an auto accident; Ms. B, a relatively safe driver who had a 1% chance of an

accident, or Mr. A, a relatively careless driver who had a 33.3% chance of an accident. After

viewing risk scales depicting these two individuals' accident risks, 11% of respondents wrongly

answered that Mr. A had the lowest risk. All of these respondents got the correct answer (Ms. B)

when given a second chance at the question. After completing the practice problems, parents

used the risk scale to estimate lifetime chances of getting leukemia for themselves and then for

their sample child. These estimates are interpreted as subjective assessments of illness likelihood risk.

The first three rows of Table 1 characterize the frequency distributions of these leukemia likelihood risk estimates. Three features of parents' initial risk perceptions are worth noting. First, there is considerable variation in risk estimates. Second, parents on average estimated that their own lifetime risk of getting leukemia was about the same as that for their sample child. The null hypothesis that mean perceived leukemia risks are equal for parents and children is not rejected at the 1% level in a matched-samples test. This outcome is broadly consistent with data on actual leukemia risks faced by adults and children. According to the National Cancer Institute (Ries *et al.* 2006), lifetime risk of contracting leukemia falls by less than 1 in 1000 between ages 10 and 50 years. Third, parents appear to have overestimated leukemia risk both for themselves and for their children. On average, parents estimated their own risk of getting leukemia at about 9.6% and estimated their children's chances at about 9.7%. These estimates are about 6-7 times higher than the actual risk of approximately 1.3% that can be estimated from National Cancer Institute data (Ries *et al.* 2006). Median risk estimates are 3-4 times higher than actual risk. Overestimation of relatively small risks is a well-known phenomenon (see, for example, Lichtenstein *et al.* 1978).

Revised perceptions of leukemia likelihood risk (S_k and S_p). Parents were given an opportunity to revise their estimates of the chances of getting leukemia after considering information about this disease. After making their initial risk estimates, they were presented with the National Cancer Institute estimate of 1.3% and told that an individual's risk may differ from this average because of many factors including cigarette smoking, exposure to pesticides, exposure to benzene as might occur if the parent lived in an area with high automobile traffic, as

well as genetic factors. After answering questions about their exposure to these risk factors,

parents were shown their initial leukemia risk estimates (both for themselves and for their sample

child) as previously marked on the risk scales and were given a chance to revise their answers.

As shown in Table 1, about 57% of parents revised their own and their children's lifetime

risk estimates. Downward revisions predominated. Revised leukemia likelihood risk estimates

for parents averaged about 5.6% and revised perceived risk estimates for children averaged about

5.0%. Even though the downward revisions are substantial, mean perceived risk still

overestimates actual risk by a factor of about four. Median revised risk estimates are equal to

actual risk (1.3%).

Perception of conditional mortality risk from leukemia (D_k and D_p). After revising

initial risk estimates, parents were told to imagine that they had received a diagnosis of leukemia

from a doctor and were asked to estimate the chances in 1000 of dying within five years of the

diagnosis. Parents were unaware that they would be asked about the chance of dying from

leukemia when they answered the previously described questions about the risk of getting this

disease. Estimates of conditional mortality risk were obtained for each parent and her child

using the previously described risk scale.

As shown in Table 1, the average parent believed that the conditional risk of death from

leukemia is about 29.9% for herself and about 25.8% for her child. The difference in mean

conditional death risks between parents and children is significant at the 1% level in a matched-

samples test. Over three-quarters of parents saw the conditional risk of dying from leukemia as

higher than the risk of getting leukemia. The null hypothesis that mean subjective assessments

of risk of illness and conditional mortality from illness are equal is rejected at 1% for both

parents and children, whether risk of illness is measured by initial or by revised assessments. Thus, parents appear to have distinguished between the two risks.

Although these risk estimates suggest that parents were aware that leukemia can be fatal, parents appear to have overestimated the chance of dying conditional on a diagnosis of leukemia for their children and underestimated this risk for themselves. As reported in Ries *et al.* (2006), the five-year survival probability for leukemia falls with age, from 85% for children younger than 5 years to 49% for those between ages 15 and 19 years. The overall five-year survival probability for all adults is 49% and falls with age beyond age 45 years.

Willingness to pay for reduced illness likelihood risk and conditional mortality risk.

Parents valued leukemia risk reductions by expressing purchase intentions for each of two hypothetical vaccines. One of the vaccines permanently reduced the risk of getting leukemia for both parent and child, while the other permanently reduced conditional mortality risk from leukemia for both persons. Each type of vaccine was described as similar to newly developed vaccines against cervical cancer. As the vaccine was described, its effectiveness was varied randomly across parents and children. In all, there were eight descriptions of the effectiveness of the vaccine. Four vaccine types reduced risk of getting leukemia (by 10% for both parent and child, by 90% for both persons, or by 10% for one and 90% for the other) from the revised assessments of likelihood risk for the parent and the child. The other four vaccine types reduced conditional mortality risk from leukemia by 10% or 90% from the previously assessed conditional mortality risk for the parent and the child (see Table 2).

Each parent was randomly assigned two of the eight vaccine types. One of the assigned vaccines offered reduced risk of getting leukemia and the other offered reduced conditional mortality risk from leukemia. The two vaccines were presented one at a time in randomized

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order. The parent was asked to read the description of the vaccine and then was shown the previously marked risk scales for herself and for her child, which now indicated the risk reduction that the vaccine would offer and the amount of risk remaining if it was purchased.

For the first of the two vaccines, the parent was asked, "Now please think about whether you would buy the new vaccine for yourself and your child. Please do not consider buying it for anyone else. Suppose that buying the vaccine would cost $X. Of course, if you did buy it, you would have less money for all of the other things that your family needs. Would you be willing to pay $X to vaccinate you and your child?" The cost ($X) was randomly selected from among five values ($150, $300, $600, $1200, $2400).[14] To introduce the second type of vaccine, the parent was told, "Suppose that instead of the previous vaccine, we showed you the following one." Information then was presented and purchase intentions were elicited as before.

Responses to leukemia willingness to pay questions are summarized in Table 2. The right-most column of Table 2 shows how the proportion of parents expressing a willingness to purchase the vaccine varies with the risk change, after aggregating over all costs. Considering all risk changes and costs, 49% of parents said that they would purchase a vaccine offering a reduction in the risk of getting leukemia and 67% of parents said that they would purchase a vaccine offering a reduction in conditional mortality risk of this disease. Parents were more likely to say they would purchase the vaccine to reduce risk of getting leukemia both for themselves and for their child when it offered larger as compared to smaller risk reductions. These differences in proportions achieve statistical significance at the 5% level using a two-tail

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[14] In the focus groups mentioned previously, particular attention was devoted to selecting prices at which some respondents would agree to purchase the vaccine while others would decline. The idea here was to avoid a situation where all or nearly all respondents presented with the lowest price would offer to purchase the vaccine, and/or all or nearly all respondents presented with the highest price would refuse to purchase it.

independent samples test.[15] Parents also were more willing to purchase the vaccine at lower costs than at higher costs.

For the vaccine to reduce conditional mortality risk, increases in risk protection for the child significantly increased the propensity to purchase at 5% using the same type of differences in proportions test as before. Increases in risk protection for the parent, however, lowered the purchase propensity, but these differences in proportions are too small to achieve statistical significance at conventional levels. This outcome appears to be driven mainly by respondents' reluctance to buy at the two highest cost values (either $1200 or $2400). The bottom row of Table 2 shows how the proportion of parents who would buy a vaccine varies with the cost, after aggregating over all four magnitudes of risk change. These rows show a general tendency for the propensity to purchase to decline as cost increases.

A parallel design was used in the skin cancer survey. Each parent expressed purchase intentions for two hypothetical sun lotions. Whereas a single vaccination permanently reduced leukemia risks, parents were told that sun lotions would have to be applied to exposed areas when outdoors over a lifetime in order to be effective. One sun lotion reduced the risk of getting skin cancer for the parent and child, and the other reduced conditional mortality risk of skin cancer for the parent and child. The sun lotions offered either 10% or 50% risk reductions at annual costs ranging from $20 to $125.

4.   *Econometric methods and results*

Estimates of parents' willingness to pay to reduce illness likelihood risk, conditional mortality risk, unconditional mortality risk, and morbidity risk are presented in this section together with tests for perfect substitution between illness likelihood risk and conditional

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[15] At given prices, differences in proportions measuring increased risk protection for both parents and children are too small to be statistically significant at conventional levels.

mortality risk. Econometric methods are developed in Subsection A and estimates based on the

skin cancer and leukemia data are presented in Subsections B and C.

A.   *Development of econometric methods*

Recall that in the field studies: (1) the parent uses the same good (sun lotion in the case of

skin cancer or a vaccine in the case of leukemia) to reduce illness likelihood risk for herself (S_p)

and for her child (S_k) and the same good to reduce conditional mortality risk for herself (D_p) and

for her child (D_k) and (2) reductions in the two types of risk were presented to respondents in the

form of percentage changes. Additionally, assume that the risk reducing goods are valuable to

the parent only insofar as they reduce her own risk and the risk faced by her child.

Consequences of possible violations of this assumption are considered momentarily.

In this case, *ex ante* willingness to pay for the good to reduce illness likelihood risk

(WTP^S) equals the change in income that holds expected utility constant in the face of

simultaneous proportionate changes in S_k and S_p. Using the model of Section 2, this amount

equals

$$WTP^S = \frac{\partial I}{\partial S_p / S_p}\left(\frac{dS_p}{S_p}\right) + \frac{\partial I}{\partial S_k / S_k}\left(\frac{dS_k}{S_k}\right). \tag{12}$$

Similarly, willingness to pay for the good to reduce conditional mortality risk is

$$WTP^D = \frac{\partial I}{\partial D_p / D_p}\left(\frac{dD_p}{D_p}\right) + \frac{\partial I}{\partial D_k / D_k}\left(\frac{dD_k}{D_k}\right). \tag{13}$$

Equations (12) and (13) are re-expressed in more compact notation as

$$WTP^t = \gamma_p^t \Delta_p^t + \gamma_k^t \Delta_k^t, \qquad\qquad t = S, D. \tag{14}$$

Equation (14) pertains to the *h*th sample parent although the observation index has been suppressed, WTP^t denotes this parent's willingness to pay for the good (sun lotion in the case of skin cancer or a vaccine in case of leukemia) that reduces risk $t (= S, D)$, and Δ_p^t and Δ_k^t are variables representing the randomly assigned proportionate reductions in the *t*th component of risk for the parent and child, respectively. Also, γ_k^t and γ_p^t denote parameters to be estimated that are interpreted as the parent's willingness to pay to eliminate risk t (i.e., for a 100% risk reduction) to the child and to herself. Thus, equation (14) treats willingness to pay to reduce a given risk as proportionate to the size of the risk reduction (Hammitt and Graham 1999).

Stated willingness to pay (W^t) is allowed to differ from true willingness to pay (WTP^t). A discrepancy between stated and true willingness to pay may arise, for example, because the choice of whether to buy the risk reducing good was presented as a hypothetical question and/or this question may not have been adequately considered in light of preferences and financial constraints. The difference $W^t - WTP^t$ is modeled as sum of systematic (α^t) and random (v^t) factors

$$W^t - WTP^t = \alpha^t + v^t, \quad v^t \sim N(0, (\sigma^t)^2) \qquad t = S, D \tag{15}$$

To obtain the equations to be estimated, insert equation (14) into equation (15) to obtain

$$W^t = \alpha^t + \gamma_p^t \Delta_p^t + \gamma_k^t \Delta_k^t + v^t \qquad\qquad t = S, D \tag{16}$$

and recall that the dependent variable, stated willingness to pay for the risk reducing good, is latent: Parents only were asked to say whether they would be willing to make a randomly assigned expenditure. Parents are assumed to answer this question in the affirmative if $W^t \geq C^t$, where C^t denotes the randomly assigned cost of the risk reducing good, or if

$$(\alpha^t / \sigma^t) + (\gamma_p^t / \sigma^t)\Delta_p^t + (\gamma_k^t / \sigma^t)\Delta_k^t + v^t / \sigma^t - (1/\sigma^t)C^t \geq 0 \tag{17}$$

Thus, equations are estimated for whether the risk reducing goods are purchased with covariates for the randomly assigned percentage risk changes and costs. A supplementary covariate also was included to indicate the order in which the good was presented. Estimation is by bivariate probit to allow for the possibility that $E(v^S v^D) \neq 0$.

An advantage of this estimation procedure is that the randomly assigned risk reductions and costs are independent of each other and also independent of parent and child characteristics that are included in the error term. For instance, parent and child demographic characteristics and the parent's discount rate vary across observations and may influence the decision to purchase risk reducing goods however, these variables are distributed independently of the randomly assigned risk reductions and costs. This means that if the functional form of equation (16) is correct: (1) endogeneity problems in estimating γ_k^t and γ_p^t are avoided, (2) estimates of parameters are unaffected by whether observed parent characteristics are included as additional covariates, and (3) any systematic tendency for respondents to misstate their purchase intentions affects only the constant term which plays no role in testing the hypotheses of interest.[16] The coefficient of cost is an estimate of $-1/\sigma^t$ that can be used to recover un-normalized coefficients of risk reductions from the normalized estimates (see Cameron and James 1987).[17]

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[16] This specification does not remedy all potential problems with hypothetical valuation questions. For example, Carson, Groves and Machina (2007) examine incentive compatibility of binary discrete-choice valuation questions for new private goods. In their analysis, if subjects believe that survey responses will influence whether the new good will be provided, then overstatement of purchase intentions and insensitivity to risk changes and costs would result. On the other hand, if subjects believe that the new good will be provided but that survey responses will influence the price of the good, then excess sensitivity to costs would result. The specification in equation (15) does not address these problems but instead treats misstatement of willingness to pay as an individual-specific error that is unrelated to risk changes or costs.

[17] If the risk reducing goods are direct sources of utility, a possibility suggested earlier, the correct price to use in equation (17) would be the randomly assigned price of the risk reducing goods net of monetized utility/disutility. Suppressing subscripts and superscripts, suppose that the price of the risk reducing good is $C^* = C + u$, where C denotes the value of price used in the survey and u denotes monetized utility/disutility. Then substitute $C + u$ into the equation (17) to replace the true value C^*. The term $-(1/\sigma)u$ then can be treated as an additional component of the error already present in the equation. This term will affect the estimate of the constant term if it has a non-

B.   *Results*

Tables 3 and 4 present maximum likelihood bivariate probit estimates of equations for whether parents stated that they would buy the goods to reduce illness likelihood risk and conditional mortality risk for skin cancer and leukemia together with sample means of all covariates. Binomial probit coefficients (not presented) were used as starting values. The tables report estimates of normalized coefficients. Estimates of un-normalized coefficients are discussed momentarily. Table 3 shows that in the skin cancer estimates, the error correlation between the illness likelihood risk and conditional mortality risk equations is 0.767. The corresponding error correlation in the leukemia estimates is 0.608 (see Table 4). Both estimates significantly differ from zero at 1% indicating that bivariate probit offers an efficiency gain over binomial probit applied separately to the two equations.

For skin cancer, estimates of normalized coefficients of both parent and child risk change variables are positive and differ significantly from zero at 1% in both equations. The coefficients of cost are negative and are significantly different from zero at 1%.   Order of presentation of risk reducing goods does not matter at the 1% level.[18]

For leukemia, estimates of normalized coefficients of both parent and child risk change variables are positive and differ significantly from zero at 1% in the likelihood risk equation. In the conditional mortality risk equation, the normalized coefficient estimate of child risk reduction is positive and differs from zero at 1%; however, the normalized coefficient estimate of parent risk change is negative and does not differ from zero at conventional significance levels. Order of presentation of the risk reducing goods again does not matter at the 1% level.

zero mean, but will not affect the point estimates of the coefficients of price and parent/child risk reduction because these variables were randomly assigned.

[18] Whether presentation order of valuation tasks influences respondents' intended purchase decisions has long been a concern in repeat-response stated preference studies (see Day *et al.* (2012) for further discussion).

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Further perspective on these estimates can be obtained by testing whether illness likelihood risk and conditional mortality risk are perfect substitutes. Wald tests for perfect substitution, reported in Table 5, are based on the null hypotheses: (1) $H_o: \gamma_k^S - \gamma_k^D = 0$ and (2) $H_o: \gamma_p^S - \gamma_p^D = 0$. These tests make use of the un-normalized coefficient estimates of the risk change variables; thus, they involve comparisons of parents' willingness to pay for 100% risk reductions. Point estimates of the un-normalized coefficients of the risk change variables are computed by multiplying the normalized coefficients reported in Tables 3 and 4 by estimates of σ^t. The standard error of the difference in un-normalized coefficients is estimated using the delta method.[19] If a given null hypothesis is not rejected, one implication would be that the parents' common value for willingness to pay to reduce illness likelihood risk and conditional mortality risk is also equal to their willingness to pay to reduce unconditional mortality risk (see Section 2).

For skin cancer, p-values from Wald tests indicate that $H_o: \gamma_k^S - \gamma_k^D = 0$ and $H_o: \gamma_p^S - \gamma_p^D = 0$ are not rejected both individually and jointly at conventional significance levels. This outcome suggests that illness likelihood risk and conditional mortality risk are perfect substitutes and that utility if sick is the same as utility if healthy. This outcome is plausible in that skin cancers generally can be cured by removal, particularly if diagnosed at an early stage. If allowed to spread to other parts of the body, melanoma skin cancers (representing less than 5% of all skin cancers) have a 5-year survival rate of about 15% (American Cancer Society 2010, pp.19-20).

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[19] The standard error is estimated based on a first order Taylor's series expansion of the estimated difference $\hat{\sigma}^S \hat{\beta}_k^S - \hat{\sigma}^D \hat{\beta}_k^D = 0$, where $\hat{\beta}_k^S = (\hat{\gamma}_k^S / \hat{\sigma}^S), \hat{\beta}_k^D = (\hat{\gamma}_k^D / \hat{\sigma}^D)$, around the true values of the parameters. Because the illness likelihood and conditional mortality equations are estimated jointly, this procedure accounts for the cross-equation correlation between the equations for risk-reducing goods.

For leukemia, the hypothesis $H_o : \gamma_k^S - \gamma_k^D = 0$ is not rejected at conventional significance levels, but p-values indicate that the hypothesis $H_o : \gamma_p^S - \gamma_p^D = 0$ would be rejected at levels of significance greater than or equal to 1%. A Wald test jointly rejects the two null hypotheses at significance levels above 2.3%. Also, supplementary tests (not shown in Table 5) for $H_o : \gamma_p^S = 0$ and $H_o : \gamma_p^D = 0$ indicate that the first of these hypotheses is rejected at conventional significance levels, while the second hypothesis is not rejected at conventional significance levels (p=0.333). [20] This outcome suggests that parents' willingness to pay to reduce their own conditional mortality risk from leukemia is equal to zero.

Test results for leukemia are more difficult to interpret than those for skin cancer. The implication of perfect substitution between illness likelihood risk and conditional mortality risk for children is unexpected. Leukemia symptoms are debilitating and the suffering of a child would be expected to result in a utility loss for parents. Also, while the five-year survival rate for childhood leukemia is 85%, remission is the goal in treating this disease, rather than a once-and-for-all cure (American Cancer Society 2010). Once a child is in remission, parents still may be concerned about a possible relapse or a future diagnosis of another type of cancer. Among adult leukemia patients, activity limitations, and treatment goals are similar to those for children, although five-year survival rates are considerably lower and decline with age at onset. In any case, a finding of a zero willingness to pay to reduce conditional mortality risk is plausible if adults view the leukemia illness state as a fate equivalent to death.

An additional question of interest centers on whether parents are willing to pay the same amount to eliminate a given risk for their children as for themselves. Table 5 also shows results

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[20] In the skin cancer estimates, both of these hypotheses are rejected at 1%. Parallel hypotheses for children are rejected at 1% based on both skin cancer and leukemia estimates.

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of Wald tests of the null hypotheses: (3) $H_o : \gamma_k^S - \gamma_p^S = 0$ and (4) $H_o : \gamma_k^D - \gamma_p^D = 0$. In the skin

cancer case, p-values indicate that both hypotheses are not rejected individually and jointly at

conventional levels of significance. Using the leukemia data set, the hypothesis for illness

likelihood risk is not rejected (p-value = 0.911), but the hypothesis for conditional mortality risk

is rejected at significance levels above 1.7%. Additionally, the two hypotheses are jointly

rejected at significance levels above 1.6%. In summary, parents appear to be willing to pay an

equal amount for an equal percentage reduction in a given risk, whether the risk affects the

parent or the child, in 3 of 4 cases considered.

> C. *Willingness to pay estimates to reduce mortality and morbidity risks*

Estimates of willingness to pay to reduce unconditional mortality risk to parents and

children from skin cancer and leukemia can be found by re-estimating the equations reported in

Tables 3 and 4 with cross-equation constraints to impose perfect substitution in the three

situations where this null hypothesis was not rejected. These constraints ($\gamma_k^S = \gamma_k^D$ and $\gamma_p^S = \gamma_p^D$

for skin cancer and $\gamma_k^S = \gamma_k^D$ for leukemia) are motivated by discussion in Section 2 which

indicates that perfect substitution leads to common values of willingness to pay to eliminate

illness likelihood risk, conditional mortality risk, and (therefore) unconditional mortality risk.[21]

Willingness to pay values obtained from the constrained estimates are presented in Table

6. These estimates show that parents are willing to pay $70.06 annually for a 100% reduction in

unconditional mortality risk from skin cancer for themselves and are willing to pay $105.44

annually for a 100% reduction in unconditional mortality risk from skin cancer for their children.

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[21] Likelihood ratio tests were used to compare restricted estimates to unrestricted estimates presented in Tables 4 and 5. Using the skin cancer data, the two restrictions imposed are not rejected, $p=0.914$. Using the leukemia data, the one restriction is not rejected, $p=0.491$.

For leukemia, constrained estimates suggest that parents are willing to pay $811.29 to eliminate their children's unconditional mortality risk. This estimate exceeds the corresponding estimates for skin cancer possibly because in the leukemia study, parents were asked for an immediate, one-time payment for vaccines that would be effective for life; whereas in the skin cancer study, parents were asked how much they would pay in the first year for sun lotions when a stream of annual purchases would be required to maintain effectiveness. Table 6 also indicates that parents are willing to pay $760.81 to eliminate leukemia likelihood risk for themselves and -$295.02 (estimate not significantly different from zero at conventional levels) to eliminate conditional mortality risk for this disease for themselves.

Table 7 reports estimates of parents' willingness to pay to reduce illness likelihood risk, conditional mortality risk, unconditional mortality risk, and morbidity risk by an absolute amount (1 in 10,000), rather than a by proportional amount. Estimates presented make use of the constrained estimates reported in Table 6 together with sample means of the risk variables (see Table 7, footnotes a and b). Estimates of mean unconditional mortality risk for both diseases and for parents and children were computed by multiplying revised illness likelihood risk by conditional mortality risk for each parent and then averaging across all sample members.

An "average" parent's willingness to pay to reduce her children's and her own unconditional mortality risk of skin cancer by 1 in 10,000 are $0.48 and $0.21, respectively. These point estimates suggest that parents are willing to pay more than twice as much to reduce unconditional mortality risk for their children than they are willing to pay to reduce their own risk.[22] In light of the finding of perfect substitution between illness likelihood risk and

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[22] Results in Table 6 and 7 may overstate the child health premium for skin cancer. As discussed previously, the hypotheses that parents are willing to pay an equal amount to eliminate a given risk, whether the risk affects the parent or the child, were not rejected for illness likelihood risk and for conditional mortality risk. If equality of willingness to pay to eliminate risk is imposed along with perfect substitution when re-estimating equations reported

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conditional mortality risk, the value of reduced morbidity from skin cancer is zero. The "average" parent's willingness to pay to reduce unconditional mortality risk from leukemia by 1 in 10,000 to their child is $4.28. In light of perfect substitution, the value of reduced morbidity risk for children implied by the estimates is equal to zero.

Parents' willingness to pay to reduce their own unconditional mortality risk and morbidity risk by 1 in 10,000 can be obtained from the corresponding estimate of willingness to pay to reduce leukemia likelihood risk shown in Table 7. If $(EU_{S\square} - EU_{D\square}) = 0$ (recall that $H_o : \gamma_p^D = 0$ was not rejected), then $\partial I / \partial r_k = (1 - q_k)(\partial I / \partial S_k)$ and $\partial I / \partial q_k = (1 - r_k)(\partial I / \partial S_k)$ (see Section 2). Willingness to pay to reduce the "average" parent's own unconditional mortality risk of leukemia by 1 in 10,000 can be computed therefore by multiplying the value of willingness to pay to reduce leukemia likelihood risk by 1 in 10,000 ($1.37) by an estimate of

$(1 - q_p) = [1 - ((S_p - r_p) / (1 - r_p))] = [1.0 - ((0.06 - 0.02)/(1.0 - 0.02))] = 0.96.$ [23] This calculation yields $1.32. Correspondingly, the "average" parent's willingness to pay to reduce morbidity risk by 1 in 10,000 can be found by multiplying $1.37 by (1.0-0.02) to obtain $1.34. Thus, total health benefits sum to $2.66, which is about 62% of the corresponding value for children. Although the adjustment factors of $(1 - q_p)$ and $(1 - r_p)$ applied to the estimate of $\partial I / \partial S_k$ are relatively close to unity in this illustrative calculation for leukemia, they may well be smaller and therefore more important to consider for a different illness with larger values of r and q.

VSL estimates can be obtained by multiplying the estimates of willingness to pay to reduce unconditional mortality risk shown in Table 7 by 10,000. The skin cancer estimates,

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in Table 3, results indicate that parents are willing to pay $87 to eliminate illness likelihood risk or conditional mortality risk to either the parent or the child. The implied values of 1/10,000 reductions in unconditional mortality risk are $0.26 for the parent and $0.40 for the child. The 50% child health premium is similar to that obtained by Hammitt and Haininger (2010).

[23] The mean value of S_p reported in Table 1 is 0.06 and the mean value of r_p reported in Table 7 is 0.02.

which pertain to one-year risk reductions, suggest VSL values of \$4,800 for children and \$2,100 for adults. The corresponding VSL values for leukemia, which pertain to permanent risk reductions, are \$42,800 for children and \$13,100 for adults.

Two factors may help to explain why these VSL values are much lower than those generally obtained in labor market studies (Viscusi and Aldy 2003). First, labor market estimates of VSL are interpreted as the marginal value of saving one life; whereas estimates presented here are interpreted as the average willingness to pay to save one life in the case where unconditional mortality risk is eliminated.[24] Marginal willingness to pay for a unit of risk reduction would be expected to decline as successive increments in risk reduction are considered (see Section 2), thus the VSL obtained here is expected to be lower than the estimates of VSL obtained in other studies. Second, parents tended to overestimate illness likelihood risk and conditional mortality risk in both the skin cancer and leukemia data sets. A given value for willingness to pay to eliminate reduced unconditional mortality risk may therefore underestimate willingness to pay to reduce a unit of risk.

A possible concern about the results just presented is that analyzing the skin cancer and leukemia samples as a whole may mask differences in willingness to pay among various subsamples. This concern is motivated by three observations. First, the γ_z^t coefficients in equation (14) in general depend on individual parents' incomes and the risks faced by parents and children (see equations (7) and (8)). This motivates testing for differences in parents' willingness-to-pay by income and by the levels of risk faced. Second, findings in previous studies of parental health investments in children suggest testing for differences by child gender

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[24] For instance, the mean of unconditional mortality risk for children's leukemia (see Table 7, footnote b) suggests that eliminating this risk would save the lives of 189 children in 10,000. An interpretation of estimates presented here would be that willingness to pay to save all of these lives would be \$8,089,200, so that average willingness to pay per life saved is \$42,800.

and age. In developing countries Haddad *et al.* (1996) and Liu *et al.* (2000) find evidence that parents may favor sons over daughters and studies in developed countries, particularly the United States and Europe, have investigated whether child gender prompts parents to make different intra-family resource allocation decisions (e.g., Behrman, Pollack, and Taubman 1986; Lundberg and Rose 2004; Alberini and Scasny 2011). Recent evidence also suggests that when making health investments, younger children are favored over older children (Dickie and Messman 2004; Blomquist, Dickie, and O'Conor 2010). Third, few studies have examined whether mothers and fathers make different health investment decisions for their children, but this possibility still is worth investigating.

Additional bivariate probit regressions (available from the authors on request) were estimated to determine the extent to which differences in parents' willingness to pay to reduce illness likelihood risk and conditional mortality risk were associated with selected demographic factors. For instance, to test for differences in willingness to pay by child gender, each sample was stratified by girls/boys. The regressions reported in Tables 3 and 4 were estimated separately for each of the subsamples. A restricted model, constructed by augmenting the Table 3 and 4 regressions with a dummy variable indicating child gender was estimated for the full sample. A test of whether child gender "matters" then was carried out by testing whether slope coefficients of willingness to pay functions are equal between the two groups, allowing different intercepts, using a likelihood-ratio test at the 5% significance level. A similar approach was used to test for differences in willingness-to-pay functions by whether parent income was above or below its sample median, age of the child was above or below its median, and by parent gender. Tests performed revealed no effect of the demographic factors considered on parents'

willingness to pay to eliminate illness likelihood risk or conditional mortality risk either for skinc cancer or leukemia.

5. **_Summary and conclusions_**

This paper develops and applies an integrated model of human mortality and morbidity valuation consistent with principles of welfare economics. The model extends the standard one-person/two health-state VSL model in two directions. First, it allows for a third health state (sick) with a utility level that is intermediate to utility in the healthy state and utility in the death state. Second, it adopts a family instead of one-person perspective by envisioning a parent who makes choices about risk exposure both for herself and for her child.

Three key findings are obtained from the model. (1) Total health benefits equate to the sum of willingness to pay for reduced unconditional mortality risk plus a fraction of the willingness to pay for reduced morbidity risk. (2) Willingness to pay to reduce unconditional mortality risk accounts for the risk of getting sick and willingness to pay to reduce morbidity risk accounts for the risk of death. Thus, willingness to pay to reduce these two types of risk differs from the corresponding values that would be obtained by making independent estimates of each. (3) A parent's willingness to pay to reduce a given health risk to herself may be larger or smaller than her willingness to pay to reduce this same risk to her child. This outcome suggests that adult VSL values may be a questionable guide to corresponding VSL values for children.

The model is applied to demonstrate how to calculate estimates of willingness to pay to reduce mortality and morbidity risks using two similarly structured field studies dealing with skin cancer and leukemia in the U.S. The empirical analysis rests on an examination of stated preference values for hypothetical goods used by both parents and children. A novel econometric approach is used to control for effects of possible misstated purchase intentions for

hypothetical goods so that they do not contaminate the willingness to pay estimates. Evidence for both diseases suggest that parents are willing to pay more to reduce unconditional mortality risk for their children than for themselves. Estimates of willingness to pay to reduce unconditional mortality risk also are quite low in comparison to related estimates from the labor market. In this study, however, VSL estimates are obtained from parents' willingness to pay to eliminate unconditional mortality risk of an illness; whereas in most prior studies VSL estimates are based on small reductions in unconditional mortality risk from a job-related accident.

A future extension might adapt the theoretical and econometric framework developed in this study to investigate whether alternative sources of mortality risk (e.g., an auto accident and cancer) are perfect substitutes. Such an extension would be of possible interest for three reasons. First, if all sources of risk are perfect substitutes, then a value of mortality risk reduction obtained in one setting (e.g., the labor market) would be fully transferrable to other settings such as those arising from environmental health hazards. Second, whether people are willing to pay more to reduce one cause of death than another has attracted attention in recent empirical papers (e.g., Hammitt and Haininger 2010; Alberini and Scasny 2011). Third, government policy-makers have considered whether a "cancer-premium" should be applied in computing monetized benefits of public programs to reduce mortality risk (U.S. Envrionmental Protection Agency, National Center for Environmental Economics 2010; Postle *et al.* 2003 on behalf of the Directorate General-Environment of the European Commission; U.K Department of Food, Rural, and Environmental Affairs 2003).

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Table 1. Parents' Perceived Leukemia Likelihood Risk and Conditional Mortality Risk. Chances per 1000 (N=815).

Risk Component		Sample Statistics						
		Mean	Std. Dev.	Min	25%-tile	Median	75%-tile	Max
Illness Likelihood Risk (Initial)	Parent (S_p)	96.27	140.72	0	10	50	100	1000
	Child (S_k)	97.20	134.96	0	10	37	145	985
	Difference	-0.93	7.00	-450	-25	0	5	850
Illness Likelihood Risk (Revised)	Parent (S_p)	55.60	108.68	0	10	13	50	1000
	Child (S_k)	50.24	97.26	0	10	13	50	975
	Difference	5.35	73.86	-490	-3	0	5	950
Illness Likelihood Risk: Revised minus Initial	Parent	-40.67	109.54	-897	-65	0	0	570
	Child	-46.96	108.33	-860	-70	0	0	249
Conditional Mortality Risk	Parent (D_p)	298.51	261.03	0	50	250	500	1000
	Child (D_k)	258.34	255.33	0	40	200	500	1000
	Difference	40.17	143.44	-700	0	0	100	700

Table 2. Responses to Questions to Assess Willingness to Pay to Reduce Leukemia Likelihood Risk and Conditional Mortality Risk.

Risk Component	Risk Reduction (%)		Proportion of Parents that would Buy the Leukemia Vaccine (Number of Observations)					
	Parent	Child	$150	$300	$600	$1200	$2400	Total
Illness Likelihood Risk	10	10	0.37	0.56	0.36	0.38	0.29	0.39
			(27)	(39)	(45)	(42)	(45)	(198)
	10	90	0.81	0.74	0.45	0.30	0.34	0.51
			(31)	(43)	(47)	(47)	(38)	(206)
	90	10	0.78	0.58	0.51	0.39	0.21	0.48
			(41)	(31)	(47)	(51)	(47)	(217)
	90	90	0.75	0.71	0.60	0.45	0.42	0.59
			(37)	(45)	(35)	(44)	(33)	(194)
	Total		0.70	0.66	0.47	0.38	0.31	0.49
			(136)	(158)	(174)	(184)	(163)	(815)
Conditional Mortality Risk	10	10	0.73	0.76	0.61	0.53	0.56	0.64
			(44)	(37)	(41)	(40)	(39)	(201)
	10	90	0.91	0.82	0.54	0.59	0.67	0.73
			(57)	(33)	(39)	(29)	(37)	(195)
	90	10	0.77	0.67	0.63	0.44	0.48	0.60
			(43)	(43)	(43)	(39)	(40)	(208)
	90	90	0.92	0.86	0.68	0.46	0.52	0.70
			(48)	(37)	(47)	(37)	(42)	(211)
	Total		0.84	0.77	0.62	0.50	0.56	0.67
			(192)	(150)	(170)	(145)	(158)	(815)

Table 3. Sun Lotion Purchase Intentions: Bivariate Probit Estimates (N=610).

Covariate (Parameter Notation)	Sample Mean or Proportion		Coefficient Estimate (standard error)	
	Illness Likelihood Risk	Conditional Mortality Risk	Illness Likelihood Risk	Conditional Mortality Risk
Parent's percentage risk reduction (= 0.1 or 0.5)	0.299	0.299	0.624* (0.238)	0.778* (0.236)
Child's percentage risk reduction (= 0.1 or 0.5)	0.300	0.296	1.000* (0.241)	1.115* (0.236)
Cost of sun lotion ($/year)	62.560	63.840	-0.010* (0.001)	-0.010* (0.001)
Order (=1 if risk change in column presented last, 0 if first)	0.497 (0.500)	0.503 (0.500)	-0.127 (0.108)	-0.188 (0.109)
Constant			0.665* (0.157)	0.559* (0.154)
Correlation of errors between equations			0.767* (0.041)	
Log-likelihood			-649.330	

*Denotes significantly different from zero at 1% statistical level.

Table 4. Leukemia Vaccine Purchase Intentions: Bivariate Probit Estimates (N=815).

Covariate	Sample Mean or Proportion		Coefficient Estimate (standard error)	
	Likelihood Risk	Conditional Mortality Risk	Likelihood Risk	Conditional Mortality Risk
Parent's percentage risk reduction (= 0.1 or 0.9)	0.503	0.511	0.349* (0.105)	-0.106 (0.108)
Child's percentage risk reduction (= 0.1 or 0.9)	0.492	0.499	0.332* (0.105)	0.340* (0.109)
Cost of vaccine ($)	962.210	894.480	-0.0005* (0.00005)	-0.0003* (0.00005)
Order (=1 if risk change in column presented last, 0 if first)	0.497	0.497	-0.159 (0.091)	0.031 (0.093)
Constant			0.161 (0.111)	0.634* (0.110)
Correlation of errors between equations			0.608* (0.048)	
Log-likelihood			-968.130	

*Denotes significantly different from zero at 1% statistical level.

Table 5. p-values for Tests of Differences between Un-Normalized Coefficients of Risk Reduction.

	Skin Cancer	Leukemia
(1) Child illness likelihood risk - Child conditional mortality risk $H_o: \gamma_k^S - \gamma_k^D = 0$	0.823	0.508
(2) Parent illness likelihood risk - Parent conditional mortality risk $H_o: \gamma_p^S - \gamma_p^D = 0$	0.708	0.009
Wald test, both differences, (1) – (2) = 0	0.925	0.023
(3) Child illness likelihood risk - Parent illness likelihood risk $H_o: \gamma_k^S - \gamma_p^S = 0$	0.257	0.911
(4) Child conditional mortality risk - Parent conditional mortality risk $H_o: \gamma_k^D - \gamma_p^D = 0$	0.305	0.017
Wald test, both differences, (3) – (4) = 0	0.323	0.016

Table 6: Parents' Willingness to Pay to Eliminate Illness Likelihood Risk and Conditional Mortality Risk: Constrained Estimates

Skin Cancer			
Parents' WTP to eliminate illness likelihood risk to themselves (γ_p^S)	$70.06 (17.27)	Parents' WTP to eliminate conditional mortality risk to themselves (γ_p^D)	$70.06 (17.27)
Parents' WTP to eliminate illness likelihood risk to their child (γ_k^S)	$105.54 (18.99)	Parents' WTP to eliminate conditional mortality risk to their child (γ_k^D)	$105.54 (18.99)
Leukemia			
Parents' WTP to eliminate illness likelihood risk to themselves (γ_p^S)	$760.81 (245.00)	Parents' WTP to eliminate conditional mortality risk to themselves (γ_p^D)	-$295.02 (308.65)
Parents' WTP to eliminate illness likelihood risk to their child (γ_k^S)	$811.29 (199.69)	Parents' WTP to eliminate conditional mortality risk to their child (γ_k^D)	$811.29 (199.69)

Table 7: Parents' Willingness to Pay to Reduce Illness Likelihood Risk, Conditional Mortality Risk, Unconditional Mortality Risk, and Morbidity Risk by 1 in 10,000: Based on Constrained Estimates

Skin Cancer[a]							
Illness likelihood risk to parent	$0.03	Conditional mortality risk to parent	$0.06	Unconditional mortality risk to parent	$0.21	Morbidity risk to parent	$0
Illness likelihood risk to child	$0.06	Conditional mortality risk to child	$0.11	Unconditional mortality risk to child	$0.48	Morbidity risk to child	$0
Leukemia[b]							
Illness likelihood risk to parent	$1.37	Conditional mortality risk to parent	$0	Unconditional mortality risk to parent	$1.32	Morbidity risk to parent	$1.34
Illness likelihood risk to child	$1.62	Conditional mortality risk to child	$0.31	Unconditional mortality risk to child	$4.28	Morbidity risk to child	$0

[a] Estimates are based on sample means of: (1) 0.2391 for parent revised illness likelihood risk, (2) 0.1897 for child revised illness likelihood risk, (3) 0.1224 for parent conditional mortality risk, (4) 0.0943 for child conditional mortality risk, (5) 0.0340 for parent unconditional mortality risk, and (6) 0.0218 for child unconditional mortality risk. Mean unconditional risk estimates computed by multiplying revised illness likelihood risk times conditional mortality risk for each observation and averaging across the sample.

[b] Estimates are based on sample means of revised illness likelihood risk and conditional mortality risk reported in Table 1. Mean unconditional risk estimates computed by multiplying revised illness likelihood risk times conditional mortality risk for each observation and averaging across the sample. These means are: (1) 0.0205 for parent unconditional mortality risk and (2) 0.0189 for child unconditional mortality risk.