Morbidity and Mortality: How Do We Value the Risk of Illness and Death?

PROCEEDINGS OF SESSION I: RISK ASSESSMENT AND VALUATION OF HEALTH EFFECTS FROM AIR POLLUTION (INCLUDING INTRODUCTORY REMARKS)

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U.S. EPA NCER/NCEE Workshop
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Introductory Remarks
William H. Farland, Chief Scientist, Office of the Science Advisor, and Acting Deputy Assistant Administrator for Science, Office of Research and Development

This is the 13th of the Economy and Environment Series workshops that have been sponsored by the Office of Research and Development's National Center for Environmental Research and the Office of Policy, Economics, and Innovation's National Center for Environmental Economics. The opportunity here is really to bring together a group of colleagues to think about some of the issues around approaches to valuation of human health effects—both mortality and morbidity. These kinds of issues are particularly important to the Agency.

The group that we expect to be interacting with over the next two-and-a-half days makes up a broad section of the scientific community and the economic community. Clearly, our colleagues from the National Center for Environmental Economics will be represented here as well as our Science To Achieve Results grantees, who have the opportunity to use Agency resources to explore many of these kinds of issues. We also expect EPA economists and other scientists from a number of our program offices as well as ORD and OPEI. In addition, we had a broad solicitation and have a number of researchers from academic institutions and other federal agencies, and we're particularly pleased to welcome our international guests for this program.

Again, our purpose here is really to learn more about research that improves our understanding with regard to the valuation of health outcomes, and to assure that the research that is done really feeds into opportunities for improving how we make our decisions. Now, I want to spend just a few minutes on this idea of the importance of the workshop, because as we look at research results, as we begin to think about the kinds of data that come out of the work that you all do, whether they're out of the academic or federal community, these results need to be credible and relevant and timely so they can inform the kind of policy decisions that EPA and many other federal agencies are making every day.

Clearly, the value of cost/benefit analysis is very high. If we look at things like the Executive Orders that are coming out and new legislation like the Safe Drinking Water amendments that really focus on having this type of information in order to judge the quality and relevance of particular options for environmental decisions, we see that this becomes extremely important. It really affects the way we do business now at the Agency for many of the things that are important to us. Clearly, accurate cost/benefit analysis leads to better decisions. It allows us to really understand, where appropriate, the role of economics in terms of environmental decision making, and we're really proud of the good relationship that has developed between the Office of Research and Development and OPEI with regard to these particular issues and advancing the state of the science.

So, as I said, the idea of human health valuation is a very important topic for the Agency. Clearly, it drives much of what we do. Particularly, as you begin to look at the issue of morbidity and mortality, we realize that our community has recognized that getting a handle on approaches to assessing morbidity is really a top priority for the field, and it strongly highlighted in the most recent environmental economics research strategy that the Agency has put forward. The challenge of trying to deal with valuation of morbidity is one that we'll talk a little bit more about, but it clearly is something that we need to put our collective best minds toward as we begin to think about how we approach it.

As you know, mortality valuation is always high profile and plays a very, very large role in many of the decisions that we make. It is the one area where we have made some significant progress in valuation. For some of the most recent Clean Air Act decisions, for instance the particulate matter decisions that have led to rules recently, more than 90 percent of the monetized benefits come out of these mortality valuations. So, again, we recognize the importance of mortality in trying to get the approaches to mortality valuation right, but we also realize the issue of how we approach morbidity and the very strong role that non-monetized benefits currently play and the importance of trying to value those.

So, over the next two-and-a-half days you'll have an opportunity to deal with a number of very important issues. Some of these are old favorites—if we think about asthma, pollutants in drinking water, lead paint and IQ loss, PCBs, and so on. Those are issues that we've all been dealing with for quite a while, but the field is really opening up for us. There are opportunities here for us to really emphasize things like children's health valuation. As you begin to think about that, think about it from the standpoint of children being differentially susceptible, in many cases, to some of the pollutants that we're dealing with. So, clearly their life stage and their lifestyle—their behavior—is very different from that of adults. At the same time, children are not full economic actors, if you will, so trying to look at the valuation of children's health impacts and even dealing with the issue of early life exposures leading to later life impacts becomes a real challenge for us. Clearly there are opportunities here for methodologic advances in valuing health risk reductions and modeling household decision making—again, a challenge for us as we think about the fact that our households are changing and the types of situations that we're looking at now are particularly important.

We're looking for an opportunity to deal with the issue of updates on cost-effectiveness analysis, mortality valuation, and efforts to include economic questions in our large-scale health surveys. Clearly, this is an integration of the field of monitoring and modeling health effects with the economic valuation of those effects. We are expecting to have a real opportunity to move forward.

One of the things that we're intending to do later on in the session is a panel discussion on the pros and cons of web surveys. Many of you are building web surveys into your protocols, and in the most recent OMB guidance there has been some concern raised about the use of web surveys. This is an approach that is heavily in use, and it's something that we need to look at very carefully so we understand the pros and cons.

Finally, at the end of the session, during the last half day, is something that we've not done before. It is an opportunity to focus, in depth, on a particular set of research results from a single grant that EPA has funded. This is a grant that has gone to UCLA and Oregon State investigators, and we're going to be very interested in your feedback on this particular approach for the workshop. We will focus in on a particular set of results and really have a half-day, in-depth discussion on that.

So, clearly, the research results that we are going to be talking about are going to be very important, and they are currently being used by the Agency. We're looking for opportunities to do things even better than we have in the past. Clearly, the record shows that previous results have been used in important analyses—our Section 812 report in the Clean Air Act, which actually lays out costs and benefits of Clean Air Act decision making, has illustrated the way that the Agency has been successful in laying out the economic benefits of the Clean Air Act. It is actually among the leading regulatory actions with regard to monetized environmental benefits of any of the actions that we take.

The results of our research have been cited by OMB in their guidance on mortality valuation. Some of you may remember the discussions that came forward on exactly how we were going to value mortality for the elderly and the advice that we got from OMB with regard to the so-called "senior death discount" and not discounting the issues with mortality later in life.

Certainly we expect the future to hold expanded use of these techniques, and we're looking forward not only to improving the approaches that we use for this, but also to being able to demonstrate results—to deal with things like our program evaluation ratings and other opportunities that we have to demonstrate how research is used to inform decision making and how those decisions can lead to improved environmental results.

So, looking toward the future, what research will we be looking to fund and support? Clearly, some of that will depend on the kinds of discussions that we have over the next two-and-a-half days. A lot of these issues have been foreshadowed in the Environmental Economics Research Strategy, and this provides a good opportunity for us to work within a framework of important research needs. Some of the things that are clearly going to be part of that research that we fund have to do with the fact that they will be results-oriented types of work; they will be things that we can apply routinely; they will focus on issues such as the question of benefit transfer, which is something that is particularly important as you get into understanding particular situations and applying that to a broader population or a broader situation. Another important issue will be the question of marginal risk changes, so that we can really get at the question of how we monetize over time with changes that occur with regulatory activities. It's very clear that the field is moving toward an inter-disciplinary approach, much like many of the fields that we interact with at EPA. We're looking forward to meetings like this one to really have an opportunity to hear from various disciplines that have a role to play in the important research that's going on.

With that I'll close and wish you well in terms of the research discussions that will occur over the next two-and-a-half days. I'd like to thank Will and the other organizers from both of the offices who co-sponsored this. I look forward to a very successful workshop. Thanks.

DRAFT

Willingness to Pay for Improved Health: A Comparison of Stated and Revealed Preferences Models

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Abstract:
In this paper we discuss two approaches to estimating the willingness to pay (WTP) for reduced asthma morbidity, contingent valuation and health production function. The study population includes 250 children ages 5-11 with clinically diagnosed asthma, residing in a section of Fresno County, California. Asthma symptoms, including coughing, wheezing and/or shortness of breath, ranged from mild and intermittent to severe and persistent in this group. Detailed health measures (including atopy and pulmonary function), utilization of health services, levels of antigens in the households and exposures to criteria air pollutants were collected as part of a five-year epidemiological study. We administered two economic surveys to measure 1) households' perceptions of risks to an asthmatic child, 2) averting and/or mitigating actions taken, and 3) households' stated willingness-to-pay for a reduction in their children's asthma morbidity.

In the health production model the health outcome is a function of exposure to asthma triggers, mitigating and averting behavior and household's perceived risks. We find that variation in WTP is explained by attitudes towards asthma specific health investments including concerns of associated risks and perceived effectiveness. The survey data indicate that households select from a small number of discrete health investments and that most risk reducing behavior are daily behavioral modifications with no relevant market prices.

We argue that the discrete nature of health investments and socio-cultural patterns of health care utilization make the revealed preference approach inadequate for the case of asthma. As an alternative we present a contingent valuation scenario that was specifically developed to minimize systematic variation in preferences for characteristics related to the scenario rather than the reduction in asthma morbidity. For this purpose, guided by extensive testing in focus groups, we selected a scenario based on a hypothetical asthma monitor that provides to the wearer an indicator of current asthma status.

INTRODUCTION

The economic concept of value implies a tradeoff. The monetary value of any item is defined in economics as the amount of money that a decision-maker – an individual, a household, or a firm, depending on the context – would be willing to exchange for the item. That monetary amount measures the worth of the item in monetary units in the sense that the exchange of this monetary amount has the same impact on the decision maker's wellbeing (utility) as the item itself.[1] The challenge for economic measurement is to identify a trade-off through which value can be measured. Revealed preference approaches work by observing actual choices by decision-makers and inferring the trade-off underlying these choices. Depending upon the nature of the choice (whether it is a discrete, continuous, or mixed discrete/continuous choice) the choice behavior may reveal the trade-off either directly (a simple discrete choice) or indirectly (the cases involving continuous choices) by permitting the identification of an underlying set of preferences which had motivated the observed choice behavior. In the latter case, the trade-off is inferred from the recovered preferences underlying the observed choice rather than directly from the observed choice itself. Stated preference approaches work by placing subjects in a survey or experimental setting and confronting them with choices that, directly or indirectly, reveal their preferences.

In the context of valuing health outcomes, the standard revealed preference approach assumes that health-related choice behavior reflects preferences for health outcomes that are generated by a perceived health "technology". This separation between preferences and production requires the researcher to differentiate between behavior that is an end in itself and behavior that is a means to an end. Consider, for example, assessing the value of good water quality at a beach from this perspective. In the case of amenity value, an individual's choice of which beach to visit (trading off cleaner but more distant beaches versus dirtier but closer beaches) bears directly on the trade-off of interest since going to a nice beach is presumably an end in itself. In the case of health outcomes, an individual's choice of which precautions to take (spending money to purchase goggles, taking an antibiotic before going surfing, etc) is a means to an end – namely, good health – rather than an end in itself from which the individual derives enjoyment per se. In the latter case, the valuation analyst has to disentangle the production component from the pure preference component that underlies the sought-after trade-off. We suggest that this complication may sometimes tilt the balance in favor of stated preference rather than revealed preference as the preferred valuation approach[2].

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[1] Generically, there are two ways to formulate the exchange: the maximum amount that the individual would be willing to pay (WTP) to obtain the item, if it is favorable, or to avoid it, if unfavorable; and the minimum amount of money that the individual would accept (WTA) to forego the item, if it is favorable, or to endure it, if unfavorable. The relationship between WTP and WTA is a separate issue that will not be pursued here. For simplicity, the discussion below focuses on the WTP measure of welfare.

[2] An important consideration in modeling health outcomes for children is the question of the identity of the decision maker. The decision maker is surely *not* the child but rather one or both of the parents; therefore, the framework is the household rather than individual decision making. Making the household the unit of analysis raises several important but difficult analytical issues that are addressed in other literature. In this paper we focus on the relationship between health preference function and health production function, and we make the simplifying assumption that household decisions regarding children's health reflect a unitary model of household preference and production.

We examine the application of the revealed preference and stated preference approaches to the valuation of reduced asthma morbidity. Our economic study was done in collaboration with an epidemiological study that was the most detailed socio-demographic, indoor air quality and pollution monitoring data collection effort to date (California Air Resources Board). Findings from multiple focus groups and two economic surveys suggest that the discrete nature of health investments and socio-cultural patterns of health care utilization make the revealed preference approach inadequate for the case of asthma. As an alternative we present a contingent valuation scenario that was specifically developed to minimize systematic variation in preferences for characteristics related to the scenario rather than the reduction in asthma morbidity.

This paper is organized as follows. In Section One we describe the epidemiological study and economic surveys used to collect household level data. Second, we summarize the average households expenditures related to asthma morbidity and conceptual limitations to using these costs as a measure of value. In the third section we present the standard household health production model. Conceptual limitations to the standard model are presented in the fourth section. Fifth, we present empirical evidence of these complexities and their implications for the household production model. Next we discuss how we used the findings from the first economic survey to create a contingent valuation scenario. Concluding remarks are included last.

1. Empirical Study

A. Study Setting

This project is a collaboration with an extensive epidemiological study of the effects of air pollution on asthmatic children [Fresno Asthmatic Children's Environment Study, FACES]. The study is located in Fresno, California, which has highest rate of asthma hospitalizations in California at 28.8 per 10,000 (California Facts, 2003). Located in the Central Valley of California, Fresno County has a population of 815,734 and this population 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 median 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 FACES cohort included children with clinically diagnosed asthma, residing in a section of Fresno County, California[3]. Children were 6-10 years of age at intake and were followed for approximately 4 years. The study population included children who had 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

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

criteria may be enrolled regardless of the severity of asthma. Children with major comorbidities that would confound the measurement of pulmonary function were excluded.

The FACES study screened 473 households, completed baseline interviews for 241 households, and retained 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, child sleeps at home less than five nights/week, and family planned to move within two years (Mann, 2003).

Demographics and characteristics of the FACES cohort are in tables 1. The percentage of blacks enrolled in the FACES program (13.7%) is greater than the percentage of blacks for the Fresno population (5.3%), while Asian Americans are underrepresented. The average age of children in the FACES cohort is between eight and nine years. 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. One observable characteristic of the FACES cohort that differs from the Fresno population is the frequency of smoking in the home.

Table 1: Demographics of FACES Cohort

Demographics	**Relative Frequency**
Race	
White	40.7
Hispanic	41.8
African American	13.7
Other	3.8
Male	58
At least one parent employed	90
At least one parent completed high school	88
Participant's health status	
Ever prescribed oral steroids	61
One or more hospitalization(s)	25
Positive skin test to at least one antigen	65
FEV1	1.06 (range, 0.51-1.59)
Any smokers in home	23%
Asthma severity	
step 1	27
step 2	46
step 3	24
step 4	3

Note: Based on baseline interviews completed as of June 30, 2002 (n=182). Severity scores based on the NHLBI guidelines.

B. Economic Surveys

Two economic surveys were conducted in the FACES cohort. The first survey, a written mail survey was conducted February to August 2004. This survey included detailed questions on asthma related expenditures, asthma related symptoms and activity limitations, and health beliefs. A total of 202 households completed the first survey (representing 209 children with asthma). The second survey contained a contingent valuation scenario and was conducted October 2005-February 2006. The purpose of completing two surveys was to explore the strengths and limitations of the two approaches to valuing children's health: stated preferences and household health model. In this paper we present the findings from the first survey to motivate our design for the contingent valuation scenario.

The median household size those completing for survey one was 4, (range: 2-9), and 41% of the households had two children under the age of 18. The survey respondent was typically the household member who interacted with the healthcare provider: 95% responded that they are the ones to take children to medical appointments. Employment status of the respondent varied: 37% were employed full-time, 27% were employed part-time, 11% were not employed but were looking, and 24% were not employed outside the home and were not looking for employment. The distribution of household income for participants that completed the first economic survey is reported in Table 2.

Table 2: Household Income

Household income	Relative Frequency
Less than $10,000	11.5
$10,000 to less than $20,000	11.5
$20,000 to less than $30,000	8.2
$30,000 to less than $40,000	15.9
$40,000 to less than $50,000	11.5
$50,000 to less than $75,000	19.2
$75,000 to less than $100,000	12.6
$100,000 or more	9.3

Note: Total responses =182

Tables 3 and 4 describe the asthma status participants who completed the first economic survey. Following the GINA recommendations, asthma severity was based on frequency of daytime and nighttime symptoms. Less than 20% of the children had severe day or night symptoms. More children had moderate symptoms in the day than at night (43% versus 35%), and consequently more children had mild symptoms at night than during the day (46% versus 38%). There was a high degree of correlation between day and nighttime severity.

Table 3: Count of Asthma Severity by Day and Night Symptoms

	Nighttime Symptoms			
Daytime symptoms	**Mild**	**Moderate**	**Severe**	**Total**
Mild	64	11	1	76
Moderate	26	53	8	87
Severe	2	6	31	39
Total	92	70	40	202

Note: Mild is defined as symptoms less than two times a week. Moderate is defined as symptoms 3-5 times a week. Severe is defined as symptoms every day.

The majority of respondents had prescriptions for a rescue and controller medication.

Table 4: Frequency of Medication Usage

	Percentage who have prescriptions for:	
Number of Medications	**Control Medication**	**Rescue Medication**
None	13	14
1	15	44
2	25	38
3 or more	47	4

Of the survey respondents 79% reported that no one smokes in the home: of respondents that reported smoking in the home 58% reported that the father smoked, 28% reported maternal smoking and 20% reported that another adult smokes in the home. These smoking rates are below that for the Fresno population, but are inline with those for the FACES cohort.

2. Costs related to Asthma

A. Health expenditures

Direct expenditures on asthma were broken into four categories: fixed costs[4], household supplies, pharmaceuticals (prescription and over-the-counter) and alternative therapies. Variable costs are the sum of supplies, pharmaceuticals and alternative therapies.

Table 5: Asthma Related Expenditures

	Median	**Mean**	**Standard deviation**	**N**
Fixed costs	240	357	716	202
Variable costs	110	139	114	199
Household supplies	49	81	86	202
Pharmaceuticals	37	53	61	202
Alternative therapies	0	4	22	199

Note: Fixed costs included service costs or purchases of: air filters, allergy mattress covers and/or pillow covers, humidifiers, dehumidifiers, air conditioners, HEPA vacuum cleaner, landscaping of yard, carpet removal, pest extermination, mold/mildew removal, removing pets, humidity gauge, nebulizers, peak flow meters, spacers for inhalers, replacement for window coverings, and fans. Household supplies include: replacement filters for air filters, filters for air conditioners, HEPA vacuum filters, heater filters, cleansers for mold and mildew, hypoallergenic or non-aromatic cleaners, allergen control sprays, sprays for pest removal. Pharmaceutical costs included: prescription asthma or allergy medication, over the counter allergy or asthma medications, herbal remedies, and home remedies. Costs related to alternative therapies include visits to: chiropractor, acupuncturist, doctor of osteopathy, homeopathic/herbalist, nutritionist, spiritual healer, or other alternative health care provider.

Indirect costs related to asthma morbidity include employment impacts and time used for planned or unplanned medical visits (including in-clinic and emergency room). Of the 202

[4] For fixed investments we delineated 1) purchased specifically to help asthma 2) purchased prior to asthma diagnosis 3) never purchased.

households, 43% reported that they usually needed to take time off from work to take their child for medical appointments, and the median time taken off from work for each medical appointment was 75 minutes (mean 83 and standard deviation 37 minutes). Twenty- four percent of the families reported that they had gone to the emergency room for the child's asthma in the previous 12 months, requiring a median of 215 minutes per visit (mean 211 and standard deviation of 128)[5]. Although lost work time due to asthma is one indirect cost of asthma morbidity, 18% of the households reported changes to their employment due to the frequency or severity of their child's asthma. Of those that had changed their employment status: 28% had been subjected to employers reducing their work hours due to previously missing work for child's illness; 22% had been fired or laid-off due to missing work for child's asthma; 38% had chosen to not seek employment outside the home due to child's asthma; 32% chose to work only part-time due to asthma; 27% worked fewer hours during asthma seasons. These statistics suggest that limiting indirect costs to workdays lost underestimates the impact of asthma morbidity on household income.

B. Limitations to Costs as a Measure of Value

There are three reasons why using expenditures and indirect costs as measures of value of reducing asthma morbidity has shortcomings. The first is that there is an important difference between the concepts of cost and value, the latter being the concept of interest to economists. The second issue is the critical distinction between marginal and non-marginal value. The last limitation is that these cost miss larger impacts of asthma morbidity on households. We discuss each of these in this section.

Economists have been aware of the fundamental distinction between *what things cost* and *what they are worth* ever since Adam Smith exposited the diamonds-water paradox (water is essential for life but inexpensive, while diamonds are entirely inessential but extremely expensive). Both may be important to know, but they are different things. What something costs is a question about *supply*; what it is worth is a question about *demand*. What something costs is *objective* and a matter of production and engineering; what it is worth is *subjective* and a matter of preference and taste.

The distinction between marginal and *total* value also underlies the diamond-water paradox is. *At the margin,* an additional kilo of water may have a lower value to people than an additional kilo of diamonds because water is abundant while diamonds are rare, but the *total* value of all water to mankind is likely to be greater than the total value of all diamonds: if we lost all access to water, people would surely judge this a greater harm than losing all access to diamonds. Similarly, Dupuit emphasized the distinction between marginal and *infra-marginal* value. Dupuit observed that, for any consumer and any commodity, while the last unit of an item to be consumed would be just equal in value to its price (which is why it is the last unit to be consumed), the infra-marginal units would be worth *more* than the price because of the phenomenon of diminishing marginal utility. For the infra-marginal units, the consumer would be willing to pay more than the price. Hence, the consumer receives a sort of "profit" or "surplus" on these units which he would lose if the item were not available at that price. This observation provides the foundation for Dupuit's concept of consumer's surplus – the excess of

[5] Total time spent on medical visits and emergency room visits will be reported in future work.

what a consumer would be willing to pay for an item over and above what he actually does pay. If the consumer had valued all units of the item exactly at their price his consumer's surplus would be identically zero, but this does not generally happen. Dupuit's larger point was that value is measured by reference to the consumer's demand curve – by what we now call the Marshallian consumer's surplus[6].

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The third limitation of the expenditure approach is that beyond the indirect and direct costs there are psychosocial impacts on the households from asthma morbidity. These impacts include changing family activities, interactions with peers and the burden of uncertainty surrounding the status of a child's asthma. For example, in focus groups parents frequently discussed difficulties in communicating their child's needs to school officials and to physical education teachers in particular. In our survey 21% (out of 170 responding) disagreed with the statement "My child's classroom teachers are helpful with my child's asthma needs." and 24% (out of 140 reporting) disagreed with the statement "The physical education teacher works with us to include my child." Other impacts were restrictions on normal childhood play: 38% of respondents (n=200) reported that they restricted the *amount of child's activity* more often specifically due to asthma; 46% of respondents (n=201) reported that they restricted the *amount of time outside* more often specifically due to asthma; 44% of respondents (n=201) reported that they restricted the *where the child could play or visit* more often specifically due to asthma. A more dramatic, though less frequently reported change (11 households out of 199 reporting), was moving to a new home to avoid asthma triggers and to improve the child's asthma. The frequency of these impacts and extent to which they affect quality of life suggests that using expenditures to measure value of reduced morbidity misses the complexities of how asthma affects household behavior.

In short, economic valuation is generically about what things are worth, not what they cost. While costs may provide some information about how households value health, costs alone are not adequate measures. In the next section we present a standard household health production model and discuss some conceptual challenges in applying it to valuing children's health.

3. Revealed Preference Approach to Valuing Reduced Asthma Morbidity

A. Health Production Function

We begin with a standard model for household health and to then proceed to show how it is a special case of the Lancaster-Maler utility model. The critical characteristic of the indirect utility function of the household health production model is that it has the same structure of the indirect utility function produced by the Lancaster-Maler utility model, and hence the implications of the Lancaster-Maler for welfare measurement are applicable to the case of the health model. We begin by developing the indirect utility function for the health model.

In the standard model, marketed commodities are divided into two groups, those which have some relation to health (z) – either in preventing ill health or in curing illness once it occurs – and those which have no relation to health (x). The corresponding price vectors are denoted p_x

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[6] Hicks (1941, 1943) formalized Dupuit's and Marshall's concepts of the difference between the value of infra-marginal units price and their concept of consumer' surplus. Hicks formalized what Dupuit and Marshall asserted in terms of what he called the compensating and equivalent variation.

and p_z with individual elements denoted p_i and p_j, respectively. One could further subdivide the health related market consumption activities into those which promote good health and prevent illness (e.g., taking asthma control medication regularly), z_A, sometimes called averting behaviors, and those which reduce the adverse effects of falling ill (e.g. taking an asthma rescue medication), z_M, sometimes called mitigating behavior, so that $z = (z_A, z_M)$. For our present purpose, we can just work with the vector z. Health status could be a scalar or vector of health states or outcomes but, for simplicity, we will treat H as a scalar here.[7] Finally, q is some measure of environmental pollution that affects health. Thus, for the household there is a health production function given by:

$$H = H(z,q)$$

where

z is a vector composed of averting behaviors (z_a) and mitigating behaviors (z_m).

There are several alternative formulations of the household's preferences, depending on what enters the household's utility function. Obviously, household health (H) and the consumption of non-health-related market commodities (x) enter the utility function. The question is whether any of the elements of z and/or q enter the utility function as well. The point is that, while z and q affect household utility *indirectly* through their influence on health/illness, H, they could also affect household utility directly if it cares about q or z for motives unconnected with their effect on H. The empirical evidence from our surveys suggests that both z and x are important elements of the household's utility. Thus we will use the most general case is where all of the variables affect household utility directly, and the household maximizes utility subject to the health production function and a budget constraint (Y= income):

$$Max_{x,z} \quad U = U(x,z,q,H)$$

$$\text{subject to } \; H = H(z,q) \quad \text{and} \quad p_i x_i + p_j z_j = Y$$

The result is a set of ordinary demand functions for all market goods, both non-health-related and health-related, $x_i = x_i(p_x, p_z, q, Y)$ and $z_j = z_j(p_x, p_z, q, Y)$ and a corresponding indirect utility function $v(p_x, p_z, q, y)$.

If we compare the indirect utility function produced in the health model $v(p_x, p_z, q, y)$ to that in the generalized Lancaster-Maler utility model, v(p,q,y), we can see that the former is a special case of the latter in which prices have been partition into non-health related good and health-related goods. The difference between the Lancaster-Maler model and the standard household health production model is simply that the household health production model makes the health production function explicit and implies that the production function can be estimated separately from the pure preferences represented by U(x,z,q,H).

[7] In this highly simplified version of a unitary model we are not bothering to distinguish between the health or illness of the different members of the household.

B. Welfare Measurement with the Household Production Model

Recall that within the Lancaster-Maler framework, a consumer's utility depends not only on his consumption of market commodities, denoted by the vector x, but also on some other items, q; the utility function is thus u(x,q). While the consumer controls the level of x, subject to his budget constraint, q represents some things that affect the person's welfare but which he does not control. The Generalized Lancaster-Maler model provides both a theory of how q affects the consumer's choice of market commodities (x) and a framework for welfare evaluation of changes in q. The specific implication for purposes of valuing morbidity in children is that the Hicksian compensating and equivalent variation are expressed in terms of the indirect utility function. In the most general case, all elements (p',q',y') can change to a new level (p",q",y") and indirect utility can change from v(p',q',y') to v(p",q",y"). Then the compensating variation for this change is the quantity C such that

$$v(p'',q'',y''- C) = y(p',q',y'),$$

while the equivalent variation is the quantity E such that

$$v(p'',q'',y'') = v(p',q',y'+ E).$$

If the change is an improvement in the sense that u"> u', the quantity C measure the consumer's willingness to pay (WTP) for the securing the change, while E measures her willingness to accept to forego it, and vice versa if the change entails a reduction in utility. We can use the concepts of compensating and equivalent variation as measures of the economic value of a change in environmental health risks for children.

Consider two important polar cases with regard to the impacts of the change in environmental health risks: A) The change in environmental health risks could simply and automatically trigger a reduction in the family's disposable income, but with no other concurrent effect, so that the change is from (p,q,y') to (p,q,y"). (B) The change in environmental health risks could simply trigger a change in q, with no other concurrent effect on p or y, so that the change is from (p,q',y) to (p,q",y). In the first case, the direct effect of the environmental change is that the household has less disposable income but everything else remains the same: the impact is equivalent to a lump-sum reduction in income. The only impact is a purely monetary loss and the economic value of this is the monetary loss itself. In the second case, by contrast, the direct effect of the change is a loss of utility – wellbeing – for the household, C and E are different, and they represent alternative ways of expressing this loss monetarily in terms of a loss of income that is equivalent in the magnitude of its impact on the household's wellbeing.

The practical implication of the distinction between (A) and (B) is that, in the first case, one can get along with information on the magnitude of the monetary loss without necessarily knowing anything about the structure of household preferences, u(x,q), while, in the second case, one cannot avoid the need to know about household preferences. In that case, the comparison between revealed- and stated-preference approaches to welfare measurement will hinge on the relative ease and reliability of the two approaches in providing an insight into the structure of household preferences. We argue below that characterizing household preferences is essential to defendable welfare measurement and present the limitations of using the household health production model, as typically applied, to measure welfare changes. In the next section we present two areas in which these limitations arise:

- Use of the health cost function to estimate the value of a change in health due to a change in pollution.
- Validity of a production function for health.

4. Conceptual Limitations of the Household Production Model for Welfare Measurement

A. Health Cost Function

First we describe a common use of the health cost function to estimate the value of a change in health due to a change in pollution. For purposes of illustration, we assume that there are no changes in the price of any market goods (p_x, p_z) or income (Y), and environmental quality changes from q_0 to q_1. This scenario is equivalent to Case B described above, and here we describe the limitations to the standard approach to estimating a welfare measure in this case. Suppose the change is for the worse, so that $U_0 \equiv v\left(p_x, p_z, q_o, Y\right) \geq U_1 \equiv v\left(p_x, p_z, q_1, Y\right)$. In this case the equivalent variation measure (denoted E above) is the household's willingness to pay to *avoid* the change. The marginal WTP to avoid is given by:

$$\left.\frac{dE}{dq}\right|_{E=0} = \frac{v_q(p_x, p_z, q, Y)}{v_y(p_x, p_z, q, Y)}.$$

Moreover, by suitable manipulation of the first first-order conditions for the solution to the household's maximization problem, one obtains

$$\frac{v_q(p_x, p_z, q, Y)}{v_y(p_x, p_z, q, Y)} = \frac{u_q(x, z, q, H)}{v_y(p_x, p_z, q, Y)} + \underbrace{c_q\left(p_z, q, H\right)}_{\substack{\text{derivative of health cost}\\ \text{function w.r.t q}}}$$

Recall that we presented the most general utility specification in which environmental quality, q, entered directly into the household preference function. If instead we restricted environmental quality to entering the health production function only, in which case the preference function takes the form U(x,z,H), then the first term above would drop out. Then under this special case the expression becomes:

$$\frac{v_q(p_x, p_z, q, Y)}{v_y(p_x, p_z, q, Y)} = c_q(p_z, q, H)$$

This simplification has given rise to following pragmatic approach to measuring the marginal value of pollution in a household production context: (1) Estimate the household health production function, H(z,q). (2) From the health production function derive the corresponding health cost function, $c(p_z, q, H)$. (3) Given the health cost function, calculate the marginal cost of pollution, $c_q(p_z, q, H)$ and assess the value of the given change in pollution, dq, as the product

$$\text{Value of health damage} = c_q(p_z, q, H)\, dq \,.$$

An attractive feature of the expression above for researchers who use it is that it is only requires information derived from the health production function and it avoids the need to use information about the household's utility function. We believe there are two major flaws in this approach. First, as discussed in the second section, the appropriate measure for valuing welfare change reflects the difference between the margin and infra-marginal unit. The expression above considers only the market-clearing price not the Marshallian consumer's surplus. Our second concern with this approach is the assumption that neither q nor z enters the utility function directly: The construction of the utility function as U(x,H), which omits both the health inputs and environmental quality seems contrary to observations about household preferences[8].

In Section Five we present empirical evidence of three ways in which health averting/mitigating behaviors are central to the concept of the preference function.

B. Validity of a Production Function for Health

While the notion of a health production function is illustrative in the discussion of household choice, the extent to which it captures the complexity of trade-offs in the household is questionable. The conceptual concerns regard the deviation between objective and subjective risk assessments and the degree to which health is determined by individual choice.

In the literature on revealed preference valuation of market commodities based on their attributes, researchers have often found that here is a divergence between the objective measures of attributes and people's perceptions of them. Whether people see a beach as clean, an automobile as safe or comfortable, a computer as high-tech looking, say, is a matter of

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[8] The household production literature often makes reference to an approach to welfare measurement derived from work by Bockstael and McConnell (1983) based on the demand function for z's or I. Bockstael and McConnell *do* permit q to enter the utility function directly, but not the z's. they show that that the Hicksian measure of WTP for a change in q can be measured exactly from information about the demand function for health, H, or the demand function for one or more of the z's that are input to the production of health. There are two qualifications that are critical to the application of their result to the health production context. The first qualification is that their result is about the area under the *compensated* demand function for H or for the z's, not the ordinary demand function. If there are income effects in the demand for H or for the z's, the two demand functions are different and it is not valid to use the area under the ordinary demand function as an approximation to the area under the compensated demand function. These areas involve a price change from the current "price" (marginal cost) of H to the cut-off price at which the demand for H would become zero, which is by no means a marginal change. Hanemann (1980) showed in an analogous situation that the difference in areas can be quite substantial. The second qualification is that preferences satisfy Maler's (1971, 1974) property of weak complementarity with respect to either H or the z's. In this context, weak complementarity implies , that, if a person is in poor health ($I = 0$), she is indifferent to a change in air quality (q). That seems unlikely to be true. Indeed, one can imagine circumstances under which, as long as the person is still alive, a worsening in air quality becomes more serious to her when she is ill ($I = 0$) than when she is healthy ($I > 0$). Bockstael and McConnell were thinking of a household production function for recreation, not health, when they wrote their paper about weak complementarity and the fact is that their analysis seems ill-suited to health applications.

perception. How people see these attributes can be quite different from how an expert would assess them. But, people's choices are likely to be based on their own perception and understanding of the attributes, not on those of the experts. Therefore, researchers often find that, to model choice behavior successfully, they need to elicit the decision makers' subjective perceptions of attributes involved in the choices. The same can be true of household decision making on health production. What may matter is what the household – the parents – see as efficacious courses of action, not what the medical experts or the econometricians determine to be efficacious. Another way of making the same point is to suggest that, while households' decisions are based on ex ante expectations of the effectiveness of health producing actions, what the econometrician measures when fitting a health production function is the ex post outcome. If there were perfect knowledge or rational expectations, the ex ante expectation and the ex post outcome would coincide. To the extent that these conditions are not met, the ex post household production estimated by the econometrician might be misleading as a guide to understanding household choice behavior. If this is so, it has the potential to bias not only the estimation of the production function but also the estimation of household preferences.

The concept of a household production function implies that the household exercises a degree of control over its member's health that is exaggerated and unrealistic from at least two perspectives. First, postulating a household production function H= H(z,q) implies that, for given q, the household can in principle attain *any* desired level of health, H, providing it has sufficient financial resources to cover the cost of the required z's. If it is rich enough to purchase sufficient z's it can make itself as healthy as it wants, regardless of what might befall it in terms of q. From introspection, this notion is implausible. Second, the notion of an interior solution to the household's health production decision is unrealistic. It is conventionally assumed that, in the context of the household's production function, the z's are finely divisible, so that the household arrives at an exact, interior solution to its optimization decision. Households often face a limited and constrained set of options. These constraints may be imposed by the structure of the healthcare sector and the nature of averting/mitigating behaviors.

Thus, while the notion of the household's production of its own health certainly has some basis in reality, it can be pushed too far. People can look after their own health, but this does not mean that they can achieve *any* desired health outcome; therefore some levels of H are not attainable, regardless of the input of z's. The production function H(z,q) is likely to be bounded and it may have some flat segments. Similarly, people do not have an unlimited array of options and therefore they are more likely to be at corner solutions than interior solutions in their household production decisions. As Bartik (1988) has noted: "Defensive options often may be limited; for example, a household seeking to reduce the effects of toxic waste on its water supply might be able to defend itself only by a water filter, bottled water, or moving away."

If these doubts are justified, this can have important implications for health valuation. The usual first-order conditions do not hold and the simple approximations are apt to be unreliable. The household's marginal WTP for improved health might be considerably larger than the marginal cost, c_q, but it may have no viable option for further action. Also, in this case non-marginal valuation can become more complicated because of the need to specify a realistic, non-monotonically increasing health production function or a limited choice set with a few discrete alternatives.

We suggest that these concerns lead to five practical limitations of the approach: 1) defining the health outcome, especially for chronic, episodic conditions such as asthma, is nontrivial 2) households' have varying degree of control for relevant health inputs 3) there is a probable divergence between an objective physiological health production model and the household subjective perception 5) there is likely to be endogeneity between choice of z and H. We present evidence for each of these in Section Five.

5. Empirical Evidence of the Limitations of the Household Production Model for Welfare Measurement

A. Health Cost Function

In Section 4.A, we suggest that simplifying the household model such that environmental quality, q, and health inputs, z, appear only in the health production function and not the utility function, does not capture the complexities of household tradeoffs. In this section we present three examples of ways in which the averting and mitigating behaviors play important roles in the household preference function.

1. Preferences for Health Inputs

Although the majority of the households reported that their children took medications to treat asthma, 30% reported that they had concerns about those medications. A surprisingly common concern was that taking asthma medication as prescribed could lead a child to become addicted or dependent to asthma medication (49% agree or strongly agree, n=187). Other households reported that they believed that having to take medications regularly was embarrassing to children (23% agree or strongly agree, n=189). These concerns over medications affect how a household perceives their benefit and omitting their consideration distorts the model of household choice. In addition to these general concerns, households reported both that their child experienced negative side-effects from asthma medications as well as a belief that these drugs presented a risk to children's health. Table 6 reports the frequency of that household reported their child experiencing side-effects for specific drugs as well as the frequency that household reported that they believe children in general experience side-effects. Note that 29% of households reported their child having side-effects from oral steroids, 27% reported side-effects from rescue medications (albuterol) and 16% reported side-effects from control medications (inhaled steroids). Medication is the largest category of direct costs for a typical asthmatic; however, the market prices of these medications do not reflect the perceived costs to households. Experiencing negative side-effects is likely to have substantial influence on household behavior and this should be incorporated into the preference function to adequately measure and welfare changes.

Table 6: Frequency of Reported Side-Effects and Perceived Side-Effects

Medication	Personal	Others
Oral steroids	29	37
Albuterol	27	20
OTC allergy medications	18	13
OTC cold/flu medications	18	15
Inhaled steroids	16	16
Antiobiotics	16	9
OTC asthma medications	13	10
Intal	10	5
Tylenol	8	3
Vitamins	5	5

Note: Personal is the percentage of households *reporting their child having* side-effects as a result of that medication. Others is the percentage of households reporting they *believe children generally* have side-effects as a result of that medication

2. Adherence to Prescription Medication

Even if prescription medication did not enter the household's preference function directly, there would still be difficulties in using the observed household choice. This difficulty stems from the imperfect information and uncertainty surrounding actual prescription medication usage. Much attention has been given in the public health literature on the discrepancies between national guidelines on prescribing asthma medication and actual prescribing patterns. Furthermore, even if the prescriptions do meet the asthma management guidelines, there is ample evidence of non-compliance on the household level, and moving households towards appropriate usage of medication is a major goal of many asthma interventions. The first hurdle to adherence to prescription medication is ensuring that the prescription is filled: in our sample 25% of the households (n=210) report that they had at some time been given a prescription that they were not able to buy because it was too expensive. It is unclear whether not filling the prescription reflects a fully informed trade-off by the household or the result of a subjective assessment that underestimates the benefits of medication usage. For example, use of asthma medication to control the chronic inflammatory component of asthma is a case of investment under uncertainty. In order to decrease inflammation, control medications need to be taken consistently for 4-6 weeks which leads to a delay between taking the medication and experiencing the benefits. After this fixed investment, the benefit is the reduction of the probability of an asthma exacerbation. Families may be unwilling to make the investment in a prescription medication it the benefits are uncertain and occur in some future period. A more complex issue is the difficulties of communicating to households that the benefits will not be realized until after the initial investment, and there is substantial evidence in the public health literature that households confuse the delayed benefits of control medications with the more immediate benefits of rescue medications.

Within our sample, 17% of those prescribed a control medication were not taking the medication in the manner in which it is intended and of those prescribed a rescue medication, 43% were not taking the medication as intended. These patterns suggest an over-reliance on rescue medications, which has been reported in other populations (Boschert, Sadof, Brandt, 2006). The frequency with which households incorrectly use the rescue medication not only reflect what can be thought of as an inefficiency in health production in the current period, but it also perpetuates the inefficiency into future periods. Approximately 15% of the households reported that the prescription medication used by their child had either worsened their child's asthma or left it unchanged. These assessments are likely to drive the choices over medications in the next period, and if they are a result of non-adherence, then "non-optimal" choices could be perpetuated.

While the causes for non-compliance are complex and not well understood, it does suggest that using observed expenditures on medications may be confounded by factors other than preferences over health states.

3. Non-market Behavioral Choices

In addition to using medication to treat both components of asthma, chronic inflammation and acute bronchial constriction, standard asthma management guidelines include recommended behavioral changes. Most of these behavioral changes are focused on reducing exposure to possible asthma triggers (Boschert, Sadof, Brandt, 2006). Table 7 lists the changes undertaken on a regular basis as well as large, one-time changes that were made to prevent asthma exacerbations.

Table 7: Non-market Household Mitigating and Averting Behaviors

Routine Behaviors	**Frequency**	**N**
Check for smog alert 2 or more times a week in summer	83%	190
Change activity on high smog days	78%	189
Dusting frequently	59%	200
Vacuuming frequently	59%	200
Mold removal	51%	197
Close windows	46%	199
Restrict amount of child's time outside	46%	201
Restrict where child can play	44%	201
Restrict amount of child's activity	38%	200
Limit where pet can spend time	31%	154
Restrict child's diet	15%	196
One-Time Changes		
Move household to avoid triggers	6%	199
Stopped smoking	15%	189

In focus groups parents reported that these averting behaviors required both substantial time investments and a level of persistence, which in itself was a burden on household relations. A second observation from the focus groups was that when households were asked what they do to prevent asthma exacerbations, the first reported changes were of the type listed above, not purchases nor taking medication. Our interpretation is that these behaviors are pertinent to how household's perceive the impact of asthma, because these are behaviors that they must maintain over time. The implication for data analysis is that because there are no markets for these regular choices the market data that are used in estimating a cost function are incomplete. Second, households described the fatigue from constantly monitoring their child's health and modifying the home to reduce triggers and this psycho-social burden is not reflected in any market data.

B. Validity of a production function for health.

In section 4.b we discussed conceptual limitations of the health production function. Here we discuss findings from the survey that suggest how these conceptual limitations apply to the case of valuing asthma morbidity.

1. Defining health status

Characterizing asthma severity is the subject of substantial epidemiological research, because of the difficulty of capturing the natural variation in frequency and degree of symptoms. In our focus groups we asked households to describe what they consider "typical", "good" and "bad" asthma days. This process generated a set of impacts commonly used to describe asthma morbidity and included many impacts in addition to the standard asthma symptoms or healthcare utilization. The impacts considered important to households included symptoms (wheezing or coughing, shortness of breath, black under eyes, increased mucous/phlegm or sputum, ribs showing, easy of breathing), activity limitations (interrupted playtime, ability to walk stair, ride bike or jump rope, ability to talk and sing) and social impacts (avoiding places with triggers, restricting time outdoors). Social impacts were used 79% of the time to describe asthma morbidity, activity limitations were used 96% of the time, and physical symptoms were used 98% of the time. This finding is consistent with the literature that suggests that households tend to describe the severity of their medical condition in terms of activity limitations or impact on quality of life, where as medical professional tend to categorize severity based on frequency of physical symptoms. For the purposes of estimating welfare effects of morbidity, it is the household perspective that matters and drives behavior. Furthermore these impacts affect households much more regularly than do the extreme events of emergency room visits or hospitalizations. Table 8: Asthma Related Morbidity, presents the percentage of household who report that their child experiences limited activity levels, a social impact or a physical symptom on each type of asthma day.

Table 8: Asthma Related Morbidity

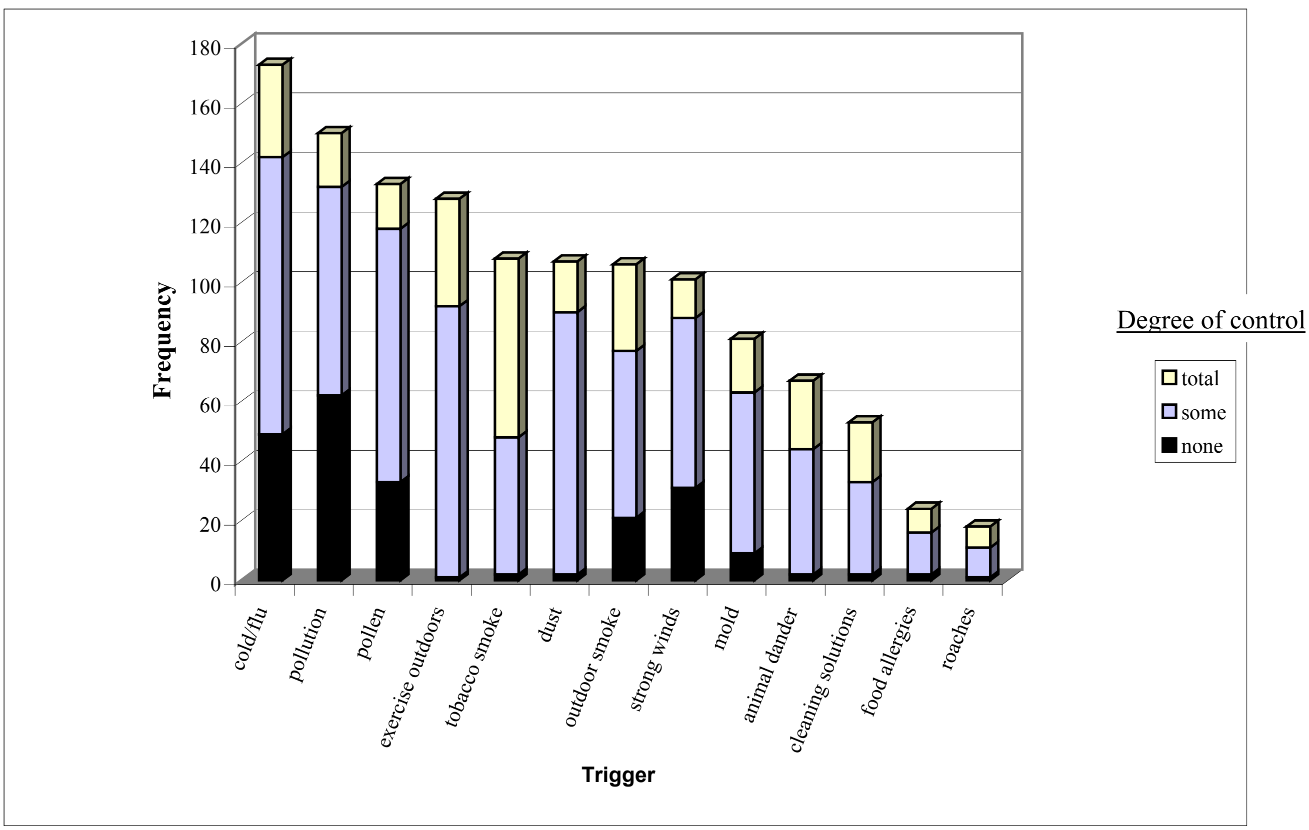
	Percent experiencing		
	Limited activity level	**Social impact**	**Physical Symptom**
Good day	13	29	28
Normal day	47	43	63
Bad day	93	73	97

These data suggest three modifications of the standard household health models. First, welfare estimates that are based on avoiding unplanned medical visits, emergency room visits or hospitalizations miss the larger more routine impact of asthma morbidity on quality of life. The vector that describes health status should include quality of life impacts that are disease and age specific and should not be limited to physical symptoms. Last, because the outcome of interest is a vector of related impacts, data analysis should utilize a multivariate approach with both symptoms and psycho-social outcomes.

2. Constrained Choice Sets

Reducing exposure to asthma triggers is an important part of asthma management and is often described as the most important behavioral change a household can take. In our sample, households were able to identify triggers for their child. The ten most commonly reported triggers for asthma exacerbation were: an existing cold/flu (86%), air pollution (74%), pollen (66%), exercising outdoors (63%), tobacco smoke (53%), dust (53%), outdoor smoke (52%), strong winds (50%), mold (40%), animal dander (33%). Given the parents' perception of asthma triggers, the household model would then posit that households would make the relevant choices to reduce (avert) these risks; however, reducing exposure is not feasible for an important class of asthma triggers. The total height of the bars in Figure 1 shows the frequency households reported the exposure to be an asthma trigger for their child. The shaded are of the bars indicate the degree to which households that reported the item as a trigger felt they had control over their child's exposure. While households reported the ability to limit or reduce exposure to many of the commonly cited asthma triggers (exercising outdoors, tobacco smoke, dust, mold, animal dander, cleaning solutions, food allergies, and roaches), this was not uniformly the case. Of the top ten potential triggers, there were five triggers that more than 20% of the household reported that they had no control over their child's exposure (pollution 41%, strong winds 31%, cold/flu 28%, pollen 25%, and outdoor smoke 20%).

Figure 1: Perception of control of asthma triggers



One assumption of the health production function is that the household is able to purchase any number of units of inputs if they are willing to pay the price. The reality was different for 11% of our sample (n=202) who reported difficulties in making appointments with their medical doctor when needed, and the 7% (n=202) who report that their medical doctor is not helpful when their child's asthma worsens.

These findings suggest that one of the cornerstones of asthma management, averting risk through reducing exposure to triggers, does not readily translate into a production function framework, because the ability to control these exposures is limited. In addition to limited control of asthma triggers, households also reported limitations in the quantity and quality of available medical inputs. The results of our survey corroborate our concern that there may be no interior solutions to the household's maximization problem as commonly formulated.

3. Divergence Between Objective and Subjective Health Production Function

A fundamental assumption of the household production model is that households perceive a health production function and make health choices accordingly. We found substantial differences in how households conceptualize the process that determines asthma status. Of our sample, 16% (n=191) disagreed that asthma can be managed so that a child does not have symptoms; 13% (n=189) agreed with the statement that asthma episodes can cause problems but are not really harmful or dangerous; 58% (n=189) agreed with the statement that asthma episode usually occur without warning; 16% (n=202) report being uncertain about what to do when a child begins to have asthma symptoms. These statistics suggest that households often have incomplete and imperfect information with which to make choices, in other words there is substantial divergence between an objective physiological model of health production and the household's perceptions. They also suggest that rather than households conceiving of a production function, they consider their child's asthma status as exogenous and try to optimize welfare given the asthma status.

We present two avenues in which these divergences may arise. First, prior to making a health related expenditure, households do not have an assessment of how helpful an input will be. To explore this, we asked households both the amount spent on fixed health inputs and their ex post evaluation of the effectiveness of each investment. Table 9 lists the households' assessments of purchases, and three patterns should be noted. First, although each of these investments are commonly suggested averting/mitigating behaviors none were unanimously helpful (ranging from 44% to 98% reporting that the investment was helpful). Second, the investment that was most often reported to be helpful was the nebulizer, which provides relief during a current asthma exacerbation followed by a spacer which helps in delivery of medication, while those investments that were less likely to be reported as helpful were those that reduce triggers thus reducing the probability of an exacerbation in the future (e.g. air filters, removing pests, and HEPA vacuums). Third, households perceived a value to the peak flow meter, which provides information useful in asthma management but which in itself does not reduce triggers or alleviate symptoms. These patterns suggest that households' ex ante expectation and ex post outcome do not coincide for all investments, and the time frame for delivery of benefits may play an important role in household's subjective assessment.

Table 9: Household Investments and Assessments

Investment	% purchased	% reported helpful	N
Air filter	30	69	200
Mattress cover	28	73	200
Pillow cover	27	82	201
Humidifier	31	74	202
HEPA Vacuum	38	70	202
Removed carpet	25	78	201
Removed pests	25	44	202
Remove mold	39	72	201
Nebulizer	31	98	199
Peak flow meter	35	73	199
Spacer	54	93	200

These empirical observations substantiate our concern that a production function for health may impose a relationship between health and choice that is artificially strict and complete.

4. Endogeneity Between Health Inputs and Health Status

One source of endogeneity between the choice of health inputs (z) and asthma morbidity (H) arises from families "benchmarking" their concept of what is normal or attainable respiratory health. For example, one observation in asthma case management programs is that families either do not perceive their respiratory difficulties as asthma symptoms or they come to accept the asthma symptoms as unavoidable. Even within the FACES population, we found that the concept of asthma control deviated from the standard medical concept of asthma control (normal or near normal respiratory function). In our survey, 26% of the households who described their child's asthma as well to completely controlled, actually would be classified as moderate to severe based on the frequency of their daytime symptoms during the winter 2003-2004. As was shown in Table 8: Asthma Related Morbidity, even on a "normal day" from the perspective of the household, children commonly experienced limitations in their level of physical activity (47%), constraints on social interactions (43%) and symptoms (63%). As households that have children who routinely experience asthma morbidity come to expect these impacts as normal or "best possible" level of asthma control, their health investments will reflect this perceived limitation. This benchmarking could be thought of as a creating categories of households with differing perceptions of the frontier for H(z,q), and the perceived frontier would be correlated with the unobservable characteristics that affect the baseline asthma severity.

In the case of household health, the typical instrumental variables approach to the problem of endogeneity is confounded by the complexity of fully specifying the production model. As shown by Griliches and Mairesse (1999), instrumental variables estimates of the production relationship will not produce valid estimates of the coefficients on the health inputs if there are omitted variables from the health production function that are correlated with the elements in the vector of health inputs, z. As shown in the previous sections, households vary in their perceived risks and benefits of health inputs, and unless a model can adequately capture the factors that determine this variation instrumental variables will be an incomplete solution.

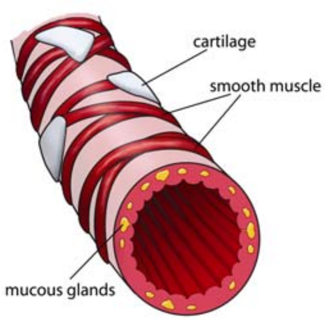
7. Stated Preference Approach

A major advantage of the stated preference approach relative to the revealed preference approach is that it allows the researcher to create a trade-off with which to confront survey respondents, thus it makes it possible for the researcher to control the specification of the household production function. Instead of having to estimate an unknown production function, commingled with unknown household preferences, and complicated by the household's unknown subjective perceptions of what it can do to protect or improve its health, the researcher may be able to create his own specification of the trade-off, thereby limiting the unknowns to be estimated from the data to the respondent's preferences.

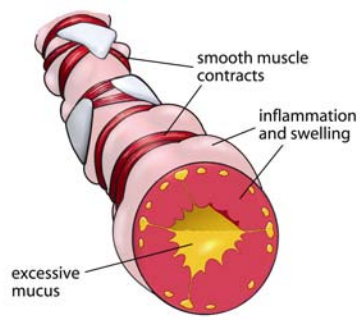
A second survey was conducted in-person at the FACES office over October 2005-February 2006. This second survey included questions on frequency of asthma symptoms that correspond to the updated Gina asthma severity classification (Luppi, 2004), severity of asthma symptoms, asthma triggers, asthma specific health beliefs, rating and ranking of the impact of asthma on quality of life, causes of household stress and a contingent valuation scenario. A total of 130 FACES households completed the second survey[9].

After the interviewer completed the health status questions, (s)he presented the contingent valuation scenario. The participant was given a brochure that described a hypothetical asthma monitor that could be worn like a watch. The description of how the watch worked included a diagram of a normal airway and an asthmatic airway with both constriction and inflammation.

Figure 2: Brochure Diagrams



Normal Airway



Asthmatic Airway

Asthma Monitor

[9] We began conducting the contingent valuation survey in Oakland, California in March 2006. Our target is an additional 200 surveys by the end of 2006.

The brochure explained that the watch monitors the level of oxygen in the child's blood and provided an indication when it varied. A green face on the watch indicated that oxygen was optimal whereas a yellow indicated caution and a red face indicated an emergency. By monitoring the child's asthma, it was suggested, action could be taken to stop the asthma from progressing to the point that physical symptoms developed. The hypothetical monitor, the *BreatheRight* watch, was said to have been shown to cut the number of days with asthma symptoms by one-half. We used a one and a half bounded dichotomous choice format to elicit bids for the hypothetical scenario. Initial bids were based on the distribution of responses from a pilot of twenty-two non-FACES households in the Fresno area conducted in August of 2005[10]. Stating bids and subsequent bids were updated following Cooper, Hanemann and Signorello (2002).

We crafted the hypothetical scenario to have six characteristics relevant to the findings of the first survey that were discussed in Section 5:

1. The scenario reduced morbidity without relying on medication, and thus would not be confounded by preferences for medication.
2. The device did not require behavioral changes to be effective, thereby reducing the issue of non-adherence.
3. The tool reduced both the physical symptoms and the stress of monitoring the child's asthma, which addresses the larger issue of how asthma morbidity affects quality of life.
4. The device helped families communicate quantitative information about their child's asthma, improving access to health care when needed.
5. The instrument provided objective information on the child's health status and assisted families in assessing health risks and effectiveness of averting and mitigating behavior.

Results from the contingent valuation survey will be reported in future research.

Conclusions

In this paper we discuss two approaches to estimating the willingness to pay (WTP) for reduced asthma morbidity, contingent valuation and health production function. In the health production model the health outcome is a function of exposure to asthma triggers, mitigating and averting behavior and household's perceived risks. We find that variation in expenditures is explained by attitudes towards asthma specific health investments including concerns of associated risks and perceived effectiveness. The survey data indicate that households select from a small number of discrete health investments and that most risk reducing behavior are daily behavioral modifications with no relevant market prices.

We argue that the discrete nature of health investments and socio-cultural patterns of health care utilization make the revealed preference approach inadequate for the case of asthma. As an alternative we present a contingent valuation scenario that was specifically developed to minimize systematic variation in preferences for characteristics related to the scenario rather than the reduction in asthma morbidity. For this purpose, guided by extensive testing in focus groups, we selected a scenario based on a hypothetical asthma monitor that provides to the wearer an indicator of current asthma status.

[10] Participants for the pilot were recruited through a newspaper ad in the local paper (*Fresno Bee*) and a recruitment table at the American Lung Association's annual walkathon in Fresno.

References
To be added

Individual Preferences and Household Choices: The Potential Role of Dependency Relationships

Mary F. Evans, Christine Poulos, and V. Kerry Smith

Background

- STAR grant: applying weak substitution to value air quality improvements that improve health
- 3 phases of research for two study populations:

	Children	Older adults
1. Develop theoretical model	✓	
2. Verify environmental health impacts using secondary data	ongoing	✓
3. Survey parent-child and older adult-caregiver pairs to value air quality improvements		Focus groups in 2005

Motivation

- Phase 3 requires understanding of dependency relationships (young child/adult parent, older adult/caregiver).

- Central to characterizing and interpreting behavior, and to designing stated preference surveys:
  - Intra-household allocation process

Purpose

- Describe a conceptual framework and testable theoretical model of dependency relationships that are expected to influence the value of environmental quality improvements that affect children and older adults
- Describe internet survey activities that:
  - Informs conceptual structure
  - Complement/substitute for focus group activities and/or cognitive interviews

Theoretical background

- Collective model (Chiappori and co-authors) permits the recovery of individual preferences from household behavior. Offers strategy for analyzing household structure and dependency relationships.
- What information is used for identification?
  - Chiappori: Focus on the *intensive* margin.
  - Our proposal: Focus on the *extensive* margin.
- Current tests of the collective model rely on observing the full system of demands.
- Is there an alternative test that does not rely on this information?

Review of Chiappori collective household framework

- Background
  - Household is best viewed as a collection of individuals with different preferences; analysts usually observe *household* not individual demands for goods and services.
  - Household “behavior” is unlikely to be described adequately by the unitary model – *i.e.* treating choice as if it was motivated by a single agent’s decisions.
- Assumptions
  - Each household member has own preferences that are known by other household members
  - Collective decisions of household are Pareto efficient

Focus of Chiappori and co-authors' research

Browning and Chiappori [1998], Chiappori and Ekeland [2006; forthcoming]

- **Key Issue**: What does the efficiency assumption imply for household demands and specifically for the matrix of Hicksian price effects?
  - Question directs attention to the *intensive* margin of choice

Basic structure of argument

Context and definitions

- Assume two members (I and II) of household
  - p = prices of market goods (T x 1 vector)
  - X = quantity of market goods consumed by household, $x^I + x^{II} = X$
  - Z = private good that is public consumption to members of household
  - $U^i\left(x^i, x^j, Z\right)$ = i^{th} individual's utility function ($i \neq j$)
  - y = household income, $y = p^T \cdot \left(X + Z\right)$

Key efficiency assumption

- There exists a differentiable, homogeneous of degree zero, function μ(*p*, *y*) such that for any (*p*, *y*) the vectors (x^I, x^{II}, *Z*) are solutions to the following optimization problem:

$$\max_{x^I, x^{II}, Z} \mu(p,y) U^I\left(x^I, x^{II}, Z\right) + \left(1-\mu(p,y)\right) U^{II}\left(x^I, x^{II}, Z\right)$$

$$\textit{subject to } p^T \cdot \left(X + Z\right) = y$$

- Yields household (Marshallian analog) demand functions: $f_s\left(p, y, \mu\right)$
- Expenditure minimization problem yields (Hicksian analog) demand functions: $h_s\left(p, U, \mu\right)$

Key generalization

- Duality implies, holding μ constant

$$\frac{\partial h_s}{\partial p_t} = \frac{\partial f_s}{\partial p_t} + \frac{\partial f_s}{\partial y} \cdot f_t$$

- Allowing μ to vary with prices and income,

$$\frac{\partial h_s}{\partial p_t} = \frac{\partial f_s}{\partial p_t} + \frac{\partial f_s}{\partial y} \cdot f_t + \frac{\partial f_s}{\partial \mu} \left(\frac{\partial \mu}{\partial p_t} + \frac{\partial \mu}{\partial y} \cdot f_t \right)$$

Element of matrix of Hicksian price effects (pseudo-Slutsky matrix)

Element of conventional Slutsky matrix (symmetric)

Leads to matrix that is at most rank one (in two-person household) = **basis of test**

Illustrative example

- Provides intuition for alternative test of the collective model
- Informs development of choice questions
- Assumptions
  - Up to a two-person household
  - Linear indirect utility function
    - Form varies according to structure of household
  - Consider change in indirect utility from improvement in air quality, *q*, that reduces the amount of care giving time required for self or another individual (small child, teenager, older adult)

Individual only (no altruism, no income sharing)

- Indirect utility function with initial air quality

$$V_0 = \alpha_0 + \alpha_1 w + \alpha_2 y + \alpha_3 q_0 - \lambda \bar{L}$$

  - with *w* the wage rate, *y* non-wage income, $\bar{L}$ (fixed) care giving time to self, q_0 initial level of air quality.

- Indirect utility function with improved air quality

$$V_1 = \alpha_0 + \alpha_1 w + \alpha_2 (y - T) + \alpha_3 q_1$$

  - with *T* the cost of the program to improve air quality (and reduce care giving time).

- Change in indirect utility

$$\Delta V = \lambda \bar{L} + \alpha_3 (q_1 - q_0) - \alpha_2 T$$

Altruism (no income sharing)

- Indirect utility function with initial air quality

$$V_0 = \alpha_0 + \alpha_1 w + \alpha_2 y + \alpha_4 h(q_0) - \lambda \overline{L}$$

  - with *h* describing the health of the dependent as a function of air quality, $\overline{L}$ care giving time to dependent.

- Indirect utility function with improved air quality

$$V_1 = \alpha_0 + \alpha_1 w + \alpha_2 (y - T) + \alpha_4 h(q_1)$$

- Change in indirect utility

$$\Delta V = \lambda \overline{L} + \alpha_4 [h(q_1) - h(q_0)] - \alpha_2 T$$

Income sharing (no altruism)

- Indirect utility function with initial air quality

$$V_0 = \alpha_0 + \alpha_1 w + \alpha_2 \left[b_0 + b_1 y + b_2 w + b_3 q_0 + b_4 \overline{L}\right] - \lambda \overline{L}$$

  - where the term in brackets represents the individual's share of household income.

- Indirect utility function with improved air quality

$$V_1 = \alpha_0 + \alpha_1 w + \alpha_2 \left[b_0 + b_1 (y - T) + b_2 w + b_3 q_1\right]$$

- Change in indirect utility

$$\Delta V = (\lambda - \alpha_2 b_4)\overline{L} + \alpha_2 b_3 (q_1 - q_0) - \alpha_2 b_1 T$$

Altruism and income sharing

- Indirect utility function with initial air quality

$$V_0 = \alpha_0 + \alpha_1 w + \alpha_2\left[b_0 + b_1 y + b_2 w + b_3 q_0 + b_4 \overline{L}\right] + \alpha_4 h(q_0) - \lambda \overline{L}$$

- Indirect utility function with improved air quality

$$V_1 = \alpha_0 + \alpha_1 w + \alpha_2\left[b_0 + b_1(y - T) + b_2 w + b_3 q_1\right] + \alpha_4 h(q_1)$$

- Change in indirect utility

$$\Delta V = (\lambda - \alpha_2 b_4)\overline{L} + \alpha_2 b_3 (q_1 - q_0) + \alpha_4\left[h(q_1) - h(q_0)\right] - \alpha_2 b_1 T$$

Matrix of household types

Label	Coefficient on Δq	Coefficient on $\bar{L}$	Coefficient on T	Number in household
Individual only	α_3	λ	$-\alpha_2$	1
Altruism only	?	λ	$-\alpha_2$	1
Income sharing only	$\alpha_2 b_3$	$\lambda - \alpha_2 b_4$	$-\alpha_2 b_1$	2
Altruism and income sharing	?	$\lambda - \alpha_2 b_4$	$-\alpha_2 b_1$	2

Choice questions

- Objective: understand how people make choices (not to obtain WTP estimates for policy use)
- Strategy:
  - Two double-bounded questions per respondent
    - One focusing on respondent
    - Another focusing on another individual: young child (2-5), teenager (13-17), or older adult (>62)
  - Design attributes constant within questions for respondent
  - Interval censored model to estimate valuation function

Choice questions

- Respondent asked to suppose that subject (self or other individual) has asthma
- General choice question: “Would you pay $$T$ for a program that will improve air quality and reduce the amount of time you allocate to care giving for [yourself / young child / teenager / older adult] from L to zero?
  - Double-bounded question with respect to T
  - L (2 levels), T (4 levels) randomly assigned
  - Sequence of responses to each double-bounded question sort individuals into four bins (yes/yes, yes/no, no/yes, no/no)

Survey details

- Add survey questions to weekly internet panel
  - 1000-2000 respondents (18+ years); $600-$1000/question
  - Socioeconomic data provided: education, income, household size and composition
  - Data available in days
- Questions
  - Choice questions
  - Additional characteristics (presence and age of children in HH, presence and age of older adults in HH, asthma in HH members)

Conclusion

- Dependency relationships and household structure are potentially important in estimating the benefits to improved environmental quality.
- Proposed tests have focused on the *intensive* margin. We propose an alternative that focuses on the *extensive* margin that does not require observation of full system of demands.

Air Pollution and Asthma:
Preliminary Results from a Daily Time-Series Study of San Francisco

By

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Air Pollution and Asthma:
Preliminary Results from a Daily Time-Series Study of San Francisco

By Charles W. Griffiths and Nathalie Simon[1]

Asthma is a chronic lung disease 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 -- with a staggering 80 percent since 1982.

While the exact causes of the illness remain unknown, asthma attacks can be triggered by a number of factors including exposure to allergens (e.g., 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 temporal relationship between

[1] Disclaimer: The views expressed in this paper are those of the author(s) and do not necessarily represent those of the U.S. Environmental Protection Agency. In addition, although the research described in this paper may have been funded entirely or in part by the U.S. Environmental Protection Agency, it has not been subjected to the Agency's required peer and policy review. No official Agency endorsement should be inferred.

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air pollution and asthma attacks resulting in Emergency Room visits or Hospital Admissions. However, these studies by design focus on severe outcomes and miss milder ones – asthma attacks that are alleviated through medication use and do not require immediate medical attention. Those studies that do examine milder forms of asthma symptoms (e.g., respiratory symptoms or increased use of asthma medication) generally take the form of cohort or panel studies and have tended to focus on children. This paper presents the preliminary results of a time-series analysis of the effects of acute exposure to ambient air pollution on the incidence of asthma attacks, as measured by prescription counts for short term "quick relief" medications. Using prescription data from San Francisco, California, we estimate the relationship between exposure to ozone and PM10 and asthma symptoms.

Background

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 cohort or panel studies. 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. A relatively large segment of these studies have focused on asthma. In a study by Walters et al. (1993), for instance, daily levels of SO_2 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.1993). 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 effects of air pollution exposure on asthma outcomes that are milder in nature.

Panel or diary studies 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. While most cohort studies are focused on children, some studies have found positive and significant effects of air pollution exposure on exacerbation of asthma symptoms at other ages. 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, Newhouse et al. (2004) found that ozone concentrations on the previous day were associated with a number of symptoms including wheezing, headache, and fatigue in their panel of 24 individuals aged 9-64 with physician diagnosed asthma. 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. 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 while others are limited by panel size or length of study period.

In contrast to the studies described above, our study examines the effect of short term or acute exposures to air pollution on asthma symptoms as measured by the purchase of quick relief asthma medications in San Francisco, California. Zeghnoun et al. (1999) explore a similar relationship in Le Havre, France and find statistically significant effects of black smoke, NO2 and SO2 on respiratory drug sales for mucolytic and anti-cough medications for children and adults. Our study in contrast is focused on quick relief asthma medications. We hypothesize that acute exposure to air pollution may make an individual more susceptible to asthma attacks, causing an increase in the use of quick relief medications.

Methodology

This study looks at the effects of differences in short term air pollution exposures on the occurrence of asthma attacks, where asthma attacks are proxied by the number of prescriptions for quick relief asthma medication filled. 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: short-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. The urgency with which a prescription needs to be filled will vary across individuals and their initial stock of asthma medication, making short term effects more difficult to observe.

An individual suffering from asthma will use his inhaler with some probability based upon the amount of pollution present, current weather conditions, and seasonal factors.

$$\text{Pr(Inhaler use)}_t = \text{f(Pollution}_t, \text{Weather}_t, \text{Seasonal Factors}_t) \qquad (1)$$

We assume that each day the individual makes an independent decision, where the choice is whether or not to use the inhaler based on the contemporaneous pollution, weather, and seasonal factors. If we were able to witness the individual's use of his inhaler, then we could model this behavior using daily cofactors. Minor modification would be possible if asthma attacks were serially correlated, or if the use of an inhaler one day was related to the conditions on the previous day as well as the current day.

In our case, we do not witness the individual's use of the inhaler, only the purchase of a new inhaler when the old one is empty (or close to empty). Therefore, the observable event, the number of prescriptions, is a function not only of the contemporaneous factors, but the total amount of pollution and weather conditions over the recent past, as well as the seasonal factors.

$$\begin{aligned}\text{(Number of Prescriptions)}_t = \text{f(Pollution}_t, \text{Pollution}_{t-1}, \ldots, \text{Pollution}_{t-m}, \text{Weather}_t,\\ \text{Weather}_{t-1}, \ldots, \text{Weather}_{t-m}, \text{Seasonal Factors}_t) \qquad (2)\end{aligned}$$

The number of days, m, which defines the recent past needs to be long enough to capture the signal of inhaler use, but should not be so long as to add additional noise to the model. Seasonal variation does not need to be modeled as an aggregation over time since it can be captured using other methods – in this paper, through the use of continuous trigonometric cycles of varying length. If the number of prescriptions follows a Poisson distribution, then we can model the mean incidence rate, that is, the number of prescriptions on any given day, as

$$\begin{aligned} r_t = \exp(\alpha + \beta[&Pollution_t + Pollution_{t-1} + \ldots + Pollution_{t-m}] \\ &+ \gamma[Weather_t + \gamma Weather_{t-1} + \ldots + \gamma_m Weather_{t-m}] \\ &+ \delta\, Seasonal\ Factors_t \end{aligned} \qquad (3)$$

Since each day should be given the same weight, β and γ can be estimated for the sum of pollution and weather cofactors over the recent past.

Since we are modeling a single CSMA over time, we assume that the exposure rate does not change from one day to the next and, therefore, do not include it explicitly in the estimation.

Modeling the number of prescriptions in this fashion means that β is then a semi-elasticity of the impact of a one-unit change in pollution. In other words,

$$\frac{\partial r_t}{\partial P} \cdot \frac{1}{r_t} = \beta \qquad (4)$$

where a one unit change in pollution produces a β percent increase in inhaler prescriptions.

Data

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.

Prescription data were provided for San Francisco by NDC, segregated by 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.

Table 1: Asthma Medication
<u>Symptomatic Therapy (Quick Relief)</u>
Albuterol
Bitolterol
Isoetharine
Metaproteronol
Pirbuterol
Terbutaline
<u>Controller Therapy (Long-term preventative)</u>
Inhaled Corticosteroids
Beclomethasone
Budesonide
Flunisolide
Fluticasone
Triamcinolone
Leukotriene Antagonists
Motelukast
Zafirlukast
Zileutin
Long Acting Beta Agonists
Salmeterol
Xanthine Derivatives
Aminophylline
Dyphylline
Oxtriphylline
Theophylline
Mast Cell Stabilizers
Cromolym
Nedocromil

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 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.

The air pollution data are publicly available from the California Air Resource Board. Daily observations on the levels of PM10, SO2, NOx, and ozone are available for 71 monitors in San Francisco.

The weather data come from the National Climatic Data Center. Daily observations for the average, minimum, and maximum temperature, as well as relative humidity, and the minimum and maximum relative humidity were obtained for 97 active weather stations in San Francisco.

The summary statistics for the data used in this analysis are listed in Table 2.

Table 2: Summary Statistics

Variable (units)	Number of Observations	Mean	Min	Max
Total Daily Prescriptions (number)	1428	852.0	28	1714
Mild Intermittent	1428	389.5	15	950
Mild Persistent	1428	276.4	9	579
Moderate	1428	128.8	1	260
Severe	1428	57.3	3	122
Daily Minimum Temperature (^{o}F)	1672	39.69	15	67
Daily Average Relative Humidity (%)	1672	68.09	37	98
Daily Average PM10 (µg/m^3)	1499	38.01	2.60	227.72
Max of Ozone 1Hr (ppm)	1672	0.08	0.04	0.18

Results

We estimate equation 3 above using a standard negative binomial regression – the more generalized form of the Poisson model. Total counts of prescriptions filled over the course of a week are regressed against minimum temperature, relative humidity, pollution measures, time trends and trigonometric terms designed to capture cyclical trends ranging from 1 year to 2.4 months in length. Weekly counts are used to minimize day of week effects and effects of pharmacy closures due to holidays. Temperature and pollution measures are summed over 180 days preceding the weekly counts. As described above, summing these factors in this way allows us to more accurately capture the effects of pollution and weather on the dispensing of quick relief asthma medications. A 180-day window was selected upon inspection of the plot of the residuals of prescription counts (with seasonal variation and time trends removed) against pollution measures.[2]

The model was constructed in a step-wise manner in which we first added our season and time controls, using the Akaike Information Criterion to inform the choice of model before incorporating other factors. Once the seasonal factors were selected, we incorporated meteorological metrics including temperature and relative humidity. Minimum, maximum and daily average measures were tested against one another. Minimum daily temperature and average daily relative humidity provided the best fit according to AIC.

With weather factors controlled for, we added ozone and PM10 measures to the model. We experimented with 8-hour and 1-hour ozone measures, and found that daily maximum observations of 1-hour ozone readings provided the best fit. Daily average PM10 was similarly selected for inclusion.

Once the model construction was completed for counts of total prescriptions, we applied the same model construct to counts of prescriptions by severity level. Results for all five regressions are reported in Table 3.

[2] Troughs and peaks in the residuals were matched with those observed in the pollution data.

Table 3: Regression Results

Variable Name	Total Prescriptions		Mild		Mild Persistent		Moderate		Severe	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
trend	-0.0001	0.0001	-0.0001	0.0001	-0.0001*	0.0001	0.0000	0.0001	-0.0002*	0.0001
Year 1999	0.1238***	0.0315	0.1206**	0.0386	0.0978***	0.0302	0.1299***	0.0269	0.2836***	0.0290
Year 2000	0.2051***	0.0589	0.2285***	0.0714	0.1473**	0.0568	0.1559**	0.0506	0.4056***	0.0545
Year 2001	0.0062	0.0884	0.0097	0.1075	-0.0867	0.0851	0.0354	0.0758	0.3489***	0.0816
sin1yr	-0.4187***	0.0302	-0.5011***	0.0372	-0.3914***	0.0287	-0.3140***	0.0255	-0.2129***	0.0274
cos1yr	0.2556***	0.0098	0.3547***	0.0120	0.1974***	0.0093	0.1440***	0.0082	0.1044***	0.0087
sin6mo	-0.0707***	0.0058	-0.0924***	0.0070	-0.0774***	0.0055	-0.0221***	0.0049	-0.0101*	0.0053
cos6mo	0.0102**	0.0034	0.0179***	0.0042	-0.0034	0.0032	0.0075**	0.0029	0.0111***	0.0031
sin4mo	0.0317***	0.0046	0.0477***	0.0056	0.0207***	0.0044	0.0167***	0.0039	0.0177***	0.0042
cos4mo	0.0286***	0.0034	0.0447***	0.0042	0.0200***	0.0033	0.0042	0.0029	0.0091**	0.0031
sin3mo	-0.0162***	0.0040	-0.0194***	0.0049	-0.0177***	0.0039	-0.0080*	0.0034	-0.0112**	0.0037
cos3mo	-0.0102**	0.0034	-0.0075*	0.0042	-0.0158***	0.0033	-0.0095**	0.0029	-0.0061**	0.0031
sin2.4mo	-0.0191***	0.0037	-0.0220***	0.0046	-0.0213***	0.0035	-0.0082***	0.0032	-0.0105**	0.0034
cos2.4mo	0.0200***	0.0035	0.0331***	0.0042	0.0105***	0.0033	0.0064*	0.0029	0.0002	0.0031
Minimum Temperature	-0.0003***	2e-05	-0.0004***	2e-05	-0.0003***	2e-05	-0.0002***	2e-05	-0.0001***	2e-05
Average Relative Humidity	0.0002***	2e-05	0.0002***	2e-05	0.0002***	2e-05	0.0001***	2e-05	0.0001***	2e-05
Average PM10	2e-05***	5.13e-06	2e-05***	6.29e-06	2e-05***	4.90e-06	1e-05**	4.36e-06	5.89e-06	4.65e-06
Max of Ozone 1Hr	-0.0536***	0.0085	-0.0705***	0.0105	-0.0397***	0.0081	-0.0462***	0.0072	-0.0279***	0.0077
constant	9.5639***	0.2153	9.0780***	0.2633	8.1843***	0.2059	7.4835***	0.1833	6.0107***	0.1956

Note: ***= statistically significant at 99% confidence level; **=statistically significant at 95% confidence level; *=statistically significant at 90% confidence level

Looking across the five models presented in Table 3, we find mixed results. Minimum temperature enters all five equations with the expected sign. As temperature decreases, we expect to see an increase in asthma symptoms as exhibited in the results. The decrease in the magnitude of the effect across severity levels is not altogether surprising given the increased use of maintenance therapies as asthma severity increases. This is in keeping with a recent study by Delfino et al. (2002) that found stronger associations between air pollution and exacerbation of asthma symptoms among asthmatic children who were not taking anti-inflammatory medications.

The effects of relative humidity are somewhat puzzling, however, as we expected dryer air to exacerbate asthma symptoms. In our results, it seems we have the opposite effect -- as relative humidity increases, so does the number of asthma prescriptions filled.

The effect of pollution exposure on asthma symptoms is also mixed. Daily levels of PM10 have a positive and significant effect on asthma prescriptions with a 1 microgram per cubic meter increase in PM10 resulting in a 0.00002 percent increase in asthma prescriptions each week (or approximately 0.12 additional prescriptions). Assuming each inhaler contains approximately 200 metered doses of the quick relief medication with the recommended usage to relieve symptoms being 2 doses, this translates to approximately 12 "attacks" per week. The effect of ozone exposure however is contrary to what we expected, with our model showing negative but statistically significant effects across all severity levels.[3]

Next Steps

Our regression results are unsatisfying in many respects. We fully expected to see a

3 We intended to incorporate the effects of NOx and SO2 as well, but the data coverage was too spotty for these pollution measures.

negative (and statistically significant) effect of ozone exposure on asthma prescriptions. Still, our analysis is preliminary and we hope that a number of improvements to our model will likewise improve our results.

First, we recognize that our negative binomial model is rather crude. The model does not take into account the autoregressive nature of the data and as such could be producing biased results. Now that we have selected the appropriate terms to incorporate into the model, we intend to explore the use of generalized additive models.

We also recognize that we applied the model we constructed for total prescriptions to other endpoints (counts by severity level) with little regard for whether it produced the best fit in these other contexts. Ideally, we would apply the same methodology for constructing the model to these other endpoints – controlling for the factors we believe to be important (e.g., weather, pollution, and seasonality) but using the AIC to assess which measures best control for these factors and eventually applying generalized additive models here as well.

The selection of the window over which to sum our observations was admittedly rather ad hoc. We intend to explore other more "rigorous" means of selecting the proper window. One option is to conduct a rather crude "expert elicitation" and identify (fewer than 10) physicians whom we could survey on this point. Essentially, we would want to learn from them approximately how often their patients refill their prescriptions.

In addition, we have access to the counts of prescriptions by age group as well as by severity. While time did not permit us to present the results of regressions by age here, we intend to explore the effects of pollution exposure on asthma prescriptions by age group in future analyses.

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No documents are available regarding Bryan Hubbell's discussion comments.

Comments by Glenn Blomquist on
"Risk Assessment and Valuation of Health Effects from Air Pollution"
EPA Workshop on Morbidity & Mortality: How Do We Value the Risk of Illness & Death?
April 10, 2006, Washington, DC

Comments on "Willingness to Pay for Improved Health: A Comparison of Stated and Revealed Preference Models" by W. Michael Hanemann and Sylvia Brandt

This paper discusses two approaches to valuing changes in asthma morbidity among children: (1) contingent valuation and (2) household production of health. The study is designed to facilitate comparison of estimates based on the two approaches by estimating willingness to pay (WTP) for the same households and children. While the comparison is incomplete at this stage of the project, the potential for comparison between the stated WTP in contingent valuation and WTP inferred from household averting and mitigating behavior is great. The focus of this paper is on the results of Hanemann and Brandt's survey of households with asthmatic children, parents' perceptions of risks of asthma attacks, and their behavior with regard to those risks.

The study group was recruited by Fresno Asthmatic Children's Environment Study (FACES) in Fresno, California. All children had clinically diagnosed asthma and nearly 70% of the households had at least one parent who was affected by asthma. These households are familiar and experienced with asthma. The written, mail survey of 202 households was conducted in 2004. Information about asthma severity, medication use, asthma-related expenditures, items and services purchased, household income, and time spent dealing with children's asthma was collected. The comprehensiveness and detail are incredibly good. Any doubt that asthma health risks are partly endogenous surely disappears when confronted with these data.

Table 5 is particularly informative. Seventeen types of fixed costs (expenditures) are listed including purchases of air conditioning, air filters, pest extermination, carpet removal, and pet removal. Eight types of variable costs for household supplies are listed including heater filters, cleansers for mold, and hypoallergenic cleaners. Four types of pharmaceutical costs are listed including prescription asthma medication, over-the-counter drugs, and herbal remedies. Seven types of alternative therapies are listed including nutritionists. The time periods for fixed and variable costs are not specified in Table 5, but if they are (recklessly) lumped together average (mean) expenditures appear to be roughly 1% of median household income for group.

As Grossman (1972) showed more than 30 years ago, time inputs in the production of health matter. My educated guess is that ways in which households change their time allocations due to their children's asthma will be at least as important as changes in money expenditures. About this behavioral response, Hanemann and Brandt have information reminiscent of diary data collected for EPA for a small sample of adult asthmatics in the 1980s. These data for adults are extraordinary and, as evidenced by the recent study by Yen, Shaw, and Eiswerth (2004), are still being gleaned. The new data for households with asthmatic children should be at least as useful. They deserve their own table comparable to Table 5. Hanemann and Brandt report that time costs are sizable. They should be able to estimate them well. They report that 43% of the households took time off from work to take a child to a medical appointment and that the average (mean) time taken off was 83 minutes. They report 24% of the households took time off from work in the previous year to take a child to an emergency room with an average (mean) of 211 minutes spent. If wage data are available for each household, dollar values of these time costs can be estimated and added to the dollar expenditures on marketed goods and services. If wage data are not available, then given the available information on household income and characteristics of the household, Hanemann and Brandt should be able to use a data set such as the Current Population Survey and estimate wages and/or shadow wages for each of the members of the household. While these time costs may be less than 1% of annual household income, there are indications of substantially higher time costs. These higher costs are due to changes in employment status due to having hours reduced (28%), being fired or laid off (22%), or choosing to work fewer hours during asthma season (27%). More than two-thirds (70%) of the households reported that a parent had chosen to work part-time or be a stay-at-home parent due to a child's asthma. While the value of time not spent at work for those who have decided not to work in the market is not zero, the value of these time costs could be much greater than the money expenditures for some households. We should look forward to estimates that exploit these data using the best techniques that labor economics has to offer. The fact that some of the household time is unpriced is a barrier that can be overcome.

Hanemann and Brandt note several conceptual and empirical limitations of the household production approach that they believe are threats to the "validity" of the production function approach to estimating WTP for reducing children's asthma morbidity. My view is that their concern is legitimate, but that none of the limitations is a fatal flaw that should prevent them from making a meaningful comparison with the WTP estimates from contingent valuation. My assessment is that a number of high quality studies have been done valuing changes in morbidity using a household production approach despite limitations. A recent example is Dickie's (2005) article on valuing children's health, work for which he received the Georgescu-Roegen Prize. Hanemann and Brandt have excellent information on what goes on in, what to some is, the black box of household production of health. Perhaps it is the richness of the information that makes them hint that a meaningful comparison cannot be made. For example, they report that more than 20% of the households said they had no control of the top ten potential asthma triggers. Viewed differently, the fact that nearly 80% said they had at least some control would be reassuring to many who would apply the household production approach.

In Table 7, nonmarket, household averting and mitigating behaviors is listed based on Hanemann and Brandt's first survey. They include activities such as checking for smog alerts, closing windows, and restricting where the child can play as well as parents giving up smoking cigarettes. These activities can be difficult for researchers to value in dollars for a household production estimate, as they note. This information guided them in designing their contingent market for a hypothetical BreatheRight watch for monitoring. In addition to trying to put dollars values on the activities directly, they might consider adding some contingent time tradeoffs and/or contingent behavior questions to value the nonmarket averting and mitigating behaviors.

All in all, I think that Hanemann and Brandt believe that they have laid the groundwork for a first-class contingent valuation study to estimate the values that parents place on improved control of their children's asthma. I share that belief and think further that they have laid the groundwork for a first-class household production study, and comparison between the two. I look forward to seeing the successful completion of all three.

Comments on "Individual Preferences and Household Choices: The Potential Role of Dependency Relationships" by Mary F. Evans, Christine Poulos, and V. Kerry Smith

Since this project is a work in progress and no paper was available, my comments, unlike good Kentucky bourbon, have aged only one hour. Here are a few quick reactions. One is that the motivation for valuing changes in the environment is not entirely clear. Modeling households as groups in which individuals' roles are treated as economic decisions is offered as a way to gain insights into household relationships. Evans, Poulos, and Smith believe that insights gained could be used as an alternative to focus groups in the development of surveys and survey instruments. Presumably the values that are elicited for changes in environmental quality could depend on which member of the household is asked. My comment is that several good reasons exist for using focus groups and that even if we learn something about household relationships, there are still potentially great benefits to focus groups. If focus groups are held, the marginal cost of exploring household relationships is probably low.

A second comment is that it would be interesting to work through the system of equations for an exogenous change in a quantity, as we often do in environmental economics, instead of a change in price. I am not sure that makes sense based on the brief presentation, but it might be worth considering.

My third and last comment is that the household structures presented did not include the one that I consider the most important, namely a household with at least three individuals. Because I have been father in a household of four in which two parents were involved in raising a child with chronic asthma, I think that an important household configuration has been omitted in the modeling so far. In our household, I think the values you would have elicited in surveys would have been fairly close regardless of which of us you asked. It would be good to have a model that allowed for that situation. What comes from this research could be fascinating.

Comments on "Air Pollution and Asthma: Preliminary Results from a Daily Time Series Study of San Francisco" by Charles W. Griffiths and Nathalie B. Simon

This paper is similar to Hanemann and Brandt's in that deals with morbidity related to asthma and air pollution and studies residents of a city in California. The idea is that since air pollution can trigger asthma attacks, the pattern of filling prescriptions for medications that relieve asthma symptoms, should be influenced by the pattern of air pollution. Air pollution episodes lead to prescription episodes with some lag. My main comment is that the probability of inhaler use, as shown in equation 1, should be broadened to incorporate human behavior. In the context of household production of health, the use of a market input such as an inhaler will depend on exogenous factor such as pollution, weather, and seasonal factors, as Griffiths and

Simon indicate. In addition, however, inhaler use will depend on averting and mitigating behavior such as limiting outdoor exercise, and the myriad of things documented by Hanemann and Brandt. Inhaler use will depend on how well the individual manages controller therapy. Use of these long-term maintenance drugs is an investment that yields a return weeks later when asthma attacks are prevented or reduced in severity.

Weekly count data of prescriptions for quick relief asthma medication for San Francisco for the years 1998-2001 were analyzed using a standard negative binomial regression. Increases in average PM10 increased counts and increases in average minimum temperature decreased counts as expected. Increases in average relative humidity are found to increase prescription counts, a result which Griffiths and Simon did not expect. As one who lives in the Bluegrass Region of Kentucky and associates humidity with lush growth, abundant pollen, thriving mold, and other asthma triggers, I am not surprised by the positive sign on humidity. The result that ozone is associated with a decrease in prescription counts is unexpected. My suggestion, based on my main comment, is to think about inhaler use as determined by individual factors to see if that suggests other variables. If a pollution episode is correctly anticipated, asthmatics are carefully engaged in averting behavior, and long-term maintenance drugs are effective, the increase in use of rescue drugs and increase in prescription counts will be small. This explanation does not distinguish between PM10 and ozone, but perhaps it will lead to a better specification that produces results that are more in line with expectations.

My last comments are that I agree with Griffiths and Simon that they should do more time series diagnostics and more sensitivity analysis of the 180 day window that they use for pollution measures. The windows for PM10 and ozone may be different.

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Summary of the Q&A Discussion Following Session I

Reed Johnson, (RTI)
Directing his comment to Mary Evans and Christine Poulos, Dr. Johnson stated, "I thought I followed your model pretty well, Mary, and then you offered the format of the question you were going to ask, which was as I recall: For a given improvement in air quality that would reduce the amount of care giving time, how much would you be willing to pay? I don't quite understand, in the context of the other presentations we've heard today, what you're assuming about the household production function. That is, are you assuming some fixed proportion of time for a decrease in . . . ?"

Mary Evans, (University of Tennessee)
"Yes, at least in the pilot survey the care giving time is going to be exogenous, so that will be determined in the stated preference survey. So we exogenously specify both the initial care giving time and the reduction in the final care giving time."

Reed Johnson
Dr. Johnson continued, "And what are they going to get in terms of improved health? Is it possible to value the time independently of the change in the health outcome experienced in the household?"

Mary Evans
Dr. Evans clarified, "In some household structures, they'll value both the health impact as well as the reduction in time allocation."

Reed Johnson, (RTI)
Dr. Johnson responded, "So if it's not altruistic, they wouldn't value the health outcome."

Mary Evans
"Right. If there's only that income-sharing model, the only way that air quality would impact that particular model is through the mu function essentially—through the individual's share of the household income."

Reed Johnson
Dr. Johnson added, "I guess it wasn't clear to me how the model handles substitution among various household production inputs and how that plays out in the willingness to pay."

Lauraine Chestnut, (Stratus Consulting, Inc.)
Ms. Chestnut addressed Charles Griffiths: "Regarding the negative ozone coefficient—that colder temperatures give higher medicine use—I was just wondering how much you looked into the correlation between that, since the ozone tends to be worse in warmer weather."

Charles Griffiths, (U.S. EPA, NCEE)
Dr. Griffiths responded, “That’s actually an excellent point that was raised to me just recently, which is why I kept saying that the way we’ve modeled ozone is counter-intuitive.” Acknowledging that the factor “currently enters in straight,” he offered that he “should account for the fact that the ozone effect may be seen only during a certain season.” He said, “It may be washed out by the fact that I’m not accounting for the seasonality of the ozone effect.”

END OF SESSION I Q&A