Valuing Environmental Health Risk Reductions to Children

PROCEEDINGS OF

SESSION V: AIR POLLUTION AND ASTHMA IN CHILDREN

A WORKSHOP SPONSORED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS (NCEE), NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH (NCER), AND OFFICE OF CHILDREN'S HEALTH PROTECTION; AND THE UNIVERSITY OF CENTRAL FLORIDA

October 20-21, 2003
Washington Plaza Hotel
Washington, DC

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ACKNOWLEDGEMENTS

This report has been prepared by Alpha-Gamma Technologies, Inc. with funding from the National Center for Environmental Economics (NCEE). Alpha-Gamma wishes to thank NCEE's Kelly Maguire and Project Officer Nicole Owens for their guidance and assistance throughout this project.

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Valuing Reduced Asthma Morbidity in Children*

Presented at
EPA Workshop of Valuation of Children's Health
October 20-21, 2003

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Abstract
This economic study models household willingness-to-pay to minimize a specific health endpoint: morbidity effects on children with asthma (defined as asthma symptoms including coughing, wheezing and/or shortness of breath). The project addresses three main questions: 1) what determines households' perceptions of risks to an asthmatic child, 2) what averting and/or mitigating actions do households take, and 3) what are households' stated willingness-to-pay for a reduction in their children's asthma morbidity.

Acknowledgements
The research is funded by the U.S. EPA - Science to Achieve Results (STAR) program grant R-8296650. Mihail Samnaliev provided excellent research assistance for this project. Valuable input on survey design was provided by members of the Fresno Asthmatic Children's Environment Study [FACES] including Dr. Kathleen Mortimer, Dr. Jennifer Mann, and Beth McDonald. We thank Dr. Matthew Sadof, Associate Director of Ambulatory Pediatrics at Baystate Children's Hospital for his helpful suggestions and gracious assistance. The authors take full responsibility for any errors or omissions.

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I. Introduction

While both our medical understanding of the mechanisms involved in asthmatic episodes and the resources devoted to its treatment have increased, the rise in asthma is a well-documented international phenomenon. The CDC estimates that 14 million Americans have asthma, including 5 million children. Despite dramatic improvements in the understandings of the mechanisms of asthma and asthma therapies, from 1980-1994, the prevalence of the disease has increased 75% and the mortality rate for children under 19 has increased 79%. Asthma is the 2nd leading cause for pediatric emergency room visits (behind accidents) and is the most common reason for school absenteeism.

The economic burden of asthma and asthma therapy in the United States is large and growing. The majority of economic analyses of asthma use a cost of illness method (for reviews see Jönsson (2000) and Weiss and Sullivan (2001)). These studies categorize costs into direct costs (cost of medical treatment) and indirect costs (loss of production). The total direct and indirect cost of asthma in the U.S. was estimated to be $6.2 billion in 1990 (Weiss, Gergen and Hodgen, 1992) and $12.7 billion in 1998 (Weiss and Sullivan, 2001)[1]. Lozano et al. (1999) estimate that children, ages 1 to 17 years, with asthma incurred an average cost of $1129 per child per year in total health care expenditures compared to $468 for children without asthma[2]. The intangible cost of asthma, the loss of utility due to the disease, is omitted from this body of literature. A second component missing from cost of illness studies is the cost of risk avoiding or risk mitigating behavior. Cost of illness studies therefore should be taken as a lower bound of the true cost of asthma.

While these direct costs of asthma are large enough to justify substantial policy interest, asthma is also of great interest because it is a disease whose burdens have significant distributional ramifications. The health burdens associated with asthma fall disproportionately on the young and the poor in the United States. The increase in asthma has been largest in children (under age 18), and the rate of hospitalization for the disease is greatest for those from poor neighborhoods. (See Koren, 1995, and Claudio et al., 1999.) A comparison of asthma hospitalization rates in New York neighborhoods found that while children in lower Manhattan and Queens neighborhoods with average household incomes greater than $57,000 had zero hospitalizations from asthma, children in East Harlem, where the average household income is $19,000, had hospitalization rates of 222 per 10,000 youths. (Claudio et al. 1999)

The valuation of reduction in asthma morbidity is of significant relevance for public policy decisions targeted at children and susceptible populations. Asthmatics have physiologic differences, such as more narrow airways, and, therefore may be more susceptible to the health effects of air pollution. Relative to adults, children also may be more susceptible because they are more physically active, spend more time outdoors and therefore breathe more pollutant per

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[1] The direct costs include cost of medical treatments: inpatient hospitalization, inpatient physician services, emergency room care, outpatient care, outpatients physician services, medications). The indirect costs include: lost workdays of caregiver, lost workdays of asthmatics, loss of lifetime earnings from asthma mortality.

[2] Total expenditures included prescriptions, ambulatory provider visits, emergency room visits, and hospitalizations.

pound of body weight than do adults (American Academy of Pediatrics, 1993). Therefore, asthmatic children represent a susceptible population of particular policy interest. This project consists of a first survey to analyze households' risk perception, their risk reduction behavior and the costs of averting and mitigating behavior and a second survey on stated willingness to pay for reduced asthma morbidity in children.

II. Theoretical Models

A. Modeling Willingness to Pay: A Household Production Approach

Households' behavior will be modeled using a health production approach as introduced by Grossman (1972). Unlike Cropper (1981), this study will follow the approach of Gerking and Stanley (1986) in which ambient air quality will enter as a factor in the production of health.

This study models household behavior to minimize a specific health endpoint: morbidity effects of pollution on children with asthma (defined as asthma symptoms including coughing, wheezing and/or shortness of breath). We are interested in the incidence of asthma symptoms among children clinically diagnosed with asthma, not with the prevention of the disease. The surveys will ask what choices the household makes to minimize the risk of asthma exacerbation in that survey period; therefore, the household model will not be dynamic.

Following the standard household model (Freeman, 1993), the health outcome is a function of pollution exposure and the mitigating and averting behavior of the household. The standard approach assumes that individuals know their health production function, choose their level of output optimally and choose inputs to minimize costs. An important contribution of this study is that our surveys on households will provide information on households' risk perceptions, their averting and mitigating behavior, the costs of such behavior, and the households' evaluation of effectiveness of their actions. Our estimation therefore does not rely on proxies for perceived risks and does not assume households perfectly predict risk.

The health outcome, S, is a measure of asthma morbidity (e.g. cough, wheezing, or shortness of breath). This outcome will depend on pollution exposure, D; mitigating behavior, B; and other socio-demographic variables, Z. Mitigating behavior includes preventative medication and other investments that *reduce the effect* of pollution exposure. For example, control medications, an entire class of drugs for mitigation, are prescribed to reduce the hyper-responsiveness and inflammation of asthmatics' airways[3]. In addition to mitigating behavior, the household can also engage in averting behavior, A, which includes actions to *minimize the exposure* to pollution; an example of averting behavior is the purchase of home air filters. As a result, pollution exposure, D, is a function of both pollution level, C, and averting behavior, A.

To summarize, the measure of asthma morbidity is written as a function of exposure, mitigation, and other covariates that affect health outcome:

[3] Control medications for severe asthmatics include inhaled corticosteroids. For moderate asthmatics, cromolyn sodium can be prescribed to reduce airway hyper-responsiveness.

(1) $S = S(D, B, Z)$

where the exposure to pollution is a function of the levels of pollutants and the household averting behavior:

(2) $D= D(C, A)$

where
S = measure of asthma morbidity
D = realized exposure to environmental pollution
C = levels of pollutants
B = mitigating behavior of household
A = averting behavior of household
Z = covariates that affect health outcome

The utility of the household is a function of consumption goods (X), leisure (L), and morbidity of the asthmatic child (S). As in Dickie (1999), the household maximizes a single utility function where children are "passive" in that they comply with parents'/guardians' decisions.

(3) $U= U(X, L, S)$.

The implication of this utility function is that pollutants affect household well-being only through their impact on health and they have no other associated disutility.

The household has a budget constraint that total income equals total expenditures on consumption goods and on averting and mitigating behavior. The household loses days at work when the severity of the asthmatic symptoms warrants the child's absence from school. The budget constraint is written:

(4) $I + W(T - L- \alpha S) = X + P_a A + P_b B$

where
I = non-wage income
W = wage rate
T = total available time to work
X = consumption goods
L = leisure time
P_a = price of averting behavior
P_b = price of mitigating behavior
αS = lost days of work due to attending to child with asthma symptoms
P_x = 1, the price of bundle of consumption goods is normalized to one

The household maximizes its utility function (3) subject to its budget constraint (4) with respect to the choice variables, X, L, A and B. Using (1) and (2) in the utility function, the household's maximization problem is:

(5) $\max_{X,L,A,B} \quad U(X, L, S(D(C,A), B, Z))$

subject to $X + P_a A + P_b B = I + W(T - L) - W \alpha S(D(C,A), B, Z)$

The resulting first order conditions for an interior solution are:

(6a) $\partial U/\partial X = \lambda$

(6b) $\partial U/\partial L = \lambda W$

(6c) $(\partial U/\partial S)(\partial S/\partial D)(\partial D/\partial A) = \lambda [P_a + W\alpha (\partial S/\partial D)(\partial D/\partial A)]$

(6d) $(\partial U/\partial S)(\partial S/\partial B) = \lambda [P_b + W\alpha (\partial S/\partial B)]$

where λ is the Lagrangean multiplier. Some manipulation yields:

(7a) $$\frac{(\partial U/\partial S)}{(\partial U/\partial X)} = W\alpha + \frac{P_a}{(\partial S/\partial D)(\partial D/\partial A)}$$

(7b) $$\frac{(\partial U/\partial S)}{(\partial U/\partial X)} = W\alpha + \frac{P_b}{(\partial S/\partial B)}$$

The solution to the first order conditions is a set of household demand functions for leisure, for consumption goods, for averting behavior, and for mitigating behavior:

(8) $X = X(P_a, P_b, W, I + WT, C, Z)$
(9) $L = L(P_a, P_b, W, I + WT, C, Z)$
(10) $A = A(P_a, P_b, W, I + WT, C, Z)$
(11) $B = B(P_a, P_b, W, I + WT, C, Z)$

Our collaboration with Fresno Asthmatic Children's Environment Study [FACES] makes it possible for us to use parametric methods to estimate the functions for realized exposure to environmental pollution, $D = D(C,A)$, and for asthma morbidity given exposure to pollutants, $S = S(D, B, Z)$. The data from our economic surveys of risk mitigating and averting behavior will enable us to estimate the demand functions for A and B in (10) and (11). Combining these pieces of information and choosing appropriate functional forms for these expressions will make it possible for us to identify the underlying household utility function, $U(X,L,S)$ (see Hanemann, 1991 and Hanemann & Kanninen, 1999).

This information can be utilized to estimate the household's willingness to pay for either a marginal or non-marginal reduction in pollution levels. If the demand functions (8) – (11) are substituted into the original utility function, one obtains the indirect utility function

(12) $U = V(P_a, P_b, W, I + WT, C, Z)$.

Given a change in pollution levels from C^0 to C^1, the household's utility changes from $U^0 = V(P_a, P_b, W, I + WT, C^0, Z)$ to $U^1 = V(P_a, P_b, W, I + WT, C^1, Z)$. Suppose this change is an improvement. The household's willingness to pay for the change is given by the quantity WTP_c where:

(13) $V(P_a, P_b, W, I + WT - WTP_c, C^1, Z) = V(P_a, P_b, W, I + WT, C^0, Z)$

The household's marginal willingness to pay for a small increment in pollution, $\Delta WTP_c / \Delta C$, can be shown to be measured in terms of mitigating behavior by

(14) $\Delta WTP_c / \Delta C = -P_b [(\partial S/\partial C) / (\partial S/\partial B)].$

and in terms of averting behavior by

(15) $\Delta WTP_c / \Delta C = -P_a [(\partial S/\partial C) / (\partial S/\partial A)].$

The implication of this household health production model is that the marginal WTP for a reduction in pollution can be estimated using observable costs of household behavior, and the non-marginal WTP can be estimated using the utility function that is recovered when one combines the observed demand functions for mitigating and averting behavior together with the health production functions D(C,A) and S(D, B, Z).

B. Stated Willingness to Pay: Contingent Valuation

Our model assumes that a child's well being is a part of a household utility function which determines parent's behavior. We propose a utility maximization model which follows previous models in that area (Rosenweig and Shultz, 1983; Gerking and Stanley, 1996; and Dickie and Gerking, 1986). Household's utility is a function of a vector of market goods not related to health, X, a vector of health related goods, Z, income, I and health, H. The utility function is a random utility model linear in income and covariates, and has the general form:

(1) $U_0 = U_0 (X, Z, H, I) + \varepsilon_0$

A simple model of health production defines health as a function of health capital (K) and averting/mitigating behavior (A) which is determined by a set of health beliefs (B). This set of beliefs, includes risk perceptions, self-efficacy regarding desired outcomes, etc.

(2) $H = H (A, K,)$

The theoretical marginal willingness to pay (WTP) is the maximum amount that households are willing to pay to mitigate their asthma by forgoing some of the market goods and hold the utility at a constant level. Individuals are asked to pay a dollar amount, W for reduction in asthma morbidity, and with some positive probability they agree to this amount. Then their utility function is:

(3) $U_1 = U_1(X, Z, H, I\text{-}W) + \varepsilon_1$

The probability that they will say yes to this amount is

(4) $Pr[Yes] = Pr [U_1(X, Z, H_1, I\text{-}W) + \varepsilon_1 > U_0(X, Z, H_0, I) + \varepsilon_0$

which can be rewritten as

(5) $Pr [\varepsilon_0 - \varepsilon_1] < U_1(X, Z, H_1, I\text{-}W) – U_0(X, Z, H_0, I) = \Delta U = WTP$

i.e. at the point of indifference, where

(6) $U_1(X, Z,H_1, I\text{-}W) – U_0(X, Z,H_0, I) = 0$

the marginal value of reduction in morbidity equals to the marginal disutility of paying for this reduction. The utility function is assumed to have the following functional form
$u = u (\alpha + \beta *I)$ and the difference in utility, ΔU is assumed to have a logistic cumulative density function.

(7) $\Delta U = (1 + e^{-\Delta U})^{-1}$

Then,

(8) $\Delta U = (\alpha_1 - \alpha_0) – \beta *W$

The median WTP is calculated by

(9) $Pr [U_1(X, H_1, I\text{-}W) > U_0(X, H_0, I)] = 0.5$

Modeling directly the WTP function (which is assumed to be a linear random function), an approximation of compensating surplus, using the formula derived by Hanemann (1984) has the form:

(10) $Pr[Yes] = (1 + e^{-\alpha-\beta W})^{-1}$

where α is the grand intercept evaluated at the mean values of the covariates and β is the estimated coefficient for W.
Median WTP is calculated by solving the above expression for Pr[Yes] = 0.5 which yields

(11) $\text{Median WTP} = e^{-(\alpha /\beta)}$

Median WTP is calculated for the positive part of the probability function, by integrating within the interval

(12) $\text{Mean WTP} = \int_0^T [1 - Gwtp] dW$,

where G_{wtp} is the distribution function of the true willingness to pay. T is infinite for the true willingness to pay and is truncated at some value for the purpose of estimation.

C. Socio-economic Indicators and Risk Reducing Behavior

Significant research has documented the disparities across ethnicities in hospitalization rates for asthma; however, the empirical quandary is disentangling which of the correlated social economic status indicators are the factors that create the disparity in morbidity. Recent research indicates that minority children were more likely to underuse preventative medications that could reduce asthma severity (Fiscella et al., 2000; Halterman et al., 2000; Eggleston et al., 1998). This underuse of preventative medication in minority populations is consistent even when there are not disparities in financial access and insurance coverage (Lieu, et al, 2002). Thus we are complementing standard economic instruments with elements used in the public health literature and psychological literature, specifically the Health Belief Model and Theory of Planned Behavior.

The Health Belief Model [HBM] predicts health behavior as a function of four groups of determinants, each of which leads to specific beliefs and incentives that are then motivators for preventative action. Commonly used to predict preventative behavior, HBM is particularly appropriate to our study of households' actions to minimize asthma triggers and comply with asthma control medication regime. The four major components of the HBM are: perceived susceptibility/vulnerability, perceived severity of the disease, perceived benefits from taking action, perceived barriers from undertaking action.

The Theory of Planned Behavior [TPB] explains behaviors as functions of behavioral *intentions*, which are explained by the individual's attitude and subjective norms toward performing the specific behavior (Fishbein and Ajzen, 1975). Attitudes are based on beliefs about the likelihood of an event and evaluation of the consequences of a particular action (Smith and Stasson, 2000). Social norms are determined by what is socially acceptable and by personal motivation to comply with family expectations. An additional element of interest is that of self-efficacy, the individual's perceived ability to perform specific actions under specific conditions (Bandura, 1977). We believe that the elements of these models will contribute to understanding of risk reducing behavior, particularly with respect to compliance with asthma management protocol.

D. Prior expectations

Self-efficacy will be quantified through a standard five-point psychometric scale measuring self-reported efficacy in managing asthma. Applied to asthma mitigating behavior, parents with high level of self-efficacy would be expected to be more effective in their interventions in their child's asthma. In the context of the major domains affecting asthma care, self efficacy affects averting behavior on three levels: (1) the amount of attention that the child receives from the medical care providers[4]; (2) school acceptance and attention on the part of teachers and nurses, and (3) compliance to medications, in cases where the long term beneficial effect of asthma medications is not known to parents.

[4] Due to subtlety in asthma symptoms, some parents could not get admission by the emergency room registration unless they were very assertive, and others reported to have avoided emergency rooms because they couldn't persuade the registration that their child needed to be examined

Perceptions about risk are expected to have a positive effect on WTP, however this effect would be uneven. Risk factors which have a 'salient' effect, (i.e. perceived to be riskier to asthma outcomes as compared to what the scientific risk is) is expected to inflate WTP. Factors that are perceived less risky than they should be will have a deflating effect on WTP.

E. Statistical Analysis of Survey Data

Three types of statistical analysis will be performed, dealing with household choice of averting and mitigating behavior in the context of a health outcomes production function, the determinants of household risk perceptions, and estimation of responses to stated preference questions.

Household Choice of Averting and Mitigating Behavior, and Health Production Function

This involves estimating the behavioral equations for averting and mitigating behavior (10) and (11), together with the reduced form health production function $S = S(D(C,A),B,Z)$. Both of these involve some issues arising from how the variables are measured.

Because both mitigating and averting behavior consist of discrete actions, an index of behavior will be constructed. For mitigating behavior that is repeated daily, the components of the index will be the frequency of each type of behavior over the previous three months. Likewise, for averting behavior that is repeated, the index will be a function of the frequency of each type of averting behavior. In the case of averting behavior, however, there is a class of actions that are essentially one-time investments. Therefore, there will be a second component of the averting index for fixed averting investments. Because the behaviors are discrete and the indices are inherently ordered, the demand system will be estimated using ordered probit. Maximum likelihood estimation will be used.

The dependent variable in the health production function is asthma morbidity. Because households are observed over multiple periods, we can improve upon existing valuations of asthma by disaggregating morbidity into presence of asthma symptoms and the severity of symptoms if present. The presence of symptoms is an indicator variable.

$S = 1$, if symptoms are present
$S = 0$, otherwise.

If symptoms are present, then the severity of symptoms (M) is rated on a scale from one to ten.

$M = 1, \ldots, 10$ where 1 indicates mild symptoms and 10 indicates extreme symptoms.

Therefore, a two-stage estimation will be used. The first stage is a binomial logit where the outcome is the presence of symptoms ($S=1,0$). If symptoms are present, then in the second stage the severity of symptoms (M) is estimated as a Poisson process.

Risk Perception

A goal of the study is to analyze the determinants of household's perceptions of the risk that different risk factors pose to their child and to investigate how their risk perceptions compare with objective assessments by medical and scientific experts. By asking households to evaluate the impact of typical asthma triggers on their child's asthma symptoms, we can create discrete dependent variable that is an index of the household's risk perception. An example is to ask, "If your child is exposed to tree pollen are his/her asthma symptoms: greatly affected, slightly affected, not affected at all?" The epidemiological data provides an index of the degree of that child's asthma response to fluctuations in pollen. Using these data we can construct a contingency table of the households' subject indexes and the objective risk indexes.

The risk perceptions variable takes the form of a ranking by the respondent of the seriousness of each risk factor for that household. Because of the form of this dependent variable, we will use a model for an ordered categorical response variable, such as ordinal probit or logit, when analyzing the rankings to investigate what are the significant socio-demographic factors that influence the household's perceptions of risk and whether factors such as the age of the child or recent onset of symptoms affect risk perceptions. The other major issue is the correlation between subjective household perceptions of risk factors and objective assessments of these factors by scientific experts. To test this relationship, we can use a limited dependent variable model where the dependent variable is the subjective risk index, and independent variables include the objective risk index, household characteristics and relevant interaction terms

III. Empirical Study

A. Collaborative Economic and Epidemiological Study

One criticism of studies of households' behavior is estimation bias due to omitted variables (see Atkinson and Crocker, 1992 and Harrington and Portney, 1987). By collaborating with an extensive epidemiological study of the effects of air pollution on asthmatic children [Fresno Asthmatic Children's Environment Study, FACES] we minimize the potential for omitted variable bias. The FACES study includes a large sample, follows households over multiple years and will incorporate the most detailed socio-demographic, indoor air quality and pollution monitoring data collection effort to date (California Air Resources Board). This project complements the work of Rowe and Chestnut (1986) and O'Conor and Blomquist (1997) by focusing on children's health and generating detailed data on children's clinical health status and household behavior.

The FACES cohort includes children with clinically diagnosed asthma, residing in a section of Fresno County, California[5]. Children are 6-10 years of age at intake and will be followed for approximately 4 years. The study population will include children who have a physician's diagnosis of asthma and at least one of the following: 1) reported utilization of or valid prescription for asthma medication in the previous 12 months; or 2) symptoms consistent with asthma in the past 12 months; or 3) an emergent asthma visit or hospitalization in the past 12 months. The requirements for asthma medication use, symptoms, or health care utilization are to minimize the chance of enrolling subjects whose asthma is quiescent (remission). Children who meet these criteria may be enrolled regardless of the severity of asthma.

B. The Study Area

[5] FACES has been recruiting households for the survey since 2000.

Located in the Central Valley of California, Fresno County has a population of 815,734 which has increased by 19.8% since 1990. Forty-four percent of the population is of Hispanic or Latin origin, followed by forty percent of white origin, eight percent Asian and five percent African-American. The Fresno population has lower medium income, less education, poorer living conditions and a greater percent of residents below the poverty line as compared to the rest of CA. For example, median household income for 2001 was $34,725 as compared to $47,493 for California. The proportion of residents with a high school degree was 67.5% as compared to 76.8% for the rest of the state, and the proportion of residents below the poverty line was 22.9 % while that in CA was 14.2% (US Census data, 2000). The asthma hospitalization rate in Fresno is among the highest in California at 28.8 per 10,000 (California Facts, 2003).

A study of pediatric asthma-related hospital discharges in California shows that the very young children (0-4 years of age), African-American children and males were over represented in the discharge population (see Table 1).

Table 1: Pediatric Asthma-Related Discharges in California

Variable	Frequency	Percentage of discharges
Age		
0-4	64,260	57
5-11	33,485	29
12-17	16,229	14
Race		
White	46,696	57
Latino/a	30,986	27
African-American	28,802	25
Asian	7,490	7
Gender		
Male	71,935	63
Female	42,039	37

Source: Calmes, Leake and Carlisle, "Adverse asthma outcomes among children hospitalized with asthma in CA", Pediatrics, 1998; 101(5), 845-50. This study includes 114,000 records from hospital discharge records.

C. The FACES Cohort

The FACES study has complete screening interviews for 473 households, baseline interviews for 241 households, and currently has 205 participating households. The major reasons households who inquired about the study were ineligible to participate include: other chronic disease, lived in house for less than three months, sleep at home less than five nights/week, and planned to move within two years (Mann, 2003).

The ethnicity of the children in the FACES study is representative of the Fresno general population. Forty-three percent of the sampled parents were Hispanic, followed by 16.7% black and 37.5% white. The unemployment among the FACES cohort is more similar to that of the population hospitalized for asthma, than the general Fresno population.

Table 2: Number of Asthma-Related Hospitalizations of FACES Cohort by Race

Race	% of FACES Sample	Zero Hospitalizations	One or more Hospitalizations
Hispanic	43.0%	19 (61%)	12 (39%)
Black	16.9%	5 (42%)	7 (58%)
White	33.8%	19 (76%)	6 (24%)

Source: Authors' analysis of FACES survey data.

The majority of the interviewed households were covered by health insurance (90.3%). Almost 70% households had at least one parent who was affected by asthma. Table 3 presents a general description of the households participating in FACES.

Table 3. Characteristics of Households Participating in FACES

Household Characteristics	Selected Variables	Relative Frequencies	
Employment	Mother employed	61.1% Yes	38.9% No
	Father employed	69.4% Yes	27.8% No
Health Insurance	Is child currently covered by health insurance?	90.3% Yes	9.7% No
Health History	Mother diagnosed with asthma?	48.6% Yes	51.4% No
	Father diagnosed with asthma*?	31.9% Yes	61.3% No

Source: Authors' analysis of FACES baseline survey data.
* 2.8% missing

FACES data on asthma hospitalization, ER visits and intensive care unit visits showed that 34.7% of the children had been hospitalized at least once in their life, 36.1% had received unscheduled asthma care (such as emergency room) and 12.5% had been placed in intensive care units because of asthma. As expected, number of hospitalizations was lower among Hispanic and white (Table 2), which is consistent with state level hospital discharge data. For the state of California, African-Americans were hospitalized 3 times more for asthma than any other ethnic group. In our sample we get consistent results: the percentage of blacks enrolled in the FACES program (16.7%) is much greater than the percentage of blacks for the Fresno population (5.3%). The average age of children in the FACES cohort is between eight and nine years.

Table 4. Characteristics of Children Participating in FACES

Child Characteristics	Selected Variables	
Ages of children	Mean age (standard deviation) Median age	8.6 years (1.8) 9 years
	Frequency by current grade in school	5.6% in kindergarten 1st grade = 20.9% 2nd grade=13.4%

		3rd grade= 16.4% 4th grade= 17.9% 5th grade = 23.9% 6th grade = 7.5%
Health History	age of mother when child was born	Mean = 26.7(5.5) Median = 27.5 years
	Gestation length	26.4% Early 29.2% Late 44.4% On time
	Child seen by doctor or other health care provider for a chest illness before the age of 2 years	44.4% Yes 54.2% No
	Was child ever hospitalized because of asthma?	34.7% Yes 65.3% No
	Presence of hayfever or allergic rhinitis	29.1% Yes 65.3% No 5.6% missing

Source: Authors' analysis of FACES baseline survey data.

D. Initial Findings of EPA-STAR Project

Survey One

We have conducted five focus groups in Fresno, California and nine personal interviews in Springfield, Massachusetts. The focus groups and interviews were conducted over an eleven month period, from July 2002 to May 2003. In the summer of 2003 the survey instrument was reviewed by asthma specialists including Drs. Kathleen Mortimer, University of California-Berkeley School of Public Health, and Matthew Sadof, Associate Director of Ambulatory Pediatrics at Baystate Children's Hospital. During the fall of 2003, the team wrote the protocol for contacting families and tracking all surveys and correspondence. By late October 2003, the survey will be mailed to all households participating in the Fresno Asthmatic Children’s Environment Study and households with an asthmatic child who were either ineligible or declined to participate in longitudinal environment study. We extended the sample group to include families outside of FACES because recruiting for the epidemiological study was lower than predicted.

Risk Reducing Behavior

Through these focus groups and interviews we identified issues central to the survey. In common to all respondents was the increase in the monitoring of the child's health, and in some cases caregivers changed or terminated careers to increase supervision. The goal of the monitoring was to "catch the asthma before it was too late", that is to employ rescue medication while they were still effective in increasing lung function. The need for constant monitoring entails both reduced earnings and psychosocial costs due to the strain on family and social relationships.

There was a wide range in responses to questions on risk reducing behavior employed by households. A surprising result of the focus groups and interviews was that when initially asked if the household had changed anything due to the asthmatic child's health, respondents tended to significantly underestimate their change in behavior. Then when directed through a series of specific changes or activities pertaining to reducing triggers, households revealed a range of changes from small to extensive. Our conclusion is that it is often very difficult for households to identify "what they do for asthma" because either the child had been experiencing respiratory distress for such a long time that there is no basis for comparison or the changes have become such a routine that it is difficult to compare their behavior over time.

One disturbing finding in the focus groups was the length of time between onset of symptoms and correct diagnosis of asthma. Despite national guidelines on diagnosing and managing asthma, the median time until diagnosis was over 1 year. In multiple cases, children were repeatedly hospitalized over multiple years before being correctly diagnosed with asthma. This delay reflects both a need for more training of healthcare providers (Halterman et al, 2000; Cloutier et al, 2002) as well as lack of continuity of care.

Past experience with healthcare providers was correlated with a sense of self-efficacy in controlling asthma symptoms. Those households that experienced a long delay between symptoms and diagnosis were less likely to feel that they were able to control asthma symptoms. In contrast households that were provided with asthma management plans had a sense of improved self-efficacy. Self-efficacy has been shown in previous studies to be positively correlated with risk reducing behavior. Thus in modeling compliance with medication, and mitigating and averting behavior, then length of time between symptoms and diagnosis may be an important factor.

An early hypothesis was that income, transportation and lack of health insurance were dominant barriers to general healthcare. We found that in our study group the most significant barriers to care were lack of access to asthma specialists due to insurance protocols and insufficient supply of urgent care facilities. In addition, "gatekeepers," either receptionists who schedule appointments within the medical practice or triage nurses in emergency rooms, were commonly cited as impediments to reaching physicians during asthma episodes.

Several respondents voiced concern over balancing all the actions that could reduce asthma morbidity versus instilling a sense of confidence or creating a sense of being "normal" for the child. This points out that the clinical guidelines for optimal household behavior may deviate from household behavior when the psychosocial costs of the risk reducing behavior are incorporated.

Risk Perception

Respondents were able to list common asthma triggers and to rate which they felt were most significant to their child (see Table 5). When the allergy testing is completed we will be able to compare stated risk of allergens to clinically measured objective risk.

During the focus groups we observed inconsistencies between subjective and objective risk from air pollution. Respondents felt strongly that air pollution was a significant trigger and was significantly worse during the summer months. However, in the Fresno-Clovis area the concentrations of particulate matter are higher during the winter months, posing a real threat to asthmatics. The discrepancy could be due to the public awareness of high ozone alert days in the summer and the lack of such campaign for particulate matter.

Table 5: Parents' Perception of Asthma Triggers

Rank	Environmental factors that made child wheezing worse	% of Yes responses
1	Weather (multiple options allowed)	44.8
2	Physical activity	44.8
3	Cold or flu	39.7
4	Cold air	37.9
5	Air pollution	36.2
6	Pollen, grasses	32.8
7	Windy conditions	29.3
8	House Dust	22.4
9	Outdoor smoke or fires	15.5
10	Molds	13.8
11	Perfume or Odor	12.1
12	Wood smoke	12.1
13	Cigarette smoke	12.1
14	When crops are being sprayed	10.3
15	Pets	10.3
16	When fields are being plowed	6.6
17	Others	5.2

Source: Authors' analysis of FACES baseline survey data.

Medical Intervention

A critical component of risk reducing behavior is compliance with prescribed asthma medication and monitoring of respiratory function using a peak flow meter. While respondents were able to list most of the medications their child took for asthma, it was apparent that there were wide discrepancies in understanding of the role of each medication. There was significant concern over the side-effects of inhaled steroids despite the clinical evidence that their benefits greatly outweigh their risks. In addition personal disposition was evident in both the manner in which the child's guardian interacted with the healthcare provider and with compliance. For example, while a written asthma management plan and peak flow meter are standard and critical tools for asthma management, less than half of the FACES cohort used either.

Table 6: Asthma Management

Has a physician or other health provider given a written plan for managing asthma?	48.6% Yes 50.0% No 1.4% missing
Does child use a peak flow meter?	40.3% Yes 59.7% No

Source: Authors analysis of FACES baseline survey data.

Counter to our expectations, there was not an ethnic disparity in the use of a written management plan (Table 7).

Table 7: Use of a Written Management Plan by Race

Race	Yes	No
Hispanic	15 (48%)	15 (52%)
Black	7 (58%)	5 (42%)
White	11 (44%)	14 (56%)
Total % with management plan (1.4%=missing)	48.6	50.0

Source: Authors' analysis of FACES baseline survey data.

Initial analysis indicates an association between parents' behavior and personal experience with asthma. For example more than half of the children were not seen by a medical care provider for a chest illness before the age of 2, which was associated with whether parents had history of asthma themselves as shown in Table Eight. Among 62.5% of families where both parent were diagnosed with asthma child was seen by a health care provider for chest illness before the age of two, as opposed to 27.3% in families where none of the parents had asthma. Child was taken to a HCP for chest illness more often in families where the mother had asthma as compared to families where the father had asthma. It should be noted that due to the small number of observations, whether the differences are significant is not determinable. Additionally we are not asserting a causal link. At the same time race did not play a role in whether the child was seen by a doctor for chest illness (Table Nine).

Table 8: Parental Asthma and Respiratory Illness of Children Before Age Two

Parental Asthma	% of total	Child was seen before age of two Yes	No
Neither	31.4%	6 (27.3)	16(72.7%)
Both mother and father	11.4%	5 (62.5)	3 (37.5%)
Mother but not father	35.7%	14 (56%)	11 (44%)
Father but not mother	21.4%	7 (44%)	9 (56%)

Source: Authors' analysis of FACES baseline survey data.

Table 9. Race and Respiratory Illness of Children Before Age Two

Race	% of total	**Child was seen before age of two**	
		Yes	**No**
Hispanic	43.0%	12 (38.7%)	19 (61.3%)
Black	16.9%	6 (50%)	6 (50%)
White	33.8%	12 (50%	12(50%)
Other (or missing)	5.6%	2 (50%)	2(50%)

Source: Authors' analysis of FACES baseline survey data.

Survey Two: Contingent Valuation

The second component of the economic valuation of reduced morbidity is a contingent valuation question. Critical to this instrument is that the scenario be relevant and realistic. From the discussions in the focus groups we developed two types on contingent valuation questions. In the first scenario we asked parents to trade work-hours for reduced number of bad asthma days. The second scenario proposed a hypothetical insurance program that would provide additional services that were predicted to reduce asthma symptoms. We will conduct additional focus groups and interviews to refine these questions.

IV. Future Research

Currently the team is awaiting the data from the first survey on risk perception and household behavior. We are in addition in the process of designing a contingent valuation instrument. Similar to the development of the first survey, we will use extensive focus groups and interviews to develop a valid instrument. Some aspects of previous CV instrument are discussed below.

Some of the studies employing WTP for a specific commodity include earlier studies by Chestnut and Row (1986) and Dickie and Gerking (1996). In the first study asthmatics were asked about their maximum WTP to implement a program that would abate pollution and will reduce the number of asthma bad days by half. The payment vehicle in this study was WTP for an increase in taxes per year. In the Dickie and Gerking (1996) study elicited maximum WTP to relieve one symptom for 1 day and WTP to reduce daily one-hour maximum concentrations of pollutants by $1/10^{-6}$ for 1 day.

Blumenschein et al. (2001) conducted a field experiment comparing hypothetical and actual purchase decisions for an asthma management program. Subjects received either a dichotomous choice contingent valuation question (where three bids were offered, $ 15, 40, and 80) or were given the opportunity to actually enroll in the program. In an earlier study (Blumenschein and Johannesson 1998), as well as in Blumenschein et al. (2002) the same authors used both a dichotomous choice and a bidding game approach to elicit willingness to pay for asthma cure. In another study by Barner J.C. et al. (1999) patients were presented with a hypothetical 8-week asthma management program and patients were asked how much they would be willing to pay for the program as well as how much time they would be willing to spend on the program.

Risk-risk valuation and risk income tradeoffs were proposed by Viscusi, Magat and Huber (1991) to value risk reduction for contracting a lung disease. Respondents were asked to choose between two alternative cities which differed in the probability of getting a lung disease and the probability of dying in an auto accident. Individuals were presented with different scenarios until they were indifferent between the alternatives. The point of indifference was used to measure the MWTP for decrease in the risk of lung disease as well as the ratio between the two risks. Krupnick and Cropper (1992) used the same valuation setting to measure the effects of familiarity with the disease on WTP and Sloan et al. (1998) used the same tradeoffs to estimate the value of risk of multiple sclerosis. In a more recent study, Blomquist and O'Conor (1997) emphasized the need to separate respondents into people familiar and people unfamiliar with the disease. They proposed a hybrid form of WTP elicitation and found that it worked among people familiar with asthma but was unreliable among respondents unfamiliar with the disease. In the WTP question, respondents were asked to choose between two hypothetical drugs A or B, that differed in their effectiveness and safety and then elicited WTP for a third, improved drug that has greater effect (but was equally safe) than drug A and was safer (but had the same effect) than B .

In summary, earlier contingent valuation studies have elicited WTP for programs aimed at reduction of asthma symptoms, while later research has focused on risk reduction and risk-risk tradeoffs. Elicitation of WTP needs to be conducted using a specific payment vehicle that makes the payment scenario tangible to respondents, and in case of risk valuation, the benefits from a proposed risk reduction need to be easily comprehensible by respondents.

V. Conclusion

Asthma presents social scientists with complex questions. This project seeks to integrate elements of the Health Belief Model and Theory of Reasoned Action to model household risk reducing behavior and risk perceptions. We can use these survey results to model a household health production function. In addition using the epidemiological data we can compare subject to objective risk assessments. The final stage of the project will be to administer a contingent valuation instrument on reduced asthma morbidity.

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Behavioral Reactions to Ozone Alerts:

What Do They Tell Us About Willingness-to-Pay for Children's Health?

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October 2003

Paper prepared for presentation at

EPA/UCF Workshop: Valuing Environmental Health Risk Reductions to Children*,*
October 20-21, 2003

Twelve-year-old Justin Turnage's asthma flared up again this year, and his doctors say ozone is the likely culprit, said Turnage's mother, Deborah Leonard of Raleigh. Now Leonard hopes that board games and music lessons will keep her son indoors on ozone alert days.
"Summer is going to be very hard for him," Leonard said.
(James Eli Shiffer "Triangle Skies Smoggier," News & Observer, May 1, 2001)

1. Introduction

Ozone does not directly cause asthma, but triggers symptoms in susceptible individuals, including young children and asthmatics. The most direct averting action an individual can take to avoid the health problems associated with ozone is to stay indoors. In addition to the medical costs associated with treating and controlling asthma, high levels of ozone pollution limit the outdoor activities in which susceptible individuals, such as a young, asthmatic child can participate. In the language of economics, high ozone levels reduce an individual's or a family's choice set, and as the quote at the top of the page implies, this imposes welfare costs on the family beyond the expenses for medical treatment.

According to the latest report by the American Lung Association (ALA), while ozone levels have declined in some areas of the country ozone pollution is increasing in others (ALA, 2001b). Table 1 lists the 15 counties with the highest ozone levels and the number of orange, red, and purple ozone alerts between 1997-1999. According to the U.S. Environmental Protection Agency (EPA), in 1998 approximately 21% of children lived in counties where ozone standards were exceeded on at least one day (EPA, 2001). Asthma prevalence also increased over the decade of the 1990's. Among children in the U.S., asthma is now the most common chronic illness (EPA, 2001). An estimated 26.3 million people had been diagnosed asthma at some point in their lives according to data collected in the 1998 National Health Interview Survey presented by the ALA (ALA, 2001b). The 5-17 year old age group had the highest prevalence of physician diagnosed asthma, which is estimated to have increased from 130.1 per 1,000 people in 1997 to 135.0 per 1,000 individuals in 1998. Several studies provide evidence of the link between ozone and asthma. A recent study in the Journal of the American Medical Association (Friedman et al., 2001) documented fewer admissions of children to the emergency room for asthma attacks in Atlanta during the 1996 summer Olympics. Atlanta residents were encouraged not to drive and ozone levels were lower during that period than normal.

Several studies have looked at defensive behavior in response to high levels of ozone pollution. Bresnahan, Dickie, and Gerking (1997) used data from a panel of adults in the Los

Angeles area who were contacted between 2-5 times over a 12 month period and asked about their activities in the previous 2 days and their medical expenses. Their results indicate that individuals do change their behavior in response to poor air quality by reducing time spent outside on a day-to-day basis.

A recent survey conducted by RTI International in the summer of 2000 provides additional evidence supporting the results from Bresnahan, Dickie and Gerking (1997). Approximately 6,100 respondents from over 1,000 counties were asked about their knowledge of the ozone alert program. Forty-six percent of the counties represented in the survey experienced at least one day of code orange (or worse) air quality in 2000, covering 75 percent of the respondents. Thirty-seven percent of respondents in these counties were aware of the ozone alert system, compared with 28 percent of respondents in counties that did not experience a code orange (or worse) day.

Table 1. Number of High-Ozone Days in America's 15 Most Ozone-Polluted Counties

		Number of High Ozone Days in the Unhealthy Ranges, 1997–1999		
County	**State**	**Orange**	**Red**	**Purple**
San Bernardino	California	160	74	52
Riverside	California	154	54	24
Kem	California	167	55	4
Fresno	California	178	44	5
Tulare	California	180	19	0
Harris	Texas	78	43	21
Fulton	Georgia	92	18	8
Los Angeles	California	72	28	10
Rockdale	Georgia	70	31	4
Anne Arundel	Maryland	85	23	2
Mecklenburg	North Carolina	89	18	0
Sevier	Tennessee	91	11	0
Blount	Tennessee	88	12	0
Ventura	California	89	8	2
Knox	Tennessee	81	13	0

Source: American Lung Association (ALA). 2001a. "State of the Air: 2001." New York: American Lung Association.

In counties that had experienced a code red (or worse) day during the summer of 2000, 41 percent of respondents were aware of the system, compared with 33 percent in counties that had not experienced a code red (or worse) day. Of those who resided in counties that had experienced a code red day and were aware of the ozone alert system, 58 percent correctly reported that their county had experienced a code red day during that summer. On ozone alert days, 38 percent of the respondents reported driving less and spending less time outdoors, 19 percent reported only spending less time outdoors, 7 percent reported only driving less and 36 percent reported no changes in their behavior. In addition, people who are not working at least part-time, including homemakers, the unemployed, students and retirees were more likely to report reducing the time they spent outdoors on high ozone days. Because these groups have more opportunity to be outside and more control over their schedules, we might expect to see greater responsiveness on their part. Furthermore, people who reported excellent or good health were less likely to report reducing outside time on high ozone days compared to people with fair or poor health.

A number of studies have valued the benefits of reducing ozone through averting behavior or with a contingent value (CV) study. Dickie and Gerking (1991) examined the decision to seek medical care. They found that willingness-to-pay (WTP) for ozone levels that never exceeded 12 ppm was 2 to 4 times higher than medical cost savings associated with the reduction in ozone. Rowe and Chestnut (1985, 1986) asked a WTP contingent value question for a 50% reduction in "bad asthma days." WTP estimates based on 65 responses from adult asthmatics and approximately 18 parents of children with asthma range from $11.81 to $53.80 to avoid one day of asthma symptoms ranging from no symptoms to moderate symptoms (in 1990 dollars). More recently, Yoo and Chae (2001) conducted a CV survey of WTP to reduce ozone levels in Korea, and Farber and Rambaldi (1993) conducted a CV survey to determine adult exercisers' WTP to improve air quality. Johnson, Banzhaf, and Desvousges (2000) report WTP of CAN$158 for one day of asthma symptoms with significant activity restrictions and lower amounts for less severe restrictions.

Importantly, however, none of these studies has specifically examined behaviors and values related to protecting children from ozone exposure. There are many difficulties involved with estimating benefits for children. Children do not make decisions for themselves and do not have income, thus traditional WTP measures cannot be elicited from them. In the place of values elicited from children, researchers typically measure the WTP of parents to protect their children from health risks, often inferring WTP from decisions to purchase market goods that contribute to safety such as cars or bicycle helmets (Schulze et al., 2000; Jenkins et al., 2000).

This study was designed to fill this gap in children's health research. Its primary focus is to investigate how parents of young children alter their behaviors in responses to high ozone concentrations and how these behaviors are affected by the presence of high-risk (i.e., asthmatic) children in the household. In the process, it addresses a number of key research questions including:

To what extent are children's risks from exposure to high ozone levels offset by defensive/averting behaviors?

- How much do parents value reductions in potentially harmful ozone exposures to their children?
- What costs (direct and indirect) are incurred by parents and children as a result of behaviors to avert ozone exposures?
- To what extent are people aware of and how much do they benefit from the presence of ozone alert systems?

The primary data for this study was collected during the summer of 2002 through a series of surveys with selected households across the US. This paper describes the conceptual foundation for the study, the methods used for data collection and analysis, and the results of some preliminary analysis.

2. Conceptual Framework

Bresnahan, Dickie and Gerking (1997) use a household production approach to develop a model of decisions about seeking medical care and limiting time outdoors to avoid high ozone levels. Following their model, we can specify the child's utility function as:

$$U = U(H, X, A, Z)$$

where H measures health status, X represents market goods, A measures an activity such as outdoor leisure and Z measures exposure to ozone. In this very simple model, we assume that parents have altruistic feelings for their child and maximize their child's utility. The child's utility depends on his or her health and the activities he or she pursues during the day. Under the assumptions of Bresnahan, Dickie and Gerking, health is produced using activity, exposure to pollution, stock of preexisting health capital (K), and other human capital (S).

$$H = H(A, Z, K, S)$$

Finally, the parent faces a full-income budget constraint:

$$I + wT = q_x X + q_A A + q_M M(H) + wG(H)$$

Full income is composed of non-labor income (I) and the wage rate (w) multiplied by total time available (T). The variables q_x, q_A, and q_M represent time-inclusive prices for X, A and M(H) (medical care) and equal the sum of the money price and time required to consume one unit of the good ($q_j = p_j + wt_j$). Finally, G(H) is the time lost on market and non-market activities as a function of current health status. The parent maximizes the child's utility subject to the budget constraint. Under standard assumptions, the optimal level of A* can be derived from the first order conditions for utility maximization.

$$(1) \qquad A^* = A(q_x, q_A, q_M, w, T, I, K, S, Z)$$

3. Survey Design

To inform the model, we conducted a series of eight surveys with a common set of households across the country during the 2002 ozone season. The core of the data collection effort is a series of six activity diaries (i.e., time and activity surveys). Time and activity surveys are commonly used in transportation studies and in risk assessment and exposure analysis to estimate actual exposure levels that individuals experience based on their activity patterns.

Each panel member completed an initial survey at the beginning of the summer to collect some basic information and explain the activity diaries. After this, each member of the panel was sent six activity diaries. A debriefing survey/stated preference survey was administered in mid-December. The eight surveys adhere to the format described below:

- Survey 1 (June 2002)
  - – Screener—identifies households who qualify for the sample.
  - – Baseline Questionnaire—collects information about the household, their dwelling, neighborhood and health
- Surveys 2-7 (July – September 2002)
  - – 6 Activity Diaries—record child's activities and health status for selected day

- Survey 8 (December 2002)
  - Stated Preference Survey—presents hypothetical activity choice scenarios
  - Debriefing—collects information on awareness and perceptions about ozone levels and alert system.

In the following sections, we describe the characteristics of our sample and provide more detail on the design of the surveys, in particular the time and activity surveys

3.1 Panel Selection and Mode of Administration

We focused our data collection efforts on two samples—children with asthma and their parents and children without asthma and their parents. Because of the acute effect of ozone on asthmatics, parents of children with asthma may be more educated about ozone pollution and the need to take defensive action (stay indoors) on high ozone days. Organizations such as the American Lung Association publish guidelines that recommend limiting time outdoors on high ozone days to avoid asthma and other respiratory problems. In addition, the ozone alerts themselves provide information on which subpopulations should be limiting time outdoors for each level of alert (see Table 2).

Table 2. Air Quality Index Color Code Guide

Air Quality	Health Effects
Good—AQI: 0-50 (Green)	No health effects are expected.
Moderate—AQI: 51-100 (Yellow)	Unusually sensitive people should consider limiting prolonged outdoor exertion.
Unhealthy for Sensitive Groups—AQI: 101-150 (Orange)	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
Unhealthy—AQI: 151-200 (Red)	Active children and adults, and people with respiratory disease such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.
Very Unhealthy—AQI: 201-300 (Purple)	Active children and adults, and people with respiratory disease such as asthma, should avoid all outdoor exertion; everyone else, especially children, should avoid prolonged outdoor exertion.

Notes: AQI refers to the Air Quality Index. An AQI of 100 is equivalent to the National Ambient Air Quality Standard (NAAQS). An AQI greater than 100 is considered to be above the national standard or NAAQS. An AQI Calculation Table is available online to convert raw ozone concentrations to the Air Quality Index.

Source: U.S. Environmental Protection Agency (EPA). 2002. “Air Quality Guide for Ozone.” <http://www.epa.gov/airnow/aqguide.pdf>.

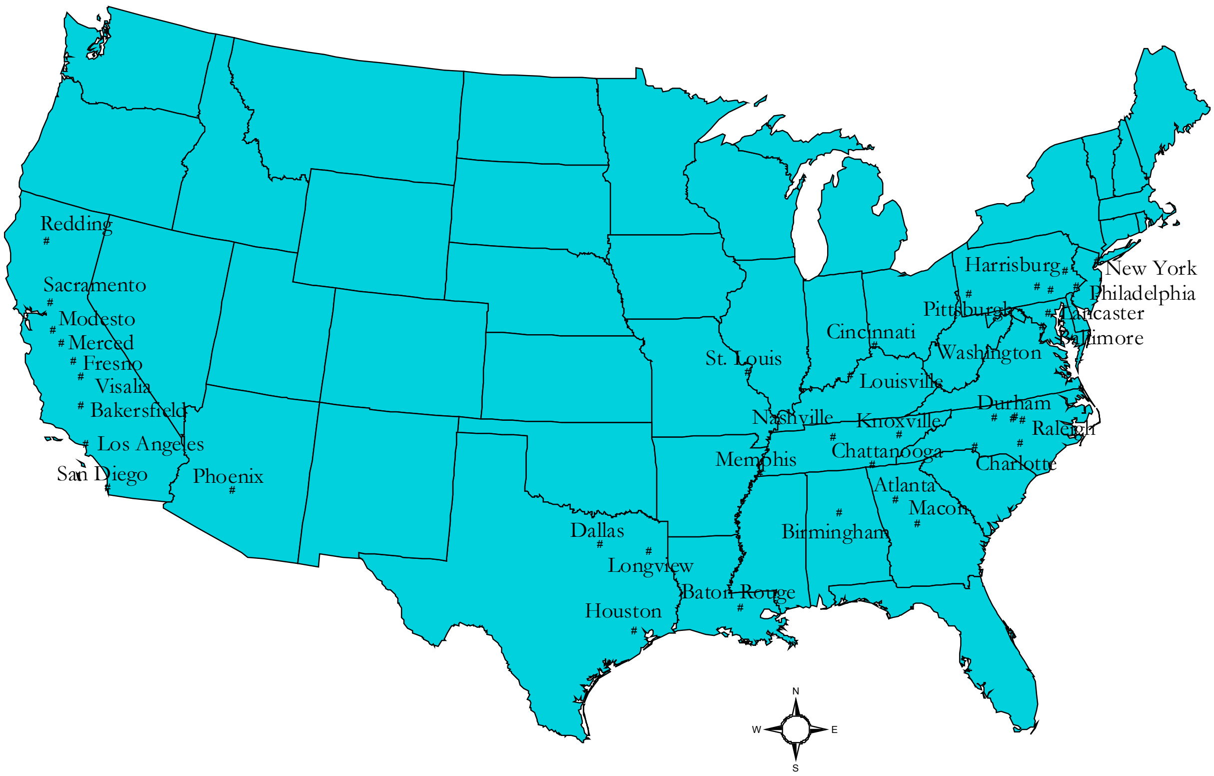
The respondents are all members of the Harris Interactive (HI) online market research panel. The Harris panel consists of individuals who self-select onto the panel and have agreed to participate in surveys over the internet. HI recruited the sample for this project and administered the survey over the internet. The panel includes families in which, during the summer of 2002, there was an asthmatic child or nonasthmatic child aged 2 to 12 years old and at least one parent stayed home with the child during the day. An initial sample of 777 households was recruited in June and began taking surveys in July. An additional 200 households were recruited in July and began taking surveys in August. Approximately one-half of the children in the panel are asthmatic. Response rates for the activity diary surveys were as follows:

- 95% of those who qualified based on a brief screening survey took baseline survey to form a panel of 977 individuals
- 977 people completed 2,940 diaries
  - – 80% completed at least 1 diary
  - – 12% completed 1 diary
  - – 11% completed 2 diaries
  - – 11% completed 3 diaries
  - – 14% completed 4 diaries
  - – 15% completed 5 diaries
  - – 17% completed 6 diaries

We chose this population because we believe this sample provides the most direct measure of the efforts parents take to protect their children against the health risks of ozone. Very little data exists on the averting behavior of both children and adults on high ozone days. Children and especially children with asthma are a sensitive sub-population. We expect that in general these groups (or their parents) will engage in a higher level of averting action than other groups in the population. While the activities of this population may not generalize to other groups, such as working parents with children in daycare, by focusing on the actions of children who are home with their parents during the day, we expected to get the cleanest measure of the direct actions parents take to protect their children's health. The survey was conducted over the summer, when ozone is a problem and most school-age children are at home.

Respondents were drawn from the 35 metro areas in the US with the worst ozone pollution (roughly corresponding to the counties with the worst ozone pollution in Table 1). The ranking is based on the number of code purple, red or orange days in 2001 (ALA, 2001a). See Figure 1 for the locations of the 35 metro areas.

Figure 1. Metro Areas in the United States with the Worst Ozone Pollution.



3.2 Survey 1: Screener and Baseline Questionnaire

The HI panel was screened at the beginning of the summer for families who met the inclusion criteria. Those families who met the criteria completed the baseline survey. In this survey, we collected information about the household's demographic characteristics, dwelling in which the family lives, the child including the child's health and questions about the amount of time the child usually spends on different activities. In addition, the parents of children with asthma were asked a series of questions about the severity of the child's asthma, medications the child takes, and changes to their house and lifestyle they have made to help control their child's asthma.

3.3 Surveys 2-7: Daytime Activity Diaries

The core of the research project is the activity diaries. These diaries were to be filled out on-line by the parent within 48 hours of receiving the diary to minimize problems with recall. Unlike a mail-in paper activity survey, we know the date and time the respondent completed the survey. When a respondent missed a particular day or too much time elapsed, we asked the respondent to provide information on their activities for another day rather than asking them to remember what they had done several days ago. In total, each respondent was sent 6 diaries to complete.

The diary takes the respondent through their child's day from the time the child woke up until they went to sleep or 8:00pm (whichever came first). Respondents were instructed to choose from a menu of activities and indicate the starting and stopping time of each activity. The activities were drawn from the CHAD database, a database of activity diary studies maintained by EPA. The CHAD database provides some information on the average level of exertion (sufficient to calculate metabolic rates) associated with the activity, which will be useful for the exposure assessment.

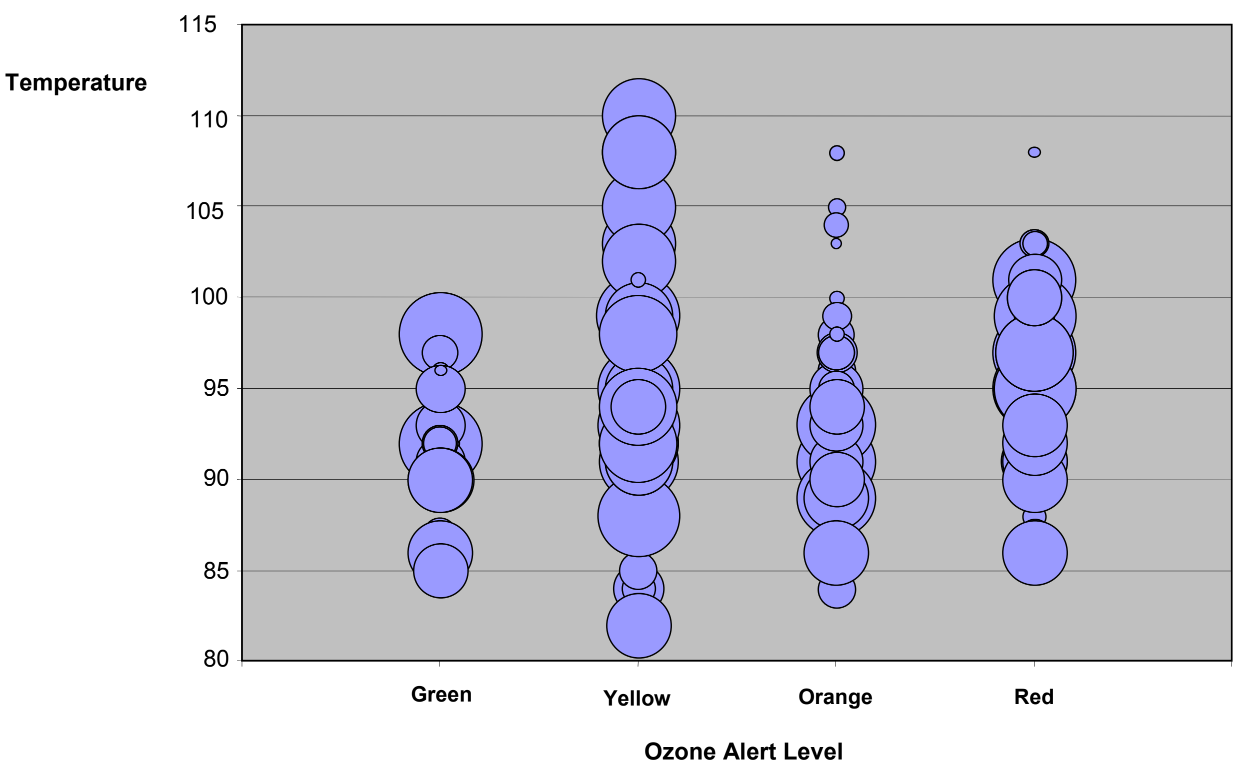
In addition to the start and stop time, respondents were asked to specify their assessment of the level of physical exertion associated with the activity, whether the activity took place indoors or outdoors, the location of the activity (at home or away from home with a general description of how far from home in terms of driving time), whether there was a cost to the activity and whether the activity was scheduled in advance. At the end of the diary, respondents were asked about symptoms their child suffered during the day. Parents of children with asthma were asked questions about their child's asthma and medication use during that day and over the past week.

To avoid sensitizing the panel to ozone pollution through participation in the survey, we did not inform the panel about the purpose of the survey beyond telling them that we were looking for data on their activities. We have linked behavior to actual ozone levels on reporting days.

The survey days were selected to include a variety of ozone conditions, where some of the low ozone days were chosen with the same temperature as high ozone days. Ozone alerts are predicted in the afternoon for the next day. Because the panel was connected by the internet, HI was able to respond quickly and send out surveys based on these reports. The strategy for choosing the days of the interviews was based on balancing the need to collect activity information under a variety of weather and ozone conditions with the cost of administering the survey and burden on the panel.

Figure 2 presents the range of ozone and temperature conditions captured during the study period. The larger circles correspond to cities with larger sample sizes. Ozone and temperature are highly correlated, with worse ozone conditions associated with higher temperatures.

Figure 2. Temperature-Ozone Distribution on Survey Days



Note: Larger bubbles indicate larger groups of respondents.
Los Angeles and San Diego respondents have been excluded from this figure.

3.4 Survey 8: Stated Preference Survey and Debriefing

We conducted the final debriefing and stated-preference survey in April 2003. The purpose of this survey was to collect information about other variables that are important for interpreting the time and activity data. Information collected includes the individuals' level of knowledge about ozone and the health effects of ozone, their self-reported response to ozone (whether they consciously changed their schedule on high ozone days), and their subjective assessment of the risks they and their children face from ozone pollution.

The activity diaries provide information about whether and how the child's schedule changes in response to ozone conditions. The primary averting behavior to avoid ozone exposure is to stay indoors. We expected that on high ozone days, some of the children on the panel would stay indoors more than on low ozone days. But the activity diaries do not directly collect information on the value the parents place on this lost outdoor time. To estimate that value, the debriefing survey contains one of two series of stated-choice tasks based on either a medicine commodity or city commodity. We discuss only the medicine version of the survey here.

Like some actual antibiotics, the hypothetical medicine commodity requires limited exposure to sunlight. Figure 3 contains the text that explains this feature of the medicine. Table 3 shows the attributes and levels used to construct the choice profiles. The experimental design consisted of three randomly assigned blocks of five choice sets with two alternatives each. We employed Zwerina, Huber, and Kuhfeld's (1996) algorithm to search for a near-optimal design. Figure 4 shows an example choice task.

Figure 3. Definition of Outdoor Time Attribute

Assume that at the beginning of the summer, your family doctor tells you that [child's name] needs to take a medicine during the summer as a preventive measure. In other words, [child's name] is not sick, but [he/she] needs to take medicine to prevent an illness from developing. …

[Child's name] would have to limit the time spent outdoors on the days [he/she] takes [his/her] medicine. Even on cloudy days or when [he/she] is wearing sunscreen, extended exposure to the sun will make the medicine less effective.

Table 3. Medicine Attributes and Levels

Attribute	Levels
Maximum number of minutes in the sun allowed per day	• 10min • 45 min • 1 ½ hours
Length of time child takes medicine	• 3 day • 12 days • 20 days
Total cost of medicine for the summer	• $10 • $40 • $75 • $150

Figure 4. Example Choice Task

Medicine Features	Medicine A	Medicine B
Number of days [name] would have to take the medicine.	3 days during the summer	12 days during the summer
Maximum recommended outdoor time on days when [name] takes medicine.	45 minutes	10 minutes
Total cost of medicine to you. (The cost not covered by insurance).	$150 for the summer	$10 for the summer

Which medicine would you purchase? (Please check one box.)	**Purchase A** ☐	**Purchase B** ☐

3.5 Supporting Data Collection Activities

In addition to the information collected from the panel we collected information on predicted and actual AQI levels and weather-related data such as high temperatures on survey days for each city. We also collected a copy of the newspaper in each city to document the manner in which air pollution and ozone pollution information is presented.

4. Preliminary Results

4.1 Activity Survey

Our sample consists of 977 parents. As reported above, 780 households (80 percent) of the sample completed at least one activity diary. Out of the 780 households, 486 (62 percent) responded to the valuation and debriefing survey. Table 4 reports demographic characteristics of the sample, including comparison between the households with asthmatic and non-asthmatic children. On average, a household had 2 children with an annual household income less than $75,000. One-third of the parents had college education or higher. Table 5 presents summary statistics for the children and their activities by asthmatic and non-asthmatic. The median age was 6 years old. Sixty-four percent of the asthmatic children and 50 percent of the non-asthmatics were male. Thirty-three percent of the asthmatics and 25 percent of the non-asthmatics participated in organized sports teams or lessons that practiced and played outdoors during 2002 summer. Besides organized sports teams and other scheduled activities, both asthmatic and non-asthmatic children spent 3 hours watching TV and 1 hour or more playing video games each weekday.

Based on equation 1, the optimal level of averting behavior is a function of prices, health capital and ozone exposure. We use two measures of averting behavior, the total hours that the child spends indoors during the day and the proportion of the child's day spent inside. The ozone forecast for the day represents the level of ozone exposure. We created a dummy variable for days that were code orange or red where the excluded category is days that were code green or yellow. Individuals who check the ozone forecast for the day may reduce their child's outdoor time on code orange or red days. Individuals who do not check the ozone forecast may observe their child suffering from symptoms and reduce the child's outdoor time. Leaving aside the use of medicine, we expect that the optimal level of averting behavior will increase in children with lower health capital, in our sample children with asthma. However, children with asthma may use either long-term daily medications or short-acting medications to control their asthma that could affect the relationship between spending time outdoors and health risks. Because the sample includes stay-at-home parents, the wage rate (or reservation wage to join the workforce outside the home) is not included in the equation.

Table 4. Sample Characteristics

	Non Asthmatic (n = 506)	**Asthmatic (n = 473)**	**All Households (N=979)**	**U.S. Population**
Children (median)	2	2	2	1
<$35,000	23%	16%	19%	42%
$35,000-75,000	40%	40%	40%	34%
% white	82%	88%	85%	75%
% high school grad	17%	19%	18%	32%
% coll grad or grad school	29%	37%	33%	25%

Table 5. Children: Characteristics and Activities

	All Children (N=979)	Asthmatic Children (n=473)	Non-asthmatic Children (n=506)
Average age	6	7	5
% male	57%	64%	50%
% outdoor sports (median hrs)	29% (6)	33% (6)	25% (5)
% outdoor other (median hrs)	15% (7)	19% (7)	11% (6.5)
% indoor sports (median hrs)	14% (3)	16% (4)	12% (3)
% indoor other (median hrs)	15% (3)	15% (3)	15% (2)
Hours Spent on Watching TV (median)	3	3	3
Hours Spent on Playing Video Games (median)	1	2	1

We used the proportion of the child's day spent indoors (%INDOOR) to estimate the level of averting behavior in response to high ozone levels and other factors that influence parents' decisions about their children's daily activities. Besides temperature (TEMP), we also monitored the ozone forecast for the selected days, which represented the level of ozone exposure. CODE_RED indicates high-ozone days and AWARE indicates whether the parent was aware of the color-coded ozone warning system. Three regional dummies (WESTCOAST, NORTHEAST, and SOUTHEAST) capture climatic and other geographic differences. In addition, we also include household and child characteristics in the analysis, including annual household income (INCOME), whether the child is male (MALE), child's age (AGE), whether the child prefers to play outdoors in the summer (OUTDOOR), and number of hours each weekday the child spent on watching TV and/or playing video games (TVGAME). The mean value and expected sign of each variable at diary level are reported in Table 6.

We excluded observations from Los Angeles and San Diego for the analysis. Both cities have more than one weather monitoring station. We have not yet identified which sample household lives near which station. so we have not included these observations in the preliminary analysis. In addition, diaries covering less than 4 hours on a given day were dropped from the sample.

Table 7 reports multivariate regression results, controlling for repeat observations from the same household. Overall, both asthmatic and non-asthmatic children regressions are significant at 1% level, but explanatory power is low. TEMP and CODE_RED are positive and significant for both asthmatic and non-asthmatic regressions, indicating that children spent less time indoors on cooler and non-code red days. Both effects are larger for children with asthma than for children without asthma. These are the only coefficients that are significant for both groups.

The interaction term (RED_AWARE) between CODE_RED and AWARE is negative in both regressions, but not significant. Asthmatic children who live on the west coast spent less time indoors while non-asthmatic children in the southeast spent more time indoors. The positive asthmatic interaction term WESTCOAST_AWARE indicates that parents who were aware of the ozone alert system and live on the west coast were more likely to have their asthmatic children spend more time indoors. Oddly, parents who were aware of the ozone alert system and live in the southeast were more likely to have their non-asthmatic children spend less time indoors.

Table 6. Mean Value of Dependent and Independent Variables and Hypothesized Coefficient Sign

Variable	Asthmatic	Non-Asthmatic	Hypothesized Sign
%INDOOR (%)	65.75	64.08	
TEMP (°F)	94.38	94.82	+
CODE_RED	0.29	0.28	+
AWARE	0.55	0.53	+
RED_AWARE	0.14	0.15	+
WESTCOAST	0.09	0.09	?
NORTHEAST	0.41	0.29	?
SOUTHEAST	0.28	0.34	?
WC_AWARE	0.03	0.04	?
NE_AWARE	0.23	0.15	?
SE_AWARE	0.22	0.23	?
MALE	0.50	0.72	+
AGE (years)	6.15	6.93	–
PREFERS OUTDOORS	0.41	0.38	–
TV/GAMES (hrs)	6.09	6.23	+
INCOME ($10,000)	7.09	6.27	?

An interesting result is that children with asthma who play more video games and watch TV also spend a greater proportion of their time indoors, while nonasthmatic children do not. It seems tautological that more time spent in an indoor activity will increase the proportion of indoor time. However, nonasthmatic children who play more video games apparently offset this effect by also engaging in more outdoor activities.

Among children without asthma, male children, older children, and children in higher-income households spend more time outdoors.

Table 7. Regression: Dependent Variable Proportion of Time Indoors

	Coefficient (Standard Error)					
	Asthmatic			Non Asthmatic		
TEMPERATURE	0.83	***	(0.18)	0.51	***	(0.19)
CODE_RED	6.01	*	(3.21)	4.53	*	(2.65)
RED_AWARE	-5.58		(4.20)	-3.79		(3.52)
WESTCOAST	-14.29	**	(6.06)	3.58		(5.48)
NORTHEAST	6.14		(4.27)	1.40		(3.36)
SOUTHEAST	-5.30		(4.97)	7.87	*	(4.13)
WESTCOAST_AWARE	17.30	***	(6.81)	1.10		(7.85)
NORTHEAST_AWARE	-2.32		(5.31)	1.89		(3.52)
SOUTHEAST_AWARE	4.40		(5.60)	-7.14	*	(4.33)
MALE	-3.05		(2.28)	-5.57	**	(2.24)
AGE	-0.47		(0.32)	-0.99	***	(0.33)
PREFERS OUTDOORS	-7.87	***	(2.47)	-3.79		(2.44)
TV/GAMES	0.72	***	(0.19)	-0.19		(0.12)
INCOME	-0.09		(0.26)	-1.04	***	(0.29)
CONSTANT	-15.79		(16.45)	27.91		(18.88)
Number of observations	669			853		
Probability > F-statistic	0.0000			0.0001		
R-squared	0.1204			0.0822		
Number of clusters	149			174		

3.5 Stated-Preference Survey

Table 8 reports results of random-effects probit analysis of the stated-preference data for all respondents, children with asthma, and children without asthma. A likelihood-ratio test for structural difference between the two subsamples is marginally insignificant (p=0.12). All coefficients are divided by the negative of the cost coefficient to eliminate scale differences among models. The number of summer days affected by the medication has a strong, negative, and significant affect on indirect utility for all three samples. The direct effect of the restriction on the number of outdoor minutes per day was insignificant and was dropped from the models. However, the interaction between days and minutes is significant and has the correct positive sign in all cases. The coefficients for both DAYS and DAYS*TIME are significantly smaller for the asthmatic sample than the non-asthmatic sample, indicating a smaller willingness of households with asthmatic children to pay for outdoor play time.

Cost was interacted with four variables to permit heterogeneity in the marginal utility of money and thus WTP. The income interaction has the correct positive sign, but is significant only in the pooled model. The asthmatic sample is willing to pay significantly less if the child is male and significantly more if the child prefers to play outside. In contrast, the non-asthmatic sample is willing to pay more if they live in the northeast, but none of the other cost interactions are significant.

Table 9 contains some illustrative WTP estimates for the pooled model using the worst combination of DAYS and TIME (20 summer days with maximum outdoor time of 10 minutes per day). Households are willing to pay an average of $73 to reduce the number of days from 20 to 12, holding the time restriction constant at 10 minutes. They are willing to pay an additional $29 to increase outdoor time to 45 minutes per day, holding affected days constant at 12. Moving from the worst combination of DAYS and TIME to the best combination in the experimental design (3 days and 90 minutes) is worth an average of $175. With the exception of the difference between $150 and $175, all estimates are significantly different from each other.

Table 8. Random Effects Probit: Dependent Variable Probability of Choice
Coefficients Scaled by $-\beta_{cost}$ (Standard Error)

	Pooled			Asthmatic			Non-Asthmatic		
Days	-8.740	***	(0.632)	-7.046	***	(0.705)	-11.952	***	(1.239)
Days*Time	0.070	***	(0.007)	0.064	***	(0.008)	0.086	***	(0.013)
Cost	-1.000	***	(0.143)	-1.000	***	(0.161)	-1.000	***	(0.286)
Cost*Income	0.037	*	(0.018)	0.028		(0.022)	0.050		(0.036)
Cost*Male	-0.384	**	0.150)	-0.175	*	(0.174)	-0.674		(0.289)
Cost*Northeast	0.488	**	(0.154)	0.632		(0.184)	0.260	***	(0.291)
Cost*Prefers Outside	0.477	*	(0.146)	0.339	*	(0.174)	0.612		(0.283)
Number of observations	1135			540			595		
Log likelihood	-648.08871			-292.73422			-349.6708		

Number of clusters	227	119	108

*significant at the α = 0.05 level; **significant at the α = 0.01 level; ***significant at the α = 0.001 level

Table 9. Money-Equivalent Utility Differences Relative to (Days=20, Time=10) Full Sample

Total Summer Days	Outdoor Minutes per Day	WTP	90% Confidence Interval	
3	90	$175	$146	$207
12	90	150	128	178
12	45	107	90	127
12	10	73	62	87
20	10	0	0	0

5. Future Directions

This paper outlines the research strategy and data collection efforts including a preliminary analysis of the data. Ultimately, we will use the revealed preference (RP) data from the activity diaries with the stated preference data from the conjoint survey to address the four key research questions identified in the introductory section. Further analysis of the RP data in particular will be used to measure how parents and children alter their indoor/outdoor and related behaviors in response to ozone alerts. Second, by combining RP and SP data, we hope to estimate parents' welfare losses from their child's exposure to high outdoor ozone levels. Preliminary results suggest modest differences between revealed and stated preferences for outdoor playtime between parents with a child who has asthma and parents with a child who does not have asthma. Other household characteristics also affect outdoor play preferences.

Third, through the RP-SP analysis, we will measure the implicit costs to parents of restricting their children's outdoor activities (independent of outdoor ozone levels). Because the SP data allows estimating the marginal utility of money, we can estimate parents' demand for childrens' outdoor time, at least in the context of the hypothetical commodity, and to estimate how this demand varies systematically across households.

A fourth component of the research project, which was not discussed in this paper, involves a risk assessment and exposure model. The modeling effort will follow the children through their day using a GIS-based system to capture actual exposure to ozone on the activity diary data. The model will be used to predict the net impact of behavioral changes on health risks from ozone exposures.

Finally, each of the components above will allow us to assess the informational benefits associated with ozone alert system. Preliminary results suggests a relatively low level of awareness of the system. The survey data will allow us to gauge both the awareness of and reactions to different levels of ozone alerts and how they vary across households and urban areas. The net benefits of the ozone alert system will include both the value of reductions in health risks associated with these defensive activities and the lost value (opportunity cost) associated with restricting outdoor and other activities.

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A Cross-Sectional Analysis of Asthma Medication Use and Air Pollution: A Preliminary Analysis

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Asthma is a chronic lung disease that is characterized by intermittent, recurring episodes of wheezing, breathlessness, tightness of the chest, and coughing. These episodes are caused by inflammation of the airways that carry air into and out of the lungs. Asthma is considered to be a growing problem in the United States, especially among children. The prevalence of asthma increased 46 percent between 1982 and 1993 in the United States. While increases in prevalence have been documented in all age, race, and gender groups, the increase has been most significant among children, individuals under the age of 18, in which prevalence has increased by a staggering 80 percent since 1982.

While the exact causes of the illness remain unknown, asthma attacks can be triggered by exposure to allergens (such as dust mites, pollen, mold, pet dander, and cockroach waste), strong fumes, respiratory infections, exercise, dry or cold air, as well as air pollution (including ozone and particulate matter). Despite recent efforts to reduce ambient levels of air pollution, approximately 46 million people lived in counties that did not meet the air quality standards for at least one of the six criteria pollutants in 1996. The combination of poor air quality with other triggers is often most extreme in urban centers where a disproportionate number of minority and low income households reside.

A relatively large number of studies exist that focus on the relationship between air pollution and serious asthma attacks resulting in Emergency Room visits or Hospital Admissions; however, very few studies exist that focus on mild to moderate asthma attacks. Those studies that do examine mild forms of asthma symptoms generally are diary studies that follow a small group of asthmatic individuals over time and focus on the effects of short-term increases in air pollution exposure. This paper presents the preliminary results of a cross-sectional analysis of the effects of chronic exposure to air pollution on the incidence of asthma attacks, as measured by the use of short-term "quick relief" medication.

Literature Review

The relationship between short-term increases in ambient levels of air pollution and asthma outcomes has been documented in a number of venues using two types of studies: daily time series studies and diary studies. Daily time-series studies are used to model the relationship between daily levels of ambient air pollution and daily counts of a health outcome. By focusing

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[1] The views expressed in this paper are those of the authors and do not necessarily reflect the position of the Environmental Protection Agency.

on a particular city or area, these types of studies limit the amount of data required since the population acts as its own control. For instance, there is no need to control for socio-demographic characteristics or behavioral patterns as these are thought to remain relatively constant in the population from one day to the next. Only weather and seasonal variation need to be included in the model in addition to the daily air pollution levels. Diary studies on the other hand, follow a group of individuals over time and ask that participants keep track of symptoms, behaviors, and medication use over the study period. Studies of this type must control for personal characteristics of the panel members, differences in behaviors, as well as weather and pollution.

Daily time-series studies have been used to model the relationship between air pollution and a number of health outcomes including daily mortality and other relatively severe respiratory outcomes such as hospital admissions, emergency room visits and doctor visits – with a relatively large segment of the studies focused on asthma. In a study by Walters et al. (1993), for instance, daily levels of SO2 and black smoke were found to have a positive association with hospital admissions for asthma in Birmingham, UK. A similar result was found in Birmingham, Alabama in a study focused on hospital admissions due to pneumonia and Chronic Obstructive Pulmonary Disease (of which asthma is a component) among elderly inhabitants (Schwartz 1994). Also found was a positive association between air pollution levels and doctor visits for asthma in London (Hajat et al. 1999). In Barcelona, Spain, a positive association between emergency room visits for Chronic Obstructive Pulmonary Disease and air pollution levels was found (Sunyer et al.). While these studies are indicative of the detrimental effects of short-term increases in air pollution on rather severe asthma outcomes, they give no indication of the chronic effects of air pollution exposure on respiratory health nor do they generally provide evidence of detrimental effects that are milder in nature.[2]

Diary studies, using data collected from a panel of individuals, can provide some indication of the effects of air pollution on less severe health outcomes. They model symptoms experienced by panel members as a function of air pollution levels. A number of studies of this sort have found positive and significant effects of air pollution exposure on exacerbation of asthma symptoms. Neukirch et al. (1998) found measurable short-term effects of low-level air pollution in Paris France on nonsmoking asthmatic adults diagnosed with mild or moderate asthma. Similarly, Peters et al. (1996) found that asthmatic children in Erfurt and Weimar Germany and Sokolov in the Czech Republic suffered more symptoms (cough, shortness of breath, wheezing) and reduced pulmonary expiratory flow when exposed to higher levels of air pollution, although same day effects were relatively weak compared to cumulative effects over 5 days. Ostro et al. (1991) also found a strong association between daily air pollution levels (specifically airborne acid aerosols, particulates, and sulfates) and increased asthma symptoms among a panel of asthmatics in Denver, Colorado. Similar results have been reported in the Utah Valley (Pope et al. 1991), Glendora California (Krupnick et al. 1990), and the Netherlands (Hiltermann et al.

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[2] Two exceptions to this statement are a study by Zeghnoun et al. (1999) conducted in Le Havre France and an ongoing study by Simon et al. (2002) in San Francisco, California. Both studies look at air pollution and the purchase of quick relief asthma medications.

1998) among other places.

While diary studies are useful in isolating the effects of short-term increases in pollution on milder outcomes, these studies face several difficulties. Among these difficulties, as noted by Schwartz et al. (1991) is the fact that daily symptom rates are often highly correlated from one day to the next and the heterogeneity among subjects causes dependencies in the data. Some study results are also limited by the availability of particulate pollution measures – relying on TSP data rather than PM10 data – while others are limited by panel size or length of study period.[3] Because these studies tend to have relatively short study periods (often less than 1 year), they do not generally provide any indication of the effects of chronic exposure to air pollution on asthma symptoms.

In contrast to the studies described above, our study examines the effect of longer term or chronic exposures to air pollution on asthma symptoms as measured by the purchase of quick relief asthma medications across the state of California. We hypothesize that chronic exposure to air pollution may make an individual more susceptible to asthma attacks, causing an increase in the use of quick relief medications. Rather than consider the effects of daily increases in air pollution levels, this study focuses on differences in average pollution levels across zip codes and the effect of these observed differences on the purchase of quick relief asthma medications.

Methodology

This study looks at the effects of differences in long-term or chronic air pollution exposures on the occurrence of asthma attacks, where asthma attacks are proxied by the number of prescriptions for quick relief asthma medication. The total count of prescriptions for quick relief asthma medication is explained using measures of asthma triggers and other cofactors. The study utilizes a dataset of asthma drug prescriptions for a large percentage of the pharmacies in the state of California and GIS layers of spatial factors.

In this study, our "health" outcome (filling asthma prescriptions) is not a "direct" effect of air pollution exposure, but rather a secondary effect. That is, the true sequence of events goes as follows: long-term exposure to air pollution makes an individual more susceptible to asthma triggers leading to an exacerbation of asthma symptoms which in turn causes an increase in asthma medication use. The increase in asthma medication use eventually (perhaps with a lag) leads to the filling of a prescription. Because the urgency with which a prescription will need to be filled will vary across individuals and their initial stock of asthma medication, making short term effects difficult to observe, we focus on longer periods of time during which increased air pollution should be correlated with increased prescriptions, over and above the amount necessary for normal stock replacement.

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[3] TSP or Total Suspended Particulates includes all suspended particulates regardless of size. PM10, on the other hand, is defined as those particulates measuring 10 microns in diameter or less. PM10 is considered a more relevant measure of particulate pollution for epidemiological studies. These particulates are thought to be the most detrimental since they can be inhaled deeply into the lung.

Prescription data are provided for each five-digit zip code in the state and are segregated by five-year age groups and the level of asthma severity of the patient. Asthma severity is classified as mild intermittent, mild persistent, moderate persistent, and severe, based upon the number and combination of prescriptions that the patient fills for both quick-relief and maintenance asthma medicine over the 12 month calendar year (NIH, 1997). Generally, asthma medications fall into one of two categories: (1) short-term treatments intended to provide quick relief in the event of an asthma attack and (2) long-term maintenance therapies intended to prevent asthma attacks. Mild asthmatics are those patients prescribed a quick-relief medication only. Patients with mild persistent asthma not only are prescribed a quick-relief medication but are also prescribed a single controller or maintenance therapy. Moderate asthmatics are prescribed two controllers operating by different modes of action in addition to the quick relief medications, while severe asthmatics are prescribed three controllers with different modes of action. Should an individual's asthma severity level shift over the 12 month period, the individual is assigned to the most severe of the categories for which he/she qualifies. A list of the quick acting and controlling asthma medication is listed in Table 1.

Asthma triggers included in the study include air pollutants (e.g., particulate matter and ozone), which are the primary factors of concern, as well as temperature. Additional cofactors included are population demographics (e.g., median household income, percent urban population), and seasonal or quarterly dummies. The inclusion of other spatial factors such as pollen and the road network were considered, but not included in this model.

Data Description

The number of prescriptions for quick acting asthma medication was obtained from NDChealth (hereafter, NDC), a Phoenix-based company that maintains prescription-related data for marketing research. NDC maintains two datasets of use for this study, a "retail pharmacy" database and a "patient" database. The pharmacy database contains dispensing records from approximately 36,000 pharmacies nationwide, and captures approximately 70% of the volume of traditional pharmacy-dispensed prescriptions. Hospital, military and mail order pharmacies and prescriptions dispensed to institutionalized patients are not included in this database, which may pose a problem in the future as mail order prescriptions grow, but is probably not important here. The patient database is a subset of approximately 14,000 of the pharmacies in the pharmacy database. The patient database is a more complete database, in many cases including the patients age and gender, along with a unique patient identifier so that the history of a patient may be followed. Not included in the database, and unknown to NDC, is any information that could personally identify a patient (such as a name, address or phone number) and NDC has been very careful not to release any individual patient data, even with the anonymous identifier.

For this study, the total counts of the number of prescriptions for quick-acting asthma medication in a five digit zip code for each quarter from 1998 to 2001 were used. Data are given by dispense quarter and the zip code of the dispensing pharmacy. These data are further disaggregated by the age of the patient, with age groups defined as: ages 0 to 4, ages 5 to 9, ages 10-14, ages 15-17, ages 18-44, ages 45-64, ages 65 and up, and age unknown as well as asthma severity.

The prescription data used in this analysis are limited in the following way. They only include counts of prescriptions for quick relief asthma medication from those pharmacies that "consistently" report this information. "Consistent" reporting is defined by NDC as pharmacies for which fewer than 11 days of data are missing in any 30 day period. While the number of consistently reporting pharmacies remains relatively stabile in a zip code over time, the number of pharmacies reporting across zip codes varies widely and may affect the number of prescriptions dispensed for quick relief asthma prescriptions.

To control for the number of pharmacies reporting while maintaining the privacy of the pharmacies themselves, NDC provided us with a proxy measure that would be strongly, if not identically, correlated with number of pharmacies in each zip code reporting asthma prescriptions. Specifically, they calculated the ratio of the number of pharmacies reporting asthma prescriptions to the number of pharmacies reporting prescriptions for either antibiotics or pain relief medications during the same time period. This ratio allows us to identify and control for fluctuations in asthma prescriptions attributable to variations in the number of pharmacies reporting rather than those that are attributable to changes in weather, air pollution or other factors.

The air pollution data come from the California Air Resource Board and are made publicly available. Daily observations on the levels of PM10, SO2, NOx, and ozone are available for 361 monitors across California. PM10 (in micrograms per cubic meter) and the 8 hour maximum value of ozone (in parts per million) were available with good spatial coverage across California. The 24 hour average value of SO2 (in parts per million) and the daily average concentration of NOx (in parts per million) were available for a subset of the sites. The daily observations for all of the pollution measures were averaged over the quarter for each monitor.

The weather data come from the National Climatic Data Center. Daily observations for the average, minimum, and maximum temperature, precipitation, as well as the dew point temperature, and the minimum and maximum relative humidity were obtained for 37 active weather stations across California. The dew point temperature and relative humidity measures were eventually dropped due to a lack of adequate spatial distribution. Since it is generally believed that cold weather events are correlated with asthma attacks, the average minimum temperature over the quarter was used in this analysis.

While the coverage of air pollution and weather data offer an acceptable representation of the state, each zip code does not necessarily contain an air pollution or weather monitor. An algorithm was needed to link the zip code with two disparate points: the zip code and the air pollution monitor or the weather station. Kriging methods to spatially interpolate the data were explored, but given the preliminary nature of this analysis, the simpler method of linking each of the zip codes with the nearest monitor and station that contained data within 25 miles was used. Zip codes were linked to monitor and stations for each of the four years individually, so a zip code could potentially draw data from more than one location over the course of the study. To be considered in a year, a pollution monitor was required to have PM10 data and a weather station was required to have precipitation data in the first quarter. Of potential concern is that zip codes were linked to monitors without regard for airshed, elevation, or wind direction, and spatial autocorrelation and spatial heterogeneity were not evaluated in this study. Future analyses will try to incorporate these elements as well.

Demographic data for each zip code were obtained from the 2000 U.S. Census. Total population counts by age and race, as well as other demographic data, were collected at the zip code level from both the SF1 (100-percent, short form) and SF3 (sample, long form) datasets. Ultimately, we decided to control for population by using prescriptions per capita as the left hand side variable; however, we included various characteristics of the population as explanatory variables, including the percent of the population in each race, population density, percent urban, and median income.

The summary statistics for the data used in this analysis are listed in Table 2. The unit of observation is the five-digit zip code. For the sixteen quarters from 1998 to 2001, data were available at one point or another for 852 of the 1919 zip codes in California. Together, 7,735 observations of quarterly counts for quick relief medications were available. When linked with the regressors, however, between 7639 and 7097 observations were available for primary analysis, and 3284 observations were available if SO2 and NOx were included.

Empirical Results

Since our prescription data were reported by five-digit zip codes of various sizes and population density, we control for this variation by normalizing the prescription counts by the size of the total population of the zip code using information from the 2000 Census. The effects of cold temperature extremes are captured using the average minimum temperature for the zip code over the quarter, and cyclical variation and seasonal allergies are controlled for using quarterly dummies. Demographics included here are race and median household income. Since we are explaining prescriptions per capita, the percentages of these demographic categories in each zip code are used. In addition, we have included both population density and percent of population in an urban area as explanatory variable, as well as an interaction between percent urban and median income. Finally, we have included a trend variable to control for annual changes that are not otherwise captured.

Since counts of quick relief asthma medications are relatively large for each quarter at the zip code level, we examine the effects of pollution using simple, weighted OLS regressions, where the weight is the ratio of the number of pharmacies reporting in each zip code during the quarter to the number of pharmacies reporting in the alternative market.[4] We built the model by first incorporating time and weather variables. In this case, the weather variable of interest is minimum temperature, as cold temperatures are thought to exacerbate asthma symptoms. We then added population density and demographic characteristics at the zip code level. Finally, we

[4]The alternative market is defined as prescriptions for analgesics and/or antibiotics.

added pollution variables to our models. PM10 and ozone measures were introduced separately in the analysis before including them in the same regression. We then added SO2 and NOx to the final regression to see the effect. The results of the final regressions including the pollution measures are reported in Table 3.

Focusing first on the demographic variables, household income is positive and statistically significant in all of our models, indicating that households with higher incomes are more likely able to afford the prescriptions. Race also seems to matter, with Hispanics showing a greater likelihood of purchasing asthma prescriptions in California. On the other hand, being Asian or black has a negative effect on asthma prescriptions for quick relief medications. We had no predispositions as to the direction of the coefficient on the race variables, recognizing only that race could be a significant determinant of exposure to triggers and susceptibility to them. It could be that Hispanics live in areas with higher levels of pollution or are otherwise exposed more often to other asthma triggers compared to other segments of the population. Or, perhaps differences in the occupations held by individuals comprising the various race/ethnic groups exist that lead to differential exposure to asthma triggers. While population density has a consistently positive and statistically significant coefficient, the coefficient on percent of the population living in an urban area tends to be negative. We initially expected that urbanization would have a positive effect on asthma prescriptions since exposure to asthma triggers is often thought to be higher in urban environments.

Turning to our variables of interest, we find mixed results. Interestingly, PM10 has a consistently positive and statistically significant effect on asthma prescriptions for quick relief medications, with the exception of model 4 in which SO2 and NOx are included as well as ozone. Generally this means that higher levels of PM10 in one location are associated with a greater number of total prescriptions per capita for quick relief asthma medications, all else equal. In model 4, however, the effects of SO2 and NOx dampens the effect of PM10 considerably. SO2 and PM10 tend to be correlated, however, with SO2 a potential indicator of the acidity of the particulate pollution. Some argue that the acidity of the particulates contributes to the incidence of various health effects including asthma. Because of the relatively poor coverage offered by monitors reporting SO2 and NOx, it is important to note that the number of observations declined considerably compared to the other models reported here.

The effects of ozone on quarterly prescription counts of quick relief medications is not nearly as pronounced. In fact, we find no statistically significant effect of ozone measures in any of our models. Model 4 again provides a weak exception, with a barely statistically significant (at the 90 % level) coefficient on the ozone measure included in the regression. The sign of the ozone coefficient in Model 4 is puzzling, though, as it is negative.

Effects by Asthma Severity

Recognizing that maintenance therapies could be dampening the effects of air pollution on quick-relief asthma medication use and prescriptions, we stratified our data according to asthma severity. Using counts of prescriptions per capita for each severity level as the dependent variable, we ran four separate regressions using model 3 from Table 3. These results are reported in Table 4.

As suspected we see differential responses to air pollution levels by asthma severity. As in Table 3, PM10 has a consistently positive and statistically significant effect on asthma prescriptions for quick relief medications regardless of severity level. The magnitude of the effect does vary, however, with mild and severe asthmatics showing the largest response. This is not entirely surprising since mild asthmatics by definition do not take controller medications but rely only on the quick relief medications to ease their breathing. On the other extreme, severe asthmatics, while taking several maintenance therapies, may be more susceptible to exposure to asthma triggers including air pollution levels, requiring larger numbers of prescriptions for quick relief medications.

The effect of ozone levels on asthma prescriptions remains puzzling. When this variable is statistically significant, it has a negative sign– the opposite of what we were expecting. It may be that the effects of ozone exposure on asthma are more acute requiring daily time series models to capture. This is a subject of future investigation.

While the direction of the effects of our other explanatory variables remain relatively unchanged from our core model reported in Table 3, some of the differences in magnitude by severity level are quite interesting. For instance, median household income has a statistically significant and positive effect on asthma prescriptions across the board, but the magnitude of the effect is larger for mild and severe asthmatics. One explanation of this effect could be cost related in that households with lower incomes may choose to forgo prescriptions for mild asthmatics. For asthmatics with more serious, persistent symptoms, the income effect is less pronounced, indicating perhaps a willingness to purchase the prescriptions to alleviate these more intense symptoms in spite of their cost. For the severe asthmatics, the effect of median household income is again quite pronounced – approximately twice the size of the effect for the mild asthmatic. This may again reflect cost concerns in that the multiple medications prescribed to the severe asthmatic may result in a substantial expense. Instead, households with lower incomes may forgo the additional treatments, continuing instead to purchase the medication combinations prescribed to the moderate asthmatic.

Age Specific Effects

Given the dramatic rise in asthma among children, it is important to determine whether or not the effects described above are age-specific. Including age-specific cofactors (such as the percentage of specific age groups in each zip code) in the regression above was considered, but using the prescriptions by age group in separate regressions gives a much more complete picture. The difficulty in this disaggregation, however, is that while few zip codes have zero prescriptions in the aggregate, a zip code may report zero prescriptions for a given age group in a particular quarter. As can be seen by the number of observations equal to zero reported in Table 2, zero counts are a concern, particularly for the severe asthma category. This makes the linear model used in Table 4 inappropriate.

The standard model for count data with zero observations is a Poisson model. The results of this model for the children's age categories of 0-4, 5-9, 10-14, and 15-17 are reported in Tables 5, 6,7, and 8 respectively. Table 9 is the Poisson regression of the remaining prescriptions, included for completeness. Note that Table 9 includes the prescriptions for the adult category of age 18 and above, but also all of the prescriptions listed for those of "unknown" age. Since the dependant variable in the Poisson model is simply counts of prescriptions, we include population and land area in the model as explanatory variables and remove population density. Otherwise, all of the other explanatory variables used previously are included in the Poisson model as well.

In general, the Poisson models yield significant relationships, of the same form as in Table 4, between air pollution and the number of asthma prescriptions. Strikingly, this is true, with few exceptions across all age groups, for both PM10 and ozone. Of particular interest is the result found by comparing the magnitude of the first order term for air pollutants across age groups for any given severity level. When statistically significant, coefficients are generally larger for children than for adults. Exceptions to this result for ozone are the 0-4 age group with mild asthma and the 15-17 age group with severe asthma. The exception for PM10 is the 10-14 age group with severe asthma. Additionally, this result appears to hold across severity classes. Although we initially stratified our sample by severity level due to concerns that maintenance drugs could dampen the impact of air pollution on the use of quick relief medications, this does not appear to be the case. The implication of these general results is that children are more highly affected by air pollution than adults. To more thoroughly test this hypothesis, however, we would need to formally test if the coefficients are statistically different from one another across models.

A potential alternative explanation for higher coefficients for children is that child asthmatics are more quick to be medicated than adults. Because parents are making, or at the very least assisting in, the decision to go to the doctor and fill prescriptions, there is a concern that parental altruism could lead to higher rates of medication for children than for adults. That is, parents could be more concerned about providing their children relief from asthma symptoms than adults are for their own symptoms. We do not believe that our results provide evidence of this altruistic effect however since the coefficients on the 10-14 and 15-17 age groups are still higher than those for the adult age group. Since these teenaged groups are less reliant upon their parents to make their decisions, we would expect to see a drop off in magnitude for these groups if parents were in fact over-providing for their children. The absence of this decline leads us to believe that the alternative explanation is not the primary driver of our results.

As before, minimum temperature is not significant but holds the expected negative sign for most models. Population and land area are unsurprisingly positive and significant, but of a relatively small magnitude in effect. The sign of the coefficient for the race percentages are often reversed from Table 4, which will require further analysis.

One interesting result from these models is the reversal in sign for percent urban, median household income, and their interaction. Median income was positive in Table 4, which can be explained as the ability of wealthier households to afford prescriptions; but this is not the only story that can be told with income. Wealthier households also have the ability to pay to avert the asthma triggers, which would suggest a negative coefficient for income. The fact that the number of prescriptions for children declines with income suggests that wealthier parents are better able to avoid the asthma triggers for their children. Further study is clearly warranted.

Conclusion

With the growing concern about increasing asthma rates, studies that further our understanding of the causes of asthma exacerbation are timely. If, as our study shows, chronic exposure to higher levels of air pollution leads to increases in asthma symptoms and the use of asthma medication, then reductions in these air pollutants will produce benefits that have previously been difficult to quantify. The benefits of reducing *serious* asthma attacks can be analyzed by examining emergency room visits and hospital admissions. The benefits associated with a decline in the outcomes analyzed here, the reduced use of quick acting asthma medication, have been somewhat more elusive as they are not as easily observable as ER visits. In contrast to diary studies, which examine the effect of short-term exposure to air pollution, this study looks at the effect of longer term or chronic exposures to air pollution on asthma symptoms by examining prescription data at the zip code level for California.

The results of Tables 3 and 4 show a statistically significant positive association between total prescriptions per capita for quick-acting asthma medication and air pollution. Including measures for both ozone and PM10, and controlling for temperature and demographics, we find that PM10 is a more important driver in explaining the increase in prescriptions per capita than ozone.

In the Poisson model of prescription counts presented in Tables 5-9, however, both pollution measures are significant. Disaggregation by age class suggests that children are affected more by air pollution than adults, and this effect appears to be true across severity levels. Additional tests of statistical significance will be required in the future to be more certain of this effect.

This preliminary analysis shows that there are real consequences to long term exposure to air pollution. We would, however, like to refine our approach in a number of ways. First, the data used here only include pharmacies that report their prescriptions consistently, with no less than eleven days of missing data per month. Adding the additional "inconsistent" pharmacies will increase the number of zip codes analyzed and may reveal important interactions, but must be done carefully to control for the additional noise. Second, there are additional variables that we would like to consider including, such as PM2.5 and the number of days in which a zip code was above a chosen pollution threshold. Third, there are a number of spatial issues that we should address. Kriging techniques will eliminate the need to link zip codes to specific pollution monitors and weather stations. We should also consider spatial factors that are currently excluded, such as the north to south mountain line in California and the spatial impact of CSMAs. The model may suffer from both heteroskedasticity and spatial autocorrelation, and further analysis must be done. Finally, this data could be combined with cost information to get an estimate of the benefits. All of these factors are expected to improve the analysis and the usefulness of the results.

Table 1: Asthma Medication

Symptomatic Therapy (Quick Relief)
Albuterol
Bitolterol
Isoetharine
Metaproteronol
Pirbuterol
Terbutaline
Controller Therapy (Long-term preventative)
Inhaled Corticosteroids
Beclomethasone
Budesonide
Flunisolide
Fluticasone
Triamcinolone
Leukotriene Antagonists
Motelukast
Zafirlukast
Zileutin
Long Acting Beta Agonists
Salmeterol
Xanthine Derivatives
Aminophylline
Dyphylline
Oxtriphylline
Theophylline

Table 2: Summary Statistics

Variable	All Ages					Ages 0 to 4				
	Total Prescriptions	Asthma Severity				Total Prescriptions	Asthma Severity			
		Mild	Mild Persistent	Moderate	Severe		Mild	Mild Persistent	Moderate	Severe
Number of Observations	7735	7735	7735	7735	7735	7413	7413	7413	7413	7413
Num. of Obs.= 0	0	1	5	11	80	0	117	753	3083	5851
mean	654.6344	315.155	194.381	96.87964	48.21875	32.22474	20.36234	8.872791	2.404829	0.5847835
standard error	478.487	238.5405	141.9122	72.01196	40.0092	33.54975	22.52427	9.897485	3.666297	1.571809
median	540	255	161	80	38	22	13	6	1	0
min	1	0	0	0	0	1	0	0	0	0
max	3477	1819	975	509	297	416	300	115	46	26
skewness	1.280852	1.385644	1.242319	1.280196	1.498094	2.816224	3.161856	2.517794	3.026762	4.490084
kurtosis	5.031391	5.450395	4.903892	5.000356	6.157983	17.43484	21.43579	13.43679	18.81439	34.22082

Table 2 (continued): Summary Statistics

Statistic	Ages 5 to 9					Ages 10 to1 4				
	Total Prescriptions	Asthma Severity				Total Prescriptions	Asthma Severity			
		Mild	Mild Persistent	Moderate	Severe		Mild	Mild Persistent	Moderate	Severe
Number of Observations	7500	7500	7500	7500	7500	7526	7526	7526	7526	7526
Num. of Obs.= 0	0	93	397	1647	4013	0	72	391	1420	3150
mean	46.70533	25.71613	14.0568	5.108667	1.823733	54.44592	29.49043	15.52897	6.3941	3.032421
standard error	42.98077	24.56539	14.15905	5.935202	3.128466	47.55257	25.87634	14.98555	7.142006	4.452154
median	35	19	10	3	0	42	22	11	4	1
min	1	0	0	0	0	1	0	0	0	0
max	354	217	146	51	31	391	192	146	66	47
skewness	1.929676	2.076474	2.198623	2.095364	2.842234	1.760224	1.734572	1.952528	2.047073	2.57068
kurtosis	8.289729	9.382513	10.80206	9.473676	14.19708	7.588125	7.232487	9.045644	9.842268	13.16101

Table 2 (continued): Summary Statistics

Statistic	*Ages 15 to 17*					*All Other Ages (Not including Unknown Age)*				
	Total Prescriptions	*Asthma Severity*				*Total Prescriptions*	*Asthma Severity*			
		Mild	*Mild Persistent*	*Moderate*	*Severe*		*Mild*	*Mild Persistent*	*Moderate*	*Severe*
Number of Observations	*7372*	*7372*	*7372*	*7372*	*7372*	*7203*	*7203*	*7203*	*7203*	*7203*
Num. of Obs.= 0	*0*	*150*	*940*	*2885*	*4968*	*0*	*0*	*0*	*5*	*59*
mean	*24.94886*	*14.64162*	*6.619506*	*2.587222*	*1.100515*	*525.0769*	*238.6608*	*157.6731*	*84.77398*	*43.96904*
standard error	*21.68575*	*12.91774*	*6.794598*	*3.439279*	*2.216614*	*360.2993*	*168.8212*	*109.4798*	*59.77791*	*34.86793*
median	*19*	*11*	*5*	*1*	*0*	*437*	*196*	*132*	*71*	*36*
min	*1*	*0*	*0*	*0*	*0*	*13*	*5*	*2*	*0*	*0*
max	*181*	*105*	*74*	*37*	*18*	*2631*	*1344*	*847*	*426*	*259*
skewness	*1.757481*	*1.653192*	*2.08444*	*2.202667*	*2.853334*	*1.241226*	*1.331471*	*1.253321*	*1.225283*	*1.443805*
kurtosis	*7.937582*	*6.829426*	*10.7228*	*11.39897*	*12.98792*	*4.827885*	*5.198832*	*4.973804*	*4.725747*	*6.050527*

Table 2 (continued): Summary Statistics

	Air Pollution Measures (Averaged over quarter)				*Minimum Daily Temperature (Averaged over Quarter*	*Demographic Characteristics (Zip Code Level)*				
	PM10, Daily Average	*Ozone (8-hour Maximum)*	*NOx, Daily Average*	*SO2, Daily Average*		*Median Household Income*	*Percent of Population Described as Black*	*Percent of Population Described as Asian*	*Percent of Population Described as Hispanic*	*Percent of Population in Urban Areas*
Number of Observations	*7674*	*7686*	*5760*	*4094*	*7735*	*7735*	*7735*	*7735*	*7735*	*7735*
mean	*34.31513*	*0.0392582*	*0.0623078*	*0.0025247*	*71.45207*	*50861.48*	*0.0643355*	*0.1192618*	*0.7050654*	*0.9721459*
standard error	*13.34303*	*0.0153724*	*0.0435055*	*0.0015707*	*1090.728*	*20244.88*	*0.0984705*	*0.1125274*	*0.2311541*	*0.0957774*
median	*32.86667*	*0.0368043*	*0.0510809*	*0.00242*	*52.22826*	*47573*	*0.0301147*	*0.0796252*	*0.7743347*	*1*
min	*6*	*0.00924*	*0.0024422*	*0.0000247*	*25.97826*	*8855*	*0.0014281*	*0.0011747*	*0.0277646*	*0*
max	*117.3297*	*0.111*	*0.233938*	*0.0096099*	*72844.09*	*164479*	*0.7851492*	*0.5902053*	*0.9782452*	*1*
skewness	*1.022263*	*1.008934*	*1.195364*	*0.6086475*	*62.44114*	*1.296063*	*3.664492*	*1.79449*	*-1.014786*	*-6.577531*
kurtosis	*4.668436*	*4.238362*	*4.035975*	*3.138443*	*3933.274*	*5.903643*	*19.6607*	*6.317696*	*3.160587*	*58.08569*

Table 2 (continued): Summary Statistics

	Population in Each Age (Zip Code Level)						*Geographic Characteristics*	
	Total	*Ages 0-4*	*Ages 5-9*	*Ages 10-14*	*Ages 15-17*	*Other Ages*	*arealand*	*popden*
Number of Observations	*7735*	*7735*	*7735*	*7735*	*7735*	*7735*	*7735*	*7688*
mean	*36925.78*	*2708.643*	*2921.787*	*2690.622*	*1528.824*	*27075.9*	*1.08e+08*	*0.002573*
standard error	*18392.4*	*1884.077*	*2033.976*	*1764.129*	*986.8849*	*12531.04*	*3.14e+08*	*0.0031668*
median	*33520*	*2280*	*2425*	*2297*	*1344*	*25492*	*1.80e+07*	*0.0020154*
min	*294*	*9*	*9*	*7*	*20*	*179*	*0*	*1.33e-06*
max	*105275*	*11955*	*12546*	*10151*	*5505*	*70049*	*3.68e+09*	*0.0420212*
skewness	*0.7853757*	*1.315397*	*1.309443*	*1.125955*	*1.049795*	*0.6008423*	*6.519869*	*5.466631*
kurtosis	*3.69066*	*5.062044*	*5.117194*	*4.533889*	*4.25487*	*3.245719*	*57.26882*	*56.75337*

Table 3: Weighted OLS Regressions of Total Prescriptions per Capita Weight=Number of Pharmacies Reporting

Variable	Model 1	Model 2	Model 3	Model 4
Ozone (8 hour max)	0.0130 (0.0722)	--	-0.1075 (0.0727)	-0.1674* (0.0924)
$Ozone^2$ (8 hour max)	-0.2387 (0.6934)	--	0.0622 (0.6989)	-0.2853 (0.8221)
Particulate Matter (<10u)	--	0.0006** (0.0001)	0.0007** (0.0001)	0.0001 (0.0001)
Particulate $Matter^2$ (<10u)	--	$-6.22x10^{-6}$** ($8.36x10^{-7}$)	$-6.05x10^{-6}$** ($8.51x10^{-7}$)	$-1.76x10^{-6}$ ($1.36x10^{-6}$)
SO^2	--	--	--	0.8224** (0.2113)
NOx	--	--	--	0.0534** (0.0140)
Minimum Temperature	$-2.98x10^{-7}$ ($2.67x10^{-7}$)	$-2.71x10^{-7}$ ($2.65x10^{-7}$)	$-2.46x10^{-7}$ ($2.65x10^{-7}$)	$-3.30x10^{-7}$ ($2.40x10^{-7}$)
Population Density	0.2303** (0.0943)	0.1574* (0.0916)	0.0640 (0.0946)	-0.1040 (0.1901)
Percent Urban	-0.0546** (0.0086)	-0.0584** (0.0084)	-0.0584** (0.0085)	-0.6496** (0.0417)
Median Household Income	$1.11x10^{-6}$** ($1.78x10^{-7}$)	$1.10x10^{-6}$** ($1.75x10^{-7}$)	$1.12x10^{-6}$** ($1.76x10^{-7}$)	$8.51x10^{-6}$** ($8.17x10^{-7}$)
%Urban*Median HH Income	$-1.19x10^{-6}$** ($1.82x10^{-7}$)	$-1.15x10^{-6}$** ($1.80x10^{-7}$)	$-1.19x10^{-6}$** ($1.81x10^{-7}$)	$-8.61x10^{-6}$** ($8.29x10^{-7}$)
Percent Black	-0.0066** (0.0026)	-0.0020 (0.0026)	-0.0033 (0.0026)	0.0236** (0.0035)
Percent Asian	-0.0052** (0.0022)	-0.0066** (0.0021)	-0.0081** (0.0022)	0.0030* (0.0027)
Percent Hispanic	0.0234** (0.0014)	0.0256** (0.0014)	0.0260** (0.0014)	0.0155** (0.0018)
Quarter 2 (Apr, May, June)	-0.0022** (0.0008)	-0.0021** (0.0006)	-0.0003 (0.0008)	0.0042** (0.0013)
Quarter 3 (July, Aug, Sep)	-0.0046** (0.0008)	-0.0051** (0.0006)	-0.0034** (0.0008)	0.0015 (0.0013)
Quarter 4 (Oct, Nov, Dec)	0.0003 (0.0007)	-0.0011 (0.0007)	-0.0017** (0.0007)	-0.0017* (0.0010)
Trend	0.0002** (0.0001)	0.0002** (0.0001)	0.0002** (0.0001)	0.0003** (0.0001)
Constant	0.0646** (0.0085)	0.0532** (0.0084)	0.0559** (0.0084)	0.6510** (0.0414)
Number of Observations	7639	7628	7579	3284
R^2	0.2413	0.2519	0.2534	0.5149

Table 4: Weighted OLS Regressions of Prescriptions per Capita by Asthma Severity Level
Weight=Number of Pharmacies Reporting

Variable	Mild	Mild Persistent	Moderate Persistent	Severe
Ozone (8 hour max)	0.0076 (0.0343)	-0.0615** (0.0230)	-0.0352 (0.0123)	-0.0183** (0.0063)
Ozone^2 (8 hour max)	-0.4843 (0.3301)	0.2733 (0.2210)	0.1807 (0.1186)	0.0925 (0.0604)
Particulate Matter (<10u)	0.0004** (0.00003)	0.0002** (0.00002)	0.0001** (0.00001)	0.00005** ($6.30x10^{-6}$)
Particulate Matter^2 (<10u)	$-3.24x10^{-6}$** ($4.02x10^{-7}$)	$-1.53x10^{-6}$** ($2.69x10^{-7}$)	$-8.42x10^{-7}$** ($1.44x10^{-7}$)	$-4.37x10^{-7}$** ($7.36x10^{-8}$)
Minimum Temperature	$-1.04x10^{-7}$ (1.25x10-7)	$-9.25x10^{-8}$ ($8.38x10^{-8}$)	$-2.73x10^{-8}$ ($4.50x10^{-8}$)	$-2.18x10^{-8}$ ($2.29x10^{-8}$)
Population Density	0.0616 (0.0447)	0.0176 (0.0299)	0.0032 (0.0161)	-0.0185** (0.0081)
Percent Urban	-0.0270** (0.0040)	-0.0221** (0.0027)	-0.0063** (0.0014)	-0.0030** (0.0007)
Median Household Income	$4.84x10^{-7}$** ($8.33x10^{-8}$)	$2.65x10^{-7}$** ($5.57x10^{-8}$)	$2.85x10^{-7}$** ($2.99x10^{-8}$)	$8.92x10^{-8}$ ($1.52x10^{-8}$)
%Urban*Median HH Income	$-5.08x10^{-7}$** ($8.53x10^{-8}$)	$-2.80x10^{-7}$** ($5.71x10^{-6}$)	$-3.01x10^{-7}$** ($3.07x10^{-8}$)	$-1.02x10^{-7}$** ($1.56x10^{-8}$)
Percent Black	$-5.32x10^{-6}$ (0.0012)	-0.0007 (0.0008)	-0.0017** (0.0004)	-0.0009** (0.0002)
Percent Asian	-0.0043** (0.0010)	-0.0018** (0.0007)	0.0009** (0.0004)	-0.0010 (0.0002)
Percent Hispanic	0.0110** (0.0007)	0.0075** (0.0004)	0.0049** (0.0002)	0.0025** (0.0001)
Quarter 2 (Apr, May, June)	-0.0013** (0.0004)	0.0006** (0.0003)	0.0003** (0.0001)	0.0001* (0.0001)
Quarter 3 (July, Aug, Sep)	-0.0032** (0.0004)	-0.0001 (0.0002)	-0.0001 (0.0001)	-0.00002 (0.0001)
Quarter 4 (Oct, Nov, Dec)	-0.0010** (0.0003)	0.0001 (0.0002)	-0.0004** (0.0001)	-0.0003** (0.0001)
Trend	0.0001** (0.00002)	-0.00001 (0.00002)	0.00004** ($8.61x10^{-6}$)	0.00003** ($4.44x10^{-6}$)
Constant	0.0244** (0.0040)	0.0226** (0.0027)	0.0058** (0.0014)	0.0031** (0.0007)
Number of Observations	7579	7579	7579	7579
R^2	0.2398	0.2352	0.2752	0.2061

Table 5: Poisson Regressions of Prescriptions Counts by Asthma Severity, Age 0-4
Weight=Number of Pharmacies Reporting

Variable	Mild	Mild Persistent	Moderate Persistent	Severe
Ozone (8 hour max)	10.97834** (0.7579566)	20.54198** (1.095515)	14.51552** (2.160324)	-5.556807 (4.617046)
Ozone2 (8 hour max)	-124.1338** (7.629936)	-140.9479** (10.66574)	-146.5154** (21.7495)	4.105722 (46.94952)
Particulate Matter (<10u)	0.0254418** (0.0008049)	0.0146184** (0.0011707)	0.0164327** (0.0024019)	0.0357992** (0.0051865)
Particulate Matter2 (<10u)	-0.0001945** (0.0000092)	-0.0001164** (0.0000133)	-0.000122** (0.0000275)	-0.0003103** (0.0000605)
Minimum Temperature	-0.00000031 (0.0000042)	-0.000012 (0.00000794)	-0.007008** (0.0021487)	-0.0120306** (0.0044281)
Population	0.0000139** (0.000000143)	0.0000146** (0.000000221)	0.0000115** (0.000000425)	0.00000283** (0.000000902)
Land Area	5.60e-11** (9.26e-12)	5.21e-11** (1.35e-11)	2.20e-10** (2.35e-11)	2.21e-10** (4.64e-11)
Percent Urban	0.3792007** (0.1462972)	-0.5283571** (0.1878531)	-0.0521455 (0.4021566)	1.496921** (0.5826956)
Median Household Income	-0.0000191** (0.00000318)	-0.0000244** (0.00000427)	-0.0000339** (0.00000869)	0.0000285** (0.0000119)
%Urban*Median HH Income	0.0000233** (0.00000322)	0.0000262** (0.00000433)	0.0000431** (0.00000879)	-0.0000283** (0.0000122)
Percent Black	1.763746** (0.0231235)	1.344907** (0.0377671)	1.45492** (0.0712859)	0.9173831** (0.1493707)
Percent Asian	-0.0656788** (0.022915)	0.179164** (0.0338249)	0.4977336** (0.0618611)	0.6452012** (0.1255217)
Percent Hispanic	-0.442947** (0.015432)	0.0482735** (0.0237485)	-0.1543095** (0.0457842)	-0.1006465 (0.0935472)
Quarter 2 (Apr, May, June)	-0.4872949** (0.0084444)	-0.4346739** (0.0127981)	-0.2642642** (0.0282335)	-0.1460141** (0.0594354)
Quarter 3 (July, Aug, Sep)	-0.7119725** (0.008591)	-0.6088005** (0.0129702)	-0.4013929** (0.0367868)	-0.3089985** (0.0765735)
Quarter 4 (Oct, Nov, Dec)	-0.2182028** (0.0065429)	-0.0244281** (0.0101834)	-0.2728652** (0.0202581)	-0.5376679** (0.0425356)
Trend	0.0348096** (0.0005428)	0.0461616** (0.0008227)	0.1054164** (0.0016332)	0.1559188** (0.003684)
Constant	1.441439** (0.1452816)	1.004536** (0.1871769)	-0.9154803** (0.4033416)	-3.354994** (0.5953013)
Number of Observations	7305	7305	7305	7305
Pseudo R2	0.27	0.1719	0.1429	0.1098

Table 6: Poisson Regressions of Prescriptions Counts by Asthma Severity, Age 5-9
Weight=Number of Pharmacies Reporting

Variable	Mild	Mild Persistent	Moderate Persistent	Severe
Ozone (8 hour max)	25.04567** (0.6661456)	29.17234** (0.8986673)	26.42362** (1.466198)	23.88336** (2.410876)
Ozone2 (8 hour max)	-236.7028** (6.636413)	-233.8192** (8.818661)	-216.934** (14.37449)	-177.3323** (23.72769)
Particulate Matter (<10u)	0.0261766** (0.0007097)	0.0193574** (0.0009517)	0.0166144** (0.0015273)	-0.0002486 (0.0024129)
Particulate Matter2 (<10u)	-0.0002214** (0.00000802)	-0.0001766** (0.0000108)	-0.0001489** (0.0000174)	-0.0000073 (0.0000278)
Minimum Temperature	-0.0000103** (0.00000442)	-0.0000119** (0.00000592)	-0.00000757 (0.00000871)	0.0000017 (0.000011)
Population	0.0000161** (0.000000126)	0.0000138** (0.000000172)	0.0000151** (0.000000287)	0.000015** (0.000000483)
Land Area	1.01e-10** (7.67e-12)	2.33e-11** (1.07e-11)	1.30e-10** (1.61e-11)	1.75e-10** (2.60e-11)
Percent Urban	0.503357** (0.1178582)	-0.1344909 (0.1502643)	-0.6599364** (0.2223536)	0.718834** (0.3413284)
Median Household Income	-0.00000436* (0.00000251)	-0.0000151** (0.00000338)	-0.0000186** (0.00000511)	0.0000104 (0.00000712)
%Urban*Median HH Income	0.00000853** (0.00000255)	0.0000156** (0.00000343)	0.0000191** (0.00000519)	-0.00000989 (0.00000726)
Percent Black	1.680733** (0.0210708)	1.8477** (0.0276487)	1.266928** (0.0496734)	1.224149** (0.0838741)
Percent Asian	-0.0508744** (0.0202658)	-0.0538819* (0.0277586)	0.3131667** (0.043206)	0.7048495** (0.0682401)
Percent Hispanic	-0.2934698** (0.0137165)	-0.1937725** (0.0185691)	0.1950645** (0.0310077)	0.7475832** (0.0530349)
Quarter 2 (Apr, May, June)	-0.2438594** (0.0075468)	-0.2571905** (0.0102463)	-0.223105** (0.0166626)	-0.2601726** (0.0265451)
Quarter 3 (July, Aug, Sep)	-0.3288345** (0.0075107)	-0.3087052** (0.010158)	-0.3110525** (0.0164871)	-0.4230715** (0.0263215)
Quarter 4 (Oct, Nov, Dec)	0.147668** (0.0060709)	0.1694812** (0.0083697)	0.0465003** (0.0137708)	-0.1586523** (0.0226232)
Trend	0.0267533** (0.0004748)	0.0317252** (0.0006429)	0.0593349** (0.0010717)	0.0939584** (0.001806)
Constant	0.8511665** (0.1171189)	1.038824** (0.1497897)	0.1434398 (0.2223432)	-2.493021** (0.3411868)
Number of Observations	7392	7392	7392	7392
Pseudo R2	0.267	0.2003	0.1302	0.1039

Table 7: Poisson Regressions of Prescriptions Counts by Asthma Severity, Age 10-14
Weight=Number of Pharmacies Reporting

Variable	Mild	Mild Persistent	Moderate Persistent	Severe
Ozone (8 hour max)	28.03876** (0.6175952)	25.78255** (0.8377723)	24.9128** (1.298766)	34.19182** (1.88376)
Ozone2 (8 hour max)	-238.5753** (6.038243)	-203.1505** (8.048794)	-203.1219** (12.47718)	-234.6526** (18.20284)
Particulate Matter (<10u)	0.0236093** (0.0006542)	0.0180628** (0.0008845)	0.0199478** (0.0013377)	0.0039002** (0.0018807)
Particulate Matter2 (<10u)	-0.0002218** (0.00000744)	-0.0001555** (0.00000996)	-0.0001527** (0.000015)	-0.0000521** (0.0000216)
Minimum Temperature	-0.0000102** (0.00000365)	-0.00000448 (0.00000412)	-0.00000303 (0.00000632)	0.00000565 (0.00000661)
Population	0.0000169** (0.000000119)	0.0000167** (0.000000164)	0.0000154** (0.000000258)	0.0000143** (0.000000368)
Land Area	1.26e-10** (6.75e-12)	8.84e-11** (9.41e-12)	1.85e-10** (1.35e-11)	1.17e-10** (1.93e-11)
Percent Urban	-0.1884366** (0.0946442)	-0.0807457 (0.1230779)	0.7162738** (0.1918656)	-0.3309048 (0.2470555)
Median Household Income	-0.0000101** (0.00000208)	-0.00000234 (0.0000027)	0.00000718* (0.00000412)	-0.00000828 (0.00000564)
%Urban*Median HH Income	0.0000116** (0.00000212)	0.00000279 (0.00000276)	-0.00000919** (0.0000042)	0.00000626 (0.00000576)
Percent Black	1.161845** (0.0209779)	1.189558** (0.0287297)	0.9960942** (0.0454172)	1.400747** (0.0617281)
Percent Asian	-0.2380888** (0.019031)	-0.3749473** (0.026684)	-0.3028831** (0.0402521)	-0.3933124** (0.0595809)
Percent Hispanic	0.1120475** (0.0128876)	0.0784604** (0.0176528)	0.4877225** (0.0276418)	0.3494201** (0.0390927)
Quarter 2 (Apr, May, June)	-0.2254476** (0.0070148)	-0.138979** (0.0096739)	-0.1730995** (0.0148544)	-0.3981783** (0.0208331)
Quarter 3 (July, Aug, Sep)	-0.2536546** (0.0069258)	-0.2035237** (0.0096004)	-0.2518753** (0.0146603)	-0.4719592** (0.0206247)
Quarter 4 (Oct, Nov, Dec)	0.1051401** (0.0057953)	0.1196589** (0.0081355)	-0.0479534** (0.012476)	-0.1766381** (0.0177604)
Trend	0.0289785** (0.0004429)	0.0307646** (0.0006113)	0.0559504** (0.0009569)	0.0722986** (0.0013776)
Constant	1.50311** (0.0943713)	0.92306** (0.1228649)	-1.060152** (0.191468)	-0.5046592** (0.2478894)
Number of Observations	7419	7419	7419	7419
Pseudo R2	0.2237	0.1822	0.1301	0.1067

Table 8: Poisson Regressions of Prescriptions Counts by Asthma Severity, Age 15-17
Weight=Number of Pharmacies Reporting

Variable	Mild	Mild Persistent	Moderate Persistent	Severe
Ozone (8 hour max)	29.71956** (0.8649563)	27.33543** (1.286507)	14.47834** (2.03114)	8.698405** (3.117208)
Ozone2 (8 hour max)	-236.204** (8.356989)	-186.2598** (12.29424)	-105.4592** (19.44391)	-78.27337** (30.2128)
Particulate Matter (<10u)	0.0154751** (0.0009089)	0.0059427** (0.0013446)	0.0012557 (0.0020533)	0.0264459** (0.003321)
Particulate Matter2 (<10u)	-0.0001425** (0.0000102)	-0.0000679** (0.0000152)	0.00000691 (0.0000232)	-0.0002815** (0.0000387)
Minimum Temperature	-0.0000114** (0.00000494)	0.00000057 (0.00000488)	-0.0000108 (0.0000117)	-0.0000149 (0.0000222)
Population	0.0000174** (0.000000173)	0.0000148** (0.000000261)	0.0000135** (0.00000042)	0.0000189** (0.000000622)
Land Area	1.45e-10** (9.39e-12)	8.43e-11** (1.43e-11)	5.23e-11** (2.33e-11)	3.07e-10** (2.96e-11)
Percent Urban	-0.4985458** (0.1269028)	0.0284296 (0.1741472)	1.657045** (0.2981351)	1.178507** (0.4284837)
Median Household Income	-0.0000129** (0.00000286)	0.00000297 (0.00000387)	0.000019** (0.00000622)	0.0000214** (0.00000908)
%Urban*Median HH Income	0.0000126** (0.00000291)	-0.00000643 (0.00000395)	-0.0000274** (0.00000636)	-0.0000272** (0.0000093)
Percent Black	0.4924911** (0.0329554)	0.3758033** (0.0496094)	-0.2861978** (0.0817554)	0.256651** (0.1179288)
Percent Asian	0.0228642 (0.0263798)	0.241977** (0.0392867)	-0.5079986** (0.0639874)	-0.1860021** (0.0926533)
Percent Hispanic	0.3924904** (0.0186063)	0.3152129** (0.0277944)	0.9438262** (0.0446383)	1.100225** (0.0677743)
Quarter 2 (Apr, May, June)	-0.2539285** (0.0099014)	-0.2323478** (0.0148334)	-0.1070033** (0.023374)	-0.1099388** (0.0350731)
Quarter 3 (July, Aug, Sep)	-0.320088** (0.009909)	-0.3221051** (0.014892)	-0.1877639** (0.0230491)	-0.2353972** (0.0345231)
Quarter 4 (Oct, Nov, Dec)	0.0941159** (0.0082749)	0.0920717** (0.0125823)	-0.018283 (0.01995)	-0.1739332** (0.0296074)
Trend	0.0210245** (0.0006325)	0.0294507** (0.0009492)	0.0543165** (0.0015128)	0.0716631** (0.0023154)
Constant	1.20086** (0.1269083)	0.3136288* (0.1746926)	-2.058707** (0.2975482)	-3.390688** (0.4285481)
Number of Observations	7266	7266	7266	7266
Pseudo R2	0.1673	0.1009	0.0643	0.0688

Table 9: Poisson Regressions of Prescriptions Counts by Asthma Severity, Adults and Unknown Age. Weight=Number of Pharmacies Reporting

Variable	Mild	Mild Persistent	Moderate Persistent	Severe
Ozone (8 hour max)	15.26694** (0.2143931)	10.04354** (0.2594564)	10.09516** (0.3530363)	11.07596** (0.494678)
Ozone2 (8 hour max)	-137.5383** (2.068485)	-89.2845** (2.462988)	-90.0965** (3.343758)	-93.8065** (4.698299)
Particulate Matter (<10u)	0.0118307** (0.0002222)	0.0042399** (0.0002723)	0.0047997** (0.0003668)	0.0100922** (0.0005134)
Particulate Matter2 (<10u)	-0.0000975** (0.00000252)	-0.0000398** (0.00000309)	-0.0000399** (0.00000416)	-0.0001046** (0.00000589)
Minimum Temperature	-0.0000093** (0.00000108)	-0.000016** (0.00000154)	-0.00000472** (0.00000145)	-0.0000154** (0.00000289)
Population	0.0000154** (0.000000044)	0.0000153** (0.0000000544)	0.0000154** (0.0000000744)	0.0000158** (0.000000102)
Land Area	1.38e-10** (2.40e-12)	1.38e-10** (2.95e-12)	1.30e-10** (4.00e-12)	1.56e-10** (5.34e-12)
Percent Urban	-0.0999528** (0.0384481)	-0.6880752** (0.0451822)	-0.5357108** (0.0595523)	0.0711288 (0.0833222)
Median Household Income	-0.0000332** (0.000000868)	-0.000041** (0.00000104)	-0.0000366** (0.00000136)	-0.000027** (0.00000189)
%Urban*Median HH Income	0.0000309** (0.000000879)	0.0000396** (0.00000105)	0.0000337** (0.00000138)	0.0000219** (0.00000192)
Percent Black	-0.5558639** (0.0089839)	-0.484152** (0.0110197)	-0.8177009** (0.0155494)	-0.3448258** (0.0200027)
Percent Asian	-0.3890154** (0.0065659)	-0.1740856** (0.0079606)	-0.3039745** (0.0108593)	-0.7124759** (0.0155441)
Percent Hispanic	0.8090284** (0.0046989)	0.8202236** (0.0058361)	1.015736** (0.0079707)	1.1424** (0.0109535)
Quarter 2 (Apr, May, June)	-0.2346234** (0.0024129)	-0.0663938** (0.0029677)	-0.0634297** (0.0040307)	-0.0832976** (0.0055787)
Quarter 3 (July, Aug, Sep)	-0.3617096** (0.0024305)	-0.1141889** (0.0029412)	-0.1068483** (0.0039732)	-0.1276086** (0.0054838)
Quarter 4 (Oct, Nov, Dec)	-0.0433887** (0.0020208)	0.0684658** (0.002569)	-0.0132208** (0.0035097)	-0.0756691** (0.004855)
Trend	0.0003705** (0.0001565)	-0.0150399** (0.0001917)	-0.0016361** (0.0002603)	0.0097948** (0.0003599)
Constant	4.334623** (0.0382833)	4.737721** (0.0450788)	3.821455** (0.0594479)	2.392236** (0.0831055)
Number of Observations	7097	7097	7097	7097
Pseudo R2	0.2405	0.2062	0.1817	0.1549

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Comments on Air Pollution and Asthma in Children

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Context

- Since 1990, at least 18 studies have been published examining the relationship between air pollution and symptoms in asthmatics
- Findings have been equivocal, although most have found significant relationships between at least one air pollutant and asthma symptoms
- Symptom measures vary, with some focusing on individual symptom indicators, like cough, and some focusing on symptom scales or asthma attacks/episodes

Impacts of Nonroad Diesel Emission Reductions on Asthmatics

Endpoint (Study population)	Study	Avoided Incidence in 2030
Asthma Attack Indicators		
Shortness of Breath (African American asthmatics, 8-13)	Ostro et al. (2001)	15,000
Cough (African American asthmatics, 8-13)	Ostro et al. (2001)	31,000
Wheeze (African American asthmatics, 8-13)	Ostro et al. (2001)	24,000
Asthma Exacerbation – one or more symptoms (Asthmatics, 5-13)	Yu et al. (2000)	530,000
Cough (Asthmatics, 6-13)	Vedal et al. (1998)	240,000
Asthma Attacks (Asthmatics, all ages)	Whittemore and Korn (1980)	160,000
Other symptoms/illness endpoints		
Upper Respiratory Symptoms (Asthmatics 9-11)	Pope et al. (1991	120,000
Moderate or Worse Asthma (Asthmatics, all ages)	Ostro et al.	120,000
Acute Bronchitis (Asthmatics, 9-15)	McConnell et al. (1999)	4,700
Chronic Phlegm (Asthmatics, 9-15)	McConnell et al. (1999)	12,000

Context

- We currently do not assign a separate monetized value to “asthma attacks” or other indicators of asthma exacerbations
  - Estimates are dated (Rowe and Chestnut 1986)
  - May not reflect current best practices
  - Often not a good match between what has been valued, i.e. a “bad asthma day” and what has been measured, i.e. a day with wheeze or an “asthma attack”
- Gives the impression that asthma impacts are unimportant relative to other health impacts

What do these 3 papers add?

- 2 valuation/epidemiological studies
  - Hanemann and Brandt stated preference will provide a specific WTP for asthma related symptoms plus an understanding of costs of averting and mitigating behavior
  - Mansfield et al. revealed/stated preference provides a lower bound check on WTP for ozone related asthma symptoms, reflected the value of reductions in averting behavior.
- 1 epidemiological/valuation study
  - Griffith et al. examination of link between air pollution and asthma medication use (could also provide a lower bound estimate of marginal cost of higher pollution levels)

Valuation

- Current estimates of values for asthma symptoms are based on:
  - Rowe and Chestnut (1986) WTP for a “bad asthma day” ($43)
  - Tolley et al. (1986) WTP for a day with coughing ($25)
  - Berger et al. (1987) WTP for avoided “coughing spell” ($80)
  - Dickie and Ulery (2002) WTP for a child’s “symptom day” ($160)
- Not clear whether any of these provide a direct match with the WTP for specific symptoms or clusters of symptoms associated with an air pollution related asthma exacerbation

Hanemann and Brandt

- Provides a consistent framework for estimating health outcomes and valuation, incorporating averting and mitigating behavior
- Provides information on both revealed and stated preferences
- Morbidity outcomes capture both incidence and severity
- However:
  - Does not appear to integrate information on ozone or other pollution predictions (alert days)
  - Full set of data won't be available for 4 years!
  - Not clear on the CV question format. Consideration of conjoint approach to allow for variation in the type and severity of symptoms to match the epi design.

Mansfield et al.

- Excellent temporal sampling design, especially in selecting survey days to control for ozone-temperature interactions
- Large sample with detailed activity diaries on days with high and low pollution levels
- Unique combination of revealed averting behavior data with stated preference data on value of averting behavior
- However:
  - Difficulties with benefit transfer because of the limitation to stay at home parents
  - Representativeness of the Harris Interactive panel is questionable
  - Would be useful to include ozone/PM directly in model rather than "code red" day dummy

Bottom line: Will the 2 new valuation studies provide us with acceptable estimates of WTP?

- Hanemann RP will work IF we can get epi functions that have treated exposure averting behaviors as endogenous (the FACES study seems like it might provide this). SP would benefit from a conjoint design. Long time frame for study still leaves us in limbo…..
- Mansfield et al. specification yields some relatively modest results → a code red day only reduces time spent outdoors by around 43 minutes for asthmatic children, and 32 minutes for non-asthmatic children. Based on the SP results, this is valued at around $4 for asthmatic children and $3 for non-asthmatic children. Fairly low relative to other estimates.

Asthma Epidemiology

- Most asthma studies use a small sample (<200) with a diary approach
- Examination of medicine use has been limited
- Medicine use may provide an endpoint for which cost information is readily available

Griffith et al.

- Creative use of available data
- Use of quarterly averages for pollution effects to capture longer term "excess" prescriptions seems appropriate
- Suggestions
  - Prescriptions are actually a measure of demand, conditional on asthma attacks triggered by high pollution levels
  - Derive the demand functions using a household production function so that the econometric specification will have a grounding in economic theory and can be more easily compared/combined
  - Prescriptions per capita is potentially not as relevant as prescriptions per asthmatic, especially for younger age groups where asthma prevalence is higher
  - Use of alternate ozone metrics, e.g. cumulative number of hours over 60 ppb, may show a stronger relationship.
  - PM2.5 may be a better indicator than PM10
  - Should include interactions between quarter and air pollution metrics to control for potential exposure differences
  - Controls for numbers of prescriptions for maintenance medications might be important effect modifiers, representing substitutes for averting behaviors or expected rescue medication use

Implications of Griffith et al. for impact assessment

- Based on the Model 2 results in Table 3, a program like the proposed Nonroad diesel rule which would reduce annual mean PM2.5 (and PM10) levels by about 0.5 ug, might result in over 250,000 fewer prescriptions per year. (note that CA alone has over 2.1 million prescriptions for "quick relief" medicines each year)
- The age and severity stratified Poisson results seem to make more sense for ozone, which may indicate that the pooled OLS model is not the correct specification

What Can We Learn by Integrating?

Everyone should use a household production framework

- Makes life easier for those trying to compare/contrast results
- Ensures that averting and mitigating behaviors are considered

The Role of Medication Use in Assessing the Benefits of Air Pollution Programs is Important

- Hanemann and Brandt results show that use of medicine to mitigate risks from exposure is potentially important
- Griffith results show that the impacts of air pollution on "quick relief" prescriptions is significant
- Remaining issue is how use of prophylactic medicine modifies the effects of air pollution on "quick relief" medicine use

Averting Behavior Matters

- Hanemann and Brandt show that some parents are aware of air pollution as a potential trigger for asthma. They include exposure averting behavior in conceptual model for WTP – however, need to assure that measures of averting behavior include those specific to certain triggers, i.e. air pollution
- Mansfield et al. show that time spent indoors by asthmatic children is related to information on ozone alerts, and that parents are able to provide values for that lost time outdoors.
- Not clear how Griffith et al. results might be impacted by averting behavior. Might be able to use ozone alert days in a quarter as a measure of likely averting behavior.

Conclusions

- Hanemann and Brandt are taking an important step by integrating the epidemiology and economic valuation studies, however, the estimating equations for the epi study should be derived from the same behavioral framework, perhaps including prices and income as exogenous variables
- To measure the benefit of air pollution reductions, a full understanding of how knowledge of future air pollution affects averting behavior needs to be integrated into the epi and valuation models. Johnson et al. are providing that type of understanding.
- Complete benefits models should take into account the endogenous nature of the full pathway including event aversion (preventative medicine), exposure aversion (reducing time outdoors), response mitigation (use of rescue medication), and response (loss of school days, doctor visits).
- All three of these papers use data from CA. A comparative analysis bridging all three datasets will be very informative.

Laurie Chestnut, Discussant Comments Session V, Air Pollution and Asthma in Children October 21, 2003

Common to all three studies

- All three of the studies consider one or more behavior choices that avert or mitigate potential health effects of air pollution for people with asthma. These represent new contributions to the literature on valuation of asthma cure, management and symptom reduction. Considering behavior choices is important because:
  - Benefits estimates based solely on epidemiology dose-response estimates miss most averting and mitigating costs, because the studies capture the health effects that occur after averting and mitigating has taken place.
  - This behavioral context provides an opportunity for revealed preference analysis.
  - Stated preference survey design is enhanced when a realistic context is given to the valuation questions, which household behavior and choices provide.
  - Surveys can be used to collect information useful for estimating household production models. These questions may be easier to answer than direct valuation questions.
- These studies will extend and deepen the literature where there are a limited number of empirical estimates available for:
  - WTP values for reducing the frequency of asthma symptoms
  - WTP values for asthma cure and asthma management
- All the studies face many challenges in dealing with asthma, which is a complex condition:

  Many factors and-------------> Onset of asthma -------------> Aggravation of asthma
  potentially pollution ^
  ^
  pollution and other triggers

  - Symptoms are intermittent
  - Great deal of heterogeneity among asthmatics regarding:
    - sensitivities to various triggers
    - frequency/severity of symptoms

Hanemann and Brandt – Specific Comments

- Study is focusing on asthma symptoms and exacerbations in children with asthma, and on household response and prevention efforts. Work is being conducted in association with an ongoing asthma patient research panel.

- Household production model

  - Conceptually sound

  - Good use of survey to obtain data on household behavior and perceptions

  - Challenges:

    - joint benefits of averting/mitigating activities, e.g. air conditioning

    - heterogeneity of sensitivities to triggers

    - timing dimension challenging to capture, e.g. symptoms, environmental conditions, activities, and household responses will all vary day-to-day

- Contingent Valuation

  - Good to use multiple valuation approaches with same subjects. Will have behavior information as well as answers to direct valuation questions.

  - Risk perception information should be helpful

  - Challenges

    - defining change in asthma symptoms is complicated by wide variation in frequency and severity of symptoms across subjects and over time.

    - linkages to epidemiology study results on asthma symptoms will be helpful for policy analysts, but sometimes difficult to define in valuation context.

Mansfield et al. – Specific Comments

- Good conceptual framework: How much do parents change children's time outdoors in response to ozone warnings? Sample includes about equal numbers of children with and without asthma.

- Internet survey approach with pre-selected panel allows efficient sampling of days with a range of ozone/weather conditions.

- Regardless of the WTP results, the study should proof informative regarding the public's response to the ozone warning system.

- Challenges:

  - Are about 3 days per subject enough for the planned analysis? This means the study is essentially a cross-sectional analysis making it harder to statistically identify the effect of ozone warnings.

  - Sensitivities to ozone vary among those with asthma—the asthma/non-asthma subject split may not be the best. Perceptions about sensitivity to air pollution are probably more important.

  - Odd preliminary results for the AWARE dummy variable indicating awareness of the ozone warning system. Might those who are more concerned about air pollution also be more aware of the system, making awareness more of an endogenous variable?

  - WTP to keep outdoor time is not the same thing as WTP to reduce asthma symptoms. The authors will need to think about how this information is useful to policy analysts. Should this WTP value be added to WTP to reduce pollution-related symptoms? How is the WTP value applicable in assessing benefits of pollution control?

Griffiths et al. – Specific Comments

- Addressing the question of whether purchases of quick relief asthma prescription medicines vary by location in relation to air pollution concentrations.
  - Quick relief asthma medicines are generally used in response to the onset of specific symptoms, rather than as a regularly used preventative medication.
  - Implications if the study finds an association is that asthma aggravations are more frequent in locations with higher pollution.
  - Use of quick relief medicine is a mitigating behavior expected to prevent symptoms from getting as severe as they might otherwise have.
- As with any cross-sectional study design, challenges are collinearity and unidentified confounders:
  - Quick relief prescriptions (counts or per capita rates) will capture higher prevalence of asthma as well as more frequent symptoms, unless the number of patients with asthma in each location is known.
  - Relative mix of controller and quick relief medicine usage may vary across locations because of differences in health care providers, socioeconomics, etc.
  - Density, poverty, traffic, pollution and asthma prevalence and management practices may be inter-related. This may have something to do with differences in preliminary results between PM10 and ozone. PM10 tends to be correlated with urban density, ozone less so because it tends to drift from original emission sources.
  - There may be differences across locations between average pollution concentrations and frequencies of pollution spikes.
  - Not normalizing the age group analysis by population size in an area could introduce population-related distortions. Using counts works fine for time series analysis where the population is stable day-to-day, but more problematic for a cross-sectional analysis.

Summary of Q&A Discussion Following Session V

Ronnie Levin (U.S. EPA, Region 1) commented that a study has been done in France on GI medications and drinking water quality "that has done some of what you're doing with time series and prescriptions—it's sort of a combination of time series and drug dispensures over time."

Ms. Levin also commented on the heterogeneity issue, which Laurie Chestnut dealt with, saying, "Yes, it's preferable for analytical purposes to use continuous vs. dichotomous variables. On the other hand, what *parents* get is dichotomous. So, if you want to not only test the *system* but really want to test the *effect*, it's the dichotomous variable that matters." She suggested perhaps just coding it, because "you lose information by reducing it all to continuous measures."

Shifting her comments to the asthma study, Ms. Levin stated that "17 percent of repeat hospital visitations are *not* people who are not following the orders—those are people who have severe asthma that is not controlled." She added that despite our desire and best efforts to reduce our exposures, both indoors and outdoors, that's not always an option, and she mentioned that available medications often don't provide real options either (she particularly cited the behavioral side-effects that many children experience on steroids). Furthermore, Ms. Levin noted that "high-performing athletes who have asthma" are exceptions, no more representative of typical asthma sufferers than Lance Armstrong, the most recent winner of the Tour de France, is representative of cancer survivors. She also clarified that "respiratory infection *does* cause asthma and people may use that as a reason to get through the gatekeeper, but these *really are* associated, and they're associated for lots of physiological reasons."

Ms. Levin acknowledged that parents of asthmatic children face tough challenges (saying "no, you can't go outside" or "you have to take this medicine"), and said it's important to recognize options. "Parents can mitigate their kids' behaviour without keeping them inside—they can reduce the activity level and still let them go outside. In all of this, there are sort of heterogeneity issues." She concluded with these statements: "One thing on the use of continuous vs. the ozone alerts—you're right, you want to test whether the ozone alerts are working, and you have to keep it in those discreet categories. But, I think you're missing an important dimension of the data. . . . Even if the parents don't know about the ozone alerts, the ozone itself can give them an alert by giving their kids symptoms, and that's what the Dickie and Bresnahan study shows: just using the marker of ozone levels, people *do* show reactions, and that's very evident in the data."

Sylvia Brandt responded, "Right, but one's a predictor and one's post hoc, so it's a different *timing* issue as well."

Glenn Harrison (University of Central Florida) offered what he considered "a number of small comments. First, to pick up on Michael's point about doing a real-world dimension contingent evaluation instead of stated preference. There are precursors, actually—this

Health Partners HMO again in Minnesota, plus several web sites for asthmatics actually do provide emailed alerts that are, to some extent, tailored." Dr. Harrison wondered why Dr. Hanemann expressed concern "about the hypotheticality and abstract state of preference but *not* about the contingent evaluation, since this is possible to do and eventually deliver."

A second issue raised by Dr. Harrison was in regard to household production functions, methodological factors common to a lot of the studies presented. Addressing Dr. Hanemann, he commented, "I heard what you're *saying* but perhaps what you're *talking about* is the difference between something being locally flexible as opposed to being applied and perhaps globally irregular or globally ill-behaved. . . . If you could just talk a little bit more bout that issue, that would be good.

Dr. Harrison continued with these comments: "Related to that, actually, I still have a sense, notwithstanding Bryan Hubbell's comments, that there's a lot of what I call 'toothbrush modeling' going on in this field, where everyone will say, 'I swear allegiance to the household production function,' but, frankly, that just lets you do anything you want to do . . . it's no constraint whatsoever, and that's the important thing that you were getting at, that there needs to be perhaps some *minimal* constraint. . . . So, in the spirit of looking for minimal constraints couldn't one, in the context of the *stated* preference stuff, use the counterpart of the Garp, the weak axiom of cost minimization, as a minimal test for some sort of rationality in the choices that you're looking at? That might provide a very useful metric for the quality of the responses that you're getting that is comparable across virtually all data sets."

Dr. Harrison agreed with what he termed the "very good comment about the repeat visits" and added, "You need to be *extraordinarily* sensitive looking at those data. If people, for example, are funded under Medicaid, . . . if you want to get repeat prescriptions or there's a slight change, you have to have another visit, and that's actually a major issue, and so the funding source interacts mightily there. Your point is well taken, but I wouldn't overemphasize that 17 percent."

Directing his final comment to Charles Griffiths, Dr. Harrison cited "a wonderful data set called the National Ambulatory Care Survey data set . . . which combines prescribing details in DCs and the ICD9 codes for the same patient by a doctor, not by self reports or anything like that." He added that these data cover "many, many years and you know the location." He cited the case of a graduate student of his who was able to use the data to help correlate respiratory illness with criteria air pollutant levels. He closed by adding that there's a companion data set from a survey of numerous hospitals that provides information on outpatient and ER prescriptions. He commented that although this data set is "not quite as nationally representative as the ambulatory care one, it would be a wonderful corollary source to look at."

Michael Hanemann responded, "I'll answer a *subset* of those comments. Let me just amplify what I meant with the health production functions. You see people doing something and then you see consequences—you see health effects. That's intentional behavior, and there's a connection, but it's a mistake to think necessarily that the person *knew* that *this* behavior would lead to *that* consequence . . . and it shows the behavior in a fine-tuned way." Dr. Hanemann added that he thinks it's more an issue for evaluation because it involves interpretation after the event "because *often* the marginal evaluation is conducted by measuring the marginal cost of an outcome, and that *assumes* . . . sort of fine-tuned optimization, which might be out of place." He expounded on this by adding that someone might say, "Yes, I spent $10, but the reason I didn't spend more than $10 is because this is the only thing I knew to do" rather than "the $10 was for *this* outcome. So," he said, "I think one wants to look at behavior and everyone wants to look at production functions, but I think you also want to look at *preferences*, and I think you want to be cautious about excessive evaluation of the margin based on an *x* cost estimate in marginal costs."

Addressing another of Dr. Harrison's comments, Dr. Hanemann stated, "Your suggestion about tests of rationality and consistency certainly makes sense." He continued by responding to Dr. Harrison's comment regarding the hypotheticality of stated preference in this fashion: "You know, what's hypothetical is in the mind. . . . The important thing, I think, is addressing and engaging the respondent—looking him in the eye and saying, 'Here's a trade-off.' And the trade-off could involve statements that are *entirely* at variance with the facts, and yet people can respond to them as though they are meaningful. So . . . the issue is not 'does this item really exist?'—the issue is 'does the person think there's a commodity there which is within his grasp?' And if you can get the person to wrap his mind around it, you're in reasonably good shape. The *trick* is to make the thing *match* the person's circumstances."

Dr. Harrison replied, "On that, I agree that there's an added artificiality of the matrix, given an SP. That's your point."

Don Kenkel (Cornell University) directed his question to both of the first two studies and said he "was wondering if there are data on other types of averting behavior" besides just staying indoors. He continued, "Smoking cessation is one that pops into my mind, but to show you that I'm not focusing just on smoking, I was also struck by the list of important causes of asthma and noticed that pets weren't even on there." He said he thought that maybe that's because people who find out that their kids have asthma immediately get rid of their pets, and he said this raises a couple of issues: "One is that this is another revealed preference kind of argument—you're giving up something—you're sacrificing something—the pet, in this case. You're giving up utility, and so that's another way of getting at the value of asthma." Dr. Kenkel closed by adding, "The other issue, especially for Reed Johnson's work, is really the *relative* indoor air quality vs. outdoor air quality—maybe it's better being outdoors on a bad ozone day than it is being indoors with the three cats and the mom smoking."

Sylvia Brandt responded by saying, "In our survey, we have about twenty different kinds of averting behaviors as well as five different pages of fixed things you can invest in to reduce exposure. The issue about the pet is actually a really good example of where families *do* make trade-offs. This came out in a lot of the focus groups, this balancing of *normality* versus asthma episodes, and so there are households where, yes, the child is allergic to dander—and that was one of the asthma triggers listed under allergies—but it's worth using the control or rescue medication at times the child needs it to keep the sense of a normal household. So these are some of the issues of trade-offs that we *are* looking at.

Unidentified woman: "Related to this last question: As you said, asthmatics spend more time indoors than non-asthmatics. What if that explains why they're asthmatic, because they're spending way too much time indoors? Is that something to consider?

Michael Hanemann: "No."

Sylvia Brandt responded, "I think it's often compensating behavior. A lot of the children we talked to basically became video game players because they *couldn't* go outside and play with the other kids."

Woman: "So, it's not like diabetes."

Bryan Hubbell (U.S. EPA/OAQPS) directed his comments to Reed Johnson and said, "I wondered why you actually got a lot of endogenous variables on your right-hand side—you had the TV and the games, which could be very much a function of severity of the asthma, as could the preference of being outdoors."

Reed Johnson: "I agree."

Hubbell: "There actually wasn't severity in any of your models, which was surprising."

Johnson: "Not yet."

Michael Hanemann added, "That's also why it's valuable to have something like asthma, which has a clinical diagnosis that goes along with it, so even if it's a self report, no one's going to declare that unless they've had a doctor tell them that."

Closing Remarks

Mark Dickie, University of Central Florida

First of all, thanks, of course, to all the sponsors. All of this was done with EPA money, so I want to thank all the offices of EPA that put this on and Ed Chu, Will Wheeler, Nicole Owens, and Kelly Maguire for lassoing everybody in and keeping things going in the right direction in organizing this. I'd also like to thank some folks from outside who have made sure that everything ran on schedule—the people from the contractor in from EPA, especially Tina Connelly and Denise DeShen, for all their effort in making this come off logistically, as well as John and David and Annie from SCG. Of course, I'd like to thank all of you for your participation and for the interesting and important research that was presented and for all of the great questions and discussion and so on.

You know, if you asked anybody to do this, I think we'd all sort of have a different list of what should be summarized as being important or interesting from the workshop. These are my subjective perceptions of the highlights, offered in sort of chronological order.

I'd first like to echo Ed Chu's comment that he made the first thing the first morning: the increase in the amount of research attention that children's health valuation has gotten now. Back in 1999 there really were almost no studies, except a couple by Tom Crocker and Mark Agee and then a few that sort of incidentally included kids or some kind of kid component along the way of doing some other type of research, whereas now there was all this stuff presented here, and there are things that weren't on the agenda that really could have been presented here, and there's a lot of research that's just getting started now.

A second thing is, of course, many of the presentations, especially on the first day, highlighted the importance of really understanding the structure of the household decision process. In Bill Schulze's paper that doesn't really matter because in his model you get the same willingness to pay expression to estimate whether you use his Nash bargaining model or a Becker type of approach, but I think that's not a general result. I know in Ted Bergstrom's paper it really matters what the household decision process is in terms of just what it is we should measure. That's a question that a lot of people have been asking since 1997, since the Executive Order—what should we measure when we're out to value kids' health? Whose willingness to pay counts? I think Ted Bergstrom's paper really advances our understanding of who we need to be talking to and what we need to count and do we add it up or take the minimum, and so on. I think that would highlight, too, the importance of testing between different models and how well they capture the household decision process, along the lines of what Sandy Hoffman was proposing to do in her talk.

A very much related idea is the importance of understanding how people in the household respond to environmental risks, and that was something that came up so many times in the workshop, starting with Mary Evans' paper and then on and on and on with the household production stuff and the asthma paper all about behavioural reactions and the revealed preference papers on the value of a statistical life. I think it's clear that we need to understand better how households react to these risks and how we can use that information for valuation, and Michael Hanemann pointed out some of the difficulties of doing that with the household production framework, even though that was featured kind of prominently here.

Understanding household behavior probably includes understanding the behavior of children and teenagers themselves, which is something we tend to ignore, but especially as kids get older and have more autonomy and they're doing things like driving one of the family vehicles, or choosing whether or not to wear their bicycle helmet, or going as a teenager to a tanning salon to get a suntan, or managing their own asthma medication. You know, we typically think of the parent as sort of controlling the behavior in the household, but that's clearly not true all the time, so I think maybe some more attention to the stuff that Bill Harbaugh was talking about and what drives children's behavior would really be relevant to the outcomes that children experience and maybe to how we value them, as well.

The fourth thing on my "top five list" was what can we learn from other areas of research such as family economics, health economics, psychology, and decision sciences? All those appeared in one presentation or another over the past couple of days.

And then finally, I think in the VSL session in each case the idea of somehow consistently treating morbidity and mortality risks came up as an important feature. In the first two studies it was injuries or death in a car or on a bike, and then in the last two it would be illness or death. Consistently treating those two is often going to be necessary to adequately value either one because of the connection between them.

So, that is my stab at a summary of some key points from the research.