Household Benefits of Indoor Air Pollution Control in Developing Countries

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Abstract

More than 2 billion people worldwide rely on solid fuels—wood, dung, crop residues, or coal—and traditional stoves or open fires for cooking, lighting, and, in colder climates, heating. Exposure to the emissions caused by burning these fuels is believed to be responsible for a significant share of the global burden of disease. To achieve wide-spread health improvements, interventions that reduce exposures to indoor air pollution will need to be adopted by large numbers of households in the developing world. Households can be expected to adopt a new technology, such as an improved stove, if the perceived benefits of adoption are greater than the costs. While the physical impacts of adopting an improved stove, such as reduced emissions or improved fuel efficiency, can be observed directly, the value in monetary terms to the household of the physical changes is less evident. Yet it is essential to estimate the monetary values if we are to assess the household-level benefits of potential interventions, compare them to the costs, and thereby understand household incentives to adopt the interventions and identify policies to support adoption.

The purpose of this paper is to develop an approach for identifying the benefits to households of implementing indoor air pollution interventions and translating them into a monetary equivalent so that they can be compared to intervention costs. The monetary benefits of adopting an intervention can be defined as a combination of three terms: (1) the value the household places on the direct health benefits to children; (2) the value the household places on direct health benefits to adults (mainly women); and (3) the value the household places on health benefits to children generated by better health in adults. Applying this framework to existing data from developing country studies suggests that the value of the health improvements will exceed the costs for common interventions like improved stoves. Adopting an intervention to reduce indoor air pollution is also likely to induce a wide range of other household adjustments, such as altering household fuel use, cooking times, other household labor allocations, food and non-food consumption, fuel gathering and agricultural production. These adjustments are discussed, and priorities for research are presented.

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1. Introduction

1.1 Background to the Problem

More than 2 billion people worldwide rely on solid fuels—wood, dung, crop residues, or coal—and traditional stoves or open fires for cooking, lighting, and, in colder climates, heating. Most of these people live in rural parts of developing countries (Reddy et al. 1997). Biomass fuels, while generally the least expensive source of energy for poor households, also impose costs on the households. Most of these costs are related either to collection time or, directly or indirectly, to the health effects of high levels of indoor air pollution on young children and on older girls and women who spend a good deal of time inside during cooking and tending fires. As a result, indoor air pollution from burning biomass fuels is considered to be one of the five most serious environmental problems in developing countries (World Bank 1992), endangering the health of 400-700 million people. When defined to include environmental tobacco smoke and other types of pollution, as well as smoke from biomass and coal combustion, indoor air pollution is estimated to account for about 4 percent of the total burden of disease and 2.8 million premature deaths per year (Bruce et al. 2000). Of these, two thirds occur in rural areas of developing countries, where the main source of pollution is smoke from fires and stoves, and another 23 percent are in urban areas of developing countries (WHO 1997).

Smoke from the combustion of biomass fuels contains a large number of potentially hazardous pollutants. Exposure to these pollutants, especially suspended particular matter, is a risk factor for a wide range of diseases, including acute respiratory infections ARI, chronic obstructive pulmonary disorder (COPD), cancers, cataract, and low birth weight. Research to date has not established reliable functions linking biomass fuel emissions to pollution concentrations, exposures, and health damages for households that rely on biomass fuels and traditional stoves. Based on a number of studies in developing countries, however, it appears that young children in households that use solid biomass fuels are 2-3 times more likely to suffer ARI than children in households that use other fuels. Similarly, women who have cooked over biomass fires for fifteen years are 2-4 times more likely to develop COPD than are other women (Smith 1999).[1]

To address this problem, a number of interventions have been developed that aim to reduce household exposures to indoor air pollution. The most widely-applied intervention is the introduction of improved stoves that emit fewer pollutants than traditional stoves. Other interventions include fuel-switching (e.g. from wood to coal or kerosene); improving household

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[1] The literature on the health effects of solid fuels, and what is currently known about the relationships between solid fuels and health, is discussed in Smith and Mehta (2000).

ventilation, fuel use, and cooking practices (i.e. lids on pots); and altering childcare practices to keep children away from the kitchen during cooking times.[2]

When an intervention like an improved stove is adopted by a household, it brings about a variety of changes in the household. These changes might include, for example:

- lower emissions and concentrations of indoor air pollutants leading (presumably) to reduced incidence of ARI, COPD, etc.;
- changes in cooking practices that will increase or decrease women's and children's time in the kitchen;
- changes in the costs of cooking (e.g. by altering stove efficiency) that will increase or decrease the amount of food prepared each day and the frequency of preparation;
- reallocation of women's and girls' time spent on gathering biomass fuels;
- reallocation of household income if money is spent or saved on the stove and fuel; and
- changes in other household production activities such as agricultural production, and therefore incomes, due to the shifts in fuel costs and time allocations.

While much is known about designing and producing improved stoves to alter energy demands and reduce indoor pollution levels, and some research has been done on other interventions to reduce exposure to indoor air pollution, the broader effects on households of indoor air pollution interventions are not yet well understood or documented.

1.2 The Potential Benefits of Interventions

To achieve wide-spread health improvements, interventions that effectively reduce exposures will need to be adopted by large numbers of households in the developing world. Households can be expected to adopt a new technology, such as an improved stove, if the perceived benefits of adoption are greater than the costs. While the physical impacts of adopting an improved stove, such as reduced emissions or improved fuel efficiency, can be observed directly, the value in monetary terms to the household of such physical changes is less evident. Yet it is essential to estimate such monetary values if we are to understand the household-level benefits of potential interventions and, therefore, household incentives to adopt the interventions. A clear understanding of such household incentives also provides the foundation for identifying supporting policies that increase—and conflicting policies that reduce—the household benefits of implementing the interventions.

There has been little theoretical or empirical analysis of the household demand for indoor air pollution interventions, although some of the literature on household energy demand and stove adoption is clearly relevant. Since household demand is based on the perceived benefits to the household of adopting the intervention, the main objective of this paper is to develop an approach

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[2] See Ballard-Tremeer and Mathee (2000) for a description of these interventions.

for identifying these benefits and translating them into a monetary equivalent so that they can be compared to intervention costs. This combination of benefits and costs can then be used to understand household demand for interventions and how policies can increase demand.

This paper is organized as follows. To answer the "benefits-of-adoption" question, Section 2 uses standard benefit-cost analysis to identify the household-level benefits of interventions that are designed to reduce indoor air pollution from burning biomass fuels. After outlining a base-case household situation, Section 2 explains why the monetary benefits of adopting an intervention can be defined as a combination of three terms: (1) the value the household places on the direct health benefits to children; (2) the value the household places on direct health benefits to adults (mainly women); and (3) the value the household places on health benefits to children generated by better health in adults. Section 3 then uses existing data on interventions to illustrate how to estimate these benefits. While Sections 2 and 3 focus on the direct health impacts of interventions, it is clear that adopting an intervention to reduce indoor air pollution is likely to induce a wide range of other household adjustments, such as altering household fuel use, cooking times, other household labor allocations, food and non-food consumption, fuel gathering and agricultural production. Section 4 briefly discusses these household adjustments. Section 5 concludes with a discussion of key research and policy priorities that follow from this discussion.

2. Identifying the Household Benefits of an Intervention

As noted above, indoor air pollution interventions are intended to generate various outcomes, which might include reduced fuel use, labor savings from fuel collection, and/or improvements in children's and women's health. The benefits derived by a household from an intervention are related to the value of these outcomes, where value is defined as the change in household welfare due to adopting and using the intervention. Since "welfare" is not defined in measurable units, however, it is common to express welfare changes in a monetary equivalent. In general, the change in income that a household is willing to accept to adopt the intervention (i.e. to obtain the outcome of the intervention) is the correct monetary measure of "benefits" to the household. It should be emphasized that these are the benefits to the household, and as a result are not necessarily total "social benefits," which might include, for example, impacts on the community's resource base. Household benefits are a good place to start, however, because it is a household's private incentives that determine if an intervention is adopted and used (and how it is used).[3]

The remainder of this section describes the basic features of a representative household that uses solid fuels in a developing country. Such a household framework is needed to understand the interrelated production, consumption, and time allocation decisions that determine the total benefits to a household of adopting an indoor air pollution intervention. The household features

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[3] The fundamental importance of understanding household incentives and benefits is more or less consistent with the eight "assessment criteria" outlined in Ballard-Tremeer and Mathee (2000). Note, however, that "total household benefit," which is what determines whether the intervention will be adopted, is not listed explicitly as a criterion, although cost is included.

described in this section are intended to represent a reasonable base situation for households in developing countries; they can readily be adapted to specific locations and contexts.[4]

2.1 Outline of a Basic Model

A typical household economy in the developing world has many of the same components as a national economy. As a starting point, it is clear that households in developing countries are both producers and consumers (Singh, Squire, and Strauss 1986). Within a household, there are also individual consumers and individual producers. Household production can include female production (e.g. fuelwood, water, crops, cooked food), male production (e.g. crops, livestock, forest products, security), and combined production (crops, children, child health). For the production of these many products, households have resource endowments that can include time, information, land, and technologies.

Some of the items produced and consumed by households are "tradables" that are bought and sold on local and regional markets. Traded items usually include agricultural crops (cash crops and staple foods), household items such as cooking pans, oils, and batteries, and health services. For these traded items, market prices directly affect production and consumption decisions, and these prices determine the benefit to the household of producing or consuming the items.

Households also produce several other items that are fundamentally not tradable (e.g. child and adult health) or are often not traded because of a lack of markets (e.g. certain crops, certain forest products, and women's and children's labor time). For such non-traded items, the household's internal economy must adjust through the household's internal prices for non-traded items (often called "shadow prices"), so that household-level demand for such items equals household supply. Anything that affects the household economy (a change in crop price or the availability of fuels, a new stove, etc.) can be expected to have direct effects on all the household's decisions (production and consumption) and indirect effects through adjustments in all its shadow prices.[5] While the directs effects are often fairly easy to understand, the indirect effects are often quite difficult. As a result, the total impact on the household (the sum of direct and indirect effects) can be positive in some situations and negative in other situations, and the signs and magnitudes of the different effects are fundamentally empirical, site-specific issues.[6]

Figure 1 illustrates the key components of the household framework. They are:

i. the household objective: maximize welfare, which is dependent on child health and adult health

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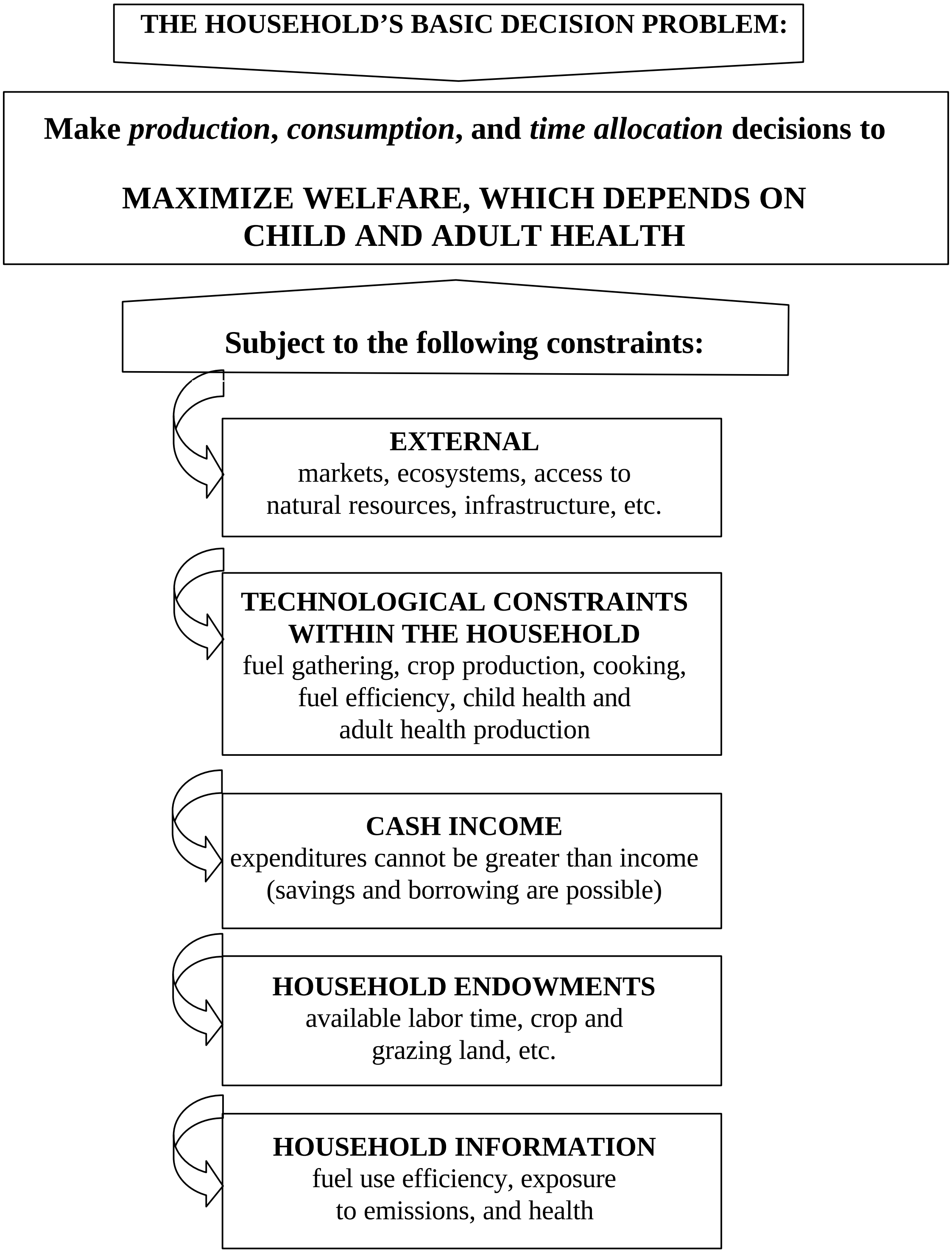
[4] The discussion in Section 2 is based on an explicit household model developed in Appendix A to this paper, which is available from the authors upon request. All details of the household model are provided in Appendix A.

[5] In economic terms, these direct effects could be called partial equilibrium effects, and the combination of the direct and indirect effects could be called general equilibrium effects within the household.

[6] Appendix B shows how to analyze these indirect effects within the household framework.

ii. constraints that are external to the household, such as market prices
iii. household technological constraints on crop production, fuel production, the production of health, etc.
iv. the household budget constraint, because cash expenditures must equal cash income;
v. constraints imposed by household endowments, including land, labor time, etc. The household’s time constraint allows available female labor time to be allocated to fuel collection, crop production, cooking, and other household-related activities.
vi. constraints imposed by information the household possesses about technologies, health impacts, etc.

Figure 1. A basic household framework



2.2 The Structure of the Model

Production

To begin on the production side, the base-case framework outlined in Figure 1, and developed in detail in Appendix A, defines a household as adult females and children.[7] This household is assumed to produce a staple crop and to gather fuel. The staple food crop (e.g., maize, cassava, rice, or millet) is produced and consumed by the household. Any surplus not consumed is sold on a local market. The household gathers fuelwood (or other biomass fuels) that is used exclusively for home consumption.[8] The household produces these items based on its agricultural production technology, which depends mainly on its land endowment and women's labor inputs, and its fuel gathering possibilities, which are determined by its access to fuel sources and available labor time.

Time allocation

In the model, it is assumed that there is no hired labor, and the household is constrained in its labor choices by its time endowment (i.e. women's time). Available female time is allocated to four main uses: fuel collection, crop production, cooking time, and other activities (other domestic tasks, child care not during cooking, etc.). Some activities, such as fuel gathering and child minding, might be jointly accomplished. The household is constrained in that these four uses of time (the household's demand for labor) must equal its available time (its supply of labor).

Consumption

Women and children in a household also consume a number of goods, such as the staple crop, fuel, market-purchased consumer goods and perhaps healthcare services. If household demand for the staple is less than household production of the staple, the household has net sales and additional cash income (and vice versa). If the gathered fuel is a non-marketed item, household fuel gathering must equal household demand for fuel. Thus, the household's shadow prices for fuel and women's time must adjust so that demand for these items equals supply.

Income

In making consumption decisions, households face a cash constraint. In this simple framework, expenditures on market-purchased consumer items and health services must equal non-labor income (e.g. cash transfers from a relative in a city) plus net market sales/purchases of the food crop.

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[7] The nonseparable household model developed in Appendix A is a variation of those described in Singh, Squire, and Strauss (1986), Thomas, Strauss, and Henriques (1990), Pitt and Rosenzweig (1985), de Janvry, Fafchamps, and Sadoulet (1991), and Larson (1994).

[8] It is a simple extension to include several types of crops and several types of fuels (e.g. crop residues, dung, charcoal, wood).

Production of health

The household, through the various production and consumption decisions described above, also produces child health and adult female health. As a starting point, child health is hypothesized to be a function of five factors:

i. prepared food, which in turn depends on the amount of the uncooked staple consumed, the amount of heating energy provided by the amount of fuel used, and women's time allocated to cooking;
ii. health services;
iii. the amount of fuel used that contributes to indoor air pollution;
iv. adult women's health; and
v. the amount of female time allocated to non-cooking domestic activities.

Note that women's health is included as an input into the child health production function. For the same time allocation, and all else constant, it is hypothesized that a healthier woman "produces" healthier children. In a similar fashion, adult female health is also hypothesized to be a function of prepared food, which depends on the amount of the staple consumed, fuel used, and cooking time, as well as emissions from fuel use.

In this health "production function," the burning technology and fuel use create emissions. Emissions in turn affect indoor air concentrations, which, along with cooking time, affects child exposures. Exposures are then related to child doses of various pollutants, which ultimately affect child health. In general, all of these relationships are included within the health production function. Given that several of the key variables inside this health production function are decisions of the household, it should be remembered that the observed links between fuel use, interventions, and health outcomes are physical relationships driven by household decisions. For example, emissions depend in part on how much fuel is burned, which is a household choice influenced by prices, incomes, etc.

There are a number of other parameters, not directly chosen by the household, that also affect individuals' health (e.g. climate, water availability, etc.). All of these "other" variables—besides fuel use and burning technology, which are incorporated in the model—are referred to as "confounding factors" in the non-economics literature.

Household's overall objective

Given the household production, consumption, and time allocation possibilities outlined above, it is also necessary to specify a household objective. For now, as outlined in Appendix A and noted in Figure 1, it is assumed that the household's objective is to maximize the utility of child health, adult female health, and consumption of market-purchased consumer items. In other words, the household does not derive benefits directly from consuming food, burning fuels, or using health services. Instead, the household cares directly about health, and these other consumption items are important insofar as they produce improvements in health.[9]

If we return to the analogy to a national economy, this framework outlines a household economy with two main consumers (women and children) and one main producer (women). Certain consumer items "imported" (i.e. are not produced by the household and are only purchased on the market), while the agricultural crop is imported or exported (sold on the market) depending on the household's situation. Besides these "tradables," there are four non-traded commodities: labor (no migration), fuel, children's health, and women's health. Assuming a competitive domestic household market, the household's "domestic market" (shadow) prices must adjust to equate demand and supply for these four commodities. Within this framework, the household tries to maximize household welfare through its many production and consumption decisions, given all the constraints that it faces (time, markets, production technologies, access to fuels, burning technologies, etc.).

2.3 Valuing welfare changes to the household

As is demonstrated in some detail in Appendix A, the solution to the household's welfare maximizing problem ("maximize welfare from child and adult health subject to constraints") can be written simply as V* = V(",$,S, Z), where V* is the level of household utility given the household's burning technology, the parameter " represents the emissions intensity of fuel used in the household (e.g. grams of PM_{10} per kg of wood), the parameter $ represents the cooking energy intensity of fuel used in the household (e.g. energy units per kg of wood), S represents income, and Z represents all other parameters influencing household choices (e.g. prices, technology, preferences).

Indoor air pollution interventions are organized into two types in this household framework: fuel efficiency interventions (i.e., <u>increases</u> in the parameter $) and emission/concentration/exposure reduction interventions (i.e., <u>reductions</u> in the parameter "). This second category of interventions is called "emission reductions" for short. For example, emissions reduction interventions in this framework can include improved stoves with and without chimneys, alternative fuel combinations, improved ventilation, and placement of stoves/fires/kitchens. The same interventions that reduce emissions can also affect the efficiency with which fuel is converted into heat and heat is transferred to the pot. Thus, even if the primary objective is to lower emissions, the efficiency consequences needed to be incorporated into the analysis to understand the overall household benefits.

For any intervention that changes $ and ", say from $o to $n and "o and "n (o = old and n = new levels), the welfare impact of the intervention is simply the welfare change)V = V($n, "n; Z, S) -

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[9] It is easy to incorporate into the utility function direct utility of consuming other items (e.g. prepared foods, social aspects of having a fire, etc.) if desired.

$V(\beta o, \alpha o; Z, S)$, where again Z represents all other parameters of the problem except income, S is income, and the "ΔV" can be read as the "change in welfare."

This welfare change, ΔV, takes into account <u>all</u> adjustments in the household induced by the intervention. If the intervention involves large changes (the change from βo to βn and αo and αn), it might be expected that these other household adjustments—such as adjustments in women's time allocations or fuel use—are large. Nonetheless, the correct measure of the welfare change remains ΔV.

Since ΔV is in "utility" or "welfare" terms, it cannot be estimated directly. From the household's perspective, the monetary equivalent of this welfare change (call it B*) can be defined implicitly by $V(\beta n, \alpha n; Z, S-B^*) = V(\beta o, \alpha o; Z, S)$, so that $B^* = B(\beta o, \alpha o, \beta n, \alpha n; Z, S)$. <u>The amount B* is the maximum amount of income the household would be willing to give up (i.e. willing to pay) to have the intervention and obtain the welfare change.</u>[10] In general, this B* can be compared to the input cost of the intervention (e.g. the market price of the improved stove) to estimate the <u>net</u> benefits of adoption.

While theoretically correct, the benefits measure B* -- the household's monetary value of all the many impacts of the intervention—is not directly observable. Fortunately, it is possible to use the structure of the household model to decompose the welfare change ΔV and the monetary equivalent B* into different components that can be directly estimated and/or approximated.[11]

To begin, consider an intervention that increases fuel efficiency by a small amount, so that the parameter β increases by a small amount (and α remains constant). As outlined in Appendix A, the welfare change ΔV from a <u>small change</u> in fuel efficiency $\Delta\beta$ can be decomposed into the sum of three basic terms:

i. the welfare increase due to the direct improvement in children's health, which can be denoted as $[\Delta V/\Delta h^c]*[\Delta h^c/\Delta\beta]$;
ii. the welfare increase due to the direct improvement in women's health, which can be denoted as $[\Delta V/\Delta h^d]*[\Delta h^d/\Delta\beta]$; and
iii. the welfare increase due to the indirect effect on child health of improved adult female health, which can be denoted as $[\Delta V/\Delta h^c]*[\Delta h^c/\Delta h^d]*[\Delta h^d/\Delta\beta]$

where h^c is used to represent child health and h^d represent adult female health. For example, from effect (1) above, a small change in fuel efficiency improvements $\Delta\beta$ (holding everything else constant) produces some improvement in health Δh^c, which in turn leads to an improvement in the

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[10] More specifically, B* is a measure of compensating variation.

[11] It would be possible, however, to use the contingent valuation method to elicit information directly from households on their demand for some intervention. These values would, of course, depend on their current information and their understanding of the relationship between the intervention and health (taking into account all other decisions such as fuel use, cooking time, etc.).

welfare measure $)V$ (also holding everything else constant).

As noted earlier, these welfare changes are not directly measurable because they are expressed in "utility" terms. It is possible, however, to translate the three welfare effects outlined above into their monetary equivalent. As shown in Appendix A, the overall welfare change from a small change in fuel efficiency $()V/)\$)$ based on these three changes can be translated into a monetary equivalent, denoted as $P(\$)$, using the following three terms:

i. the monetary equivalent of the direct improvement in child health, denoted as $P_{hc}*[)h^c/)\$]$;
ii. the monetary equivalent of the direct improvement in adult health; denoted as $P_{hc}*[)h^d/)\$]$; and
iii. the monetary equivalent of the indirect effect on child health of improvements in adult female health $P_{hc}*[)h^c/)h^d]*[\ )h^d/)\$]$.

These monetary equivalents, as explained in Appendix A, are simply a price times a quantity; the quantity is the physical effect of some intervention on child and adult health, and the price is the household's implicit monetary value of improved health for children (P_{hc}) and adults (P_{hd}).[12/13]

The monetary benefits defined above as $P(\$)$ are a "local" measure based on a small change in fuel efficiency and/or emission intensity. For any specific intervention that creates a discrete, non-marginal change in fuel efficiency, say $)\$ = \$n - \$o$ as discussed above, it is standard practice in the risk valuation literature to assume that $P(\$)$ remains constant within the range of the change $)\$$, so that an estimate of the benefits of a non-marginal change in $\$$ is often approximated as B^ = $P(\$)*)\$$.[14]

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[12] These implicit values, also called shadow prices, are defined as the household's welfare increase from more healthy family members divided by the welfare increase from having one more unit of income (represented by $)V/)S$), so that $P_{hc} = [)V/)h^c]/[)V/)S]$ and $P_{hd} = [)V/)h^d]/[)V/)S]$. A change in welfare for a small change in fuel efficiency $)V/)\$$can be translated into a monetary equivalent based on the household's income situation (specifically the increase in household welfare from an additional unit of income denoted as $)V/)S$). Using the basic idea of a consumer demand schedule in introductory economics, the household's willingness to reduce its income level (i.e. its willingness to pay) to obtain the benefits of the intervention is simply equal to the ratio of the welfare change divided by the additional welfare from additional income. Thus, $P(\$) = -)S/)\$ = [)V/)\$/[)V/)S]$ defines the household demand schedule–the household's willingness to pay--for additional fuel efficiency improvements.

[13]Recall from basic microeconomic theory that the the demand for any item, say a cup of coffee, is based on the ratio of a person's increase in utility from consuming one more cup of coffee divided by that person's increase in utility from having an addditional dollar (which is then spent on consumption). If this ratio, which is the person's implicit monetary value of a cup of coffee, is greater than the price of the cup of coffee, the person can be expected to buy the cup of coffee. If this ratio is less than the price of the cup of coffee, the person can be expected to pass on the cup of coffee.

[14] In general, the integral of $P(\$)= -)S/)\$$ over the change in $\$$ from $\$o$ to $\$n$ provides the exact measure for household benefits B*. However, since the willingness to pay $P(\$)= -)S/)\$$ depends in general on "everything" in the household's decision problem, actually calculating this exact measure is not practical. For examples in the literature, see Viscusi (1993).

The approximate benefits measure B^ from a discrete change in)$ can be easily understood in terms of a simple demand curve (also see footnote 13). With P($) constant, the household's demand curve for efficiency improvements (a higher $) is horizontal. As a result, the total monetary benefits B* from the change)$ is just price times quantity (i.e., the area under the horizontal demand schedule for $ over the change from $o to $o +)$). If P($) for the household does not remain constant over the change)$, for example because the household's implicit values on health P_{hc}* and P_{hd}* change as $ improves (and presumably health improves), the benefits measure B^ is still a practical approximation for empirical work.

If an intervention simultaneously affects fuel efficiency (say)$) and indoor air emissions (say)"), as is the case for an improved stove with chimney, then total household benefits can be approximated as:

B^ = P($)*)$ + P(")*)".

For any intervention with a cost of C, simple benefit-cost logic then suggests that the household has an incentive to adopt the intervention as long as B^ > C.

3. Estimating the Benefits Measure (B^) Using Existing Data

Basic example

This section uses data from various intervention studies to demonstrate how to estimate the benefits measure B^ in specific situations. Five basic pieces of information are needed to estimate B^.

i. the intervention's impacts on fuel efficiency and emissions ()" and)$) and the resulting effect on indoor air concentrations;
ii. the specific health impacts h^c and h^d to be included in the analysis (e.g. decreased morbidity events and mortality risks as well as baseline values);
iii. the dose-response relationships that link)" and)$ to direct health changes)h^c and)h^d;
iv. the dose-response relationships that link changes in women's health to children's health; and
v. estimates of the household's shadow prices P_{hc}* and P_{hd}* for changes in child and adult health.

While some data are available on the effects of interventions on indoor air concentrations of particulates (item i above), there is so far almost no published work on dose-response relationships for adults and children for well-defined health impacts at the concentrations seen inside houses in developing countries (items ii, iii, and iv).[15] Household shadow prices for health

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[15] See the discussion in Smith and Mehta (2000). Forthcoming work by Ezzati and Kammen (2000) may begin to address this problem.

(item v) have been estimated, though extrapolating from one local situation to another poses difficulties.

Table 4 provides three examples of estimating the benefits B^ from improved stove interventions. The columns "traditional" and "improved" are based on Bruce (1999), who reports that TSP concentrations tend to range from 3,140-6,400 µg/m^3 during cooking using traditional methods but fall to between 1,113-4,600 µg/m^3 with improved stoves.

Based on these ranges, consider as an example a situation where TSP levels are 4,500 µg/m^3 with a traditional method and 2,000 µg/m^3 with an improved stove. In this case, the intervention generates a 2,500 µg/m^3 reduction in TSP levels during cooking. If these concentrations lasted for six hours of daily cooking time, and the background level during the remainder of the day were around 100 µg/m^3, then a daily average TSP level would be about 1,200 µg/m^3 for the traditional method of cooking and about 575 µg/m^3 with the improved stove. If PM_{10} made up 30 percent of TSP, then average daily PM_{10} levels would be about 360 µg/m^3 with the traditional method and about 172.5 µg/m^3 with the improved stove. Assuming that each day of the year is identical in terms of cooking duration, then annual average PM_{10} levels would also be 360 µg/m^3 with the traditional method and about 172.5 µg/m^3 with the improved stove. Though these levels far exceed WHO and US EPA standards, comparable ambient annual average concentrations have been reported in parts of large cities with high pollution levels.

Mortality risks

Increased mortality risk is a standard concern for PM_{10} (see, for example, Schwartz 1994). For this example, let us define the health unit of interest as <u>increased annual average mortality risk to children and adults</u>. With increased mortality risk as the health unit, information is now needed on the relationship between PM_{10} concentrations and increased mortality risk.

The literature on the health effects of air pollution provides clear evidence of increased mortality risks from inhalation exposure to particulates (e.g.,Wilson and Spengler 1996). Epidemiological studies conducted under wide-ranging conditions (environmental, climatic, demographic, and geographic) consistently indicate that an approximate 1 percent increase in total daily mortality occurs for every 10 µg/m^3 of PM_{10} in ambient air (Dockery and Pope 1996), with a range of 0.7-1.1 suggested by the literature (e.g. Schwartz 1994). In a developing country context, Ostro et al. (1996) obtained essentially the same result for Santiago, Chile. Based on such information, Larson et al. (1999) developed an initial particulate coefficient (PC) equal to $8.5*10^{-6}$ to estimate the additional annual mortality risk per person per year per 1 µg/m^3 of PM_{10}. To our knowledge, there are no separate estimates for children and adults available in the literature. Thus, at this stage, the same particulate coefficient must be used for children and adults alike.[16]

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[16] The average dose-response parameter cited in the text (1 percent per 10 µg/m^3 increase in PM_{10}) is based on epidemiological studies conducted primarily in the U.S. With about 2,100,000 total deaths in the U.S. annually, there are on average 5,753 deaths per day. A one-percent increase in daily deaths equals 57.53 additional deaths per day. If

Continuing with this example, if the intervention reduces PM_{10} concentrations from 360 to 172.5 $\mu g/m^3$, a change of 187.5 $\mu g/m^3$, mortality risk per person per year would fall by $187.5*8.5*10^{-6} = -0.0016$. If baseline annual mortality risks were, for example, around 0.015 (a 1.5% annual chance of death on average in the population), the stove intervention would be estimated to lead to roughly a 10 percent reduction in annual mortality risk for both adults and children in the household. (To our knowledge, information is not available to estimate the third health effect, which captures the relationship between women's health and children's health. This example therefore does not estimate this third effect.)

Valuing changes in mortality risks

The next step in the analysis is to determine the household's shadow prices for improved health (denoted above as P_{hc} and P_{hd}), which in this example are essentially the household's annual willingness-to-pay for the estimated reduction in annual mortality risk. A large number of studies have attempted to estimate values of mortality risks, although usually in developed countries.[17] These empirical estimates of the "value of a statistical life" (VOSL) are simply an extrapolation of an estimated willingness-to-pay for a marginal change in mortality risk (i.e. the value of a .001 reduction in risk, for example, is multiplied by 1000 to come up with the VOSL). Unfortunately, it can often be difficult to determine the underlying marginal risk changes associated with the VOSL estimates reported in the literature. For example, a typical VOSL estimate for the U.S. is \$3 million. What this might actually mean, however, is that people in the study sample were willing to pay an average of \$3,000 for a 0.001 reduction in annual mortality risk (and not that they valued an actual life at \$3 million). Table 1 summarizes some health valuation estimates from developing countries.

To translate a U.S. VOSL figure to a developing country context, it has become common practice to weight the VOSL by the income ratio between the developing country and the country in which the VOSL was estimated. For example, many of the VOSL estimates provided in Viscusi (1993) were estimated for samples of individuals with average annual incomes of around \$40,000. If a typical household in a developing country had an income equivalent of, say, \$800, the income ratio would be about 0.02. Using this ratio as a weight, then this developing country figure of \$3,000 for a 0.001 reduction in annual mortality risk would be the equivalent of \$60 for the low income household. We have not found any separate estimates reported in the literature of parents' willingness to pay for mortality risk reductions for their children. As a result, for this

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the entire U.S. population of approximately 250,000,000 individuals were exposed to an additional 10 $\mu g/m^3$ of PM_{10} daily, then the estimated additional risk of death per day *per person* would be $57.53/250{,}000{,}000 = 2.3*10^{-7}$. Multiplying this daily effect by 365 to convert it to an annual effect, the resulting *individual annual particulate mortality coefficient* (PC) is $8.5*10^{-5}$ per 10 $\mu g/m^3$ of PM_{10}, or equivalently $8.5*10^{-6}$ per 1 $\mu g/m^3$ of PM_{10} assuming linearity in the particulate dose-response function. This number is used in the text solely as an example. Separate estimates for children and adults could be based on different mortality risks at different ages, while assuming that the basic 1 percent increase in daily mortality per 10 $\mu g/m^3$ increase in PM_{10} remained the same.

[17] A thorough review of the theory and empirical results is provided in Viscusi (1993).

example, it is assumed that the monetary value of the risk reduction is identical for children and adults.

With an estimated annual mortality risk reduction of 0.0016, and an estimated willingness to pay of $60 for each 0.001 reduction in mortality risk, the estimated annual benefit per person in the household would be estimated at about $96. If all five people in our hypothetical household were exposed to such PM_{10} levels, then the household value would be $478 per year. These annual benefits are substantially higher than the typical annual costs of improved stoves, which are reported for example to be $8-21 for an improved stove with chimney (Ballard-Tremeer and Mathee 2000).

The definition of B^ also allows for the possibility that an intervention could have a positive impact on emissions but a negative impact on fuel efficiency. Based on two types of tests (a water boiling test and a standardized cooking test), McCracken and Smith (1998), for example, concluded that a stove intervention in Guatemala substantially reduced emissions from wood burning but also reduced fuel efficiency and increased cooking time. The intervention thus generated a benefit from indoor air emissions reduction while imposing a cost in terms of reduced fuel efficiency.

Examples from Guatemala and Kenya

Columns 3 and 4 of Table 4 (labeled “Plancha” and “Kenya”) provide calculations similar to those above using information reported in studies of an improved stove in Guatemala (from Table 2) and (Kenya from Table 3). In Guatemala, monitored daily average $PM_{2.5}$ levels were about 1,100 $\mu g/m^3$ with a traditional three-stone fire and about 180 $\mu g/m^3$ with an improved stove (the “Plancha”). While a separate $PM_{2.5}$ particulate coefficient for mortality risks is not available, we should expect it to be larger than the $8.5*10^{-6}$ PC used to estimate the additional mortality risk per person per year per 1 $\mu g/m^3$ of PM_{10}. Using the PM_{10} PC, the estimated 920 $\mu g/m^3$ reduction in concentration for the Plancha (assuming the annual average difference is the same as the daily difference) would be expected to reduce annual mortality risks (annual probability of death) by 0.0078. The same calculation for the Kenya example would be a 0.01 reduction in annual mortality risk. These estimated risk reductions are very large, which in large part probably reflect the very imprecise knowledge of the relationship between particulate concentrations and health in these solid fuel burning households.

Using the same value of mortality risk reduction as for the previous example ($60 per change in annual mortality risk of 0.001), the annual benefits per person would be about $469 for Guatemala and $638 for Kenya. These benefits are also large relative to typical costs of improved stoves reported in (Ballard-Tremeer and Mathee 2000).[18]

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[18] It is emphasized that the numbers in Table 4 are illustrative only—they are intended to be examples of how to calculate the benefits measure B^.

Morbidity risks

Table 5 provides an example of the value of reducing ARI using information from Pakistan. To begin, the literature suggests that using a traditional stove increases the annual risk of ARI by 2-3 times, although Smith and Mehta (2000) note that this difference exists for rural but not urban households in India, where relative risks are reported to be 2 for rural households but just 1.22 for urban households. Using the odds ratio of 2, it could be estimated that the benefits of using an improved stove (or switching to other fuels) would be about a 50 percent reduction in annual ARI risk for children. Data show that children under five in Pakistan have an average of one case of ARI per child per year, of which some lead to death and some (most) do not. As a simple estimate, then, the morbidity impact of an improved stove could be an average reduction of 0.5 cases of ARI per under-five child per year.

Table 5 uses two approaches to value this risk reduction, one based on medical treatment costs and the other using a benefits transfer approach similar to that in Table 4. As is reported in Table 1, the medical treatment cost of a typical case of pneumonia for a child under five in Pakistan is $67.[19] If a household actually sought treatment and paid these costs, then it is reasonable to conclude that the value to the household of treating the child (and presumably eliminating the direct morbidity effects of pneumonia and related mortality risks) would be at least as great as $67. If a household did not seek treatment, then its implied value would be less than $67.

For households that do seek treatment, the 0.5 reduction in annual ARI cases suggests a lower bound value of $33.50, as Table 5 shows. For households that do not seek treatment, this figure would be lower.[20] For a young child, the present value of this annual figure over 5 years is $110 with a 20 percent discount rate.

Table 5 also shows the results of using a benefits transfer approach, where the starting point is an estimated U.S. value of $100 to avoid one day of illness. The annual value of the ARI risk reduction could be estimated at $10 ($2 at 10 days per event for a 0.5 risk reduction). For a young child, the present value of this annual figure over 5 years would be $30 with a 20 percent discount rate.

These examples indicate that, if there are multiple children in a household, the direct household

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[19] This is the estimated cost of treating a case of severe pneumonia at a public health facility in Pakistan if the WHO guidelines for treatment of pneumonia in children are followed. The amount actually spent by households to treat each case is probably significantly less than $67. AMR Economics Working Group (2000) contains the data and calculations used for this estimate.

[20] As explained in Harrington and Portney (1987), medical expenses for recommended treatments is not a full measure of the household value of risk reduction. They show that the total willingness to pay for some risk reduction is in fact a combination of four terms: i) the change in medical costs actually paid by the household; ii) the change in avoidance expenditures designed to reduce the risk of a health event; iii) the savings in terms of lost income during illness (or taking care of child); and iv) a "pain and suffering" effect that is distinct from the other terms. Thus, the cost of <u>recommended</u> medical treatment could underestimate or overestimate morbidity effects.

benefits of reduced ARI in children alone could justify an investment in an improved stove. Since stoves seemingly are not widely and quickly adopted by large numbers of households, however, it much be the case that these values are substantially lower that is estimated in Table 5; are perceived to be lower due to incomplete information; and/or there are other costs (i.e. negative impacts) associated with the intervention that mitigates against its adoption.

4. A Note on Household Adjustments to Air Pollution Control Interventions

Changes in fuel efficiency and/or pollution emissions induce a household to adjust all of its consumption and production choices. In general, all of these adjustments <u>are</u> included in the benefits measure B*, but they are <u>not</u> included in the approximated measure B^.

These household "general-equilibrium" adjustments are potentially of interest for a variety of reasons. For example, if fuel efficiency improves, does the household use more or less fuel, does the household allocate more or less labor to agricultural production, or do children in the household consume more or less of the agricultural staple? Given the complicated multisectoral structure of the household's economy, which is in many ways just as complicated as a national economy, simple and clean answers should not be expected. In general, these are empirical questions that will depend on the structure of household preferences and the relative magnitudes of several terms. As with the "computable general equilibrium models" relied on in national economy modeling, the final answers will usually depend on specific functional forms and all related parameters of the problem.

Rather than creating a complete household general equilibrium numerical model at this time, Appendix B shows how to analyze these general equilibrium adjustments in the household. There are two steps in this process. First, it is necessary to understand how air pollution interventions (changes in " and $) affect the household's shadow prices for time and fuel denoted here as p_l^* and p_x^*.[21] Second, we must understand how interventions affect all the household's consumption and production decisions through three possible channels: the direct effects; the indirect affects through changes in the shadow prices p_l^* and p_x^* ; and the indirect affects through changes in income due to changes in the shadow prices p_l^* and p_x^*.

As an example, consider the impacts on household consumption and production decisions if the household adopts an intervention that improves fuel efficiency. As a direct effect, holding all prices and income levels fixed, it could be expected that improved fuel efficiency would allow less fuel to be used to produce the same amount of energy. It is well known, however, that efficiency improvements essentially reduce the price of energy to the household. When the price of energy falls, the household tends to want to consume more energy and perhaps cook more meals, cook

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[21] Note that a shadow price is the price that the household implicitly sets for goods that are not bought or sold on the market. For example, in our model the crop has a market price but fuel does not. We know that the household only collects as much fuel as it wants to consume, however. The shadow price of fuel p_x* is the price at which household supply of fuel equals its demand for fuel. The same logic applies to women's time, where p_l* is the shadow price.

each meal for more time, or switch into other foods that require more heating energy to prepare. Thus, the overall effect of an efficiency improvement could be to reduce or increase fuel use—it is an empirical question.

At the same time, if fuel efficiency improves, there will be a change in the household's shadow price of women's time p_l^*. As shown in Appendix B, this shadow value p_l^* will fall if fuel efficiency improvements act to reduce adult time spent cooking and performing other domestic activities. This fall in the shadow price of labor p_l^* would then induce more labor to be used in agricultural production, and as a result there would be more agricultural output.

While fuel efficiency improvements were assumed above to reduce adult time spent cooking, the fall in the shadow price of time p_l^* would also act to increase the amount of time allocated to cooking. Similar possibilities exist for interventions that affect emission levels and/or indoor air concentrations. While not "proven" in Appendix B, experience seems to suggest that the "external" adjustments of households to various types of policy or technical changes are smaller or more sluggish than might be expected. The main reason is that there are often countervailing influences within the household's economy that offset the effects of the intervention.

5. Implications for Research Priorities

The main purpose of this paper has been to identify the value to the household—the increase in welfare—of interventions designed to reduce indoor air pollution and to translate this value into a monetary equivalent. Based on the household framework described in Section 2, the change in welfare was defined as the sum of three terms: the value of the improvement in child health, the value of the improvement in adult health, and the indirect value of the improvement in child health brought about by the improvement in adult health. Each of these values is just the household's shadow price of health risk reductions multiplied by the change in health from the intervention. While an exact measure B* was defined in Section 2, an empirically useful approximation B^ was also defined. Section 3 then provided examples of estimating the benefits measure B^ using mortality risk information related to improved stoves in general as well as in Guatemala and Kenya. Section 3 also provided examples of implementing the benefits measure B^ based on morbidity risk reductions related to ARI in children.

As the examples in Section 3 demonstrate, with adequate information on the individual components of the benefits measure B^, it is relatively simple to hazard an estimate of the monetary value of the impact of the intervention (B^). The information needed to place a monetary value on a marginal change in health risks is important, but not more so than the information required to estimate the magnitude of those changes (emissions, concentrations, exposures, and dose response curves). The benefits estimates we can make now are based on largely inadequate evidence of the relationship between indoor air pollution and health risk changes that can be valued.

While the estimated benefits B^ of some interventions may be large, if households do not adopt the interventions, it must be the case that: (1) the intervention imposes additional costs on households (e.g. increased cooking time or loss of the social benefits of a traditional stove), such that the benefits transfer approach overvalues local benefits; and/or (2) households do not know or do not understand the relationship between fuel use, cooking technology, and household health. Given that the scientific community is not yet certain of the precise relationships between indoor pollution and health, it is not surprising that households also do not. Eliminating this market failure due to inadequate information (both at the scientific level and at the household level) is an important step in the process of creating incentives to adopt interventions.

The priority research questions that follow from this analysis fall into four main categories.

1. Develop a better understanding of the relationships between indoor air concentrations and key health outcomes for children and for adults (e.g., increased mortality risk, increased morbidity risk). To be useful, it is necessary to develop a more-or-less continuous dose-response relationship, and to develop separate curves for children and adults if the health impacts are age-specific. Knowing that households that rely on liquid fuels experience fewer cases of ARI than those using solid fuels is useful, but it does not provide enough information to evaluate interventions that reduce the health impacts of solid fuels but do not replace them with liquid fuels.

2. Develop a better understanding of the effects of interventions on indoor air quality and on other important parameters that will influence the household's opinion of the intervention (e.g., fuel efficiency, fuel preparation needs, cooking times, etc.). The complete set of direct impacts of the intervention must be clear for households to evaluate the desirability of the intervention. As part of this analysis, it will be important to investigate empirically other household adjustments that are likely to be induced by the intervention (as discussed in Section 4).

3. Convey these relationships to households, and assess their existing level of understanding of the importance in the context of their daily lives of child health, adult health, and other factors that will be affected by interventions. Poor households usually must cope with a multitude of daily and seasonal problems across all the domains of their lives (social, economic, political, etc.). The lack of household information on fuels, air quality, and health is a valid reason that indoor air pollution can rightly be called an "externality."

4. Focus efforts on estimating the values households place on health risk reductions in general, which can then be combined with estimates of the health impacts of indoor air pollution interventions to obtain a measure of the benefits. In the example in section 3, we assumed that the value of health for children is the same as that for adults, but in principle it need not be, and probably is not. As research proceeds on estimating the physical relationships between fuels, interventions, indoor air quality, and health, empirical studies are also clearly

needed that attempt to estimate and/or infer household values (for adults and children) of mortality risk and morbidity risk changes in developing countries. Without this information, we cannot assess either the private or the social benefits of interventions, nor can we understand household incentives to adopt such interventions. The value of health risk reductions can be estimated from related household activities and consumption decisions (e.g., the decision to pay for clean water from a borehole, rather than collecting contaminated water from a river at no charge) that alter mortality and morbidity risks. It can also be estimated directly through contingent valuation (CV) techniques.

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Table 1: Sample values of health benefits

Country	**Value** [(a)(b)]	**Method**	**Source**
India	VOSL = $153,000-$358,000	Compensating wage differentials	Simon et al. (1999)
Pakistan	$67 to treat a case of severe, non-resistant bacterial pneumonia in a child under 5	Cost of medical treatment (clinic and hospital costs and pharmaceuticals only)	AMR Economics Working Group (2000)
Taiwan	$30.73 to avoid a 1-day episode of mild ARI, $52.01 to avoid a 5-day episode (not a cold)	Contingent valuation survey	Alberini et al. (1997)
China	VOSL = $45,547; RAD = $1.29	Benefits transfer	Florig (1993) in Pearce (1996)
Thailand (Bangkok)	VOSL = $336,000	Compensating wage differentials	World Bank (1994b) in Pearce (1996)
Indonesia (Jakarta)	VOSL = $75,000	Benefits transfer	World Bank (1994a) in Pearce (1996)
Egypt (Cairo)	VOSL = $62,021; RAD = $1.75	Benefits transfer	Chemonics International and Associates (1994) in Pearce (1996)
Mexico (Mexico City)	VOSL = $75,000	Human capital approach	Margulis (1992) in Pearce (1996)
Chile (Santiago)	RAD = $9.95	Value of a work day	World Bank (1994c) in Pearce (1996)

(a) VOSL = Value of a Statistical Life

(b) RAD = Reduced Activity Day

Table 2: “Plancha” results

Parameter(a)	**Plancha**		**Three-stone fire**	
	Mean	**SD**	**Mean**	**SD**
$PM_{2.5}$ emissions while cooking (: g/m^3)	450	550	27,200	13,600
Fuelwood use per meal (kg)	4.09	0.63	3.84	0.16
Cooking time per meal (min)	164	45	122	3
Imputed cooking time per day, assuming 2 meals (hours)	6.5		5	
Imputed average daily $PM_{2.5}$ concentration (: g/m^3)	122	149	5,667	2,833
Monitored average daily $PM_{2.5}$ concentration (: g/m^3)(b)	180	107	1,102	606

(a) All data are from McCracken and Smith (1998) except monitored average daily $PM_{2.5}$ concentration.

(b) In another study of the same intervention, McCracken et al. (1999) monitored 24-hour average $PM_{2.5}$ concentrations. No information on cooking time or fuelwood use is available from this study, however.

Table 3: Improved stoves in Kenya

Parameter	**Improved stove**		**Three-stone fire**
	Mean	**95% CI**	**Mean**
TSP emissions while cooking (7.8 hours/day) (: g/m^3)	1,822	663-2,982	3,503
TSP emissions while inactive (: g/m^3) (7.2 hours/day)	1,034	466-1,346	4,496
Imputed average daily TSP concentration (: g/m^3)	902		2,487
Imputed average daily $PM_{2.5}$ concentration (: g/m^3)(a)	316		1,567

Source: Ezzati, Mbinda, and Kammen (2000).

Table 4. Examples of estimating the benefits of reduced mortality risks

Parameter	Units	Traditional	Improved	"Plancha"	Kenya
TSP during cooking	$\mu g/m^3$	4,500	2,000		
Cooking time	hours	6	6		
TSP during non-cooking	$\mu g/m^3$	100	100		
Non-cooking time	hours	18	18		
Average daily TSP	$\mu g/m^3$	1,200	575		
PM_{10} as % of TSP	range 0-1	0.3	0.3		
Average daily PM_{10}	$\mu g/m^3$	360	172.5		
Average annual PM_{10}	$\mu g/m^3$	360	172.5		
Change in annual average PM_{10} with improved stove	$\mu g/m^3$		-187.5	-920	-1,251
Particulate coefficient	% change in annual mortality risk for 1 μg change in annual average PM_{10}		8.5E-06	8.5E-06	8.5E-06
Change in annual mortality risk			-0.0016	-0.0078	-0.0106
Value of a statistical life (VOSL)	$US		3,000,000	3,000,000	3,000,000
Risk change being valued	range 0-1		0.001	0.001	0.001
Value of marginal risk change	$US		3,000	3,000	3,000
Income level of group used to estimate VOSL	$US		40,000	40,000	40,000
Income level of developing country household	$US		800	800	800
Income Ratio	range 0-1		0.02	0.02	0.02
Developing country approximated value of marginal risk reduction	$US		60	60	60
Annual benefits of mortality risk (reduction due to improved stove)	$US per person		96	469	638
Total exposed individuals in household	Number of individuals		5	5	5
Annual benefits of mortality risk reduction due to improved stove	$US per household		478	2,346	3,190
Cost of improved stove (upper end of range)	$US		21	21	21
Net benefits in year 1 of mortality risk reduction	$US per household		457	2,325	3,169

Table 5: Examples of estimating the benefits of reduced morbidity risks for ARI in Pakistan

5a: Example using treatment costs

Parameter	**Units**	**Value**
ARI per child per year (age 0-5)	Cases	1
Change in ARI per child per year due to intervention (age 0-5)	Cases	0.5
Medical treatment cost per severe pneumonia case (see footnote 19)	US $	67
% of households seeking and paying for treatment	Range 0-1	0.5
Average WTP for ARI reduction (lower bound)	US $	33.5
Present value of benefits per child during years 0-5 (20% discount rate)	US $	50-100

5b: Example using benefits transfer

Parameter	**Units**	**Value**
Change in annual mortality risk due to intervention	Cases	0.5000
Value of a statistical morbidity event (certain outcome of one day of illness)	US $	100
Income level of group used to estimate morbidity value	US $	40,000
Income level of developing country household	US $	800
Income ratio	Range 0-1	0.02
Developing country approximated value of one day illness	US $/day	2
Days per ARI event	Days	10
Approximate value per ARI event	US $	20
Value of annual ARI risk reduction per year per child	US $	10
Present value of benefits per child during years 0-5 (20% discount rate)	US $	30

Sources: AMR Economics Working Group (2000) and Table 1.