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MEASURING THE BENEFITS OF REDUCED EXPOSURE TO PARTICULATE HATTER AND NITROGEN DIOXIDE IN CHILDREN

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DISCLAIMER

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I. Introduction

PURPOSE AND MOTIVATION OF PROJECT

This project has two purposes. One is to indicate what data are required to estimate and to value the health effects of particulate matter and nitrogen dioxide on children. The second is to indicate precisely how these data should be used to compute an estimate of health benefits.

The motivation for the project is the realization that existing benefit estimates have been based on datasets that lack either appropriate health, exposure, or economic data. In most work by economists pollution data from fixed site monitoring stations have been matched with cross sectional data on health and economic variables based on the individual's county of residence. Since fixed site data are likely to provide poor measures of personal exposure, especially for pollutants with important indoor sources, it is to the gathering of better quality exposure data that most attention needs to be paid. Economists, however, have also been guilty of using inappropriate health outcomes, e.g., work-loss days from all causes to measure the health effects of particulate matter; hence, more attention should also be paid to the appropriate measurement of health effects.

CHOICE OF POLLUTANTS AND POPULATION OF INTEREST

Since the approach used to measure health benefits depends on the population being studied and on the pollutants of interest, what follows is confined to a particular population group--children--and specific pollutants--particulate matter and nitrogen dioxide. Particulate matter and nitrogen dioxide were chosen because personal exposures to these pollutants are likely to be only weakly correlated with fixed site readings. This is also true of carbon monoxide, the third criteria air pollutant with important indoor sources; however, the health effects of CO are more difficult to measure and to value. Children are a natural group of interest because they are likely to receive bigger doses of NO_2 and particulates for a given exposure, and may be more sensitive to their effects than adults. Furthermore, the problem of measuring exposure are not as severe for children as for adults. Children are not occupationally exposed to pollution, are not likely to spend as much time in transit as adults and, for the most part, are not exposed to significant indoor sources of particulate matter (e.g., cigarette smoke) while at school. The difficulty in measuring personal exposure to particulate matter for smokers is also not encountered for most children.

OVERVIEW

The remainder of this report describes the health, exposure, and economic data that would be needed to value the health benefits to children of reducing exposure to particulate matter and nitrogen dioxide. Section II summarizes the mechanisms by which these pollutants are thought to affect the respiratory system and suggests ways in which these health effects could he measured. Which aspects of exposure are relevant to respiratory health and how they might be measured are discussed in section III. In section IV the assumptions about health and exposure needed to value health effects are made explicit, and formulas for computing short-term and long-term benefits of a reduction in pollution are presented. These benefit expressions are derived in Appendix A, which contains a formal model of parents' demand for child health. Appendix B describes in more detail the information needed to estimate benefits.

II. Measuring the Effects of Particulate Matter and Nitrogen Dioxide on Child **Health**[1]

The evidence from controlled and epidemiological studies suggests that exposure (either chronic or acute) to particulate matter and nitrogen dioxide may have detrimental effects on the respiratory system. The purpose of this section is to describe the physiological mechanisms by which these effects occur and to suggest how these effects should be measured for the purpose of valuing the benefits of air pollution control.

THE EFFECTS OF PARTICULATE MATTER ON RESPIRATORY HEALTH

It should be emphasized that the effects of exposure to a given particle concentration depend on a number of factors including the physical and chemical properties of the particles, and upon where the particles are deposited in the respiratory tract. Deposition of particles is influenced by their size and chemical composition, by the configuration of the individual's airways, and by the mechanics of breathing (the rate at which the individual breathes, whether the individual breathes nasally or through the mouth). One reason why children may be more sensitive to the effects of particulate matter than adults is that, being more active than adults, they have higher ventilation rates and thus inhale more particles. A second reason is that because children have smaller airways than adults more particles remain in their chest rather than being exhaled.

Of all factors influencing particle deposition perhaps the best understood is size. During nose breathing by healthy **adults**[2] most particles greater than 10 **µm** are deposited in the upper respiratory tract (the nasal and oral cavities and the larynx) and seldom reach the chest. By contrast, during mouth breathing only about 65% of particles > 10 **µm** are deposited in the upper respiratory tract, with perhaps 25% reaching the tracheobronchial region (the

[1] The material in this section is drawn primarily from U.S. EPA Air Quality Criteria for Particulate Matter and Sulfur Oxides (1982) and U.S. EPA Air Quality Criteria for Oxides of Nitrogen (1982).

[2] No studies exist that trace the deposition and clearance of particles in children. The figures below, cited in U.S. EPA Air Quality Criteria for Particulate Matter and Sulfur Oxides (1982, Ch. 11), refer to the deposition of insoluable particulte matter.

windpipe and large airways) and 10% the pulmonary region (the small airways and sacs where gas exchange occurs). Particles less than 10 µm (respirable particles) are more likely to reach the tracheobronchial and pulmonary regions. With nose breathing about 20% of all particles between 0.1 and 4 µm reach the pulmonary region, while as many as 70% of all particles < 2.5 µm (fine particles) may reach the lungs.[3]

Once deposited particles may alter the functioning of the respiratory tract in three ways. The first is by chemical or mechanical irritation of the tissue with which they come into contact. In the upper respiratory tract irritation may result in dryness of the nose and throat, sneezing, or rhinitis; in the chest area particulate matter may cause reflexive constriction of the airways (bronchoconstriction). This narrowing of the airways and consequent reduced respiratory function may be asymptomatic or may lead to shortness of breath (dyspnea).

Secondly, particles may interfere with the various defense mechanisms of the respiratory system. The trachea and bronchi, like the nose, are lined with a ciliated mucous membrane which aids in the clearance of particles from the respiratory tract. Exposure to particulate matter may affect the rates at which mucus is produced and, together with foreign particles, cleared from the passages. Reduced clearance rates may promote infection, thus making an individual more susceptible to infections of the upper and lower respiratory tracts. The build-up of mucus caused by chronic exposure to particles may produce symptoms such as chronic cough and phlegm. Additionally, chronic irritation, producing impaired mucus clearance, may allow infections to persist in the airways and so promote development of chronic bronchitis (inflammation of the mucous membrane of the bronchi) or other chronic obstructive pulmonary disease. Retained particles may also cause damage to macrophages and to the immune system of the lungs, further promoting the development of infection.

Finally, particulate matter may directly cause damage to lung tissue.

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[3] Particles deposited in different regions are cleared by different pathways at different rates. In the upper respiratory tract clearance occurs via nose blowing, sneezing, swallowing and mucociliary action, with clearance of insoluble particles taking only minutes. In the tracheobronchial region mucociliary action moves insoluble particles upward to the esophagus whence they are swallowed, and clearance takes hours to days. In the pulmonary region insoluble particles may remain for weeks to years before being cleared by conducting airways or by the pulmonary lymphatic system.

THE EFFECTS OF NITROGEN DIOXIDE ON RESPIRATORY HEALTH

As far as NO_2 is concerned less is known about its rate of absorption and clearance from the lungs. In animal studies approximately 50-60% of NO_2 that is inhaled is retained in the lungs, although for how long is not clear.

The mechanisms by which NO_2 affects respiratory health have been studied through controlled human experiments and toxicological studies involving animals. From the former there is evidence that NO_2 can result in bronchoconstriction and impairment of gas exchange. This is supported by animal studies, which also provide evidence that NO_2 may cause tissue damage and may promote infection by altering the defense mechanisms of the lungs. As in the case of particulate matter, NO_2 affects mucociliary clearance of foreign bodies from the upper respiratory tract and tracheobronchial regions. It also interferes with phagocytosis (the killing of bacteria by macrophages) and with humoral defense mechanisms.

SHORT-TERM VS. LONG-TERM HEALTH EFFECTS

How serious each of these effects is in children depends on the health of the child. For children with no history of respiratory disease mechanical irritation of the upper respiratory tract is unlikely to produce noticeable symptoms, with the exception of sneezing and runny nose. For a child with a history of hay fever; however, the latter symptoms are likely to be more pronounced. Likewise, while airway constriction may be of no consequence in a healthy child, it may precipitate or aggravate an attack in asthmatic children.

Reduced mucus clearance and impairment of other defense mechanisms makes even healthy children more susceptible to infections of the upper and lower respiratory tracts. (That chronic exposure to particulates may produce these effects is suggested by the studies of Lunn, et al., (1967, 1970) and Douglas and Waller (1966).) These infections, however, are likely to have no long-term effects in healthy children. For children with a history of respiratory disease, additional lower respiratory disease may produce lung damage.

The preceding discussion suggests that one might distinguish between the acute and chronic effects of particulates on respiratory health. In what follows the acute effects of particulate matter are defined as the immediate discomfort and/or functional limitation caused by acute respiratory illness or by acute symptoms of chronic respiratory disease. Examples of the former include upper and lower respiratory infection, which may be promoted by particulate matter or NO_2, while the latter include hay fever or asthma attacks, the onset of which may be triggered by particles or NO_2. The chronic effects of pollution are defined to be any long-term damage caused by particles or NO_2. Long-term damage will result if particles or NO_2 affect lung growth by promoting lower respiratory infection, or by directly causing tissue damage.

MEASUREMENT OF HEALTH EFFECTS

For the purpose of valuing changes in air pollution health measures should fulfill two objectives. They should reflect both the short-term and long-term effects of pollution, and they should be measures that are meaningful to parents and can therefore be valued by them.

The measure of acute health effects should reflect the discomfort and functional limitation caused by respiratory disease. A common method of measuring the incidence of acute illness is through the use of disability days. The National Center for Health Statistics (U.S. Department of Health and Human Services 1982) defines a restricted activity day as any day on which a person cuts down on his usual activities for the entire day because of illness. One problem with using number of restricted activity days due to respiratory conditions as a measure of acute health effects is that this measure does not capture severity of illness. This problem can be overcome in part through the use of school loss and bed disability days. The former is any day on which a child would normally have attended school but did not because of illness. A bed disability day is a restricted activity day at least half of which was spent in bed. There is, however, no obvious way to combine restricted activity, school loss, and bed disability days into a single measure which reflects both duration and severity of illness.

In order to measure the chronic health effects of particulate matter and NO_2 one must have some measure of the underlying condition of a child's lungs. In the language of mathematical programing we are looking for a state variable that at any time summarizes the effects of all part actions (including exposure and illness) on the lungs. Chronic effects induced by pollution exposure will then be measured by the change in the state variable over the period of exposure. In addition to reflecting my permanent damage to the lungs the chronic health measure, to be meaningful from the viewpoint of valuing health effects, should reflect susceptibility to respiratory infection in the future.

Possible choices for a chronic health measure are various measures of pulmonary function. These include forced vital capacity (PVC), the maximum amount of air that can be expelled after a deep inhalation, and forced expiratory volume in one second ($FEV_{1.0}$), the amount of air exhaled in the first second. FVC reflects total ventilatory capacity, whereas $FEV_{1.0}$ indicates the speed with which air exchange can occur. A ratio of $FEV_{1.0}/FVC$ below what is normal for a child's age, height, race and sex may indicate airway obstruction. Diseases that do not affect the airways but cause lung stiffness may leave $FEV_{1.0}$ normal but reduce FVC. FVC and $FEV_{1.0}$, together with other spirometry readings, are thus capable of indicating certain types of lung damage. What is not clear is how good an indicator of susceptibility to future respiratory infection spirometry readings are.[4]

[4] In studies of chronic obstructive pulmonary disease (COPD) in adults it is sometimes the case that a majority of adults reporting symptoms of COPD show normal $FEV_{1.0}/FVC$ values while only a minority of adults with abnormal $FEV_{1.0}/FVC$ values report symptoms (Ferris, et al., 1979; Foxman, et al., 1982).

III. Measuring Children's Exposure to Particulate Matter and Nitrogen Dioxide[5]

WHAT IS TO BE MEASURED?

As mentioned in the preceding section the dose of any air pollutant that a child receiver depends in part on the physical and chemical properties of the pollutant, on the concentration to which he is exposed, and on the duration of exposure. For the purpose of measuring health effects one must determine what the relevant physical and chemical properties of the pollutant are, and over what time period these properties should be measured.

The problem of what to measure is considerably simpler for NO_2 than for particulate matter. Although the effects of NO_2 may be altered by other pollutants with which it occurs, NO_2 is at least chemically and physically well-defined. Particulate matter is not, and its health effects depend on the size, shape, and physical density of particles as well as on their chemical composition.

Since the area of the respiratory tract in which a particle is deposited depends on its size and shape, a first step is to distinguish particles according to size.[6] A standard distinction, based on area of deposition in the lungs, is between fine particles ($\leq$ 2.5 µm), respirable particles ($\leq$ 10 µm) and inhalable particles ($\leq$ 15 µm). Since few particles greater than 10 µm reach the chest, measurement of respirable particles (RSP) is probably adequate for health effects research. It is also desirable to measure fine particles (FP), both because these are more likely to penetrate the pulmonary region, and because the chemical composition of fine particles, especially particles $\leq$ 1 µm, differs considerably from that of coarse particles (particles > 2.5 µm).

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[5] The material in this section, unless otherwise cited, is drawn primarily from U.S. EPA Air Quality Criteria for Particulate Matter and Sulfur Oxides (1982, Chs. 1,5,11) and U.S. EPA Air Quality Criteria for Oxides of Nitrogen 1982, Ch. 7).

[6] The particle sizes below refer to the aerodynamic diameter of a particle, i.e., the "diameter of a spherical particle of specific gravity which would settle at the same rate as the particle in question" U.S. EPA Air Quality Criteria for Particulate Matter and Sulfur Oxides, 1982, p. 1-11).

Fine particles are generated primarily by condensation of materials during combustion or by atmospheric transformation of the products of combustion. Although the chemical composition of FP varies with sources and weather conditions, some rough generalizations about chemical composition are possible. In most outdoor air sulfate ions (SO_4^{2-}), which usually occur in the form of ammonium sulfate, ammonium bisulfate or sulfuric acid, constitute the largest component of FP by weight. Other components of fine particles, in rough order of contribution to mass, are carbon and other organic matter, including hydrocarbons produced by combustion and the products of photochemical reactions, lead, nitrates, and small amounts of trace elements.

The chemical composition of coarse particles, which originate largely from mechanical processes such as grinding or wind erosion, is more variable and less well understood. Major components include oxides of silicon, aluminum, calcium and iron. In some areas carbon and organic compounds comprise a significant portion of coarse particles. Other components include chlorine, titanium and magnesium.

Although the chemical composition of FP can be analyzed,[7] the important question for health effects research is what components of FP should be measured because of their suspected effects on health. Toxicological studies are of some help in answering this question. In controlled animal studies one-hour exposures to sulfates and sulfuric acid have produced alterations in lung function, always at concentrations several times those in the ambient air. Of all the sulfur compounds tented sulfuric acid seems to be the most irritating, producing decreases in mucociliary clearance and increases in pulmonary resistance. Certain metal sulfates, e.g., cadmium sulfite and zinc sulfate, have been shown to affect bacterial defense mechanisms. Unfortunately, since non-sulfur components of fine particles have been less thoroughly studied, what components of FP should be measured in an epidemiological study remains an empirical question.

The question as to what duration of exposure is relevant for health effects is also primarily an empirical one. In controlled human studies exposure to NO_2 or sulfuric acid is usually for short periods (1 - 2 hours) at levels much higher than normal personal exposures. Since effects from acute

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[7] Reliable methods are available to analyze sulfates, nitrates, and organic compounds in fine particles, as well as the elemental composition of FP.

exposure are rarely seen in healthy adults at levels approaching those in the ambient air (even during violations of current standards) one might be tempted to conclude that it is not worthwhile to measure short-term perk exposures to RSP or NO_2 for children. This would be incorrect. First, no laboratory experiments have been conducted on children, who may be more sensitive to a given exposure than adults, or on adults using combinations of pollutants found in the ambient air. Second, laboratory experiments have not subjected humans to repeated short-term peak exposures, such as would occur in the case of NO_2 from an unvented gas stove.

Since there is some epidemiological evidence (Speizer, et al., 1980) to suggest that repeated short-term peak exposures may be significant in promoting lover respiratory infections in children, measurement of repeated acute exposures seems desirable. If there were little variation from day to day in 1-hour peak exposure for each child, as might be the case if the source of exposure were a gas stove, one could take maximum 1-hour exposure, averaged over several 24-hour observation periods, and compare it with acute health effects for the same observation **period.**[8]

If there were sharp fluctuations from day to day in 1-hour maximum exposures, as might be the case if peaks were caused by industrial sources of pollution, one would correlate intertemporal variation in acute illness with day-to-day fluctuations in peak exposure. In this case, repeated illness observations on each child would allow each child to serve as his own control; however, sufficient intertemporal variation in exposure might be difficult to obtain, and, in addition, one would have to control for seasonal and day-of-the-week effects.

Finally, one could examine the effects of exposure over a longer period, for example, average exposure over a period of several months, and correlate this with incidence of respiratory illness over the same period.

[8] This observation period might be as long as several months if the stove were operated under similar conditions each day during the winter months.

PERSONAL EXPOSURE MEASUREMENT VS. MEASUREMENT OF EXPOSURE BY SOURCE

Regardless of the duration of exposure that is considered relevant in assessing health effects, the appropriate exposure concept for an epidemiological study is the individual's total exposure to the pollutant over the period of interest.[9] For policy purposes, however, and to aid in experimental design, one must also know the relationship between total exposure and the sources of that exposure.

By definition total exposure to a pollutant can be expressed as the time-weighted average of concentrations in various microenvironments, where a microenvironment is defined as an "air space with homogeneous pollutant concentrations" (Duan, 1982). For purposes of illustration suppose that there are only two microenvironments, "indoors" and "outdoors," so that total exposure to some pollutant, P, can be expressed as

$$P = P^{O}t^{O} + P^{I}(P^{O},V,S)t^{I}. \qquad (1)$$

In (1) t^{O} and t^{I} are the fractions of the time period spent outdoors and indoors, and P^{O} and P^{I} are outdoor and indoor concentrations. The indoor concentration in turn depends on the penetration and ventilation rates, V, and on the magnitude of indoor sources of the pollutant, S. For the purpose of estimating an exposure-response function it is only the left-hand side of (1) that need be observed. For policy purposes, however; one must know how sources under government control, e.g., P^{O}, affect personal exposure. This involves knowing the relationship between indoor and outdoor concentrations and the fraction of time spent in each microenvironment.[10]

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[9] This assumes, of course, that the pollutant is physically and chemically well defined.

[10] Information on the contribution of outdoor sources to indoor concentrations can be obtained in two ways. If measurements art taken inside and outside buildings, then, given information on factors that influence penetration and ventilation rates, a model can be estimated that explains indoor concentrations as a function of outdoor concentrations (Dockery and Spengler, 1981). Chemical analysis of indoor air can also provide information about outdoor sources since some components of FP (sulfate and nitrate ions, vanadium, cadmium, nickel and selenium) are almost exclusively of outdoor origin.

HOW IS TOTAL EXPOSURE TO BE MEASURED?

Equation (1) suggests two approaches to measuring total exposure. One is to try to observe the left-hand-side of (1) directly by having children wear or carry personal monitors for the period of interest. The second is to observe the time spent in various microenvironments and to measure pollutant concentrations in these microenvironments using passive monitors. Since school-aged children might spend 60% of each week inside their homes and 20% inside school buildings, measurement of concentrations in these two microenvironments, together with measurement of outdoor concentrations, may provide an estimate of personal exposure accurate enough for use in an epidemiological study.[11]

Both the microenvironmental approach and use of personal monitors require inexpensive, portable monitors to measure RSP and NO_2. For NO_2 there are two portable samplers, the Palmes diffusion tube (Spengler et al., 1979) and a badge sampler, which provide low-cost methods of obtaining NO_2 readings. Diffusion tube samplers use a modified sodium arsenite procedure for measuring NO_2, which has a 24-hour averaging time. Badge samplers also have a 24-hour averaging time. NO_2 measurement techniques with shorter averaging times exist (e.g., the continuous-Salzman and chemiluminescence methods); however, no inexpensive monitors using these techniques are available.

The situation for RSP is similar. Portable cyclone samplers that provide integrated measurements of RSP and FP are available at a cost low enough to make their use in epidemiological studies feasible (Turner, et al., 1979; Bright and Fletcher, 1983). To collect a sufficiently great particle mass, however, these samplers must operate for 12-24 hours. Accurate measurement of short-term exposures to RSP or NO_2 does not, therefore, seem feasible on a scale necessary for an epidemiological study.[12] For this reason section IV focuses on the benefits of reducing chronic exposures to RSP and NO_2.

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[11] To determine whether this estimate is sufficiently accurate would, of course, require a comparison of personal monitoring data with estimates obtained using a microenvironmental approach. Furthermore, what is an acceptable measurement error depends on the accuracy with which health effects can be measured.

[12] This statement may not be entirely accurate, depending on the source of the peak exposure. If one wishes to measure NO_2 concentrations while a gas stove is in operation, and if these concentrations do not vary much from day to day, one could operate the monitor only during periods of stove use for enough days to achieve the minimum averaging time.

To measure long-term exposure to NO_2 for an epidemiological study badge samplers are both feasible and inexpensive. The samplers are noiseless and unobtrusive and accurately gauge personal exposures for averaging times of up to several weeks. The drawback of a badge sampler, or of any personal monitor for that matter, is that it does not provide information on pollution sources unless accompanied by detailed time and location information. Even with this information the contribution of different sources can be inferred only by regression techniques, given the integrated nature of exposure data.

The microenvironmental approach, by contrast, does provide information on source contributions. In the case of RSP it also avoids problems which may result from the bulkier and noisier nature of particulate monitors.[13] Placing cyclone samplers inside a child's home and classroom may therefore be preferable to the use of a portable monitor for RSP.

[13] In personal monitoring studies involving adults, subjects have shown a reluctance to carry portable cyclone samplers. Carrying such monitors may also cause subjects to alter their activity and exposure patterns.

IV. Valuing the Benefits of Reduced Exposure to RSP and NO_2 in Children

INTRODUCTION

The purpose of this section is to determine how one could value the benefits, both short-term and long-term, of reducing children's exposure to particulate matter and nitrogen dioxide. Short-term benefits result if children who are chronically exposed to high levels of RSP or NO_2 experience more upper and lower respiratory tract infections than children exposed to lower levels. In this case the benefits of lower chronic exposure take the form of reduced costs of medical care. The latter include the cost of doctors' and hospital visits, lab tests, medication, and nursing care, which is usually provided by the child's parents. These costs may be small per restricted activity day, but, as they are borne by most parents, substantial when aggregated over all families.

For most children the benefits of reduced exposure to pollution are probably short-term, since breathing higher levels of pollution would have no permanent adverse health effects. There are, however, two ways in which particulate and nitrogen dioxide exposure could have long-term health consequences. One is if acute infections of the lower respiratory tract cause long-term lung damage. The second is if exposure to particulate matter or NO_2 directly affects lung development without contributing to infection. In either of these cases current exposure to air pollution could make a child more prone to respiratory infections or to acute symptom of chronic respiratory disease later in life. The costs of these illnesses would include the costs of medical care referred to above. In extreme cases the child's educational achievement and career choice could be affected. To value the long-term benefits of reduced exposure; however, one must be able to measure the effects of current pollution exposure on future respiratory health. Since it is difficult to establish the effects of childhood exposure on adult health, we consider below only the effects of current particulate exposure on future childhood health.

MODELLING THE HEALTH EFFECTS OF PARTICULATES

To make explicit how the health benefits of reduced exposure could be measured, we formalize the short-term and long-term effects of pollution exposure in two equations. The first equation describes the relationship between acute respiratory illness and exposure. Formally, let A_t denote the number of restricted activity **days**[14] due to respiratory illness during year t. These would include days when a child's normal activities are curtailed because of influenza, a cold or a chest illness, or days when acute symptoms of a chronic respiratory condition, e.g., asthma, are experienced. Average exposure to air pollution in year t, P_t, may affect A_t by reducing resistance to infection or, in the case of asthmatic children, by promoting bronchoconstriction. Other factors that may influence A_t include exposure to tobacco smoke and preventive measures taken by the child's parents, such as providing good nutrition or flu shots. These are summarized by the vector $\underline{Z}_t$. The empirical counterparts of these variables are described in Appendix B. In addition, acute illness (especially lower respiratory tract infections) should depend on the state of the child's respiratory health, i.e., on the underlying condition of his lungs. This might be measured by spirometry tests and will be denoted H.[15]

All of the aforementioned determinants of acute illness can, at least in principle, be measured. Factors affecting A_t that cannot be measured include severity of exposure to viruses and bacterial infections or, in the case of an asthmatic, severity of exposure to allergens. These and other unobserved variables are summarized by u_t.

The relationship between acute illness and its determinants is thus given by

$$A_t = f(P_t, \underline{Z}_t, H_{t-1}, u_t). \qquad (1)$$

Since this functional relationship may be quite different for illnesses of the upper and lower respiratory tracts, it may be preferable to write two separate equations

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[14] This term is defined more precisely below.

[15] It is assumed throughout that H is adjusted for age, height, race and sex.

$$A_t^U = f^U(P_t, \underline{Z}_t, H_{t-1}, u_t) \ , \tag{1a}$$

$$A_t^L = f^L(P_t, \underline{Z}_t, H_{t-1}, u_t) \ , \tag{1b}$$

where A^U denotes upper respiratory tract conditions (colds, influenza, rhinitis) and A^L denotes conditions of the lower respiratory tract (bronchitis, pneumonia, dyspnea).

An important omission from equation (1) is medical care that a child receives once he is ill. This includes visits or calls to the doctor to diagnose the illness, X-rays, laboratory tests, medication, and nursing care. One justification for omitting recuperative medical care is that for certain respiratory illnesses, e.g., colds and influenza, it serves primarily to alleviate symptoms. Although relief of symptoms may reduce the severity of a restricted activity day, it need not affect the total number of restricted activity days experienced as long as a restricted activity day is broadly defined to be any day on which the child feels less well than usual.

In cases where medical care, M, can actually cure an infection it might be appropriate to express restricted activity days as some function of M and the amount of acute illness that would be experienced if no medical care were received, $f(P_t, \underline{Z}_t, H_{t-1}, u_t)$; for example,

$$A_t = h(M_t) \ f(P_t, \underline{Z}_t, H_{t-1}, u_t), \quad h' < 0. \tag{2}$$

Equation (2) says that holding severity of illness (u_t) constant, children who receive more medical care get well faster. The problem in trying to estimate (2) is that severity of illness, because it is not observed by the researcher, cannot be held constant. When u_t is omitted from (2) its effects are reflected in M_t since the amount of medical care chosen by parents varies directly with severity of illness. The sign of M_t is thus likely to be perverse.[16]

Because of these estimation problems we choose to use (1) rather than (2) to describe the relationship between acute illness and air pollution. It can be shown that omission of M_t from the acute illness equation

[16] Appendix A discusses ways in which this estimation problem could be solved: however, none of there seems very promising in practice.

will, if anything, cause the effect of air pollution on acute illness to be understated. The choice of equation (1) thus errs on the side of conservatism from the viewpoint of benefits estimation.

The long-term effects of air pollution on respiratory health are captured by equation (3), which describes the rate of change in lung function.

$$\Delta H_t = H_t - H_{t-1} = g(P_t, \underline{W}_t, A^L_t, H_{t-1}, e_t) \quad (3)$$

As mentioned above, air pollution may either affect future respiratory health directly or, indirectly, by influencing the number of lower respiratory tract infections experienced. In addition, the rate of change in lung function will depend on such factors as exposure to tobacco smoke and on the child's nutrition and general health, which are summarized in the vector $\underline{W}_t$. The variable e_t represents unobservable factors, e.g., genetic factors, which may influence ΔH_t.

MEASURING THE SHORT-TERM BENEFITS OF IMPROVED CHILD HEALTH

In the model of parents' demand for child health presented formally in Appendix A it is assumed that parents' current satisfaction (utility) depends in part on A_t, the amount of acute respiratory illness their child experiences. Utility does not depend directly on lung capacity (H_t), although this affects future utility through equation (1).[17]

Parents can affect acute illness, or the discomfort it causes, in several ways. First, certain goods that they enjoy consuming, such as cigarettes, may enter equations (1) and (3). Secondly, they may undertake preventive activities, such as seeing that their child gets proper rest and nutrition, directly for the purpose of improving their child's health. For parents of asthmatics or children with hay fever these activities might include having their child tested for allergies and seeing that allergic substances are

[17] The assumption that utility does not depend directly on H_t seems reasonable unless H_t is so low that the child's life is threatened. We ignore this possibility on the grounds that is it a rare event.

not present in the home.[18] Thirdly, the discomfort caused by acute illness can be reduced through recuperative medical care, M_t. This is reflected in the assumption that parents' utility depends not simply on the number of restricted activity days experienced by their child (A_t), but on an index of discomfort which combines restricted activity days and medical care. Specifically, it is assumed that utility depends on the ratio A_t/M_t^{β}, $0 < \beta < 1$, implying that increases in recuperative medical care reduce the discomfort associated with acute illness, but at a decreasing rate ($0 < \beta < 1$).

Given that a parent can influence his child's health, the question is what would an informed parent (i.e., one who knew equations (1) and (3)) be willing to pay for a small decrease in his child's chronic exposure to air pollution? Since the effects of air pollution on acute illness can be mitigated in part through recuperative medical care it is not surprising that the immediate benefit to a family of a change in air pollution, B_t, is proportional to the average cost of medical care per restricted activity day, $C(M_t)/A_t$, multiplied by the effect of air pollution on restricted activity days,[19]

$$B_t = \beta^{-1} C(M_t) A_t^{-1} (\partial A_t/\partial P_t) \qquad (4)$$

As noted above, the parameter 8, which indicates the efficacy of medical care In relieving the symptom of acute illness, must lie between 0 and 1. Although β can in principle be estimated, we shall set $\beta = 1$ to obtain a lower bound to benefits.

To compute the remaining terms in (4) requires an estimate of equation (1), as well as information on the cost of recuperative medical care related to

[18] If parents are sensitive to the possible health effects of air pollution then behavior to reduce exposure to air pollution, such as purchasing an air filter, would be included under preventive activities.

[19] One might wonder why (4) does not include the cost of preventive activities (including activities to reduce exposure to air pollution) as well as the cost of recuperative medical care. The answer is that informed parents, when allocating resources between preventive and recuperative activities, will equate the marginal benefits from the two activities. The value of an additional dollar of recuperative medical care is therefore equal to the value of an additional dollar of preventive medical care.

respiratory **illness.**[20] To determine the cost of medical care per restricted activity day one must know

- the number of restricted activity days due to respiratory illness over some period (e.g., a year);
- what laboratory tests and X-rays were ordered;
- what medication (shots, prescriptions) was administered;
- whether or not and for how long the child was hospitalized; and
- whether or not for for how long parents' normal activities (e.g., work) were disrupted to care for the sick child.

Specific questions that could be asked to elicit this information appear in Appendix B.

Given the detail of the information needed and the fact that this information is required for all respiratory illness (including colds and the flu) regardless of duration, it would be difficult to obtain the information except through diaries. In assessing the respondents' burden of these diaries it should be borne in mind that the information requested pertains only to respiratory illness for a single member of the family. Given that the mean number of restricted activity days per year due to acute respiratory illness is approximately 4.0 (U.S. Department of Health and Human Services, 1982), this would probably require no more than one hour of parents' time over a year. (A sample diary appears in Appendix B.)

A more difficult question is how information should be obtained about the costs of medical care. Ideally, parents could record the costs that they actually incur for hospital stays, doctors' visits, lab teats, and prescriptions in the monthly diary. Information on the cost of time spent caring for a sick child is more troublesome. If this time represents time lost from work and is not covered by paid sick leave then it can be approximated by the parents wage. Parents who do not work outside the home or whose absence is covered by paid sick leave could be asked to approximate the cost to them of activities foregone. Although it is possible to impute costs to the

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[20] If it is important to distinguish between acute illness of the upper and lower respiratory tracts then equation (4) would be computed separately for each category of acute illness.

components of medical care if they are described in sufficient detail, it is important that the actual coat to the parent he recorded. Since the type and amount of treatment selected depends on the actual costs incurred, use of imputed prices to value medical care will likely overstate the costs of care if parents have medical insurance or can use paid sick leave when they stay home to care for a child. If costs must be imputed then it is imperative that information on health insurance and paid sick leave be obtained.

MEASURING TEE LONG-TERM BENEFITS OF IMPROVED CHILD HEALTH

Equation (4) describes only the immediate benefits of a reduction in air pollution. As long as air pollution influences future respiratory health, $H_{t+1}, H_{t+2}, \ldots$, and respiratory health affects acute illness, a decrease in P_t will yield future as well as current benefits. The present value of benefits from a change in P_t is given by

$$\beta^{-1}C(M_t)A_t^{-1}(\partial A_t/\partial P_t) + (1+r)^{-1}\beta^{-1}C(M_{t+1})A_{t+1}^{-1}(\partial A_{t+1}/\partial H_t)(dH_t/dP_t) + (1+r)^{-2}\beta^{-1}C(M_{t+2})A_{t+2}^{-1}(\partial A_{t+2}/\partial H_{t+1})(dH_{t+1}/dP_t) + \ldots \quad (5)$$

where r is the interest rate. In equation (5) benefits in year t+l from a decrease in pollution in year t are proportional to the average cost of medical care per restricted activity day (discounted to the present) multiplied by the effect of P_t on the number of restricted days experienced in year t+l,

$$(\partial A_{t+1}/\partial H_t)(dH_t/dP_t) = (\partial A_{t+1}/\partial H_t)(\partial H_t/\partial P_t) + (\partial A_{t+1}/\partial H_t)(\partial H_t/\partial A_t^L)(\partial A_t^L/\partial P_t).$$

Benefits in subsequent years have a similar interpretation. Assuming $\beta = 1$, computation of (5) requires only that equation (3) be estimated in addition to equation (1).

PERSONAL EXPOSURE MEASUREMENT AND BENEFITS ESTIMATION

For simplicity of exposition the above discussion has been couched in terms of a single air pollution variable, P_t. What must be discussed in greater detail is the relationship between P_t, personal exposure to pollution, and benefits estimation.

In estimating the effects of air pollution on health the relevant variables are the child's total exposure to the pollutants of interest. If these are NO_2 and particulates one could write equation (1) as

$$A_t = f(NO_2, PM_{St}, PM_{Ft}, \underline{Z}_t, H_{t-1}, u_t) \tag{1'}$$

where NO_{2t} refers to total exposure to nitrogen dioxide, and a distinction has been made between total exposure to particulates from tobacco smoke (PM_S) and from fossil fuel (PM_F) due to differences in the chemical composition of these sources.

If for simplicity there are at must two microenvironments in which the child can be exposed to each pollutant, "indoors" and "outdoors," then total exposure to NO_2 can be written as the time-weighted average of outdoor (NO_2^O) and indoor (NO_2^I) concentrations,

$$NO_2 = t^O NO_2^O + t^I NO_2^I(NO_2^O, S_{NO_2}, V). \tag{6}$$

The latter, in turn depends on outdoor concentrations, the ventilation and penetration rates (V) and indoor sources (S_{NO_2}). A similar equation could be written for fossil fuel particulates,

$$PM_F = t^O PM_F^O + t^I PM_F^I(PM_F^O, S_{PM_F}, V). \tag{7}$$

Since particulates from tobacco smoke have only indoor sources,

$$PM_S = t^I PM_S^I(S_{PM_S}, V). \tag{8}$$

From a policy viewpoint the variables in equation (6) - (8) that are currently under government control are NO_2^O and PM_F^O. To calculate the value of a small change in one of these policy variables, e.g., NO_2^O, one must therefore determine

$$(\partial A/\partial NO_2)\ (\partial NO_2/\partial NO_2^O). \qquad (9)$$

It is this expression that would replace $\partial A/\partial P$ in equations (4) and (5).[21] Note that to compute (9) one must know not only the coefficient of total exposure to NO_2 in the illness equation, $\partial A/\partial NO_2$, but the effect of outdoor concentrations on total exposure.

[21] Likewise, if total exposure to NO_2 enters (3) $\partial H_t/\partial P_t$ must be replaced by $(\partial H_t/\partial NO_2)\ (\partial NO_2/\partial NO_2^O)$.

APPENDIX A

A Model of Parents' Demand for Children's Respiratory Health

This appendix presents a model of parents' demand for child health. The purpose of the model is to derive parents' marginal willingness to pay for an improvement in air pollution, given that air pollution affects their child's current and future respiratory health. The derivation of willingness to pay assumes that equations (1') and (3) in the text adequately describe the health-air pollution relationship. The consequences of using equation (2) to model acute illness are discussed at the end of the appendix.

THE FORMAL MODEL[1]

AS indicated in the text, parents' utility during year t is assumed to depend on acute respiratory illness experienced by their child during that year, A_t. A_t in turn depends on total exposure to various pollutants $(NO_{2_t}, PM_{S_t}, PM_{F_t})$, on past respiratory healthy (H_{t-1}), and on other variables $(\underline{Z}_t)$. Parents can increase their child's total exposure to pollution by smoking, by cooking with an unvented gas stove or by sealing windows and doors in a home where indoor concentrations of PM and NO_2 exceed outdoor concentrations. Actions to lower children's exposure would include use of an air conditioner and/or insulation to reduce penetration of outdoor pollutants in a dirty city or the purchase of an air filter. Innoculation against influenza viruses and maintenance of good nutrition are examples of health-promoting activities unrelated to exposure.

For the purposes of the appendix, however, the relevant distinction is not between variables that affect exposure and those that do not but between goods that enter the utility function as well as (1'), such as cigarettes, and good that are purchased solely for their effect on children's health, such as

[1] This model follows in general terms the "household production" approach to health, as developed by Grossman (1972a,b) Harrington and Portney (1983), Rosenzweig and Schultz (1982) and Gerking and Stanley (1983).

flu shots. The former are denoted Y_t and the latter, referred to as preventive goods, denoted N_t. Equation (1') is rewritten accordingly as

$$A_t = F(P_t, Y_t, N_t, H_{t-1}, u_t),$$

where P_t refers to that component of the child's personal exposure to pollution that is exogenous to the family.[2]

In addition to consuming Y_t and purchasing N_t parents can reduce the discomfort associate with A_t through recuperative medical care. This includes visits and calls to the doctor to diagnose illness, laboratory tests, medication, and nursing care given to the sick child. We denote the amount of recuperative medical case chosen M_t and assume that disutility of illness depends on the ratio A_t/M_t^β, $0 < \beta \leq 1$. This implies that increases in M_t reduce the discomfort of acute illness, but at a decreasing rate. Parents' utility is thus given by

$$\begin{aligned} &U_t = U(X_t, Y_t, A_t/M_t^\beta), \\ &U_1 > 0, \quad U_2 > 0, \quad U_3 \leq 0, \quad U_3(X_t, Y_t, \infty) = -\infty \qquad \text{(A.1)} \\ &U_3(X_t, Y_t, 0) = 0, \quad U \text{ strictly concave,} \end{aligned}$$

where X_t are consumption goods unrelated to health.

To formalize the parents' choice problem we consider a two-period horizon. (Extensions to n periods are straightforward.) The problem is to select values of X_t, Y_t, N_t, and M_t, for the present (t=1) and the future (t=2) to maximize the present value of parents' utility

$$V = U(X_1, Y_1, A_1/M_1^\beta) + U(X_2, Y_2, A_2/M_2^\beta), \qquad 0 < \alpha \leq 1, \qquad \text{(A.2)}$$

subject to various technological and economic constraints. These include the health relationships

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2 P_t should be identified as outdoor concentrations of the pollutant, although even these are choice variables if the family can move to another city., The complications introduced by migration; however, are ignored here.

$$H_1 - H_0 = g(P_1, Y_1, N_1, A_1^L, H_0, e_1) \qquad (A.3)$$

$$A_t^i = F^i(P_t, Y_t, N_t, H_{t-1}, u_t), \qquad t = 1,2 \text{ and } i = L,U \qquad (A.4)$$

$$A_t = A_t^L + A_t^U, \qquad t = 1,2$$

and budget constraint

$$\sum_{t=1}^{2} (X_t p_t^X + Y_t p_t^Y + M_t p_t^M + N_t p_t^N - I_t)\,(1+r)^{-(t-1)} = W_0, \qquad (A.5)$$

where W_0 is initial wealth, I_t earnings in year t, and the p_t^i's are goods prices. Because the use of X, Y, N, and M involves time, the time constraints (A.6) and (A.7) also apply.

$$X_i t^X + Y_i t^Y + N_i t^N + M_i t^M = T_i - t_i^w, \qquad i = 1,2 \qquad (A.6)$$

$$t_i^w w_i = I_i, \qquad i = 1,2 \qquad (A.7)$$

In (A.6) T is total time available and t^X is the time required to consume a unit of X. t^w is time spent working outside the home at wage rate w. Equations (A.5) - (A.7) can be combined to yield (A.8)

$$\sum_{t=1}^{2} (X_t q_t^X + Y_t q_t^Y + N_t q_t^N + M_t q_t^M - w_t T_t)\,(1+r)^{-(t-1)} = W_0 \qquad (A.8)$$

where $q_i^j = p_i^j + t^j w_i$ is the total (time plus out-of-pocket) cost of a unit the j^{th} good.

Maximization of (A.2) requires that the following necessary conditions be satisfied, in addition to equation (A.8):[3]

$$U_1 - \lambda q_1^X \leq 0 \qquad (A.9)$$

$$\alpha \bar{U}_1 - \lambda (1+r)^{-1} q_2^X \leq 0 \qquad (A.10)$$

[3] In (A.9)-(A.16) subscripts indicate partial derivatives. U_1 is evaluated at the point $(X_1, Y_1, A_1/M_1^\beta)$ and $\bar{U}_1$ is evaluated at the point $(X_2, Y_2, A_2/M_2^\beta)$. To guarantee that (are sufficient for a maximum we assume that $g(\cdot)$ and $f(\cdot)$ are concave functions. λ is the Lagrange multiplier associated with (A.8).

$$F_1 - \lambda q_1^Y \leq 0 \tag{A.11}$$

$$\alpha F_2 - \lambda(1+r)^{-1} q_2^Y \leq 0 \tag{A.12}$$

$$-U_3 A_1 \beta M_1^{-(\beta+1)} - \lambda q_2^M \leq 0 \tag{A.13}$$

$$-\alpha \bar{U}_3 A_2 \beta M_2^{-(\beta+1)} - \lambda(1+r)^{-1} q_2^M \leq 0 \tag{A.14}$$

$$G_1 - \lambda q_1^N \leq 0 \tag{A.15}$$

$$\alpha G_2 - \lambda(1+r)^{-1} q_2^N \leq 0, \tag{A.16}$$

where

$$F_1 = U_2 + U_3 \frac{\partial A_1/\partial Y_1}{M_1^\beta} + \alpha \bar{U}_3 \frac{\partial A_2/\partial H_1}{M_2^\beta} \; dH_1/dY_1$$

$$F_2 = \bar{U}_2 + \bar{U}_3 \frac{\partial A_2/\partial Y_2}{M_2^\beta}$$

$$G_1 = U_3 \frac{\partial A_1/\partial N_1}{M_1^\beta} + \alpha \bar{U}_3 \frac{\partial A_2/\partial H_1}{M_2^\beta} \; dH_1/dN_1$$

$$G_2 = U_3 \frac{\partial A_2/\partial N_2}{M_2^\beta} .$$

DERIVATION OF WILLINGNESS TO PAY

To derive the amount of initial wealth that could be taken away from the family in response to a small change in P_1 and leave utility constant, differentiate (A.2) and (A.8) totally and set dV = dT_t = dw = dq_t^j = 0,

$$dV = 0 = dX_1U_1 + dY_1F_1 + dM_1(-U_3A_1\beta M_1^{-(\beta+1)}) + dN_1G_1 + dX_2\alpha\bar{U}_1$$

$$+ dY_2F_2 + dM_2(-\alpha\bar{U}_3A_2\beta M_2^{-(\beta+1)}) + dN_2G_2 \tag{A.17}$$

$$+ dP_1(U_3\frac{\partial A_1/\partial P_1}{M_1^\beta} + \alpha\bar{U}_3\frac{\partial A_2/\partial H_1}{M_2^\beta} dH_1/dP_1), \text{ and}$$

$$0 = dX_1\lambda q_1^X + dY_1\lambda q_1^Y + dM_1\lambda q_1^M + dN_1\lambda q_1^N + dX_2\lambda q_2^X(1+r)^{-1} + dY_2\lambda q_2^Y(1+r)^{-1}$$

$$+ dM_2\lambda q_2^M(1+r)^{-1} + dN_2\lambda q_2^N(1+r)^{-1} + dW_0. \tag{A.18}$$

Substituting from (A.9)-(A.16) into (A.17) and from (A.17) into (A.18) yields, after some rearrangement,

$$-\frac{dW_0}{dP_1} = \frac{q_1^M M_1\beta^{-1}}{A_1}\frac{\partial A_1}{\partial P_1} + (1+r)^{-1}\frac{q_2^M M_2\beta^{-1}}{A_2}\frac{\partial A_2}{\partial H_1}\frac{dH_1}{dP_1}, \tag{A.19}$$

which is a variant of (5) in the text.

It should be noted that the derivation of (A.19) depends crucially on the assumption that M_t, recuperative medical expenditure, does not affect the amount of time spent ill or the rate of change in lung function. To see the consequences of relaxing this assumption suppose that equation (1) in the text is replaced by (2) so that M_t affects the amount of time spent ill. It follows that M_t also affects the rate of change in lung function through its effect on severity of lower respiratory infection. Since the effects of medical treatment are already incorporated into the acute illness measure, it is reasonable to write the third argument of the utility function as A_t.

With the above changes the expression for willingness to pay becomes[4]

$$-\frac{dW_0}{dP_1} = -\frac{\partial A_1/\partial P_1}{\partial A_1/\partial M_1} q_1^M - (1+r)^{-1} q_2^M \frac{\partial A_2/\partial H_1}{\partial A_2/\partial M_2}\{\frac{dH_1}{dP_1} - \frac{dH_1}{dM_1}\frac{\partial A_1/\partial P_1}{\partial A_1/\partial M_1}\}. \tag{A. 20}$$

Several points about (A.20) are worth noting. If the first terms in (A.19) and (A.20) are compared it can be seen that $M_1(A_1\beta)^{-1}$ has been replaced by

[4] It should be noted that a similar expression could be written using preventive medical care, N_t, since M_t and N_t now enter the model in formally equivalent ways. Preventive medical care, however, is more difficult to define and measure than recuperative medical care.

$(\partial A_1/\partial M_1)^{-1}$. If (2) were of the form

$$A_t = M_t^{\beta} f(P_t, \underline{Z}_t, H_{t-1}, u_t), \qquad 0 < \beta \leq 1, \tag{A.21}$$

the two terms would be equivalent. Setting $\beta = 1$ as in the text would again yield a lower bound to benefits. Even with this simplification; however, the second terms in (A.19) and (A.20) differ. As long as recuperative medical expenditures affect the rate of change in lung capacity the expression in (A.19) overstates willingness to pay for a change in pollution. The reason is simple. The more effective is medical care in reducing acute illness the less the individual should be willing to pay for substitutes for medical care.

What can be concluded from the above? If M truly affects length of acute illness then one can still use (4) in the text, with $\beta = 1$, to obtain a lower bound to short-term benefits; however, estimation of $\partial A_t/\partial P_t$ requires that M_t be included in the acute illness equation. To estimate long-term benefits equation (A.20) must be used.

Whether medical treatment indeed affects the duration of acute illness is ultimately an empirical question that requires estimation of equation (2). As noted in the test, the difficulty in estimating (2) is that the level of medical care chosen by parents depends on severity of illness, u_t, which is not observed by the researcher, and therefore enters the error term in the acute illness equation. Rosenzweig and Schultz (1982) suggest the following solution to this problem. If equations (A.9)-(A.16) are solved simultaneously, M_1 will depend on the prices of all goods now and in the future, on the family's full income, $w_1T_1 + (1+r)^{-1} w_2T_2$, on its initial wealth, W_0, and on the child's initial health, H_0. If some of these variables, denoted V_t, are distributed independently of u_t then least squares estimation of a reduced-form health equation,

$$M_t = \underline{\delta}'\underline{V}_t + u_t, \; cov(v_{it}, u_t) = 0 \qquad \text{all } i, t, \tag{A.22}$$

allows one to compute predicted medical expenditure $\hat{M}_t = \underline{\delta}'\underline{V}_t$, which is Srthogonal to u_t. Least squares estimation of (A.21) with $\hat{M}_t$ in place of M_t should yield a consistent estimator of $\partial A_t/\partial M_t$.[5]

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[5] Assuming, of course, that the other variables in (A.21) are uncorrelated with u_t.

While in theory this solves the problem of consistently estimating the effects of M_t on A_t, in practice it is likely to be difficult to construct a good predictor of M_t. When Rosenzweig and Schultz (1982) estimate reduced-form demand functions for inputs into fetal health, it is mother's education (interpreted as a variable which influences perceptions of the health production function) which explains most of the variation in inputs used. One therefore winds up using education as a surrogate for inputs into fetal health.

APPENDIX B

Information Necessary to Estimate the Benefits Of Reduced Exposure to RSP and NO_2

The information required to estimate the health benefits of a reduction in air pollution falls into two categories:

(1) information necessary to estimate the relationship between restricted activity days due to respiratory illness and air pollution (equation (1') in the text) and between change in lung function and air pollution (equation (3) in the text);

(2) information on the amount and cost of recuperative medical care provided for respiratory illness.

Table 1 lists the variables needed for estimation of the two health equations and Table 2 the information required regarding medical care.

Due to the need to eliminate seasonal fluctuations in illness and in chronic pollution exposure, the data in Tables 1 and 2 would probably be collected over a period of at least a year. Spirometry tests would be performed at the beginning and end of the year, and, at the time of these tests, most of the explanatory variables in the health equations (with the exception of the pollution variables) would be obtained form a questionnaire completed by the child's parents. An example of such a questionnaire is one used in the Harvard Six Cities Air Pollution-Health Study (Ferris, et al., 1979), which is attached. The information on restricted activity days and use of medical care would most accurately be obtained by having parents fill out monthly diaries. A sample diary is attached.

Table 1

Information Required for Estimation of Health-Air Pollution Relationship

<u>Dependent Variables</u> (to be measured over a year)

1. Number of restricted activity days due to upper respiratory conditions

2. Number of restricted activity days due to lower respiratory conditions

3. Change in FVC, $FEV_{1.0}$ (adjusted for age, height, race and sex)

<u>Independent Variables</u>

1. $FEV_{1.0}$, FVC at beginning of year (adjusted for age, height, race and sex)

2. Average exposure to RSP (broken down by chemical composition), NO_x during the year

3. Parents' education

4. Child's age

5. Child's race

6. Child's sex

7. History of respiratory illness in family

8. Whether child received flu shots during year

9. How much child smokes

10. History of serious respiratory illness prior to current year

11. History of respiratory symptoms prior to current year

12. Number of school-aged siblings

Table 2

Information Required for Computation of Recuperative Medical Costs

Number of restricted activity days due to respiratory illness

Number of these days on which a parent or other family member altered his normal activities to care for the child; value of activities foregone

Number of these days on which someone was paid to care for the child because he was sick; cost to parents of these services

Number of visits to a doctor's office or hospital emergency room as a result of respiratory illness; cost to parents of these visits

Cost to parents of laboratory tests or X-rays ordered to diagnose respiratory illness

Cost to parents of days spent in the hospital as a result of respiratory illness

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SCHOOL LUNG SURVEY
Harvard School of Public Health
Boston, Massachusetts 02115

To: Parents of Elementary Grade School Children

From: Principal

Subject: Respiratory Health Survey

Your school, as part of a district-wide program, is participating in a health survey of school children. Breathing tests, height and weight will be measured and this will be done during school time over the next week or so. The breathing test involves blowing a few times into a tube (changed for each person). The program is part of a larger study which includes adults living in your town and is being continued over the next 3 years. These results will be compared with similar data from other communities.

To obtain important information which is needed to correlate with the breathing tests we would very much appreciate your cooperation in completing the attached questionnaire and returning it to your child's teacher in the envelope provided, via your child.

PLEASE CHECK ALL QUESTIONS, EVEN IF ANSWER IS NO.

Seal the envelope, and be assured that the envelope will be opened only by the research team that is collecting the data. All data will be kept confidential.

This study has been presented to and approved by both the school administration and your elected school committee.

It is important that the permission slip at the end of the questionnaire is signed.

Thank you for your cooperation.

Do not write in this margin

1 2 3 4 5
6 7 8

Please complete all questions; use back for comments.

Child's Name ______________________ Birth Date ____ ____ ____ | 9 10 11 12 13 14

mo 9-10 | day 11-12 | yr 13-14

Home Address ______________________ 15 Child's Sex: Male ___ Female ___ | 15

______________________ Phone ______________________ | 16 17

16-17 Zip Code

18-19 How many years has this child lived in this community ____ yrs. ____ mos. | 18 19

20-21 How many adults live in this child's home? Include *everyone* 18 years of age and over ___ | 20 21

22-23 How many other children under 18 (not counting this child)? ____ | 22 23

24-25 How many younger than this child? ____ | 24 25

26-27 What fuel is used to heat the house? | 26 27

Oil ___ Gas ___ Coal ___ Wood ___ Electricity ___ Other, specify ____________

28-29 How is the heat brought into the rooms? By: | 28 29

Hot Air ___ Hot Water ___ Steam ___ Fireplace ___ Space Heater ___

Other, specify ____________

30 What fuel is used for cooking? Gas ___ Coal ___ Wood ___ Electricity ___ Other ______ | 30

7/2 Do you have an exhaust fan for your cooking stove? No ___ Yes ___ don't know ______

8/2 If yes, do you use it: Never ___ Seldom ___ Regularly ___

9/2 How is the exhaust fan vented?

into the room ___; vented to outside ___; don't know ___

31 Is this child's home air-conditioned? No ___; Yes, partially ___; Yes, completely ___. | 31

If partially, is the living room? No ___ Yes ___ Is the child's bedroom? No ___ Yes ___

32 How many rooms are there in the home (count kitchen but not bathroom)? ____ | 32

33 Does this child sleep in a bedroom by himself/herself? No ___ Yes ___ | 33

If No, does he/she have his/her own bed? No ___ Yes ___

Has this child had any of the following illnesses? (Please give ages of *all* attacks.)

34 Measles No ___ Yes ___ at age ___ | 34 35 36 37

35 Mumps No ___ Yes ___ at age ___

36 Chicken Pox No ___ Yes ___ at age ___

37 German Measles No ___ Yes ___ at age ___

38 Bronchitis No ___ Yes ___ at age(s) ___ ___ | 38 39 40 41

39 Pneumonia No ___ Yes ___ at age(s) ___ ___

40 Earache No ___ Yes ___ at age(s) ___ ___

41 Croup No ___ Yes ___ at age(s) ___ ___

42 Whooping Cough No ___ Yes ___ at age ___ | 42 43 44

43 Asthma No ___ Yes, began at age ___ Present now? No ___ Yes ___

44 Hay Fever No ___ Yes, began at age ___ Present now? No ___ Yes ___

(Recurrence)

47 In the past year has this child had a chest illness that kept him/her at home for 3 days or more? 47

No____ If Yes, how many times?____

48 Did this child have a severe chest illness or chest cold before the age of 2 years? 48

No____ If Yes, how many times?____

49 Was a doctor seen for a severe chest illness or chest cold before the age of 2 years? 49

No____ If Yes, for how many illnesses? ____

50 Was the child hospitalized for a severe chest illness or chest cold before the age of 2 years? 50

No____ If Yes, for how many illnesses? ____

PARENTS' ILLNESSES

61 Has doctor ever said NATURAL father had:

bronchitis or emphysema?	No____	Yes____
asthma?	No____	Yes____

72 Has doctor ever said NATURAL mother had:

bronchitis or emphysema?	No____	Yes____
asthma?	No____	Yes____

We also need some information about the adult household members

(If one-adult family, complete only A or B, as appropriate)

A. Father (or male guardian)

51 What is highest grade of school completed?________ 51 52 53

52-53 What is present job (title)?________________

54 Has he ever smoked? No____ Yes: cigarettes____ cigars____ pipes____ 54

55-60 Does he *now* smoke? No____ If Yes, How many cigarettes per day?____ 55 56 57 58

How many cigars per day?____

How many pipes per day?____ 59 60

B. Mother (or female guardian)

62 What is highest grade of school completed?________ 62 63 64

63-64 What is present job (title)?________________ 65

65 Has she ever smoked? No____ Yes: cigarettes____ cigars____ pipes____ 66 67 68 69

66-71 Does she *now* smoke? No____ If Yes, How many cigarettes per day?____

How many cigars per day?____ 70 71

How many pipes per day?____

73

C. Other Persons (not including mother or father)

74 How many persons in the household OTHER than Mother and/or Father smoke tobacco? ____ 74 75 76 77

(If no one, check here: ____).

0 7

78 79 80

PERMISSION REQUEST

CARD 2

I give permission for my child, ________________ to participate in this health survey. I understand this will involve only measuring the height, weight, and simple tests of breathing. The data will be used for research purposes only and will be kept confidential. The results will be made available to our family physician upon our request.

1 2 3 4 5

2

6 7 8 9

____________ ________________

Date Parent/Guardian Signature

0

RESPIRATORY ILLNESS DIARY

INSTRUCTIONS: Check this calendar every day. List the numbers of all symptoms that your child has in the square for that day. Enter zero (0) if the child has no symptoms.

If your child has any symptoms please fill out the information on the attached pages.

SYMPTOM LIST

1. Hoarseness
2. Sore throat
3. Cough
4. Phlegm from chest
5. Pain in the chest
6. Wheezing
7. Fever
8. Earache or discharge
9. Runny or stuffy nose
10. Burning, aching or redness of eyes
11. Difficulty breathing

JANUARY 1985

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

INSTRUCTIONS: Please fill out a page each day that you report any symptoms for your child on the calendar. For each question check the appropriate answers and/or fill in the blanks.

Enter today's date.	________________
1. Were any of your child's normal activities restricted because of the symptoms reported?	1. ___ Yes. ___ No.
2. Did your child stay home from school all or part of the hay because of the symptoms?	2. ___ Yes. ___ No; today not a school day. ___ No; today a school day but child did not stay home.
3. Did your child stay in bed at least half the day?	3. ___ Yes. ___ No.
4. Did you pay someone to care for your child today because he was sick?	4. ___ Yes; Amount paid ________. ___ No.
5. Did you, someone else in the family or a friend stay home from work to care for your child?	5. ___ Yes; No. of hrs. missed _____. ___ No.
6. Not counting time missed from work did you, someone else in the family or a friend alter his normal activities to care for the child?	6. ___ Yes; No. of hrs. affected ____. ___ No.
7. Briefly describe the activites which were altered.	7. ____________________ ____________________
8. Did you call a doctor because of the symptoms? (Check all answers that apply.)	8. ___ Yes; called to make appointment. ___ Yes; discussed symptoms with doctor for ____ minutes. ___ Yes; discussed symptoms with nurse for ____ minutes. ___ No.
9. Did your child visit a doctor's office or clinic?	9. ___ Yes. ___ No.
10. What was the cost of this visit, including any amount paid for by insurance?	10. ___ Cost was ________. ___ Don't know.
11. Were any lab tests performed or shots administered because of the symptoms? If so, describe them.	11. ___ No. ___ Yes. ___ X-ray ___ Throat culture ___ Blood count ___ Other test:________ ___ Shot:________
12. What was the cost of these tests and/or shots, including any amount paid for by insurance?	12. ___ Cost was ________. ___ Don't know. ___ Cost included in 10.

13. Did the child take any prescription or non-prescription medicine for his symptoms?

13. ___ No. ___ Yes; the following wer taken: ______________________

____

14. What was the cost of this medication, including any amount paid for by insurance?

14. ___ Cost was ______________.
___ Cost included in 10.
___ Don't know.

15. Was your child in a hospital today as a result of his symptoms?

15. ___ No.
___ Yes; as an outpatient.
___ Yes; as an inpatient.

ANSWER THE REMAINING QUESTIONS ONLY IF YOUR CHILD WAS IN THE HOSPITAL.

16. Was the child taken to the hospital by ambulance? If so, what was the cost, including any amount paid for by insurance?

16. ___ No.
___ Yes; cost was __________.

17. Were any tests performed on the child? If so, describe them.

17. ___ No tests were performed.
___ The following tests were perfor

____

____

18. Were any operations performed? If so, describe them.

18. ___ No operations were performed.
___ The following operation(s) were performed: ______________

____

19. Did the child require any special services while in the hospital (special nursing, intensive care)?

19. ___ No.
___ Yes; the following were require

____

____

20. What was the total cost of treatment received in the hospital, including any amount paid for by insurance? (If the hopsital stay is more than one day, costs for the entire stay may be entered on the page for the day of discharge.)

20. ___ Cost was ______________.
___ Don't know.

21. If the amount in 20. does not include the cost of doctors' services (fees of surgeons, anesthesiologists) what was the cost of these services, including any amount paid for by insurance?

21. ___ Cost was ______________.
___ All doctors' fees included in 2
___ Don't know.

PROPOSED FORMAT FOR ADMINISTRATION OF DIARY

January 1985

--Diary distributed to household by interviewer who explains how diary is to be filled out

--Follow-up phone calls made to household at end of first and third weeks of month to remind household to fill out diary and to answer questions

--Diary collected by interviewer at end of month who goes over missing inormation with household; interviewer leaves February diary

February 1985

--Follow-up phone calls made to household at end of first and third weeks of month to remind household to fill out diary and to, answer questions

--Household mails in February diary at end of month

--March diary mailed to household at end of month

March 1985

--Follow-up phone calls made to household at end of first and third weeks of month; phone calls will probe missing information in February diary

--Household mails in March diary at end of month

April 1985

--Follow-up phone calls made to household to obtain information missing from March diary

--Respondent incentive of $40 per household paid for completion of three diaries