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Health uncertainty and food consumption in low-income households in Lima, Peru

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Health uncertainty and food consumption in low-income households in Lima, Peru

by

Chris Daniel Gingrich

A Dissertation Submitted to the
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ABSTRACT

This study investigates the relationships between health uncertainty and food consumption among low-income households in developing countries. The particular sample households are from Lima, Peru's bottom expenditure quartile. Several food and nonfood inputs are important factors affecting health status and health variance. In addition, there is strong evidence that expected health status and health risk affect the consumption of several food commodities.

The model also provides a means of analyzing the effects of policy alternatives on food consumption, expected health status, and health risk. The results show that education programs and price subsidies for tubers and dairy products are the most efficient means of increasing food consumption and improving health among poor households in Lima. In addition, education programs and tuber subsidies dramatically lower health risk suggesting that policymakers give these two programs high priority.

CHAPTER 1: INTRODUCTION AND PROBLEM STATEMENT

Over the past 40 years the citizens of many developing countries have experienced substantial improvement in their living standards. Serious problems remain, however, for low-income households in some countries (World Bank, 1993b and 1990). It is estimated that over one billion people still live in poverty, defined as an annual per capita income less than $370. Moreover, in many countries general health conditions are grossly inadequate. In the world's poorest countries life expectancy is less than 60 years, compared to almost 80 years in wealthy countries. The health status of children is especially lacking, with the difference in infant mortality rates between rich and poor countries accounting for 11 million deaths every year.

Consequently, governments and international organizations are constantly searching for ways to improve the food consumption and health standards of the world's poor. Countless policies and programs have been proposed, many of which are not implemented because of political constraints (de Janvry and Subramanian, 1993). Scarce financial resources in developing countries also limit the number of feasible policy options.

However, past successes have occurred partly because of improved understanding of economic behavior in subsistence households. Research in this area has improved the design and implementation of policies to promote adequate food consumption and health. For example, to analyze the efficacy and cost of food price subsidies the corresponding demand elasticities are needed. A large body of research has investigated economic behavior in low-income households. Excellent examples include Pinstrup-Anderson and Caicedo (1978), Timmer and Alderman (1979), Strauss (1982), and Pitt (1983).

A relatively new topic under study is the interactions between food consumption and health (Pitt and Rosenzweig, 1985; Alderman and Garcia, 1994; Pitt, Rosenzweig and Hassan, 1990; Behrman, 1988). These studies improve understanding of the physical relationships between food consumption and health, the demand for health inputs, and how various policies might affect health and food consumption in subsistence households.

Problem Statement

However, existing studies of consumption and health in developing countries fail to address whether health uncertainty affects household behavior. In the above examples health is treated as a deterministic phenomena. Consequently, no consideration is given to the possible effects of health uncertainty on the demand for health inputs such as food. It should be obvious that the assumption of deterministic health is highly unrealistic. It is, therefore, worthwhile to inquire whether an important aspect of economic behavior has been overlooked.

It is surprising that health uncertainty's impact on behavior in subsistence households has been ignored. This is especially true given that other types of uncertainty have been thoroughly investigated. In addition, some authors have acknowledged the possibility that health uncertainty may affect the demand for health inputs (Grossman, 1972a and 1972b; Rosenzweig and Schultz, 1983; Dowie, 1975; Behrman and Deolalikar, 1988). In general, there has been insufficient investigation into the effects of health status, including health uncertainty, on consumption. While numerous studies have investigated the effects of food consumption in health production the possibility of health status affecting food consumption has been ignored, particularly for low-income households in developing countries. From a policy perspective severe health and consumption problems in low-income households compel an investigation of these issues.

Goals of the Study

This study investigates whether health uncertainty affects consumption decisions in subsistence households in developing countries. The study focuses exclusively on low-income households because of the importance of small changes in consumption and health when nutrition and health conditions are poor. The group studied here is a sample of low-income households from Lima, Peru. The method employed is such that expected health status and its standard deviation are included as explanatory variables in the demand equations for food and nonfood.

The policy implications of health uncertainty are also investigated. Four policies are examined for their impact on consumption and health: 1) Food price subsidies, 2) Direct income transfers, 3) Expenditures on women's education, and 4) Expenditures on public sanitation facilities. The cost-effectiveness of each policy is explored by comparing the potential health and consumption benefits in Lima for a given amount of public expenditures. Hence, the information is useful for policymakers try to achieve improvements in food consumption and health for the least amount of public cost.

One issue not addressed is the impact of health uncertainty on household labor supply. Although this may be an equally interesting topic, limitations in the data prohibit a thorough analysis. Moreover, there is recent evidence that labor supply decisions in urban subsistence households do not follow the conventional model.[1] Thus, an investigation of labor supply and health uncertainty issues is beyond the scope of this study.

Organization of the Study

The study is organized as follows. Chapter 2 discusses the measurement of health status and health production in developing countries. The chapter provides a background to analyze the health indicators used in subsequent chapters. Chapter 3 presents an expected utility model under health uncertainty for low-income households in developing countries. It is shown that expected health and the standard deviation of health are potentially important factors affecting consumption. In Chapter 4 a health production function for low-income households in Lima, Peru is estimated. Estimates of each household's expected health and its standard deviation are also derived. A nonlinear food demand equation is estimated in Chapter 5. The nonlinear demand equation includes expected health and health risk as explanatory variables. Chapter 6 estimates a linear approximation of the food demand equation. The method is also expanded to estimate the

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[1] Sharif (1991) has shown that subsistence urban households work to satisfy a survival requirement instead of finding the optimal tradeoff between income and leisure.

effects of expected health and the standard deviation of health on the demand for several food commodities. Finally, Chapter 7 investigates the policy implications of the effects of expected health and the standard deviation of health on consumption. Special attention is given to the cost-effectiveness of several policy options in Lima.

CHAPTER 2: HEALTH INDICATORS IN DEVELOPING COUNTRIES: THEIR DEVELOPMENT AND USE IN ECONOMIC RESEARCH

Health indicators are designed to approximate the overall health status of either populations or individuals. Population health indicators are used to reveal trends or differences in health among population groups, examine factors affecting population health, and to administer health programs (Uhde, 1983). Indicators of individual health, on the other hand, are typically used to evaluate the outcomes of medical care or to conduct detailed epidemiological studies (McDowell and Newell, 1987).

An additional use for individual health indicators is to investigate relationships between health and economic behavior. Economic theory suggests that individuals have a demand for health similar to their demand for other goods and services (Becker, 1965; Grossman, 1972a and 1972b). Assuming that health is produced with purchased inputs in the sense of Becker, an individual's demand for health determines their demand for health inputs. Economists have used health indicators to estimate health production functions and health demand equations that are based on this paradigm. Many of these studies focus on health production and health input demand in developing countries (e.g., Pitt and Rosenzweig, 1985; Alderman and Garcia, 1994).

This chapter discusses the construction of individual health indicators and their use in economic research. Special emphasis is given to applications of health indicators in developing countries. The first section explains alternate models of health that provide the basis for good health indicators. The next section describes how health indicators have been adapted to fit the unique conditions in developing countries. In the final section the estimation of health production functions is discussed to show an example of health indicators in applied economic research.

Concepts of Health and Health Indicators

Medical and social scientists have devoted considerable energy defining the concept of human health. Consequently, it is not surprising that a wide range of definitions exist in the literature. Excellent summaries of this literature are provided by Larson (1991), Bowling (1991), McDowell and Newell, and Goldsmith (1972). In general, these authors explain that most definitions of health are based on either a medical or holistic model. The medical model of health has historically been the most widely accepted model. Under the medical model good health is defined as the absence of disease. Varying degrees of health are defined according to the seriousness of particular diseases implying that health is a continuum, with complete absence of disease at one end of the continuum and death at the other.

Despite its popularity the medical model has been criticized for deficiencies in several areas. It ignores the mental and social aspects of health. It is unable to incorporate the concept of preventive health. The ability of the human body to heal itself is also discounted in the medical model (Culyer, 1983). Culyer also points out that there is not a strong relationship between "feeling ill" and the actual presence of disease. Social and cultural factors play a significant role in the determination of what constitutes an "illness" and these are ignored in the medical model.

Shortcomings of the medical model have inspired the holistic model of health. The holistic model incorporates mental, social, and medical aspects of health. The World Health Organization (WHO) definition of health of 1948 is still the most popular definition of holistic health. It states that health is "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (Larson). Even though many scholars consider the holistic model a significant improvement over the medical model it has been criticized for its lack of measurability and implementation. It is argued that mental and social health are relatively intangible and therefore difficult to objectively incorporate into an indicator of individual health.

More recently, however, substantial progress has been made to operationalize the holistic model. Numerous indicators of individual health have emerged based on the medical model. One of the most highly regarded holistic health indicators is the Sickness Impact Profile (SIP) developed by Bergner et al. (1981). The SIP is designed to measure the impact of sickness on individual behavior. Because the SIP focuses on behavior and not "feelings" it is generally accepted as an objective measure of holistic health (Bowling; McDowell and Newell). The SIP consists of 136 questions covering 12 categories such as mobility, social interaction, and emotional behavior.[2] Respondent's answers are combined

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[2] The SIP categories and sample questions from each category are presented in Appendix A.

into an overall score, scores for physical and psychosocial health, and scores for each of the 12 categories. Each score represents the state of particular aspects of individual health.

Perhaps the largest single attempt to measure holistic health was the Rand Corporation's Health Insurance Study (Ware et al., 1980). The Rand study used the WHO definition of health to construct a survey designed to measure the health status of over 8,000 people throughout the U.S. Separate survey "batteries" were constructed for the physical, mental, and social aspects of health. Survey questions for the physical health battery cover six aspects of an individual's functional status such as mobility, self care, and household activities. In the original Rand study clinical tests were also given for the presence of over 20 diseases including respiratory problems, hypertension, and thyroid disease (Lohr et al., 1986). The mental health battery consists of questions dealing with mood changes, self-control, etc. The social health battery contains questions about the respondent's number and depth of friendships and other interpersonal relations. The Rand health measures are scored both across batteries and for subclasses within each battery (Bowling; McDowell and Newell).

Health Concepts and Indicators in Developing Countries

Scholars who embrace the holistic model of health have benefitted from the development of indicators like the SIP and the Rand indicator. However, to date these indicators have only been used in developed countries. These indicators have not been used in developing countries for two main reasons. First, the most prevalent and serious health problems in developing countries can be adequately described by the medical model. Second, widespread implementation of the SIP or Rand indicator would be difficult in developing countries because of illiteracy and cultural differences.

Developing countries typically have many health problems not found in developed countries. Phillips (1990) and Larson state that most illnesses in developing countries are related to malnutrition and infectious diseases which are only minor medical problems in developed countries. He describes this phenomena as an "epidemiological transition" where infectious, parasitic, and malnutritional diseases are the leading causes of death and illness in developing countries but are only minor causes in developed countries. This has lead some authors to label infectious and parasitic diseases as "tropical" and chronic or degenerative diseases as "Western."

Consequently, many researchers in developing countries use health indicators based on the medical model. In developed countries health indicators based on the medical model are generally not well accepted as because they ignore important health problems in the areas of social and mental health. In developing countries, however, health indicators based on the medical model are often used because social and mental health problems are relatively less important. For example, at the population level mortality statistics are considered a good health indicator in developing countries since infectious diseases and malnutrition greatly increase mortality rates, especially among children (Martorell and Ho, 1984). On the other hand, mortality statistics are not good indicators of population health in developed countries because recent declining mortality rates ignore the fact that morbidity rates have simultaneously risen.

Similarly, popular individual health indicators in developing countries do not consider social and mental aspects of health. Especially common is the use of nutritional status measurements to proxy individual health status (e.g., Pitt, Rosenzweig, and Hassan, 1990; Behrman 1988; Wolfe and Behrman 1982).[3] Keusch (1990) explains that infectious diseases decrease nutritional status and that poor nutritional status increases the incidence and severity of infections. Martorell and Ho cite studies where poor nutritional status leads to weak immune systems, low resistance to infection, and increased severity of infectious diseases. Furthermore, since children are the most vulnerable household members their nutritional status is likely to represent a community's overall health status (Beaglehole et al., 1993).

Anthropometry is a common means of measuring nutritional status. Anthropometry is able to measure two important symptoms of malnutrition: stunting and body wasting. Stunting is defined as deceleration or cessation of growth while body wasting refers to the depletion of fat and muscle tissue and is caused by severe malnutrition (Martorell and Ho; Alleyne et al., 1977). The anthropometric measures to detect stunting and body wasting are height-for-age and weight-for-height, respectively. Other anthropometric measures of

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[3] Nutritional status refers to the physiological growth and development of an individual. It is a separate concept from nutritional intake which is the actual consumption levels of nutrients (Behrman and Deolalikar, 1988).

nutritional status are skinfold thickness, which indicates fat storage and energy balance, and arm circumference which is a practical substitute for weighing (Alleyne et al.). Body mass index (BMI), defined as the ratio of weight divided by the square of height, is used to proxy chronic energy deficiency in adults (Alderman and Garcia, 1993).

Anthropometry's primary advantage over other indicators of nutritional status is its cost effectiveness (Alleyne et al.; Martorell and Ho). Urine and blood tests can be effective warnings of poor nutritional status but are relatively expensive. In addition, anthropometric measures are sensitive over the full range of nutritional status which is not always true of laboratory tests. Anthropometric measures are not without disadvantage, however. First, anthropometric measurements are unable to suggest possible causes of malnutrition. Second, anthropometric measurements are valid only when compared to a reference group which is sometimes difficult to identify due to genetic diversity (Behrman and Deolalikar). Finally, Behrman and Deolalikar point out that anthropometric measurements often contain significant measurement error.

An alternate approach to abandoning complex holistic indicators is to simplify them to provide easier implementation in developing countries. In their original form the SIP and the Rand indicator require respondents to complete lengthy written questionnaires. Obviously, this procedure is not appropriate if a significant portion of a country's population is illiterate as in many developing countries. Moreover, without rigorous testing it is not known how variations in culture are likely to affect the properties of the

SIP and Rand indicators. Consequently, in several studies of health and economic behavior in developing countries a self-reported health indicator is used where respondents (orally) answer a few questions about their own health during a general survey of household characteristics. In Pitt and Rosenzweig (1985), for example, respondents state the number of days they were ill in the week preceding the survey questionnaire and whether their illness required them to be in bed. Another study asks respondents to rate their overall health status and whether they can perform various functional exercises (Strauss et al., 1993).

Of course, crude self-reported indicators are subject to more criticism than the SIP and Rand indicators. Self-reported indicators have been widely criticized for their poor validity and reliability (McDowell and Newell).[4] Behrman and Deolalikar state that education, culture, and socioeconomic status affect self-reported responses. Chen and Bryant (1975) suggest that individuals' memory, mood changes and acquiescence can influence their responses. Similarly, Nord-Larsen (1983) states that it is unclear what aspect of health (mental, social, or physical) is being measured with self-reported indicators.

On the other hand, Larson notes that simple self-reported indicators are a remarkably accurate indicator of physical health. In particular, self-reported evaluations have been shown to be better predictors of future physical ailments than clinical exams.

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[4] Validity of an instrument relates to whether it actually measures what it purports to measure. Reliability refers to whether an instrument is consistent over and across time.

Nord-Larsen also states that subjective evaluations of general health are highly positively correlated with other objective health indicators. Finally, self-reported indicators are easily obtained and useful for social research which does not require in-depth analysis of physical illnesses (Nord-Larsen). These last two characteristics of self-reported indicators are of obvious importance for research on health-related behavior in developing countries.

Health Production Functions in Developing Countries

One use for individual health indicators in developing countries is to quantify the effects of various inputs on health status. This had led to the estimation of so-called health production functions, which are equations relating health inputs to health status. A related but separate use of health indicators is the estimation of health demand equations which show how changes in the price of health inputs and income affect health. This section focuses exclusively on health production functions.

Of course, it is impossible to know and quantify all the possible factors that determine health. However, medical and public health specialists have identified the primary factors affecting health in developing countries. The World Bank (1975) explains that the primary factors affecting health in developing countries are variables related to infectious and nutritional diseases. Nutritional diseases, which are partly the result of low nutrient intake, weaken the body's immune system and increases the incidence and severity of infectious diseases. Infectious diseases such as intestinal parasites, dysentery, typhoid, and cholera are fecally-transmitted by poor sources of drinking water, inadequate disposal of human waste, and generally poor sanitation.

Hence, nutrient intake levels and sanitation conditions are the primary factors affecting malnutrition and infectious diseases. In addition, it is suggested that family size affects health. As family size increases numerous health risks also increase. Housing conditions are likely to be more unsanitary. Air-borne diseases such as tuberculosis and whooping cough are more easily spread under crowded conditions. Furthermore, large families place undue pressure on maternal health through risks associated with pregnancy and childbirth. It has also been shown that parental education is an important factor affecting child health (Behrman and Wolfe, 1984; Strauss, 1990). With increased education parents are able to make better and more efficient use of limited resources in providing proper child care.

Economists have included the above items as explanatory variables in estimates of health production functions. Among the many estimated health production functions in the literature (e.g., Pitt and Rosenzweig, 1985; Alderman and Garcia, 1994, Wolfe and Behrman 1982; Pitt, Rosenzweig, and Hassan 1990), it is useful to examine one study in detail. Pitt and Rosenzweig (1985) estimate household's per capita frequency of self-reported illness for rural Indonesian households. They include many of the same health determinants discussed by the World Bank as explanatory variables. For example, the household's consumption of nutrients and its drinking water source are included. In addition, tobacco consumption is an explanatory variable, presumably because increased tobacco use should increase the frequency of illness. Demographic variables for the household's education, age, and gender composition are also included.

Pitt and Rosenzweig's estimated health production function is repeated in Table 2.1. It is apparent from Table 1 that nutrient intake has a mixed effect on health. Calories, calcium, and vitamin C all reduce the frequency of illness, while protein, fat, and carbohydrates increase the frequency of illness. One explanation for the mixed effects of nutrition is that individual nutrient effects should not be examined in isolation. Pitt and Rosenzweig explain that the total nutrient content of specific foods should be calculated and compared to the all the nutritional coefficients in Table 2.1 to determine the net effects of consuming specific foods.

Another striking result from Table 2.1 is that tobacco use decreases the frequency of illness while the head's education level increases its frequency. Pitt and Rosenzweig attribute this anomaly to the self-reported health indicator used in the study. For example, tobacco users may be less sensitive to physiological changes, thus decreasing their number of self-reported illnesses. Education, on the other hand, likely increases sensitivity to changes in physical health and thus increases the number of self-reported illnesses. The effect of age on illness is consistent with intuition since increased age reduces the frequency of illness below 39 years and has a positive effect on the frequency of illness

Table 2.1. Health Production Function for Rural Indonesian Households (Pitt and Rosenzweig, 1985).

Dependent Variable: Number of per capita illnesses during seven day period prior to survey questionnaire.

Variable	Estimated Coefficient	Asymptotic t-value
Average age of household members[a]	-0.0796	3.32
Average age of household members squared ($\times 10^{-2}$)[a]	0.101	3.25
Calories per capita[a]	-0.923	3.25
Protein per capita[a]	0.444	2.97
Fat per capita[a]	0.806	3.26
Carbohydrates per capita[a]	0.376	3.25
Calcium per capita[a]	-0.454	2.56
Phosphorous per capita[a]	-0.152	0.35
Iron per capita[a]	-4.14	0.79
Vitamin A per capita[a]	0.823	0.60
Vitamin C per capita[a]	-0.146	2.51
Tobacco per capita[a]	-0.184	1.94
Per capita number of males	-0.0248	0.29
Head's schooling[a]	0.0215	3.43
Wife's schooling[a]	-0.00158	0.22
Water Source:[b]		
well or pump	-0.0241	0.57
river	-0.0416	0.79
Constant	0.578	1.39

sample size=2,347.

a = Endogenous variable.

b = Water source is classified into three categories: well or pump, river, or other (rainfall or spring).

above 39 years. The remaining variables, water source and household gender composition, do not effect the frequency of illness.

Other studies that estimate health production functions obtain results similar to Pitt and Rosenzweig's. In general, improved sanitation conditions and increased nutrient intake have positive effects on health status.[5] However, Behrman and Deolalikar point out that nutrient intake often has a smaller (and sometimes insignificant) effect on health status than expected. They argue that this may be due to a poor choice of health status variables (e.g., self-reported illness), insufficient time lags to capture the effects of nutrient intake, or that increased nutrient intake increases individual labor supply without affecting health status.

Summary

Health indicators are based on either the medical or holistic models of health. In developed countries individual health indicators generally use the holistic model. However, in developing countries researchers often 1)Use health indicators based on the medical model or 2)Use self-reported health indicators that are perhaps consistent with the holistic model but may present measurement problems such as poor validity and reliability. In the case of 1) the medical model is adequate for developing countries since infectious and nutritional diseases are the most prevalent problems. Anthropometric measures of nutritional status are generally used to proxy individual health. For 2) illiteracy and

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[5] It should be emphasized that the expected impact of nutrient intake on health is positive in these studies only because the mean health status and nutrient intakes of the surveyed households are low by medical standards. Under high levels of food consumption (as in a developed country) the expected impact of nutrient intake on nutritional status is less clear.

cultural differences may prohibit the use of complex holistic indicators known to have good measurement properties. Furthermore, if physiological information is not needed than self-reported indicators may be adequate for social research.

One of the more common uses for health indicators in economic research is the estimation of health production functions. A health production function estimated by Pitt and Rosenzweig shows relationships between health inputs and health status that are consistent with evidence from medical and public health research.

CHAPTER 3: STOCHASTIC HEALTH AND ITS EFFECTS ON UTILITY AND CONSUMPTION

This chapter develops a household utility model that incorporates stochastic health. The model applies to general situations where households make consumption decisions under health uncertainty. However, special attention is given here to the unique health problems of low-income households in developing countries. The approach used to develop the model is an expected utility function that depends on the mean and standard deviation of stochastic health.

The first section of the chapter briefly reviews previous studies in the literature that incorporate stochastic health. The second and third sections develop the household's expected utility function. The next two sections explain the household's optimization problem and derive demand equations for food and nonfood. The demand equations reveal the effects of expected health and health risk on consumption. Several example expected utility functions are presented in the following section. The examples illustrate the properties of the expected utility function and also foreshadows the effects of expected health and health risk on consumption. For comparison purposes, the final section presents a model of food and nonfood demand based on an alternative set of assumptions.

Stochastic Health and Consumption: Background

Studies in environmental economics and food safety often include health uncertainty. For example, environmental economists may investigate the effects of pollution on life expectancy or the spread of diseases (Freeman, 1993). One methodology is to assume that health condition A occurs with probability π and condition B with probability $1-\pi$. The health effects of environmental alterations are represented by $\pi=\pi(z)$, where z is a vector of environmental variables. Hence, if π represents the probability of survival and condition B represents death (with an associated utility of zero) expected utility equals $E[U(x)]=\pi(z)U(x)$, where x is a consumption vector and $U(x)$ the utility function. The model can also be extended to include endogenous z variables and thus generate willingness-to-pay estimates for environmental improvements. Similar methods are used to measure the welfare effects of nonfatal health risks (Viscusi, 1993).

Stochastic health is also modeled as a discrete random variable in the food safety literature. Choi and Jensen (1991) develop a model where expected utility is maximized over two periods and the probability of survival depends on food impurities consumed in the first period. Under these circumstances demand equations depend on the level of food impurities and the discount rate. Gersovitz (1983) also uses an intertemporal model to show the effects of health uncertainty on subsistence consumption and savings. He concludes that health uncertainty causes subsistence consumers to save less in the first period than if survival were certain.

Falconi and Roe (1991) develop an alternative to the survival probability model. They assume that health is a continuous random variable whose distribution depends on the amount of pesticides used in food production. In addition, health is an explicit variable in the utility function and agents maximize expected utility. An example utility function is employed that yields demand equations that depend on the mean and variance of stochastic health. Falconi and Roe's results are relevant to this study because they suggest that the mean and variance of stochastic health may be important for demand estimation.

A separate body of literature explores the effects of health risk information on food consumption (Brown and Schrader, 1990; van Ravenswaay and Hoehn, 1991). These studies are based on characteristic demand theory where the characteristics of commodities appear in the utility function. Perceived food safety as proxied by health risk information is considered one of these characteristics. A major drawback to these studies is that they do not include stochastic health in the utility function.

Utility and Stochastic Health

Assume that household health H equals expected health $\bar{H}$ plus a stochastic disturbance ν. The impact of ν on health depends on parameter θ such that $H=\bar{H}+\theta\nu$. Assume that ν has mean zero so that $E[H]=\bar{H}$. Normalizing $Var(\nu)=1$ implies that the variance of H equals θ^2 and the standard deviation of H is θ. Thus, an increase in θ identifies a mean preserving increase in health risk while an increase in $\bar{H}$ identifies a risk preserving increase in expected health. The household's utility U depends on its consumption of food F and nonfood C and its health status such that $U=U(F,C,H)$.

A Taylor series expansion of U(F,C,H) provides a link to the expected utility function. If U(F,C,H) is quadratic or ν is normally distributed the expectation of a second-order expansion of U(F,C,H) around F, C, and $\overline{H}$ is an exact expression for expected utility

$$E[U(F,C,H)] = U(F,C,H)\Big|_{F,C,\bar{H}} + \theta^2 \left(\frac{\partial^2 U(F,C,H)}{\partial H^2} \right)\Bigg|_{F,C,\bar{H}} \tag{3.1}$$

From (3.1) it is clear that expected utility depends on F, C, $\overline{H}$, and θ

$$E[U(F,C,H)] = \bar{U}(F,C,\bar{H},\theta) \tag{3.2}$$

It is sometimes argued that the necessary assumptions for (3.1) are too restrictive (e.g., Rothschild and Stiglitz, 1970; Feldstein, 1969). However, the only requirement in this study is that (3.1) provides a good a local approximation for expected utility.

Specification of Expected Utility

Identification and interpretation of the effects of expected health and health risk on consumption is facilitated by imposing a specific function for expected utility. The goal is to choose a function that provides a good local approximation to the true expected utility function E[U(F,C,H)]. A reasonable starting point is to specify marginal expected utilities of consumption, expected health, and health risk that are very general. This strategy is useful because the effects of expected health and health risk on the marginal expected utilities can easily be identified. Once the marginal expected utilities are specified the expected utility function can be derived and interpreted.

Assume that marginal expected utilities are linear and depend on F, C, $\bar{H}$, and θ

$$
\begin{aligned}
&\frac{\partial\bar{U}}{\partial F}=\bar{U}_F=\alpha_F+\alpha_{FF}F+\alpha_{F\bar{H}}\bar{H}+\alpha_{FC}C+\alpha_{\theta F}\theta\\
&\frac{\partial\bar{U}}{\partial C}=\bar{U}_C=\alpha_C+\alpha_{CC}C+\alpha_{C\bar{H}}\bar{H}+\alpha_{FC}F+\alpha_{\theta C}\theta\\
&\frac{\partial\bar{U}}{\partial\bar{H}}=\bar{U}_{\bar{H}}=\alpha_{\bar{H}}+\alpha_{\bar{H}\bar{H}}\bar{H}+\alpha_{C\bar{H}}C+\alpha_{F\bar{H}}F+\alpha_{\theta\bar{H}}\theta\\
&\frac{\partial\bar{U}}{\partial\theta}=\bar{U}_\theta=\alpha_\theta+\alpha_{\theta\theta}\theta+\alpha_{\theta C}C+\alpha_{\theta F}F+\alpha_{\theta H}\bar{H}
\end{aligned}
\tag{3.3}
$$

By nonsatiation $\bar{U}_F$, $\bar{U}_C$, and $\bar{U}_{\bar{H}}$ are all positive. Health risk is assumed to be an economic "bad" such that $\bar{U}_\theta$ is negative.[6] Constant α_i, $i=F,C,\bar{H},\theta$, is included in the marginal expected utility of good i to promote generality of the expected utility function. The sign of α_i can not be predicted, however.

Parameter α_{ij} measures the effects of good j on the marginal expected utility of good i. For $i=j$, α_{ii} is negative which implies diminishing marginal expected utility for F,

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[6] The assumption $\bar{U}_\theta<0$ corresponds to diminishing marginal utility of health

$$\bar{U}_\theta=\frac{\partial E[U(F,C,H)]}{\partial\theta}=2\theta\left(\frac{\partial^2 U(F,C,H)}{\partial H^2}\right)\Bigg|_{F,C,\bar{H}}$$

C, and $\bar{H}$ and an increasing (negative) impact of health risk.[7] Because the marginal expected utilities of F, C, and $\bar{H}$ are positive the corresponding cross-effects are also positive: $\alpha_{FC}, \alpha_{F\bar{H}}, \alpha_{C\bar{H}} > 0$. Similarly, because health risk has a negative effect on expected utility its corresponding cross-effects are negative: $\alpha_{\theta\bar{H}}, \alpha_{\theta F}, \alpha_{\theta C} < 0$. The predicted signs of all α parameters are summarized in Table 3.1.

The expected utility function corresponding to the marginal expected utilities (3.3) is given in equation 3.4 (for a derivation see Appendix B)

Table 3.1. Expected signs for the α parameters in the marginal expected utilities (3.3).

Parameter	Sign	Motivation
α_F	?	Can not be signed a priori.
α_C	?	Can not be signed a priori.
$\alpha_{\bar{H}}$	?	Can not be signed a priori.
α_θ	?	Can not be signed a priori.
α_{FF}	-	Diminishing marginal expected utility of food.
α_{CC}	-	Diminishing marginal expected utility of nonfood.
$\alpha_{\bar{H}\bar{H}}$	-	Diminishing marginal expected utility of expected health.
$\alpha_{\theta\theta}$	-	Increasing marginal expected disutility of health risk.
α_{FC}	+	Positive cross-effect between food and nonfood.
$\alpha_{F\bar{H}}$	+	Positive cross-effect between food and expected health.
$\alpha_{C\bar{H}}$	+	Positive cross-effect between nonfood and expected health.
$\alpha_{\theta F}$	-	Negative cross-effect between health risk and food.
$\alpha_{\theta C}$	-	Negative cross-effect between health risk and nonfood.
$\alpha_{\theta\bar{H}}$	-	Negative cross-effect between health risk and expected health.

---

[7] Diminishing marginal utility of health also implies that $\alpha_{\theta\theta} < 0$

$$\frac{\partial^2 \bar{U}}{\partial \theta^2} = \alpha_{\theta\theta} = \frac{\partial^2 E[U(F,C,H)]}{\partial \theta^2} = 2\left(\frac{\partial^2 U(F,C,H)}{\partial H^2}\right)\Bigg|_{F,C,\bar{H}}$$

$$\bar{U}(F,C,\bar{H},\theta)=\alpha_0+\alpha_F F+\alpha_C C+\alpha_{\bar{H}}\bar{H}+\alpha_\theta\theta+\frac{\alpha_{FF}}{2}F^2+\frac{\alpha_{CC}}{2}C^2+\frac{\alpha_{\bar{H}\bar{H}}}{2}\bar{H}^2+\frac{\alpha_{\theta\theta}}{2}\theta^2$$
$$+\alpha_{FC}FC+\alpha_{F\bar{H}}F\bar{H}+\alpha_{C\bar{H}}C\bar{H}+\alpha_{\theta\bar{H}}\theta\bar{H}+\alpha_{\theta F}\theta F+\alpha_{\theta C}\theta C \qquad \textbf{(3.4)}$$

Equation (3.4) is a quadratic function that provides a second order approximation to any expected utility function $\bar{U}(F,C,\bar{H},\theta)$ (Blackorby et al., 1978). Furthermore, if health is deterministic ($\theta=0$) equation (3.4) reduces to a quadratic utility function in F,C, and H.

Tradeoffs involving expected health and health risk are characterized by indifference curves of constant expected utility. Because the marginal expected utilities of F, C, and $\bar{H}$ are positive their corresponding indifference curves exhibit conventional properties. In particular, indifference curves between F, C, and $\bar{H}$ are negatively sloped and convex with declining rates of marginal substitution. In expected utility function (3.4) convex indifference curves between F, C, and $\bar{H}$ are defined by the following condition

$$\frac{d^2m}{dn^2}=(2\bar{U}_m\bar{U}_n\alpha_{mn}-\bar{U}_m^2\alpha_{nn}-\bar{U}_n^2\alpha_{mm})>0 \qquad \textbf{(3.5)}$$

where m,n=F,C,$\bar{H}$ (see Silberberg, 1990, p.90). It was previously explained that $\bar{U}_m,\bar{U}_n>0$ and $\alpha_{mm},\alpha_{nn}<0$. Hence, $\alpha_{mn}>0$ is a sufficient condition for convexity. This result coincides with the predictions for α_{mn} in Table 3.1.

Indifference curves between health risk and food, nonfood, or expected health have a different shape. First, these indifference curves are positively sloped

$$\frac{dn}{d\theta}=\frac{-\bar{U}_\theta}{\bar{U}_n}>0 \tag{3.6}$$

Furthermore, when θ is placed on the horizontal axis the indifference curves are convex (Figure 3.1).[8] Consequently, at high risk levels the amount of good n required to compensate households for accepting more health risk is relatively high. This is an intuitively appealing result. In equation (3.4) convex indifference curves between health risk and good n are defined by the following condition

$$\frac{d^2n}{d\theta^2}=(2\bar{U}_\theta\bar{U}_n\alpha_{\theta n}-\bar{U}_\theta^2\alpha_{nn}-\bar{U}_n^2\alpha_{\theta\theta})>0 \tag{3.7}$$

which follows directly from Silberberg. Since $\bar{U}_\theta,\alpha_{\theta\theta},\alpha_{nn}<0$ and $\bar{U}_n>0$ it is clear that $\alpha_{\theta n}<0$ is a sufficient condition for convexity. This result also agrees with the predictions in Table 3.1.

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[8] A formal proof for the univariate case is found in Tobin (1958 and 1965). The proof is extended to utility function U(F,C,H) in Appendix C.

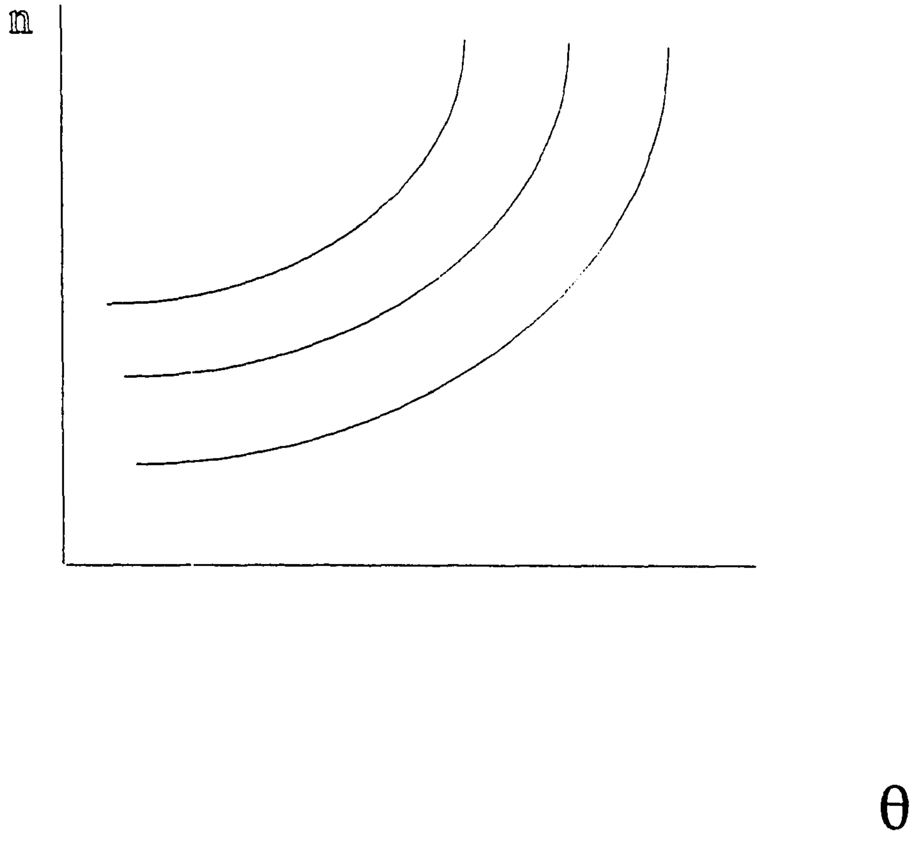

Figure 3.1. Indifference curves of constant expected utility for combinations of good $n = F, C, \overline{H}$ and health risk θ.

Expected Health and Health Risk in Demand Analysis

The paradigm used to construct the household's optimization problem is that expected health and health risk are known to the household but viewed exogenously. There are two cases where this paradigm is most appropriate, both of which describe conditions common to low-income households in developing countries. The first case is where households have little knowledge of their health production technology. Even though food and nonfood consumption may affect health there is no guarantee that households know this information. Households are especially likely to be ignorant about their health technology when parental education is lacking as in many poor households in developing countries. At the very least, these households surely have inaccurate perceptions about the effects of food and nonfood on health. At the same time, it is plausible that these households can assess their expected health and health risk levels from casual observation of their peers, even if they do not know their health technology.

It is also proper to treat expected health and health risk exogenously in demand analysis if food and nonfood's effects on health are relatively small compared to exogenous health inputs such as age, sex, and environmental conditions. This situation also best describes poor households in many developing countries. Lack of purchasing power and poor health infrastructures may prevent households from obtaining proper medical care even if they know their true health technology. In addition, poor sanitary conditions in developing countries make infectious diseases and parasites commonplace which limit the possible health gains from improved diets (Scrimshaw, Taylor, and Gordon, 1968).

For these reasons it is proper to assume that low-income households in developing countries view their expected health and health risk exogenously. Alternatively, health could be modeled endogenously if households know their health technology and also have substantial control their health. For comparison purposes, a model of food and nonfood consumption based on endogenous health production is presented later in the chapter.

Expected Utility Maximization

The household's optimization problem is to choose food and nonfood to maximize expected utility subject to its budget constraint. The constrained maximization problem is expressed as a Lagrangian using (3.4) to represent expected utility

$$\begin{aligned}\max_{F,C}\quad \mathcal{L} &= \alpha_0+\alpha_F F+\alpha_C C+\alpha_{\bar{H}}\bar{H}+\alpha_0\theta+\frac{\alpha_{FF}}{2}F^2+\frac{\alpha_{CC}}{2}C^2+\frac{\alpha_{HH}}{2}\bar{H}^2+\frac{\alpha_{00}}{2}\theta^2\\ &+\alpha_{FC}FC+\alpha_{F\bar{H}}F\bar{H}+\alpha_{C\bar{H}}C\bar{H}+\alpha_{0\bar{H}}\theta\bar{H}+\alpha_{0C}\theta C+\alpha_{0F}\theta F+\lambda(Y-P_F F-P_C C)\end{aligned} \tag{3.8}$$

where Y is total expenditures and P_i is the price of good i. The first-order conditions for an interior solution to (3.8) are

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial F}&=\alpha_F+\alpha_{F\bar{H}}\bar{H}+\alpha_{FC}C+\alpha_{FF}F+\alpha_{\theta F}\theta-\lambda P_F=0\\ \frac{\partial\mathcal{L}}{\partial C}&=\alpha_C+\alpha_{C\bar{H}}\bar{H}+\alpha_{CC}C+\alpha_{FC}F+\alpha_{\theta C}\theta-\lambda P_C=0\\ \frac{\partial\mathcal{L}}{\partial\lambda}&=Y-P_C C-P_F F=0\end{aligned} \tag{3.9}$$

which imply that the marginal rate of substitution (MRS) between food and nonfood equals the corresponding price ratio

$$(2\alpha_{FC}P_F P_C-\alpha_{CC}P_F^2-\alpha_{FF}P_C^2)=\Delta>0 \tag{3.10}$$

The second-order conditions to (3.8) are

$$\frac{\alpha_F+\alpha_{F\bar{H}}\bar{H}+\alpha_{FC}C+\alpha_{FF}F+\alpha_{\theta F}\theta}{\alpha_C+\alpha_{C\bar{H}}\bar{H}+\alpha_{CC}C+\alpha_{FC}F+\alpha_{\theta C}\theta}=\frac{\bar{U}_F}{\bar{U}_C}=\frac{P_F}{P_C} \tag{3.11}$$

which implies convex indifference curves between F and C (see Chiang, 1984, p. 403).

Solving the first-order conditions (3.9) yields demand equations for food and nonfood that depend on prices, total expenditures, expected health, and health risk

$$C=\frac{\alpha_C P_F^2-\alpha_F P_F P_C+Y[\alpha_{FC}P_F-\alpha_{FF}P_C]+\bar{H}[\alpha_{C\bar{H}}P_F^2-\alpha_{F\bar{H}}P_F P_C]+\theta[\alpha_{\theta C}P_F^2-\alpha_{\theta F}P_C P_F]}{2\alpha_{FC}P_F P_C-\alpha_{CC}P_F^2-\alpha_{FF}P_C^2}$$

$$F=\frac{\alpha_F P_C^2-\alpha_C P_F P_C+Y[\alpha_{FC}P_C-\alpha_{CC}P_F]+\bar{H}[\alpha_{F\bar{H}}P_C^2-\alpha_{C\bar{H}}P_F P_C]+\theta[\alpha_{\theta F}P_C^2-\alpha_{\theta C}P_C P_F]}{2\alpha_{FC}P_F P_C-\alpha_{CC}P_F^2-\alpha_{FF}P_C^2}$$

By construction, equations (3.12) and (3.13) satisfy the usual properties of demand systems: Engel aggregation, Hicksian symmetry, and homogeneity of degree zero in prices and total expenditures.

Effects of Expected Health and Health Risk on Consumption

Equations (3.12) and (3.13) reveal the effects of expected health and health risk on consumption. In particular, the effects of $\bar{H}$ and θ are

$$\frac{\partial F}{\partial \bar{H}}=\frac{\alpha_{F\bar{H}}P_C^2-\alpha_{C\bar{H}}P_FP_C}{\Delta};\quad \frac{\partial C}{\partial \bar{H}}=\frac{\alpha_{C\bar{H}}P_F^2-\alpha_{F\bar{H}}P_FP_C}{\Delta} \tag{3.14}$$

$$\frac{\partial F}{\partial \theta}=\frac{\alpha_{\theta F}P_C^2-\alpha_{\theta C}P_CP_F}{\Delta};\quad \frac{\partial C}{\partial \theta}=\frac{\alpha_{\theta C}P_F^2-\alpha_{\theta F}P_CP_F}{\Delta} \tag{3.15}$$

Recall that Δ is positive by the second order conditions to the optimization problem (3.8). Signs of the remaining parameters are $\alpha_{F\bar{H}},\alpha_{C\bar{H}}>0$ and $\alpha_{\theta F},\alpha_{\theta C}<0$ (Table 3.1). However, this information is insufficient to sign (3.14) and (3.15).

Nonetheless, it is useful to consider when the effects of expected health and health risk on consumption might be positive or negative. Suppose that $\alpha_{F\bar{H}}$ is greater than $\alpha_{C\bar{H}}$ such that an increase in $\bar{H}$ positively affects the consumption of F (equation (3.14), assuming $P_C^2 \approx P_FP_C$). It was previously explained that if $\alpha_{FH}>\alpha_{CH}$, $\bar{H}$ has a greater impact on the marginal expected utility of F than on the marginal expected utility of C. Consequently, an increase in $\bar{H}$ causes the MRS ($\bar{U}_F/\bar{U}_C$) to exceed the price ratio P_F/P_C at the original consumption bundle. Because the indifference curves for F and C are convex the household lowers the MRS by increasing its consumption of F and decreasing its consumption of C. This process continues until the MRS again equals the price ratio. Similar reasoning reveals the effects of an increase in θ. Imagine that θ has a larger (negative) impact on the marginal expected utility of F than it does on the marginal expected utility of C ($\alpha_{\theta F} < \alpha_{\theta C}$). An increase in θ thus causes a decrease in the MRS ($\bar{U}_F/\bar{U}_C$) at the original consumption bundle. Condition (3.10) is then restored by consuming less F and more C.

If the number of goods in the expected utility function increases the effects of expected health and health risk are more difficult to interpret. However, the two good case illustrates that the relative impacts of $\bar{H}$ and θ on the marginal expected utilities of the consumption goods determine how $\bar{H}$ and θ affect consumption. It is also apparent that econometric estimation of the demand equations is necessary to sign the effects of expected health and health risk on consumption.

Example Utility Functions

This section presents several examples of expected utility function (3.4). The example functions are useful for demonstrating the economic properties of equation (3.4). The example functions also foreshadow the effects of expected health and health risk on consumption, given that these effects could not be signed a priori. In addition, the parameters from the example functions provide good starting values for subsequent nonlinear demand estimation. The procedure for generating an example function is to find α parameters that solve a set of economic restrictions for (3.4). The restrictions reflect three areas of economic behavior: expenditure-consumption effects, elasticities of substitution, and the scale and curvature of the expected utility function.

The following restrictions are imposed on the expected utility function. Expenditure elasticities of demand for F, C, and $\bar{H}$ provide three restrictions. Six restrictions are imposed on the elasticities of substitution between F, C, $\bar{H}$, and θ. The scale and slope of the expected utility function with respect to total expenditures provide two restrictions. Finally, the household's consumption of F, C, and $\bar{H}$ is restricted using the appropriate demand equations.

Some technical matters about the restrictions deserve special attention. The household's health status is measured in days healthy per month per person. Therefore, $\bar{H}$ represents the household's expected days healthy per month per person and θ is the standard deviation of the household's days healthy per month per person. Values for the price, consumption, and health variables are chosen to yield reasonable expenditure shares for poor households in a developing country (see Appendix D). Each variable also coincides with the sample means for low-income households in Lima, Peru.[9] Health risk is a linear function of purchased input z, $\theta=\phi_0+\phi_1 z$, $\phi_0>0$, $\phi_1<0$, where the values of ϕ_0 and ϕ_1 are chosen to yield a unitary elasticity for $\partial\theta/\partial z$. The restrictions on the scale and curvature of the expected utility function are that $\bar{U}$ equals total expenditures and that the marginal expected utility of total expenditures equals one.

Table 3.2 summarizes the restrictions used for three example utility functions. Example 1 imposes unitary expenditure and substitution elasticities for all goods which

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[9] Data from these households are later used for demand estimation.

corresponds to a Cobb-Douglas expected utility function. Example 2 imposes more realistic values for the elasticities: expenditure elasticities for food and nonfood are 0.75 and 1.25, respectively, which corresponds to preliminary demand analysis from Peru and previous demand studies (Timmer and Alderman, 1979). The elasticity of substitution between F and C is also lowered to 0.75 so that the own-price elasticities for F and C are more reasonable. Example 3 is identical to Example 2 with the exception that the elasticities of substitution involving expected health and health risk are modified. Specifically, the elasticities of substitution between commodity pairs $(F,\bar{H})$ and (F,θ) are increased to 1.25 and elasticities of substitution between (C,H) and (C,θ) are lowered to 0.75.

The α parameters for the example functions are presented in Table 3.3. In general, the parameter signs in the examples coincide with their predicted signs in Table 3.1. In addition to satisfying the a priori restrictions, Table 3.4 reveals that the examples demonstrate the properties discussed earlier in the chapter. The marginal expected utilities of F, C, and $\bar{H}$ are all positive and the marginal expected utility of θ is negative. Moreover, because $\alpha_{ii} < 0 \; \forall i$, there is diminishing marginal expected utility of F, C, and $\bar{H}$ and the marginal expected disutility of θ is increasing. The price elasticities also show their expected signs. Consequently, it can be concluded that equation (3.4) is a reasonable

Table 3.2. Restrictions used to derive the example expected utility functions.

Symbol	Example: 1	2	3	Description
F	125.0	125.0	125.0	Demand equation for food.
C	75.0	75.0	75.0	Demand equation for nonfood.
$\overline{H}$	24.0	24.0	24.0	Demand equation for expected health, measured in expected number of days healthy per month per person.
ϵ_{FY}	1.00	0.75	0.75	Expenditure elasticity of demand for food.
ϵ_{CY}	1.00	1.25	1.25	Expenditure elasticity of demand for nonfood items.
$\epsilon_{\overline{H}Y}$	1.00	1.00	1.00	Expenditure elasticity of demand for expected health.
$\omega_{F\overline{H}}$	1.00	1.00	1.25	Elasticity of substitution between F and $\overline{H}$.
$\omega_{C\overline{H}}$	1.00	1.00	0.75	Elasticity of substitution between C and $\overline{H}$.
$\omega_{\theta F}$	-1.00	-1.00	-1.25	Elasticity of substitution between θ and F.
$\omega_{\theta C}$	-1.00	-1.00	-0.75	Elasticity of substitution between θ and C.
$\omega_{\theta\overline{H}}$	-1.00	-1.00	-1.00	Elasticity of substitution between θ and $\overline{H}$.
ω_{FC}	1.00	0.75	0.75	Elasticity of substitution between F and C.
$\overline{U}$	286.5	286.5	286.5	Scale of the expected utility function.
$\partial\overline{U}/\partial Y$	1.00	1.00	1.00	Marginal expected utility of total expenditures.

Formulas and additional details are given in Appendix D.

specification for expected utility. It is a function form that satisfies basic economic postulates yet is very flexible in the types of economic behavior it can represent.

The example functions also give an indication whether expected health and health risk affect food and nonfood demand. Table 3.4 shows the effects of $\overline{H}$ and θ on food

Table 3.3. Parameter values for the example expected utility functions.

		Example:	
Parameter	1	2	3
α_F	1.536	1.869	1.463
α_C	1.303	0.732	1.379
$\alpha_{\bar{H}}$	0.496	-0.121	0.261
α_θ	1.635	6.970	4.647
α_{FF}	-0.005	-0.010	-0.005
α_{CC}	-0.011	-0.009	-0.016
$\alpha_{\theta\theta}$	-0.849	-0.703	-0.744
$\alpha_{\bar{H}\bar{H}}$	-0.036	-0.030	-0.033
α_{FC}	0.005	0.008	0.007
$\alpha_{\theta F}$	-0.031	-0.054	-0.011
$\alpha_{\theta C}$	-0.009	-0.038	-0.081
$\alpha_{F\bar{H}}$	0.006	0.008	0.011
$\alpha_{C\bar{H}}$	0.005	0.010	0.016
$\alpha_{\theta\bar{H}}$	0.090	0.059	0.070

consumption for exogenous $\bar{H}$ and θ by substituting the parameters from Table 3.3 into comparative static results (3.14) and (3.15). The comparative statics are converted to elasticities to facilitate their interpretation.

Tables 3.2 and 3.4 reveal that the impact of expected health and health risk on consumption varies with the specific restrictions imposed in the example functions. Changing the restrictions on the expenditure elasticities, the marginal expected utility of total expenditures, and the elasticities of substitution between $(\bar{H},\theta)$ and (F,C) have little

Table 3.4. Marginal expected utilities and demand elasticities for the example expected utility functions.

Variable	Example 1	 2	 3	Description
$\bar{U}_F$	1.30	1.30	1.30	Marginal expected utility of food.
$\bar{U}_C$	1.20	1.20	1.20	Marginal expected utility of nonfood.
$\bar{U}_{\bar{H}}$	1.00	1.00	1.00	Marginal expected utility of expected health.
$\bar{U}_\theta$	-3.33	-3.33	-3.33	Marginal expected utility of health risk.
ϵ_{FF}	-0.98	-0.75	-0.97	Own-price elasticity of demand for food.
ϵ_{FC}	0.02	0.02	0.09	Food demand elasticity for changes in the price of nonfood.
ϵ_{CC}	-1.01	-0.93	-0.91	Own-price elasticity of demand for nonfood.
ϵ_{CF}	0.03	-0.28	-0.12	Nonfood demand elasticity for changes in the price of food.
$\epsilon_{F\bar{H}}$	0.00	-0.01	-0.08	Food demand elasticity for changes in expected health.
$\epsilon_{C\bar{H}}$	0.01	0.02	0.14	Nonfood demand elasticity for changes in expected health.
$\epsilon_{F\theta}$	-0.02	-0.01	0.05	Food demand elasticity for changes in health risk.
$\epsilon_{C\theta}$	0.03	0.01	-0.09	Nonfood demand elasticity for changes in health risk.

impact on the health-consumption effects. However, substantial changes in the health-consumption elasticities were achieved by adjusting the remaining elasticities of substitution, i.e., $\omega_{F\bar{H}}$, $\omega_{C\bar{H}}$, $\omega_{\theta F}$, and $\omega_{\theta C}$. In Examples 1 and 2 all elasticities of substitution are restricted to unity which yields negligible effects of the health variables on consumption. However, in Example 3 the elasticity of substitution between F and $\bar{H}$

exceeds the elasticity of substitution between C and $\bar{H}$ ($\omega_{F\bar{H}} > \omega_{C\bar{H}}$) and the elasticity of substitution between F and θ exceeds the elasticity of substitution between C and θ ($|\omega_{\theta F}| > |\omega_{\theta C}|$). Consequently, both $\bar{H}$ and θ have a noticeable impact on consumption. Even larger health-consumption elasticities were obtained by imposing wider gaps between $\omega_{F\bar{H}}, \omega_{C\bar{H}}$ and $\omega_{\theta F}, \omega_{\theta C}$ but these same restrictions yielded unrealistic price elasticities and the "wrong" sign for parameters $\alpha_{\theta i}$ and $\alpha_{i\bar{H}}$, $i=F,C$.

The relationship between the substitution elasticities and health's impact on consumption can be traced back to comparative statics (3.14) and (3.15). Changes in substitution elasticities $\omega_{F\bar{H}}$, $\omega_{C\bar{H}}$, $\omega_{\theta F}$, and $\omega_{\theta C}$ affect parameters α_{0i} and α_{iH} which in turn affect comparative static equations (3.14) and (3.15).[10] As explained earlier, equations (3.14) and (3.15) reflect the household's response to changes in $\bar{H}$ and θ that affect the MRS between food and nonfood.

Demand Equations and Endogenous Health

An alternative paradigm to the above model is that food consumption determines expected health and health risk: $\bar{H}=\bar{H}(F)$ and $\theta=\theta(F)$. Substituting these expressions into equation (3.8) yields the household's optimization problem under endogenous health

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[10] Also note that other parameter values were affected by changes in the substitution elasticities.

$$\begin{aligned}\max_{F,C}\quad \mathcal{L} &= \alpha_0+\alpha_F F+\alpha_C C+\alpha_{\bar{H}}\bar{H}(F)+\alpha_\theta\theta(F)+\frac{\alpha_{FF}}{2}F^2+\frac{\alpha_{CC}}{2}C^2+\frac{\alpha_{\bar{H}\bar{H}}}{2}\bar{H}(F)^2\\ &+\frac{\alpha_{\theta\theta}}{2}\theta(F)^2+\alpha_{FC}FC+\alpha_{F\bar{H}}F\bar{H}(F)+\alpha_{C\bar{H}}C\bar{H}(F)+\alpha_{\theta\bar{H}}\theta(F)\bar{H}(F)\\ &+\alpha_{\theta C}\theta(F)C+\alpha_{\theta F}\theta(F)F+\lambda(Y-P_F F-P_C C)\end{aligned}\tag{3.16}$$

with first order conditions

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial F} &= \left(\alpha_F+\alpha_{FF}F+\alpha_{F\bar{H}}\bar{H}+\alpha_{FC}C+\alpha_{\theta F}\theta\right)+\left(\frac{\partial\bar{U}}{\partial\bar{H}}\frac{\partial\bar{H}}{\partial F}\right)+\left(\frac{\partial\bar{U}}{\partial\theta}\frac{\partial\theta}{\partial F}\right)-\lambda P_F=0\\ \frac{\partial\mathcal{L}}{\partial C} &= \alpha_C+\alpha_{CC}C+\alpha_{C\bar{H}}\bar{H}+\alpha_{FC}F+\alpha_{\theta C}\theta-\lambda P_C=0\\ \frac{\partial\mathcal{L}}{\partial\lambda} &= Y-P_C C-P_F F=0\end{aligned}\tag{3.17}$$

First-order conditions (3.17) resemble those from the exogenous health model (3.9) with the addition of two additional terms in $\partial\mathcal{L}/\partial F$. Each of these terms represent the "indirect" effects of food on expected utility through its impact on expected health and health risk. Note that when food consumption does not affect expected health and health risk, $\partial\bar{H}/\partial F=\partial\theta/\partial F=0$, first-order conditions (3.17) and (3.9) are identical.

Further insights are obtained by substituting for $\bar{U}_{\bar{H}}$ and $\bar{U}_\theta$ from (3.3) and writing $\partial\bar{H}/\partial F$ and $\partial\theta/\partial F$ as constants δ_F and γ_F, respectively. After rearranging, the first-order conditions for the endogenous health problem are

$$\frac{\partial \mathcal{L}}{\partial F}=\tilde{\alpha}_F+\tilde{\alpha}_{FF}F+\tilde{\alpha}_{F\bar{H}}\bar{H}+\tilde{\alpha}_{FC}C+\tilde{\alpha}_{\theta F}\theta-\lambda P_F=0$$

$$\frac{\partial \mathcal{L}}{\partial C}=\alpha_C+\alpha_{CC}C+\alpha_{C\bar{H}}\bar{H}+\alpha_{FC}F+\alpha_{\theta C}\theta-\lambda P_C=0$$

$$\frac{\partial \mathcal{L}}{\partial \lambda}=Y-P_C C-P_F F=0$$

where $\tilde{\alpha}_F=\left(\alpha_F+\delta_F\alpha_{\bar{H}}+\gamma_F\alpha_\theta\right)$ **(3.18)**

$$\tilde{\alpha}_{FF}=\left(\alpha_{FF}+\delta_F\alpha_{F\bar{H}}+\gamma_F\alpha_{\theta F}\right)$$

$$\tilde{\alpha}_{FC}=\left(\alpha_{FC}+\delta_F\alpha_{C\bar{H}}+\gamma_F\alpha_{\theta C}\right)$$

$$\tilde{\alpha}_{F\bar{H}}=\left(\alpha_{F\bar{H}}+\delta_F\alpha_{\bar{H}\bar{H}}+\gamma_F\alpha_{\theta\bar{H}}\right)$$

$$\tilde{\alpha}_{\theta F}=\left(\alpha_{\theta F}+\delta_F\alpha_{\theta\bar{H}}+\gamma_F\alpha_{\theta\theta}\right)$$

Solving (3.18) yields the demand equations for nonfood and food under endogenous health

$$C=\frac{\alpha_C P_F^2-\tilde{\alpha}_F P_F P_C+Y[\alpha_{FC}P_F-\tilde{\alpha}_{FF}P_C]+\bar{H}[\alpha_{C\bar{H}}P_F^2-\tilde{\alpha}_{F\bar{H}}P_F P_C]+\theta[\alpha_{\theta C}P_F^2-\tilde{\alpha}_{\theta F}P_C P_F]}{\alpha_{FC}P_F P_C+\tilde{\alpha}_{FC}P_F P_C-\alpha_{CC}P_F^2-\tilde{\alpha}_{FF}P_C^2}$$

$$F=\frac{\tilde{\alpha}_F P_C^2-\alpha_C P_F P_C+Y[\tilde{\alpha}_{FC}P_C-\alpha_{CC}P_F]+\bar{H}[\tilde{\alpha}_{F\bar{H}}P_C^2-\alpha_{C\bar{H}}P_F P_C]+\theta[\tilde{\alpha}_{\theta F}P_C^2-\alpha_{\theta C}P_C P_F]}{\alpha_{FC}P_F P_C+\tilde{\alpha}_{FC}P_F P_C-\alpha_{CC}P_F^2-\tilde{\alpha}_{FF}P_C^2}$$

Equations (3.19) and (3.20) are quasi-reduced form demand equations. In principal, it would be also possible to obtain reduced form demand equations by substituting $\bar{H}=\bar{H}(F)$ and $\theta=\theta(F)$ into (3.19) and (3.20) and explicitly solving for F and C. However, the reduced form equations would not reveal the impact of $\bar{H}$ and θ on consumption and are likely to be highly complex, depending on the functional form of $\bar{H}=\bar{H}(F)$ and $\theta=\theta(F)$.

Differentiating (3.19) and (3.20) with respect to $\bar{H}$ and θ yields the effects of expected health and health risk on food consumption

$$\frac{\partial F}{\partial \bar{H}}=\frac{\tilde{\alpha}_{F\bar{H}}P_C^2-\alpha_{C\bar{H}}P_FP_C}{\alpha_{FC}P_FP_C+\tilde{\alpha}_{FC}P_FP_C-\alpha_{CC}P_F^2-\tilde{\alpha}_{FF}P_C^2} \tag{3.21}$$

$$\frac{\partial F}{\partial \theta}=\frac{\tilde{\alpha}_{\theta F}P_C^2-\alpha_{\theta C}P_CP_F]}{\alpha_{FC}P_FP_C+\tilde{\alpha}_{FC}P_FP_C-\alpha_{CC}P_F^2-\tilde{\alpha}_{FF}P_C^2} \tag{3.22}$$

Comparing (3.21) and (3.22) against their counterparts in (3.14) and (3.15) from the exogenous model reveals the potential differences for the effects of expected health and health risk on consumption between the two models. In particular, note that any differences in $\partial F/\partial \bar{H}$ and $\partial F/\partial \theta$ arise from the differences between $\tilde{\alpha}_{FF}$, $\tilde{\alpha}_{FC}$, $\tilde{\alpha}_{F\bar{H}}$, and $\tilde{\alpha}_{\theta F}$ and their counterparts in the exogenous model. Furthermore, the magnitudes of health production parameters δ_F and γ_F determine the difference between the $\tilde{\alpha}$ and α parameters. As δ_F and γ_F approach zero all the $\tilde{\alpha}$ and α parameters from each model converge.

An indication whether the exogenous health model possibly over or understates the effects of expected health and health risk on consumption is seen by inserting values of δ_F and γ_F into (3.21) and (3.22). The case of $\delta_F=\gamma_F=0$ is equivalent to the exogenous health model and thus represents a benchmark. Alternative values of δ_F and γ_F are then substituted into (3.21) and (3.22) and the change in $\partial F/\partial\bar{H}$ and $\partial F/\partial\theta$ can be examined. The subsequent values of δ_F and γ_F used here correspond to elasticities 0.10, 0.50, and 1.0 for $\partial\bar{H}/\partial F$ and $\partial\theta/\partial F$ at the sample means. Values for the α parameters come from the Example 3 expected utility function in Table 3.3. Recall that these α parameters were derived to mimic observed economic behavior for the sample households in Lima.

Table 3.5. Effects of expected health on food consumption, $\partial F/\partial\bar{H}$, for different values of δ_F and γ_F.

$\theta_F= \partial\theta/\partial F$	$\delta_F=\partial\bar{H}/\partial F$: 0.0	0.019	0.096	0.192
0.0	-0.163	-0.178	-0.240	-0.315
-0.002	-0.166	-0.182	-0.243	-0.318
-0.012	-0.180	-0.195	-0.256	-0.329
-0.024	-0.196	-0.211	-0.270	-0.342

Calculated at the sample means using α parameters from Example 3 in Table 3.3.

Table 3.6. Effects of health risk on food consumption, $\partial F/\partial \theta$, for different values of δ_F and γ_F.

$\theta_F = \partial\theta/\partial F$	$\delta_F = \partial\bar{H}/\partial F$: 0.0	0.019	0.096	0.192
0.0	1.97	2.00	2.11	2.25
-0.002	2.01	2.04	2.15	2.28
-0.012	2.15	2.18	2.28	2.42
-0.024	2.32	2.35	2.45	2.57

Calculated at the sample means using α parameters from Example 3 in Table 3.3.

Tables 3.5 and 3.6 show that when δ_F and γ_F increase (in absolute value) the corresponding derivatives $\partial F/\partial \bar{H}$ and $\partial F/\partial \theta$ also increase (in absolute value). Hence, demand equation (3.13) with $\delta_F = \gamma_F = 0$ likely understates the effects of expected health and health risk on consumption if endogenous health is present. Also note that only for large values of δ_F and γ_F do $\partial F/\partial \bar{H}$ and $\partial F/\partial \theta$ substantially differ from the exogenous health model where $\delta_F = \gamma_F = 0$.

Summary

This chapter develops a model of expected utility that depends on the mean and standard deviation of stochastic health. The model is useful because it shows that expected health and health risk are potentially important factors affecting consumption. Although a local approximation is imposed for expected utility, it is not possible to predict the effects of expected health and health risk on consumption. However, it is shown that the consumption effects depend on expected health and health risk's impact on the marginal expected utilities of all consumption goods. Since these magnitudes are unknown, the impact of expected health and health risk on consumption must be estimated econometrically.

Several examples of the expected utility function are presented that satisfy a broad set of economic restrictions. The example functions show desirable economic properties. The example functions also suggest that the impact of expected health and health risk on consumption may or may not be important, depending on the elasticities of substitution between health and the consumption goods. The magnitude of the health-consumption effects increase as the difference between substitution elasticities increases.

Finally, the demand equations for food and nonfood are examined under the alternative paradigm that expected health and health risk are endogenous. Demand equations developed under this paradigm are simply an extension of the demand equations presented earlier in the chapter. Several example functions show that the exogenous health model yields a conservative estimate of the effects of expected health and health risk on consumption.

CHAPTER 4: ESTIMATING A HETEROSCEDASTIC HEALTH FUNCTION

This chapter shows how to estimate households' expected health and health risk for use in demand estimation. The general procedure is to estimate a household health function. The predicted values of the function provide estimates of expected health. Estimates of health variance can be obtained if the health function is heteroscedastic and the variance of health depends on the level of health inputs. The health input-health variance relationship can be estimated by regression and the predicted values of the regression provide an estimate of each household's health risk.

Data from Lima, Peru are used to illustrate the procedure. The results of the estimated health function coincide with previous studies. In addition, there is strong evidence that the health inputs affect health variance. This permits estimates of each household's expected health and health risk to be computed from the regression equations.

The chapter is organized as follows. The first section presents an econometric model of heteroscedastic health production. The next section describes the data from low-income households in Lima, Peru used to estimate the model. Estimates of the health production and health variance functions are then presented, followed by a discussion of the results. The final section presents the estimates of expected health and health risk for the sample households in Lima.

The Model

Following Pitt and Rosenzweig (1985) a household's health is a linear function of its health inputs

$$H_i = x_i\delta + \epsilon_i \tag{4.1}$$

where subscript i denotes the ith household, $i=1..n$, H_i is a numeric indicator of household health, $\mathbf{x}_i$ is a $1 \times k$ vector of health inputs, $\boldsymbol{\delta}$ is a $k \times 1$ vector of coefficients, and ϵ_i is a stochastic disturbance term with mean zero and variance θ_i^2. Vector x includes variables such as food consumption, age and sex of members, parental education, and environmental conditions. Within vector **x** there are k_1 endogenous inputs (subvector y) and k_2 exogenous inputs (subvector **z**) where $k_1+k_2=k$ and $x' = [y' \ z']$.

Rosenzweig and Schultz (1983) explain that estimation of (4.1) via ordinary least squares (OLS) yields asymptotically biased estimates of $\boldsymbol{\delta}$ and the direction of the bias is unknown. The bias occurs because health endowments are heterogenous and not fully observed by the econometrician. Consequently, the estimated residuals from (4.1) are most likely correlated with y. One example is when an inherently weak infant is given an increased dose of health inputs to increase its survival chances (Alderman and Garcia, 1994). Under these circumstances it incorrectly appears that increased input consumption causes poor infant health.

To obtain consistent estimates of the health production function Rosenzweig and Schultz recommend using two stage least squares (2SLS). In the first stage y is regressed on a set of exogenous variables yielding predicted values $\hat{y}$ and instrumental variable vector $\hat{\mathbf{x}}' = [\hat{\mathbf{y}}' \; \mathbf{z}']$. Consistent estimates of the health function coefficients are obtained from the second-stage regression

$$\boldsymbol{\delta}^* = (\hat{X}'\hat{X})^{-1}\hat{X}'H \tag{4.2}$$

where $\hat{\mathbf{X}}$ and $\mathbf{H}$ are n-row matrices of $\hat{\mathbf{x}}_i$ and H_i, respectively. If $\theta^2_i = \theta^2 \; \forall i$ the health function is homoscedastic and $\boldsymbol{\delta}^*$ is an efficient estimate of $\boldsymbol{\delta}$. However, in cross-section data there is often considerable variation in θ_i^2 so that $\boldsymbol{\delta}^*$ is inefficient. The efficiency of $\boldsymbol{\delta}^*$ can be improved using a feasible generalized least squares (FGLS) procedure pioneered by Glesjer (1969) where θ^2_i is modeled as a function of the explanatory variables.

Fomby et al. (1984) explain how to implement the FGLS procedure when the specification for θ_i^2 is a linear regression

$$\theta_i^2 = \boldsymbol{m}_i \gamma + v_i \tag{4.3}$$

where $\mathbf{m}_i$ is a $1 \times p$ subset of $\hat{\mathbf{x}}_i$, γ is a $p \times 1$ vector of coefficients whose first element γ_1 is a constant, and υ_i is a stochastic disturbance. Regressing the squared residuals of the health production function on a subset of the health inputs yields a test for the null hypothesis of homoscedasticity, H_0: $\gamma_2 = \gamma_3 = \ldots \gamma_p = 0$

$$\gamma^{*}=(M'M)^{-1}M'\hat{\epsilon}^{2} \qquad (4.4)$$

where **M** is a n×p matrix of $\mathbf{m}_i$ and $\hat{\epsilon}$ is an n×1 vector of estimated disturbances from (4.2)

$$\hat{\epsilon}=H-\hat{X}(\hat{X}'\hat{X})^{-1}\hat{X}'H \qquad (4.5)$$

Fomby et al. show that γ^{*} is a consistent estimator of γ. The test statistic for H_0 is

$$\ell=\gamma_0^{*\prime}(V^0)^{-1}\gamma_0^{*} \qquad (4.6)$$

where $\gamma_0^{*}=(\gamma_2^{*}, \ldots \gamma_p^{*})'$ and $\mathbf{V}^0$ is the (p-1)×(p-1) matrix obtained by removing the first row and column of $2(\gamma_1^{*})^2(M'M)^{-1}$. Statistic ℓ has a chi-square distribution with p-1 degrees of freedom.

If the null hypothesis of homoscedasticity is rejected efficient estimates of $\boldsymbol{\delta}$ are obtained using FGLS

$$\delta^{**}=(\hat{X}'\Omega\ ^{1}\hat{X})\ ^{1}\hat{X}'\Omega\ ^{1}H \qquad (4.7)$$

where Ω is a nxn diagonal matrix whose ith diagonal element equals $\theta_i^{2*}=\mathbf{m}_i\gamma^{*}$.

An estimate of the ith household's expected health $\overline{H}_i$ is the predicted value of the health production function

$$\overline{H}_i=\hat{x}_i\delta^{**} \qquad (4.8)$$

Similarly, an estimate of the ith household's health variance is the predicted value of the health variance equation

$$\theta_i^{2*} = m_i \gamma^* \tag{4.9}$$

The Data

Data used to estimate the health function are from the 1985-86 Peru Living Standards Survey (PLSS) compiled by the Poverty and Human Resources Division of the World Bank and the Instituto Nacional de Estadistica e Informatica (INEI) in Lima (see World Bank 1993a). The PLSS contains demographic, health, and economic data for over 5,000 households throughout Peru. Survey interviews were conducted between July 1985 and June 1986. During an initial interview demographic, health, and all nonfood economic data were collected. After two weeks a second interview recorded household food expenditures during the 14 day period.

Only two-parent households in Lima's bottom expenditure quartile are considered in this study. Households outside Lima are excluded because corresponding price data were unavailable. Following Pitt and Rosenzweig, single-parent households are excluded so the effects of the husband and wife's education on health can be examined. The wealthiest quartiles are excluded to focus on households whose food consumption and health status are most likely to be substandard. The households are sorted into expenditure quartiles by deflating total monthly expenditures per capita by the monthly consumer price index matching the household's interview dates. Housing expense data are sporadic and are not included in total expenditures. The resulting bottom expenditure quartile contains 242 households with an average annual expenditures of $230 per capita, using the official exchange rate of 11.2 intis per dollar in July 1985 (IMF).

The indicator of individual health in Pitt and Rosenzweig is each person's days ill for the seven day period preceding the household's interview. However, because no person-specific health input data were available the household's total days ill per person is the dependent variable in the household health function. The authors advocate per capita estimation of the health function; this procedure is appropriate if the health technology is linear. The inputs contained in Pitt and Rosenzweig's health function are per capita nutrient and tobacco consumption, average household age, parental education, proportion of males in the household, and drinking water source.

A per capita form of the health function is also used in this study. First, the PLSS reports each individual's days ill four weeks preceding the household's first interview, which are added to yield the household's total days ill. The total days ill is then expressed on a per capita basis. Finally, days ill per capita are converted to days healthy (out of 28 possible days) so that increases in the health indicator correspond to improvements in household health.

Health input data available in the PLSS are also similar to Pitt and Rosenzweig. Parental education is measured using binary variables indicating whether the husband and wife have a primary and secondary education. The household's sewer system is measured with binary variables for a public service sewer, a septic tank, a cesspool, or no sewer system. The effects of age and sex on per capita days healthy are measured by the proportion of the household in various demographic groups: children ages 0 to 3, children ages 3 to 10, males between 10 and 18, females between 10 and 18, males between 18 and 60, females between 18 and 60, males over 60, and females over 60. Binary variables indicating the household's interview month are used to measure seasonal health effects.

The food consumption data in the PLSS are initially recorded as household expenditures. To create food consumption variables household expenditures on 30 food

Table 4.1. Composition of total food expenditures in Lima's lowest expenditure quartile.

	Expenditure Shares	
	Mean	Std. Dev.
Cereals and bread	0.27	0.10
Meats	0.14	0.09
Fish and seafood	0.04	0.05
Dairy products and eggs	0.10	0.06
Vegetables	0.07	0.04
Fruits	0.04	0.03
Beans and legumes	0.03	0.03
Tubers	0.07	0.05
Coffee and tea	0.02	0.02
Grease and oils	0.05	0.03
Sugar	0.04	0.02
Miscellaneous	0.07	0.07
Food away from home	0.06	0.12

categories were aggregated to match 13 published price indices for Lima (INEI, 1994). Summary expenditure data for the 13 food categories are shown in Table 4.1. Items with small expenditure shares were further combined to form six food categories (Table 4.2).

Indices of total household consumption for the six food categories in Table 4.2 were obtained by dividing household expenditures on each category by its corresponding price index.[11] Published price indices were readily available for cereals, dairy products, and tubers. For the remaining categories new price indices were created using Fisher's Ideal Index, which is the geometric mean of the Laspeyres and Pasche indices (Allen, 1975). The corresponding formulas are

Table 4.2. Composition of total food expenditures in Lima's lowest expenditure quartile, revised categories.

	Expenditure Shares	
Item	Mean	Std. Dev.
Cereals and bread	0.27	0.10
Meats and fish	0.18	0.10
Dairy products and eggs	0.10	0.06
Vegetables, fruits, and legumes	0.13	0.06
Tubers	0.07	0.05
Other food	0.24	0.12

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[11] Price data for each month were assigned to households according to their interview dates.

$$P_t^L = \frac{\sum_i P_t^i q_{t-1}^i}{\sum_i P_{t-1}^i q_{t-1}^i}$$

$$P_t^P = \frac{\sum_i P_t^i q_t^i}{\sum_i P_{t-1}^i q_t^i} \qquad \textbf{(4.10)}$$

$$P_t^F = (P_t^L P_t^P)^{1/2}$$

where P_t^P denotes the Pasche index, P_t^L is the Laspeyres index, P_t^F is the Fisher index, and subscript t denotes month t. P_t^i and q_t^i are the price and quantities of the ith item in each category. All P_t^i values were obtained directly from the published price indices while the q_t^i values were derived from the total combined expenditures on category i for all households interviewed in month t.

The household's food consumption is treated endogenously in the health function. Consequently, instrumental variables were created for the food consumption variables. The quantity indices of total household consumption were first regressed on a series of exogenous variables, some of which are also inputs in the health function. These exogenous variables include real total expenditures, size of demographic groups, and binary variables for parental education, sewer facilities, interview month, and the household's district in Metropolitan Lima. Descriptions of all variables and the estimated regressions used to create instruments of total food consumption are shown in Appendix E.

The instruments of total household consumption were then divided by the total number of equivalent adults in the household using equivalent scales from Stone (1954): adult males=1.0, adult females=0.90, males aged 14 to 17=0.98, females aged 14 to 17=0.90, and children under 14=0.52. Descriptions and summary statistics of all variables in the estimated health function are given in Table 4.3.

Estimated Health Production and Health Variance Equations

The health function is first estimated via two-stage least squares (2SLS), ignoring the possibility of heteroscedasticity (Table 4.4). Because all the demographic variables sum to one the proportion of males between 18 to 60 is omitted to avoid collinearity with the constant term. Consequently, the estimated coefficients on the remaining groups measure the health of the each group relative to adult males.

Tests for heteroscedasticity in the health function were performed by regressing the squared residuals from the health function on various health inputs as in equation (4.4). Significance tests for the impact of the inputs on health variance showed strong evidence of heteroscedasticity (Table 4.5). The tests also suggest that all health inputs should be used as explanatory variables to estimate the variance of health. Estimation of the complete health variance equation (4.4) is shown in Table 4.6. The health function is then estimated

Table 4.3. Variables included in the health production function.

Variable	Mean	Std.Dev.	Description
Dependent Variable			
Health	23.7	3.7	Household's health status, measured in days healthy per month per person (28 days).
Food Consumption[a]			
Meat	31.2	14.2	Index of meat and fish consumption, per adult equivalent.
Dairy	19.1	9.4	Index of dairy and egg consumption, per adult equivalent.
Cereals	48.8	11.5	Index of cereal consumption, per adult equivalent.
Vegetables	19.7	8.4	Index of vegetable, fruit, and legume consumption, per adult equivalent.
Tubers	9.9	4.4	Index of tuber consumption, per adult equivalent.
Other Food	45.2	19.9	Index of other food consumption, per adult equivalent.
Household Composition			
Under 3	0.11	0.13	Proportion of household under age 3.
Between 3 and 10	0.21	0.18	Proportion of household between age 3 and 10.
Male, 10 to 18	0.08	0.12	Proportion of household that is male and between 10 and 18.
Female, 10 to 18	0.09	0.12	Proportion of household that is female and between 10 and 18.
Male, 18 to 60	0.24	0.12	Proportion of household that is male and between 18 and 60.
Female, 18 to 60	0.22	0.11	Proportion of household that is female and between 18 and 60.
Male over 60	0.03	0.09	Proportion of household that is male and over 60.

---

a = Endogenous inputs, instrumental variables used.

Table 4.3. (continued)

Female over 60	0.02	0.07	Proportion of household that is female and over 60.
Parental Education			
Husband's educ. - primary	0.50	..	Binary variable=1 if the husband has a primary education.
Husband's educ.- secondary	0.25	..	Binary variable=1 if the husband has a secondary education.
Wife's educ. - primary	0.29	..	Binary variable=1 if the wife has a primary education.
Wife's educ. - secondary	0.13	..	Binary variable=1 if the wife has a secondary education.
Public Sanitation			
Sewer system - public service	0.66	..	Binary variable=1 if the household has a public service sewer.
Sewer system - septic tank	0.03	..	Binary variable=1 if the household has a septic tank sewer.
Sewer system - cesspool	0.19	..	Binary variable=1 if the household has a cesspool sewer.
Sewer system - none	0.12	..	Binary variable=1 if the household has no sewer system.
Seasonal Effects			
Month	..	..	Binary variable=1 if the interview occurred during the given month.

Table 4.4. Estimated health production function, 2SLS estimation, without correcting for heteroscedasticity.

Dependent Variable: Household's health status, measured in days healthy per month per person (mean=23.7).

Variable	Coefficient	t-ratio	Elasticity
Food Consumption: [a]			
Meat	-0.02	-0.71	-0.03
Dairy	-0.01	-0.29	-0.01
Cereals	0.04	1.23	0.08
Vegetables	0.01	0.18	0.01
Tubers	0.11	1.14	0.04
Other Food	-0.003	-0.16	-0.01
Household Composition: [b]			
Under 3	-3.87	-1.34	
Between 3 and 10	-4.23	-1.64	
Male between 10 and 18	-0.42	-0.13	
Female between 10 and 18	-0.23	-0.08	
Female between 18 and 60	-6.28	-1.72	
Male over 60	-3.70	-0.89	
Female over 60	-10.24	-1.85	
Parental Education:			
Husband's educ. - primary	-0.36	-0.50	
Husband's educ. - secondary	-0.77	-1.01	
Wife's educ. - primary	0.94	1.28	
Wife's educ. - secondary	2.83	2.93*	

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sample size = 242.

* = Significantly different from zero at the 5 percent level.

a = Endogenous inputs, instrumental variables used.

b = Male between 18 and 60 is the "base" demographic group.

c = Sewer system - public service is the "base" sewer system.

d = July is the "base" month.

Table 4.4. (continued)

Public Sanitation: [c]		
Sewer system - septic tank	-1.49	-0.96
Sewer system - cesspool	-0.004	-0.01
Sewer system - none	-1.09	-1.24
Seasonal Effects: [d]		
August	-1.72	-1.38
September	-1.41	-1.34
October	-0.98	-0.84
November	0.99	0.68
December	-0.73	-0.61
January	-1.01	-0.81
February	0.60	0.49
March	0.16	0.15
April	-0.49	-0.41
May	-0.38	-0.26
June	-1.61	-0.94
Constant	25.15	10.39*
$F_{31,210}$	1.58*	

Table 4.5. Tests for health inputs affecting the variance of health production, computed from equations (4.4) and (4.6).

Input group	Statistic ℓ	Degrees of freedom
All health inputs	133.9*	31
Food Consumption	15.5*	6
Household Composition	68.1*	7
Parental Education	18.2*	4
Public Sanitation	9.9*	3
Seasonal Effects	136.6*	11

Statistic ℓ has a chi-square distribution.

* = Reject at the 5 percent level the null hypotheses that the inputs do not affect the variance of health production.

Table 4.6. Estimated health variance equation.

Dependent variable: Squared residuals from the estimated health production function in Table 4.4, measured in days per month per person, squared (mean = 10.8).

Significance tests shown in Table 4.5.

Variable		Coefficient	Elasticity
Food Consumption: [a]			
Meat		-0.21	-0.62
Dairy	0.01	0.02	
Cereals		0.12	0.56
Vegetables		-0.002	-0.004
Tubers		-0.87	-0.80
Other Food		0.09	0.38
Household Composition: [b]			
Under 3		14.59	
Between 3 and 10		-9.57	
Male between 10 and 18		-9.52	
Female between 10 and 18		-14.10	
Female between 18 and 60		17.01	
Male over 60		24.54	
Female over 60		-2.13	
Parental Education:			
Husband's educ. - primary		-5.54	
Husband's educ. - secondary		-0.91	
Wife's educ. - primary		0.90	
Wife's educ. - secondary		-8.38	

---

sample size = 242.

a = Endogenous inputs, instrumental variables used.

b = Male between 18 and 60 is the "base" demographic group.

c = Sewer system - public service is the "base" sewer system.

d = July is the "base" month.

Table 4.6. (continued)

Public Sanitation: [c]	
Sewer system - septic tank	4.91
Sewer system - cesspool	0.09
Sewer system - none	7.07
Seasonal Effects: [d]	
August	13.49
September	8.48
October	2.77
November	0.15
December	5.14
January	-2.15
February	-2.02
March	-0.62
April	4.07
May	-5.71
June	4.64
Constant	8.13

Table 4.7. Estimated health production function, 2SLS estimation correcting for heteroscedasticity using feasible generalized least squares (FGLS).

Dependent Variable: Household's health status, measured in days healthy per month per person (mean=23.7)

Variable	Coefficient	t-ratio	Elasticity
Food Consumption: [a]			
Meat	-0.06	-2.67*	-0.08
Dairy	-0.01	-0.24	-0.01
Cereals	0.08	3.18*	0.17
Vegetables	0.03	0.66	0.03
Tubers	0.14	1.68	0.06
Other Food	-0.02	-1.15	-0.04
Household Composition: [b]			
Under 3	-8.63	-4.15*	
Between 3 and 10	-6.33	-3.45*	
Male between 10 and 18	0.91	0.41	
Female between 10 and 18	0.01	0.004	
Female between 18 and 60	-7.97	-2.54*	
Male over 60	-3.35	-0.74	
Female over 60	-11.03	-2.29*	
Parental Education:			
Husband's educ. - primary	0.33	0.60	
Husband's educ. - secondary	-0.48	-0.84	
Wife's educ. - primary	0.92	1.55	
Wife's educ. - secondary	2.10	3.24*	

---

sample size = 242.
* = Significantly different from zero at the 5 percent level.
a = Endogenous inputs, instrumental variables used.
b = Male between 18 and 60 is the "base" demographic group.
c = Sewer system - public service is the "base" sewer system.
d = July is the "base" month.

Table 4.7. (continued)

Public Sanitation [c]		
Sewer system - septic tank	-1.03	-0.73
Sewer system - cesspool	0.84	1.93
Sewer system - none	-1.53	-1.73
Seasonal Effects: [d]		
August	-1.02	-0.79
September	-0.51	-0.66
October	-0.20	-0.25
November	1.46	1.71
December	0.70	0.91
January	0.15	0.19
February	1.25	1.50
March	-0.46	-0.72
April	0.51	0.90
May	-0.20	-0.26
June	-0.72	-0.37
Constant	24.39	13.36*
$F_{31,210}$	13.69*	

via FGLS in Table 4.7, where the predicted values of the health variance equation provide estimates of each household's health variance.[12]

Estimation Results

Parental education has a strong impact on expected health and health variance. In particular, the wife's secondary education positively affects the household's expected health

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[12] One problem computing the FGLS estimates was that several health variance estimates were negative (20 of 242 households). Following Goldfeld and Quandt (1972), the squared residuals are used to estimate health variance in these households.

and negatively affects health variance. These results are consistent with previous studies (e.g., Strauss, 1990; Strauss et al., 1993; Cochran, Leslie and O'Hara, 1982). When women and mothers are well-educated they are more efficient users of other health inputs. One possible reason these effects are large is if women are the main providers of child care and food preparation. The husband's education does not affect expected health but does have a large positive impact on health variance. The insignificance of the husband's education on expected health might be from a lack of involvement by husbands in household management. Nonetheless, the positive effect on health variance is surprising.

The household's sewer system affects both expected health and health variance.[13] The largest impact occurs for households with no access to a sewer system. These households have a lower expected health and higher health variance compared to households with public sewer access. Another finding is that households with a cesspool have a higher expected health than households with public sewer access. Some of these effects may also occur from differences in household quality captured by the sewer variables. In general, the effects of sewer of expected health and health risk support the notion that poor sanitation is a major obstacle to good health in developing countries (World Bank, 1975). Similar results are found in rural Côte d'Ivoire where improved public sanitation positively affects children's health (Strauss, 1990).

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[13] A joint test for insignificance of the sewer variables in the health function is rejected at the 5 percent level ($F_{3,210}=3.01$).

Demographic composition greatly affects overall household health. As the proportion of children and adult females increase the expected health of the household decreases. Furthermore, the variance of households health increases as the proportion of infants, adult females, and elderly men increases. These results support the fact that children and adult women are the least healthy demographic groups. Possible reasons for these results are that children are highly vulnerable to infectious diseases and their symptoms including diarrhea (Martorell and Ho, 1984). In addition, the health status of women is likely to be affected by the stress of child bearing. Alderman and Garcia (1994) similarly found that children's health improves with age in Pakistan. Strauss et al, (1993) discovered that adult women in developing countries are generally less healthy than adult men. It should be noted that the effects of age and sex on health in this study may be affected by the particular self-reported health indicator. That is, males and females may have unique definitions of being "healthy" and parents may evaluate children's health differently than their own.

The effects of food consumption on health are mixed. Both cereals and tubers positively affect expected health, with cereals having the largest impact in percent terms. Meat consumption, on the other hand, negatively affects expected health. Concerning health variance, meat and tuber consumption have a negative impact while cereals has a positive effect. The remaining food commodities only have a small effect on health variance.

Previous estimates of food consumption's effect on health show similar results. In particular, Pitt and Rosenzweig found a wide range for the effects of specific nutrients such as calories, vitamins, proteins, etc. They attribute this result to the fact that individual nutrients are not consumed in isolation. Therefore, the net impact on health on an increase in food consumption is the total combined effect in the change in all relevant nutrients. A similar argument can be applied to the health function for Lima where consumption changes among commodity groups are positively correlated (i.e., for increases in income). In this case, the net health effect of an increase in food consumption is the total combined effects of an increase in meats, cereals, vegetables, etc. Moreover, Behrman and Deolalikar (1988) explain that insignificant health effects of food consumption are common and mainly due to inaccurate health indicators and short recall periods for surveys. The short recall periods imply that data are incapable of revealing long-run relationships between food consumption and health.

A second possible reason for the mixed impact of food consumption on health is a lack of detail in the PLSS data. Recall that the food consumption indices are obtained from expenditures divided by a price index. Consequently, the consumption indices may not accurately reflect the amount of nutrients provided by diverse commodity groups such as meats and vegetables. On the other hand, cereals is a fairly homogeneous commodity group and is the dominant item in the food budget. These facts may partly explain why cereals have a positive impact on health while most other items show no impact or a negative impact. Furthermore, the negative effect of meat consumption on expected health may be due to unsafe storage and handling practices for meat products.

The effects of seasonal changes on expected health are not important. A joint test for the significance of the seasonal variables on health status can not be rejected at the 5 percent level ($F_{11,210}=1.57$). Nonetheless, the estimated monthly coefficients show a pattern of improved health during the summer months of November to February and decreased health from April to October. Health variance, on the other hand, greatly increases in August and September which is the start of winter in Lima.

Estimates of Expected Health and Health Variance

The main reason for estimating the health production and health variance equations in this study is to measure each household's expected health and health risk. The predicted values from the regressions in Tables 4.6 and 4.7 provide estimates of expected health and health variance for the sample households. Summary statistics in Table 4.8 indicate that the mean expected days healthy per person is 24 out of 28 possible days. The sample mean for the standard deviation of days healthy per person is 3 days.

Summary

This chapter explains how household-specific estimates of expected health status and health variance are obtained from an estimated health function. Conventional estimation methods for health production functions are employed with the exception that

Table 4.8. Summary statistics of expected health and health risk for all households in Lima's bottom expenditure quartile.

Variable	Mean	Std.Dev.	Description
Expected health	23.8	1.9	Estimated expected number of days healthy per person per month (28 days).
Variance of health	11.2	8.1	Estimated variance of the household's days healthy per person per month.
Standard deviation of health (health risk)	3.1	1.3	Estimated standard deviation of the household's days healthy per person per month.

sample size=242

heteroscedasticity is explicitly considered. An estimated health function for households in Lima's lowest expenditure quartile conforms to expectations and resembles previous studies in the literature. Because there is strong evidence of heteroscedasticity it is possible to obtain estimates of each household's health variance.

CHAPTER 5: NONLINEAR ESTIMATION OF THE EFFECTS OF EXPECTED HEALTH AND HEALTH RISK ON FOOD AND NONFOOD CONSUMPTION

In Chapter 3 it was shown that expected health and health risk are potentially important factors affecting food and nonfood consumption. Chapter 4 explained how estimates of each household's expected health and health risk are obtained from a heteroscedastic health function for low-income households in Lima, Peru. That information is used here to estimate a food demand equation for the sample households in Lima. The equation is a nonlinear function that depends on food and nonfood prices, total expenditures, expected health and health risk.

The estimation results for the food demand equation are mixed. Significance levels for the estimated parameters are not high and some parameters are highly correlated. However, the effects of prices and total expenditures on food demand are highly significant and conform to estimates in previous studies. The effects of expected health and health risk on food demand are moderate but not significant at conventional significance levels.

The first section of the chapter briefly reviews the nonlinear demand equations for food and nonfood. The second section presents the data used to estimate the food demand equation. The estimate of the food demand equation is presented in the next section. The final section discusses the possibility of expanding the system to include multiple food demand equations.

Nonlinear Demand Equations for Food and Nonfood

Chapter 3 explained that when health is stochastic it is possible to formulate household consumption decisions as an expected utility maximization problem. The specific case examined in Chapter 3 is where utility depends on the consumption of food F, nonfood C, and health status H. When H is stochastic the household's demand equations are

$$C=\frac{\alpha_C P_F^2-\alpha_F P_F P_C+Y[\alpha_{FC}P_F-\alpha_{FF}P_C]+\bar{H}[\alpha_{CH}P_F^2-\alpha_{FH}P_F P_C]+\theta[\alpha_{\theta C}P_F^2-\alpha_{\theta F}P_C P_F]}{2\alpha_{FC}P_F P_C-\alpha_{CC}P_F^2-\alpha_{FF}P_C^2} \quad \textbf{(5.1)}$$

$$F=\frac{\alpha_F P_C^2-\alpha_C P_F P_C+Y[\alpha_{FC}P_C-\alpha_{CC}P_F]+\bar{H}[\alpha_{FH}P_C^2-\alpha_{CH}P_F P_C]+\theta[\alpha_{\theta F}P_C^2-\alpha_{\theta C}P_C P_F]}{2\alpha_{FC}P_F P_C-\alpha_{CC}P_F^2-\alpha_{FF}P_C^2} \quad \textbf{(5.2)}$$

where P_i is the price of good i, Y is total household expenditures, $\overline{H}$ is the household's expected health, and θ is the standard deviation of H or health risk. It should be emphasized that equations (5.1) and (5.2) are based on Chapter 3's assumption that households are oblivious to the possible effects of food consumption on expected health and health risk.

Obtaining estimates of equations (5.1) and (5.2) would serve several purposes. First, the effects of expected health and health risk on consumption could be derived. It was discussed in Chapter 3 that these effects can not be signed a priori. It is important that these effects be identified to develop effective health and nutrition policies in developing countries. Second, the demand equations are sufficiently general that estimates of the price and expenditure elasticities of demand can also be obtained from (5.1) and (5.2). These elasticities are also important for policy purposes. Finally, estimates of the α coefficients in (5.1) and (5.2) would reveal how expected health and health risk affect expected utility.

However, estimating (5.1) and (5.2) is a nontrivial procedure because the equations are nonlinear. Unlike linear estimation, it can be difficult to obtain a least squares solution for nonlinear equations. Furthermore, the likelihood of successful estimation declines when the equations contain a large number of parameters as in (5.1) and (5.2) (Bates and Watts, 1988). A major factor affecting the probability of success is the use of good starting values for the chosen optimization routine. In this case the example expected utility functions from Chapter 3 provide good starting values for the α parameters.

The Data

The data used to estimate nonlinear demand equations (5.1) and (5.2) are from a sample of households in Lima, Peru's bottom expenditure quartile. Chapter 4 explained how estimates of expected health $\bar{H}$ and health risk θ were obtained for each household by estimating a heteroscedastic health function. In the data from Lima $\bar{H}$ measures the household's expected days healthy per month per person and θ is the standard deviation of the household's days healthy per month per person.

Table 5.1. Composition of total expenditures in Lima's bottom expenditure quartile.

	Mean	Std. Dev.
Food:		
Bread and cereals	0.18	0.07
Meats	0.10	0.07
Fish and seafood	0.01	0.02
Dairy products and eggs	0.07	0.05
Vegetables	0.04	0.03
Fruits	0.03	0.02
Beans and legumes	0.02	0.02
Tubers	0.05	0.03
Coffee and tea	0.01	0.02
Grease and oils	0.03	0.02
Sugar	0.02	0.02
Miscellaneous	0.05	0.05
Food away from home	0.04	0.07
Total Food	0.66	0.13
Nonfood: [a]		
Clothing	0.05	0.06
Utilities	0.07	0.04
Household equipment	0.01	0.04
Transportation services	0.002	0.01
Vehicle fuel	0.07	0.06
Telephone and communications	0.002	0.01
Cultural services: education, entertainment, etc.	0.13	0.13
Total Nonfood	0.34	0.13

a = Housing expense data were sporadic and are not included.

Table 5.2. Summary of variables included in the food and nonfood demand equations (5.1) and (5.2).

Variable	Symbol	Mean	Std.Dev.	Description
Household size	N	6.7	2.8	Total number of household members.
Price of Food	P_F	1.30	0.21	Price index of all food items (July 1985=1)
Price of Nonfood	P_C	1.21	0.13	Price index of all nonfood items (July 1985=1)
Expenditures	Y/N	262.1	75.3	Total per capita expenditures, in Intis.
Food consumption	F/N	132.4	39.8	Index of total food consumption per capita, equal to per capita food expenditures divided by P_F.
Nonfood consumption	C/N	73.8	36.8	Index of total nonfood consumption per capita, equal to per capita nonfood expenditures divided by P_C.
Expected health	$\bar{H}$	23.8	1.9	Estimate of the household's expected days healthy per month per person.
Health risk	θ	3.1	1.3	Estimated standard deviation of the household's days healthy per month per person.

The remaining variables needed to estimate equations (5.1) and (5.2) are price and consumption indices for food and nonfood. The procedure for computing price indices P_F and P_C is identical to that used for several food commodities in Chapter 4. In summary, P_F and P_C are computed using Fisher's ideal formula (Allen, 1975) and published monthly price indices for food and nonfood commodities in Lima (INEI, 1994). Expenditure shares for all commodities in P_F and P_C are shown in Table 5.1. Indices of total household consumption for food and nonfood were then obtained by dividing household expenditures on each category by the corresponding price index. Finally, total household expenditures and the consumption indices were divided by household size to facilitate per capita demand estimation. Descriptions and summary statistics for all variables in the demand equations are given in Table 5.2.

Nonlinear Demand Estimates

Because of adding up in the budget constraint only the food demand equation (5.2) is estimated. In general, a single equation should be omitted from demand system estimates to prevent a singular covariance matrix across equations (Greene, 1993, p.499). The underlying expected utility function for the food demand equation (Chapter 3) is sufficiently general that two restrictions can be imposed on its scale and slope to reduce the number of estimated parameters. In effect, this amounts to a normalization of (5.2) since it is homogeneous of degree zero in the α parameters.

The scale and slope of the expected utility function are set at the sample means by substituting for α_F and α_C in the food demand equation. The Lagrange multiplier λ in optimization problem (3.8) is equal to the marginal expected utility of total expenditures (see Silberberg, 1990, p. 204-7). Hence, λ identifies the slope of the expected utility function. The formula for λ is obtained by solving first-order conditions (3.9)

$$\begin{aligned}\lambda=(&-P_F\alpha_{FC}\alpha_C-\alpha_{FC}^2Y+P_F\alpha_F\alpha_{CC}-\alpha_{FC}P_C\alpha_{0F}\theta-P_F\alpha_{FC}\alpha_{\theta C}\theta\\&-P_F\alpha_{FC}\alpha_{CH}\bar{H}-\alpha_{FC}P_C\alpha_{FH}\bar{H}-\alpha_{FC}P_C\alpha_F+\alpha_{FF}P_C\alpha_C+\alpha_{FF}P_C\alpha_{\theta C}\theta\\&+\alpha_{FF}P_C\alpha_{CH}\bar{H}+\alpha_{FF}Y\alpha_{CC}+P_F\alpha_{0F}\theta\alpha_{CC}+P_F\alpha_{FH}\bar{H}\alpha_{CC})/\\&(P_F^2\alpha_{CC}-2P_F\alpha_{FC}P_C+\alpha_{FF}P_C^2)\end{aligned} \tag{5.3}$$

Furthermore, recall that the expected utility function is

$$\begin{aligned}\bar{U}(F,C,\bar{H},\theta)=&\alpha_0+\alpha_FF+\alpha_CC+\alpha_H\bar{H}+\alpha_0\theta+\frac{\alpha_{FF}}{2}F^2+\frac{\alpha_{CC}}{2}C^2+\frac{\alpha_{HH}}{2}\bar{H}^2+\frac{\alpha_{\theta\theta}}{2}\theta^2\\&+\alpha_{FC}FC+\alpha_{FH}F\bar{H}+\alpha_{CH}C\bar{H}+\alpha_{\theta H}\theta\bar{H}+\alpha_{\theta F}\theta F+\alpha_{\theta C}\theta C\end{aligned} \tag{5.4}$$

The scale and slope of (5.4) is restricted by jointly solving for α_F and α_C in equations (5.3) and (5.4). The values for $\bar{U}$ and λ at the sample means are the mean of total expenditures per capita and one, respectively. These values are then substituted into the expressions for α_F and α_C, along with the sample means of all variables contained in (5.3) and (5.4). The resulting expressions for α_F and α_C are then substituted into the food demand equation (5.2).[14]

The resulting parameter estimates for equation (5.2) obtained from nonlinear least squares are shown in Table 5.3. Unfortunately, none of the estimated parameters are significantly different from zero at conventional significance levels according to their asymptotic t-values. Caution should be used, however, when interpreting the t-values because they are only asymptotically correct and the sample size is only 242 households. Another problem with the parameter estimates is that the signs of α_{FH} and α_{CH} differ from their predicted signs (Chapter 3).

It should also be mentioned that several of the estimated parameters are highly correlated. Table 5.4 indicates extremely high correlation among parameter pairs $(\alpha_{FF},\alpha_{FC})$, $(\alpha_{F\bar{H}},\alpha_{C\bar{H}})$, and $(\alpha_{0F},\alpha_{0C})$. Correlation coefficients above 0.99 can sometimes indicate overparameterization (Bates and Watts, 1988). However, Draper and Smith (1981) point out that highly correlated parameters do not necessarily imply an incorrectly specified model. They may simply indicate that the data are incapable of estimating all unknown parameters. A possible cause for the correlated parameters in equation (5.2) is that P_F and P_C mainly reflect seasonal variation and show little movement in the data

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[14] Parameters in the expected utility function (5.4) that do not appear in the demand equation are assigned values from Example 3's expected utility function in Table 3.3: $\alpha_{\bar{H}}=0.26$, $\alpha_0=4.65$, $\alpha_{\bar{H}\bar{H}}=-0.03$, $\alpha_{00}=-0.74$, and $\alpha_{0\bar{H}}=0.07$.

(Table 5.2). Another possibility is that P_F and P_C are highly correlated (correlation coefficient=0.96).

The estimates in Table 5.3 are actual parameters from the expected utility function. It is also useful to examine the estimated effects of prices, total expenditures, expected health, and health risk on food demand. The effects of P_F, P_C, Y, $\bar{H}$, and θ on food demand are computed by substituting parameter estimates from Table 5.3 into demand equation (5.2) and differentiating with respect to each variable. The asymptotic standard

Table 5.3. Parameter estimates for food demand equation (5.2).

Dependent variable: Per capita food consumption.

Parameter	Estimate Asymptotic t-ratio	
α_{FF}	-0.006	(-1.21)
α_{CC}	-0.010	(-1.24)
α_{FC}	0.009	(1.44)
$\alpha_{F\bar{H}}$	-1.344	(-1.14)
$\alpha_{C\bar{H}}$	-1.218	(-1.12)
$\alpha_{\theta F}$	-0.571	(-0.59)
$\alpha_{\theta C}$	-0.627	(-0.66)

sample size=242.
Numbers in parentheses are asymptotic t-ratios.

Table 5.4. Asymptotic correlation matrix of estimated parameters in Table 5.3.

	α_{FF}	α_{CC}	α_{FC}	$\alpha_{C\bar{H}}$	$\alpha_{F\bar{H}}$	$\alpha_{\theta F}$	$\alpha_{\theta C}$
α_{FF}	1.0						
α_{CC}	0.93	1.0					
α_{FC}	-0.991	-0.97	1.0				
$\alpha_{C\bar{H}}$	0.84	0.84	-0.86	1.0			
$\alpha_{F\bar{H}}$	0.85	0.85	-0.87	0.999	1.0		
$\alpha_{\theta F}$	0.39	0.40	-0.40	0.57	0.57	1.0	
$\alpha_{\theta C}$	0.46	0.46	-0.47	0.63	0.62	0.996	1.0

errors and t-values for these derivatives can also be computed from the variance and covariance of all α parameters (see Kmenta, 1971, p. 443-4). The effects of prices, total expenditures, and health on food demand are shown in Table 5.5.

Table 5.5 reveals that equation (5.2) provides a reasonable estimate of food demand. In particular, the effects of own-price and total expenditures are highly significant. The effects of health risk (θ) are reasonably strong although not significantly different from zero at the 5 percent level. It is also useful to calculate demand elasticities for the derivatives in Table 5.5. These are shown in Table 5.6. The demand elasticities for nonfood were also derived by substituting the parameter values from Table 5.3 into equation (5.1) and differentiating. The price and expenditure elasticities are similar to

Table 5.5. Impacts of price, total expenditures, expected health, and health risk in the estimated food demand equation. Computed from equation (5.2) and Table 5.3 at the sample means.

Effect	Estimate	Asymptotic t-ratio
$\partial F/\partial P_F$	-85.62	(-4.36)*
$\partial F/\partial P_C$	-4.18	(-0.20)
$\partial F/\partial Y$	0.44	(16.04)*
$\partial F/\partial \bar{H}$	-1.22	(-1.09)
$\partial F/\partial \theta$	2.62	(1.53)

sample size=242.
Numbers in parentheses are asymptotic t-ratios.
* = significantly different from zero at the 5 percent level.

previous studies of low-income households in developing countries (e.g., Timmer and Alderman, 1979). The demand elasticities with respect to expected health and health risk are relatively small.

The estimated effects of expected health and health risk can be interpreted in light of the theory in Chapter 3. Recall that parameters $\alpha_{i\bar{H}}$ and $\alpha_{\theta i}$, i=F,C, measure the cross-effects of expected health and health risk on the marginal expected utilities of food and nonfood. Only when $\alpha_{F\bar{H}}$ is substantially different from $\alpha_{C\bar{H}}$ is there a nonzero effect of expected health on food consumption. Similarly, the effects of health risk on food consumption depend on the relative size of $\alpha_{\theta F}$ and $\alpha_{\theta C}$. From the significance tests in

Table 5.6. Food and nonfood elasticities of demand for changes in price, total expenditures, expected health, and health risk. Calculated at the sample means from Table 5.3 and equations (5.1) and (5.2).

Elasticity	Estimate	Description
ϵ_{FY}	0.88	Expenditure elasticity of demand for food.
ϵ_{CY}	1.23	Expenditure elasticity of demand for nonfood.
ϵ_{FF}	-0.84	Own-price elasticity of demand for food.
ϵ_{FC}	-0.04	Food demand elasticity for changes in the price of nonfood.
ϵ_{CC}	-0.93	Own-price elasticity of demand for nonfood.
ϵ_{CF}	-0.30	Nonfood demand elasticity for changes in the price of food.
$\epsilon_{F\bar{H}}$	-0.22[a]	Food demand elasticity for changes in expected health.
$\epsilon_{C\bar{H}}$	0.42[a]	Nonfood demand elasticity for changes in expected health.
$\epsilon_{F\theta}$	0.06[a]	Food demand elasticity for changes in health risk
$\epsilon_{C\theta}$	-0.12[a]	Nonfood demand elasticity for changes in health risk.

a = effect not significantly different from zero at the 5 percent level.

Table 5.5 it can be concluded that none of these cross-effects are substantially different for low-income households in Lima. Nonetheless, the t-ratios in Table 5.5 are only asymptotically correct and the sample size is 242 households. Thus, it is worthwhile to further investigate the effects of expected health and health risk on food consumption. This is especially true given the moderately sized t-value on health risk.

Extension to Multiple Commodity Estimation

An additional topic to explore is the effect of expected health and health risk on the demand for multiple food commodities. This topic is important for two reasons. First, even though the above estimates show only moderate impacts of expected health and health risk on total food demand it is unclear whether there are possible effects on individual food commodities. For example, if expected health or health risk cause the demand for one food commodity to increase and another to decrease this would not be evident in the total food demand equation. Second, if there are significant effects of expected health and health risk on individual food commodities there may be implications for health and nutrition policies.

However, a problem exists when the nonlinear demand system is expanded to include multiple food commodities. It is easy to extend expected utility function (5.4) to contain a moderate number of consumption goods. Unfortunately, the number of parameters in the demand equations grows geometrically as commodities are added. This greatly reduces the probability of obtaining a least squares solution for the demand estimates. Table 5.7 illustrates how the number of parameters grows in the demand equations as commodities are added to the expected utility function.

Table 5.7. Illustration of the number of parameters in a multiple good system based on expected utility function (5.4).

Commodities parameters[a]	Parameters per commodity	Estimated	Estimated parameters
2	9	7	3.5
3	15	13	4.3
4	22	20	5.0
5	30	28	5.6

a = Actual number of estimated parameters after imposing restrictions on the scale and slope of the expected utility function.

Table 5.7 suggests that an alternative method be used to estimate the effects of expected health and health risk on the demand for multiple food commodities. A logical alternative is to estimate linear approximations to the nonlinear demand equations. This issue is addressed in the next chapter.

Summary

This chapter estimates a food demand equation that depends on expected health and health risk. The equation is a nonlinear specification derived from the expected utility model in Chapter 3. The equation is estimated using data from low-income households from Lima, Peru. The estimated demand equation shows strong effects of own-price and total expenditures. In addition, the corresponding demand elasticities are consistent with previous studies. However, the parameter estimates in the expected utility function are not as strong. In particular, significance levels are not high and several of the parameters are highly correlated.

The effects of expected health and health risk on aggregate food consumption are moderately strong, although neither effect is different from zero at conventional significance levels. It is not clear whether a lack of significance in the underlying parameter estimates causes this result. Nor can it be determined from the total food demand equation if expected health and health risk affect the demand for specific food commodities. The nonlinear demand equations are not practical to answer this question because of the large number of parameters in a multiple good demand system.

CHAPTER 6: LINEAR ESTIMATES OF THE IMPACT OF EXPECTED HEALTH AND HEALTH RISK ON FOOD DEMAND

A logical alternative to the nonlinear equations in Chapter 5 is to estimate linear approximations to the demand equations. Linear demand equations have several advantages. For instance, a least squares solution is guaranteed with linear estimation. In addition, variables can easily be added to account for household composition effects on food demand. Finally, linear equations facilitate estimation of demand equations for multiple food commodities. Another advantage of estimating linear approximations is that while parameters in the expected utility function remain unknown, the estimating equations can test the effects of expected health and health risk on consumption regardless of whether the exogenous model (equations (3.14) and (3.15)) or the endogenous model (equations (3.21) and (3.22)) are correct.

The first section of the chapter develops the linear approximation to the total food demand equation. The next two sections present the data and estimation results for this equation. In the fourth section the linear demand equation is modified to permit estimation of a demand system containing six food commodities and nonfood. The next two sections present the data and estimation results for this system. The last section discusses the estimation results.

Specification of the Linear Demand Equation

The nonlinear food demand equation in Chapter 5 has the general form $F=F(Y,P_F,P_C,\bar{H},\theta)$ where F is household food demand, P_i is the price of good i, Y is total household expenditures, $\bar{H}$ is expected days healthy per month per person, and θ is the standard deviation of days healthy per month per person. To obtain a good linear approximation for $F=F(Y,P_F,P_C,\bar{H},\theta)$ the specific functional form should have desirable econometric properties.

One major consideration is whether the demand equation is specified on a per capita or per household basis. The econometric implications of each specification are seen from a simple aggregation problem. Suppose that the kth person's demand for food within the household is

$$f_k=\pi_{k1}+\pi_{k2}\left(\frac{P_F}{P_C}\right)+\pi_{k3}\left(\frac{y_k}{P_C}\right)+\pi_{k4}\bar{d}_k+\pi_{k5}\psi_k+\eta_k \tag{6.1}$$

where P_F is the price of food, P_C is the price of nonfood, y_k is the kth person's total expenditures, $\bar{d}_k$ is the kth person's expected days healthy per month, ψ_k is the standard deviation of the kth person's days ill per month, and η_k is a stochastic disturbance term. Assume that the marginal effects of price, expenditures, and health on consumption are identical for all individuals: $\pi_{k2}=\pi_2$, $\pi_{k3}=\pi_3$, $\pi_{k4}=\pi_4$, and $\pi_{k5}=\pi_5$ $\forall$k.

Aggregating over k household members, k=1,...,N, yields the household's food demand equation

$$F=\sum_{k=1}^{N}\pi_{k1}+N\pi_2\left(\frac{P_F}{P_C}\right)+\pi_3\left(\frac{\sum_{k=1}^{N}y_k}{P_C}\right)+\pi_4\sum_{k=1}^{N}\bar{d}_k+\pi_5\sum_{k=1}^{N}\psi_k+\sum_{k=1}^{N}\eta_k \tag{6.2}$$

where $F=\sum_k f_k$. A useful assumption for estimating (6.2) is that π_{k1} is identical for individuals with similar demographic traits. Thus, if the gth demographic group has N_g members ($\sum_g N_g = N$), $g=1,\ldots,m$, equation (6.2) can be written

$$F=\sum_{g=1}^{m} \pi_{g1} N_g + \pi_2^{*}\left(\frac{P_F}{P_C}\right) + \pi_3\left(\frac{Y}{P_C}\right) + \pi_4 \bar{D} + \pi_5 \sum_{k=1}^{N} \psi_k + \mu \qquad \textbf{(6.3)}$$

where $Y=\sum_k y_k$, $\pi_2^{*}=N\pi_2$, $\bar{D}=\sum_k \bar{d}_k$, and $\mu=\sum_k \eta_k$.

There are two potential problems in the estimation of equation (6.3). First, the variance of μ is heteroscedastic because it depends on total household size. Second, the marginal impact of price on total consumption ($\pi_2^{*}=N\pi_2$) also depends on household size. However, both of these problems are eliminated by converting (6.3) to per capita demand. First divide both sides of (6.3) by N

$$\frac{F}{N}=\sum_{g=1}^{m} \pi_{g1} n_g + \pi_2\left(\frac{P_F}{P_C}\right) + \pi_3\left(\frac{(Y/N)}{P_C}\right) + \pi_4\left(\frac{\bar{D}}{N}\right) + \pi_5 \Lambda + \left(\frac{\mu}{N}\right) \qquad \textbf{(6.4)}$$

where $n_g = N_g/N$ ($\sum_g n_g = 1$), and $\Lambda=\sum_k \psi_k/N$. The disturbance term in (6.4) is now homoscedastic and the marginal impact of price on consumption is independent of N.

Note that $\bar{D}/N$ equals $\bar{H}$, the household's expected days healthy per month per person. Variable Λ denotes the average standard deviation of days healthy per month for all household members. Although this is not identical to variable θ, the standard deviation of the household's days healthy per month per person, it is reasonable to use θ in place of

Λ for estimation purposes.[15] Furthermore, it can be shown that θ and Λ respond similarly to changes in health inputs or household composition.

Equation (6.4) also suggests a convenient approach to measure the effects of household composition on food demand. The demographic variables n_g represent the proportion of the household in demographic group g and coefficient π_{g1} is the intercept in the demand equation of the gth group. Equation (6.4) can also be rewritten by substituting $n_m = 1-(n_1+n_2+,\ldots,+n_{m-1})$ and rearranging

$$\frac{F}{N}=\pi_{m1}+\sum_{g=1}^{m-1}(\pi_{g1}-\pi_{m1})n_g+\pi_2\left(\frac{P_F}{P_C}\right)+\pi_3\left(\frac{(Y/N)}{P_C}\right)+\pi_4\bar{H}+\pi_5\theta+\left(\frac{\mu}{N}\right) \qquad \textbf{(6.5)}$$

or

$$\frac{F}{N}=\phi_m+\sum_{g=1}^{m-1}\phi_{g1}n_g+\phi_2\left(\frac{P_F}{P_C}\right)+\phi_3\left(\frac{(Y/N)}{P_C}\right)+\phi_4\bar{H}+\phi_5\theta+\xi \qquad \textbf{(6.6)}$$

Hence, the constant in (6.6), $\phi_m=\pi_{m1}$, measures the intercept of the mth (reference) group's demand equation. Coefficient ϕ_{g1} measures the difference in the intercepts for the gth and the mth groups, $\phi_{g1}=\pi_{g1}-\pi_{m1}$. Equation (6.6) is also homogeneous of degree zero in prices and expenditures.

Preliminary estimates of (6.3) and (6.6) showed a similar impact of the gth group's size on total household consumption ($\partial F/\partial N_g$). However, the per household equation was

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[15] There was insufficient data to estimate individual health functions, which would be needed to obtain Λ.

heteroscedastic as expected. Thus, the per capita specification is preferred because it is homoscedastic and did not impose a price response that is independent of family size.

Data Used for Food Demand Estimation

The data used for linear estimation of food demand equation (6.6) are the same used to estimate the nonlinear food demand equation in Chapter 5. All variables are defined as before with several exceptions. Proportional demographic variables are added according to the specification in (6.6). In addition, prices and total expenditures are divided by the nonfood price. A summary of all variables used to estimate equation (6.6) is presented in Table 6.1.

Estimated Food Demand Equation

An estimate of the linear food demand equation (6.6) is presented in Table 6.2. The estimate yields highly significant effects for the relative price of food and total expenditures. Health risk has a significant positive impact on food demand while expected health has no significant effect. There are also significant effects of household composition, namely that teenage males and adult females consume less food than adult males.[16]

The corresponding demand elasticities for food and nonfood are reported in Table 6.3. The demand elasticities for nonfood are recovered from adding up and homogeneity

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[16] Obviously, children also consume less food than adult males. The wide range of items included in the food consumption index likely disguise this effect.

Table 6.1. Variables used for estimation of linear food demand equation (6.6).

Variable	Symbol	Mean	Std.Dev.	Description
Relative price of food	P_F/P_C	1.06	0.07	Price index of food over price index of nonfood (July 1985=1)
Real expenditures	$(Y/N)/P_C$	213.9	52.7	Total per capita expenditures, in Intis, divided by the price of nonfood.
Food consumption	F/N	132.4	39.8	Index of food consumption per capita. Obtained from per capita food expenditures divided by P_F.
Expected health	$\bar{H}$	23.8	1.9	Estimate of the household's expected days healthy per month per person.
Health risk	θ	3.1	1.3	Estimated standard deviation of the household's days healthy per month per person.
Household Composition:				
Children under 3	n_1	0.11	0.13	Proportion of household under age 3.
Children 3 to 10	n_2	0.21	0.18	Proportion of household between age 3 and 10.
Male 10 to 18	n_3	0.08	0.12	Proportion of household that is male and between 10 and 18.
Female 10 to 18	n_4	0.09	0.12	Proportion of household that is female and between 10 and 18.
Male 18 to 60	n_5	0.24	0.12	Proportion of household that is male and between 18 and 60.
Female 18 to 60	n_6	0.22	0.11	Proportion of household that is female and between 18 and 60.
Male over 60	n_7	0.03	0.09	Proportion of household that is male and over 60.
Female over 60	n_8	0.02	0.07	Proportion of household that is female and over 60.

Table 6.2. Estimates of the linear food demand equation (6.6).

Dependent variable: Per capita food consumption.

Variable	Estimated Coefficient	t-ratio
Relative price of food	-88.28	-3.49*
Real expenditures per capita	0.54	15.69*
Expected health	0.19	0.14
Health risk	4.67	2.37*
Household Composition: [a]		
Under 3	20.46	0.86
Between 3 and 10	0.12	0.01
Male 10 to 18	-45.27	-2.10*
Female 10 to 18	-24.47	-1.19
Female 18 to 60	-58.35	-2.07*
Male over 60	-2.95	-0.10
Female over 60	-19.30	-0.45
Constant	109.01	2.09*
R^2	0.57	

sample size=242.
* = significantly different from zero at the 5 percent level.
a = Males 18 to 60 are the "base" group.

adding up: $s_F\epsilon_{FY}+s_C\epsilon_{CY}=1,\ s_F\epsilon_{FC}+s_C\epsilon_{CC}+s_C=0,\ s_F\epsilon_{F\bar{H}}+s_C\epsilon_{C\bar{H}}=0,\ s_F\epsilon_{F\theta}+s_C\epsilon_{C\theta}=0$

homogeneity: $\epsilon_{FF}+\epsilon_{FC}+\epsilon_{FY}=0,\ \epsilon_{CC}+\epsilon_{CF}+\epsilon_{CY}=0$

where s_i is the expenditure share for good i, ϵ_{iY} is good i's expenditure elasticity of demand, $\epsilon_{i\bar{H}}$ is good i's demand elasticity with respect to $\bar{H}$, $\epsilon_{i\theta}$ is good i's demand elasticity with respect to θ, and ϵ_{ij} is good i's demand elasticity with respect to P_j. The price and expenditure elasticities of demand are reasonable for low-income households in developing countries. Note that the effects of health risk on consumption are small in elasticity terms.

Table 6.3. Food and nonfood demand elasticities with respect to prices, expenditures, expected health, and health risk, calculated at the sample means from Table 6.2.

Elasticity	Estimate	Description
ϵ_{FY}	0.87	Expenditure elasticity of demand for food.
ϵ_{CY}	1.25	Expenditure elasticity of demand for nonfood.
ϵ_{FF}	-0.71	Own-price elasticity of demand for food.
ϵ_{FC}	-0.16	Food demand elasticity for changes in the price of nonfood.
ϵ_{CC}	-0.69	Own-price elasticity of demand for nonfood.
ϵ_{CF}	-0.56	Nonfood elasticity of demand for changes in the price of food.
$\epsilon_{F\bar{H}}$	0.03[a]	Food demand elasticity for changes in expected health.
$\epsilon_{C\bar{H}}$	-0.06[a]	Nonfood demand elasticity for changes in expected health.
$\epsilon_{F\theta}$	0.11	Food demand elasticity for changes in health risk.
$\epsilon_{C\theta}$	-0.21	Nonfood demand elasticity for changes in health risk.

a=Effect not significant in Table 6.2.

In general, the linear estimate of the food demand equation is consistent with the nonlinear estimate in Chapter 5. The price and expenditure effects have similar demand elasticities and significance levels. One difference between the linear and nonlinear estimates is that the linear estimate shows a significant impact of health risk on food consumption while the nonlinear estimate does not, although its t-value is moderate ($t=1.56$). One possible reason for the differing test results on health risk is that the nonlinear t-values are only asymptotically correct.

Extending the Model to a Multiple Good System

From the previous section it is clear that linear equation (6.6) provides a good approximation to the food demand equation. It is reasonable to use the same equation to estimate the effects of expected health and health risk on the demand for multiple food commodities. Including r goods in the expected utility function yields demand equations of the form $X_i=X_i(Y,\mathbf{P},\bar{H},\theta)$ where X_i is the demand for good i, $i=1,\ldots,r$, $\mathbf{P}$ is a vector of all prices, and all other variables are defined as before. Equation (6.6) can easily be modified to approximate $X_i=X_i(Y,\mathbf{P},\bar{H},\theta)$ by including all cross-price effects

$$\frac{X_i}{N}=\phi_m+\sum_{g=1}^{m-1}\phi_{gi}n_g+\sum_{j=1}^{r-1}\phi_{2j}\left(\frac{P_j}{P_r}\right)+\phi_3\left(\frac{(Y/N)}{P_r}\right)+\phi_4\bar{H}+\phi_5\theta+\xi \qquad \textbf{(6.8)}$$

Dividing all demand equations by the price of a numeraire good P_r ensures that (6.8) is homogeneous of degree zero in prices and total expenditures.

Data Used for Multiple Food Demand Estimation

The only modification of the data needed for multiple commodity estimation is to separate the total food index into several commodity groups. The classification used here is the same as in the estimated health function in Chapter 4: cereals and bread; meats and fish; dairy products and eggs; vegetables, fruits, and legumes; tubers; and other foods. All nonfood consumption is maintained as a single category. Expenditure shares on these categories for the sample households from Lima are given in Table 6.4. Computation of the corresponding price and quantity indices is explained in Chapter 4.

Table 6.4. Composition of total household expenditures in Lima's lowest expenditure quartile.

	Share of Total Expenditures	
Item	Mean	Std. Dev.
Food:		
Cereals and bread	0.18	0.07
Meats and fish	0.12	0.07
Dairy products and eggs	0.07	0.05
Vegetables, fruits, and legumes	0.08	0.05
Tubers	0.05	0.03
Other foods	0.16	0.08
Nonfood:	0.34	0.13

The price of cereals is used as the numeraire price (P_r) in the linear demand equations (6.8). The use of cereals as the numeraire price is appealing for several reasons. First, cereals comprise the largest budget share of any food item. Second, when expenditures are divided by the price of cereals it implies that real expenditures are measured in cereal units. Given the importance of cereals in the diet this is an appealing specification. Finally, when prices are specified relative to cereals it implies that households measure all price changes relative to the price of the staple food item. Table 6.5 describes all new variables included in the multiple food demand estimates.

Estimation Results

Demand equations for the six food commodities and nonfood are estimated as a system of seemingly unrelated regressions (see Zellner, 1962) using equation (6.8) for all commodities. Because of the adding up condition it is necessary to omit one of the equations from the system. In some demand systems the same equation as the numeraire good is omitted (e.g., Deaton and Muellbauer, 1980) but in this case the numeraire good, cereals, is also the staple food item. It is more appealing to omit a commodity like other food which is not of interest in this study. Omitting the other food equation implies that the cereals equation has the following form

Table 6.5. Additional variables included in the linear demand equations (6.8).

Variable	Symbol	Mean	Std.Dev.	Description
Per capita consumption:				
Meat	X_1/N	23.9	15.8	Per capita consumption of meat and fish (index).
Dairy	X_2/N	14.8	10.4	Per capita consumption of dairy products and eggs (index).
Cereal	X_3/N	37.7	12.3	Per capita consumption of cereals (index).
Vegetables	X_4/N	15.1	8.7	Per capita consumption of vegetables, fruits, and legumes (index).
Tubers	X_5/N	7.6	5.5	Per capita consumption of tubers (index).
Other Food	X_6/N	34.9	21.4	Per capita consumption of all other food items (index).
Non Food	X_7/N	73.8	36.8	Per consumption of nonfood items (index).
Relative Prices:				
Meat	P_1/P_3	1.18	0.18	Meat price divided by the cereals price (July 1985=1).
Dairy	P_2/P_3	1.06	0.07	Dairy price divided by the cereals price (July 1985=1).
Vegetables	P_4/P_3	1.32	0.38	Vegetable price divided by the cereals price (July 1985=1).
Tubers	P_5/P_3	1.46	0.38	Tuber price divided by the cereals price (July 1985=1).
Other Food	P_6/P_3	1.01	0.07	Price of other food divided by the cereals price (July 1985=1).
Nonfood	P_7/P_3	1.05	0.05	Price of non food items divided by price of cereals (July 1985=1).
Real Expenditures per capita				
	$(Y/N)/P_3$	224.4	58.4	Per capita monthly expenditures (in intis) divided by the price of cereals.

$$\frac{X_3}{N} = \phi_m + \sum_{g=1}^{m-1} \phi_{gj} n_g + \sum_{j=1}^{7} \phi_{2j}\left(\frac{P_j}{P_3}\right) + \phi_3\left(\frac{(Y/N)}{P_3}\right) + \phi_4 \bar{H} + \phi_5 \theta + \xi; \quad \phi_{23} = 0 \qquad \mathbf{(6.9)}$$

where subscript 3 denotes cereals.

Preliminary estimates of the complete demand system showed nonsensical price effects. In particular, several of the commodities showed own-price effects that were positive. The most likely causes of this result are a lack of variation and high correlation for several relative prices (Tables 6.5 and 6.6, respectively). To alleviate this problem all relative prices are omitted from each equation except for the own-price of each commodity. For the cereals equation the relative price of vegetables (P_4/P_3) is the only relative price included. The resulting estimate of the complete demand system is shown in Table 6.7.

Table 6.6. Estimated correlation coefficients for the relative prices in the demand equations (using cereals as the numeraire).

	Vegetables	Meat	Dairy	Tubers	Other Food	Nonfood
Vegetables	1.0					
Meat	0.89	1.0				
Dairy	0.97	0.88	1.0			
Tubers	0.83	0.96	0.83	1.0		
Other Food	0.95	0.89	0.93	0.80	1.0	
Nonfood	0.97	0.82	0.91	0.73	0.90	1.0

Table 6.7. System estimation of the food and nonfood demand equations (other food is the omitted equation).

Per capita consumption of:

Variable	Meat	Dairy	Cereals	Vegs.	Tubers	Nonfood
Relative-Price: [a]						
	-27.92	-22.98	-6.34	-5.67	-4.60	-50.78
	(-5.54)*	(-2.62)*	(-2.91)*	(-3.78)*	(-4.79)*	(-1.47)
Expenditures	0.14	0.07	0.08	0.06	0.01	0.40
per capita	(8.55)*	(6.76)*	(5.88)*	(6.14)*	(1.92)	(11.79)*
Health:						
Expected	-0.25	-0.53	1.42	0.61	0.17	-0.38
Health	(-0.33)	(-1.10)	(2.28)*	(1.41)	(0.60)	(-0.25)
Health risk	-1.50	0.46	1.69	0.76	0.01	-4.08
	(-1.48)	(0.69)	(1.99)*	(1.30)	(0.02)	(-2.01)*
Household Composition: [b]						
Under 3	6.06	11.34	9.38	8.00	3.71	-30.26
	(0.50)	(1.44)	(0.92)	(1.13)	(0.77)	(-1.24)
Between	-9.29	-3.71	3.66	6.50	2.41	-7.92
3 and 10	(-0.98)	(-0.61)	(0.46)	(1.19)	(0.65)	(-0.42)
Male	-10.82	-9.91	6.24	-4.21	-3.27	34.46
10 and 18	(-0.97)	(-1.37)	(0.67)	(-0.65)	(-0.75)	(1.54)
Female between	-6.85	-9.54	1.75	-2.92	2.52	17.45
10 and 18	(-0.64)	(-1.38)	(0.20)	(-0.47)	(0.61)	(0.81)

sample size = 242. Numbers in parentheses are t-ratios.

* = significantly different from zero at the 5 percent level.

a = all relative prices are the own-price of the commodity over the price of cereals except in the cereals equation where the vegetable price relative to cereals is used (P_4/P_3).

b = Male between 18 and 60 is the "base" demographic group and is omitted

Table 6.7. (continued)

Female between	-9.76	-6.94	-4.37	5.67	-0.16	46.25
18 and 60	(-0.67)	(-0.74)	(-0.36)	(0.68)	(-0.03)	(1.59)
Male over 60	14.82	-0.14	-2.20	-10.53	-1.33	-3.84
	(0.93)	(-0.01)	(-0.16)	(-1.13)	(-0.21)	(-0.12)
Female	-44.47	7.93	0.12	2.46	8.27	9.19
over 60	(-2.02)*	(0.56)	(0.01)	(0.19)	(0.96)	(0.21)
Constant	41.15	36.39	-13.30	-10.42	6.45	49.57
	(1.72)	(2.04)*	(-0.67)	(-0.76)	(0.70)	(0.86)
R^2	0.27	0.29	0.15	0.20	0.09	0.45

The results of the estimated demand system are generally quite strong and consistent with expectations. In particular, price and expenditure effects are highly significant and show the correct sign. Expected health and health risk also show significant effects for several commodities. Some of the equations show an impact of household composition on consumption, although most of the estimated coefficients are insignificant. The strongest demographic effect is in the meat equation where consumption by elderly females is significantly less than adult males. In the dairy equation consumption by infants is large and consumption by teenagers is small relative to adult males. Nonfood items show relatively high consumption for teenage males and adult females. No major demographic effects are seen in the demand equations for cereals, vegetables, and tubers.

To clarify the effects of expected health and health risk on consumption several statistical tests are calculated for the system. A joint test for the null hypothesis that expected health and health risk do not affect consumption is rejected at the 5 percent level

($F_{12,1380}=2.10$). A joint test for the null hypotheses that health risk has no impact on consumption is also rejected at the 5 percent level ($F_{6,1380}=2.44$). However, a similar test for expected health can not be rejected ($F_{6,1380}=1.56$). This is surprising given the large t-value on expected health in the cereals equation ($t=2.28$).

Additional significance tests were calculated on the health variables in equations with low t-values. The goal of these tests is to isolate equations where expected health and health risk do not affect consumption. This step is critical for policy analysis in the next chapter mainly because it would be incorrect to construct health and nutrition policies based on an observed health effect even though the true effect on consumption may be zero.

Note that it is possible for expected health and health risk to affect only a subset of the demand equations and still be theoretically correct. To see this, differentiate the budget constraint with respect to expected health and health risk to obtain the following conditions

$$\sum_i s_i \epsilon_{i\bar{H}} = 0, \quad \sum_i s_i \epsilon_{i\theta} = 0 \qquad \textbf{(6.10)}$$

where s_i is the expenditure share for good i, ϵ_{iH} is demand elasticity for good i with respect to $\bar{H}$, and $\epsilon_{i\theta}$ is the demand elasticity for good i with respect to θ. Provided that both conditions in (6.10) are satisfied, it is possible that $\epsilon_{i\bar{H}}$ and $\epsilon_{i\theta}$ are zero for some goods and nonzero for others.

Also, recall that the demand equations in Table 6.7 are linear approximations to the nonlinear system from Chapter 3. It can be shown that when more than two demand equations are included in the system expected health and health risk can affect some commodities but not others and the adding up condition (6.10) still be satisfied.

A joint test is calculated for the significance of all health coefficients with low t-values in Table 6.7. For expected health the low t-values on meat, tubers, and nonfood suggest that expected health does not affect the demand for these commodities. Similarly, it is hypothesized that health risk does not affect the demand for dairy products and tubers. A joint test of the null hypotheses that all the above coefficients are zero can not be rejected at the 5 percent level ($F_{5,1380}=0.21$). The demand system is then estimated after these coefficients are restricted to zero. The revised estimation results are shown in Table 6.8.

Table 6.9 presents the demand elasticities at the sample means for the restricted estimates in Table 6.8. There are several points about the elasticities worth mentioning. First, the own-price and expenditure elasticities of demand are reasonable for low-income households in a developing country. The large expenditure elasticities for meats, dairy products, and nonfood suggest that these items are luxuries. Cereals and tubers are necessities because of their low expenditure elasticities. The own-price elasticities for meats and dairy products are quite high while all remaining items have own-price elasticities that are less than unity. Cross price elasticities are also presented for changes in

Table 6.8. System estimation of the food and nonfood demand equations, omitting unimportant health factors.

	Per capita consumption of:					
Variable	**Meat**	**Dairy**	**Cereals**	**Vegs.**	**Tubers**	**Nonfood**
Relative-Price: [a]						
	-28.12	-24.20	-6.31	-5.66	-4.52	-49.69
	(-5.60)*	(-2.81)*	(-2.91)*	(-3.78)*	(-4.81)*	(-1.44)
Expenditures	0.14	0.07	0.08	0.06	0.01	0.40
per capita	(8.63)*	(6.74)*	(5.88)*	(6.15)*	(1.93)	(11.91)*
Health:						
Expected		-0.67	1.28	0.53		
Health		(-1.64)	(2.31)*	(1.38)		
Health risk	-1.44		1.64	0.72		-3.63
	(-1.59)		(2.03)*	(1.28)		(-2.17)*
Household Composition: [b]						
Under 3	8.33	10.52	8.08	7.30	2.08	-27.24
	(0.81)	(1.37)	(0.82)	(1.11)	(0.52)	(-1.31)
Between	-10.62	-4.84	3.13	6.17	1.84	-6.11
3 and 10	(-0.96)	(-0.83)	(0.40)	(1.14)	(0.53)	(-0.34)
Male	-6.58	-10.01	6.13	-4.26	-3.40	34.72
10 and 18	(-0.63)	(-1.38)	(0.66)	(-0.66)	(-0.79)	(1.55)
Female between	-7.92	-10.84	1.55	-3.07	2.43	18.79
10 and 18	(-0.58)	(-1.64)	(0.17)	(-0.50)	(0.61)	(0.89)
Female between	-7.92	-6.84	-5.38	5.16	-1.55	47.99
18 and 60	(-0.58)	(-0.74)	(-0.45)	(0.62)	(-0.29)	(1.75)

sample size = 242. Numbers in parentheses are t-ratios.

* = significantly different from zero at the 5 percent level.

a = all relative prices are the own-price of the commodity over the price of cereals except in the cereals equation where the vegetable price relative to cereals is used (P_4/P_3).

b = Male between 18 and 60 is the "base" demographic group and is omitted.

Table 6.8. (continued)

Male over 60	15.85	1.14	-2.73	-10.75	-2.19	-3.86
	(1.00)	(0.11)	(-0.20)	(-1.16)	(-0.36)	(-0.12)
Female over 60	-41.63	6.33	-1.53	1.56	6.28	13.45
	(-2.05)*	(0.45)	(-0.08)	(0.12)	(0.79)	(0.33)
Constant	34.27	43.14	-9.12	-8.07	11.19	36.52
	(3.57)*	(2.99)*	(-0.51)	(-0.65)	(3.58)*	(1.01)
R^2	0.26	0.29	0.15	0.20	0.09	0.45

the price of cereals. These elasticities have a reasonable magnitude and show that with respect to cereals, vegetables and nonfood are (gross) complements while meats, dairy products, and tubers are (gross) substitutes.

The Effects of Expected Health and Health Risk

The demand elasticities with respect to expected health and health risk are the focal point of this chapter. Expected health has a positive effect on the demand for cereals and vegetables and a negative effect on the demand for dairy products. The magnitude of the expected health elasticities are all close to unity. On the other hand, the health risk elasticities range from 0 to 0.20 and are positive for cereals and vegetables and negative for meats and nonfood.

The estimated effects of expected health and health risk on the demand for multiple food commodities are consistent with the total food demand estimate earlier in the chapter.

Table 6.9. Demand elasticities with respect to own-price, cereals' price, total expenditures, expected health, and health risk.

	Per capita consumption of:					
Variable	**Meat**	**Dairy**	**Cereals**	**Vegs.**	**Tubers**	**NonFood**
Own-Price:	-1.39	-1.72	-0.26	-0.49	-0.87	-0.70
Cereals' price	0.09	0.66	-0.26	-0.40	0.59	-0.52
Expenditures per capita	1.32	1.10	0.50	0.89	0.36	1.21
Expected Health	NS	-1.08	0.81	0.83	NS	NS
Health risk	-0.19	NS	0.13	0.15	NS	-0.15

NS=not significantly different from zero.

Recall that expected health does not affect total food demand while health risk has a positive impact. The results of the multiple good system in Table 6.9 provide more detail concerning the effects of expected health and health risk within the total food index.

The demand elasticities in Table 6.9 reveal that expected health does not affect total food demand because of offsetting effects among several food groups. The positive effects of expected health on cereals and vegetables are offset by a decrease in dairy consumption. However, the effects of health risk extend to nonfood consumption. When health risk increases the consumption of cereals and vegetables rises and is offset by a decrease in both meat and nonfood consumption.

Because the estimated demand equations are linear approximations we can only speculate on the cause of expected health and health risk's impact on food consumption. If households do not perceive that food consumption greatly affects health the results in Table 6.9 are due to $\overline{H}$ and θ's impact on the expected marginal utilities of the food commodities as discussed in Chapter 3. On the other hand, if households believe that increased consumption of dairy products improve expected health they would increase their consumption of dairy products when expected health is low. However, using this logic it is surprising that $\overline{H}$ has a positive impact on cereal consumption. That is, the results in Table 6.9 suggest that households believe cereal consumption has no impact or a negative impact on expected health. This contrasts with the strong (positive) impact of cereal consumption on expected health in Chapter 4. Regarding health risk, the positive impact on cereal and vegetable consumption might occur if households perceive cereal and vegetable consumption to lower health risk. Hence, when health risk is high households increase their consumption of cereals and vegetables to lower the adverse effect of health risk on expected utility.

Household composition may account for the consumption effects of expected health and health risk for some commodities. Recall from Chapter 4 that a high concentration of children in the household decreases expected health. Consequently, if households increase their consumption of dairy products to meet the needs of children and nursing mothers this might yield a negative effect of $\bar{H}$ on dairy consumption.

The policy implications of these results are fully explored in the next chapter. However, preliminary indication of their importance is seen by calculating the change in food demand that occurs as expected health and health risk vary within reasonable levels in the data. Table 6.10 gives the percent change in consumption in food and nonfood as $\bar{H}$ and θ increase from one standard deviation below their sample means to one standard deviation above their sample means. In general, these changes cause a 10 to 15 percent shift in the consumption of each commodity. Although these effects are not large, they do suggest that as expected health status and health risk change the subsequent impacts on consumption are moderate.

Table 6.10. Percent changes in consumption as expected health and health risk increase from one standard deviation below to one standard deviation above their respective sample means.

Variable	**Meat**	**Dairy**	**Cereals**	**Vegs.**	**Tubers**	**NonFood**
Expected Health	NS	-10	14	14	NS	NS
Health risk	-15	NS	12	13	NS	-12

NS=not significantly different from zero.

Summary

The linear approximation to the food demand equation shows strong results that are consistent with the nonlinear estimate in Chapter 5. The effects of price and total expenditures are highly significant and conform to previous studies. In addition, the linear equation shows a significant positive impact of health risk on total food demand. Expected health has no significant effect on total food demand.

Linear approximations are also used to estimate a demand system with six food commodities and nonfood. The results show that both expected health and health risk significantly affect the demand for several food items. In particular, expected health positively effects cereal and vegetable consumption and negatively effects the demand for dairy products. Health risk also positively affects the demand for cereals and vegetables but has a negative effect on meat and nonfood demand. These results are consistent with the estimates of total food demand. The policy implications of these effects are explored in the next chapter.

CHAPTER 7: IMPLICATIONS FOR HEALTH AND FOOD POLICY

This chapter examines policy options for improving health and nutrition among low-income households in Lima. Using the health and food demand equations from earlier chapters, four alternative policies are analyzed: 1) Food price subsidies, 2) Direct cash transfers, 3) Construction of sewer facilities, and 4) Investments in public education.

It will first be determined whether health risk's impact on consumption effects the demand elasticities used for policy design. The cost effectiveness of each policy is also analyzed for its impact on food consumption and expected health. Special attention is given to the effects of each policy on health risk and whether these effects are important in choosing the optimal policy for Lima.

The first section of the chapter presents the demand and health equations from previous chapters as a simultaneous system. The next section discusses how the four policy alternatives are analyzed within the system. Sections three and four examine the comparative static effects of policy changes. The next two sections compare the cost effectiveness of each policy. The final section identifies the optimal health and nutrition policies for poor households in Lima.

The Model

In generic form the health and demand equations from Chapters 4 and 6 are

$$x_i = x_i(P, Y, \tilde{H}, \theta), \qquad i = 1, \dots, r \tag{7.1}$$

$$\bar{H}=\bar{H}(x_1,x_2,\ldots,x_r,Z) \tag{7.2}$$

$$\theta^2=\theta^2(x_1,x_2,\ldots,x_r,Z) \tag{7.3}$$

where x_i is the household's demand for good i, $\bar{H}$ is expected health, measured in expected days healthy per month per person, θ is the standard deviation of the household's days healthy per month per person or health risk, **P** is a vector of prices, Y is total expenditures, and **Z** is a vector of exogenous health inputs.

For policy analysis it is necessary to write equations (7.1), (7.2), and (7.3) as a simultaneous system with endogenous variables x_i, $\bar{H}$, and θ and exogenous variables **P**, Y, and **Z**. The simultaneous health and consumption effects of the exogenous variables are illustrated for a change in the price of x_i. According to equation (7.1), a change in the price of x_i affects the demand for x_i. The change in x_i affects expected health and health risk in equations (7.2) and (7.3) which may affect the demand for several commodities in (7.1) and so on. Hence, changes in the exogenous variables potentially affect both consumption and health. In addition, the interactions between health production and demand may affect the demand elasticities previously estimated from equation (7.1).

Comparative Static Effects of Policy Changes

The full effects the exogenous variables on consumption and health are obtained by writing equations (7.1), (7.2), and (7.3) as an implicit system and applying conventional comparative static methods (see Chiang, 1984, p.210-12). For the system of equations

$$J=\begin{bmatrix} x_1-x_1(P,Y,\bar{H},\theta) \\ x_2-x_2(P,Y,\bar{H},\theta) \\ \vdots \\ x_r-x_r(P,Y,\bar{H},\theta) \\ \bar{H}-\bar{H}(x_1,x_2,\ldots,x_r,Z) \\ \theta^2-\theta^2(x_1,x_2,\ldots,x_r,Z) \end{bmatrix}=\begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{7.4}$$

the comparative static effects of the exogenous variables are obtained from

$$J_{ee}[e_1]+J_1=0 \tag{7.5}$$

where $\mathbf{J}_{ee}$ is the Jacobian matrix of J with respect to all endogenous variables, $\mathbf{J}_1$ is the gradient vector of **J** with respect to a single exogenous variable, say z_1, and $\mathbf{e}_1$ is the vector of comparative static effects for changes in z_1. The elements of $\mathbf{J}_{ee}$ and $\mathbf{J}_1$ are obtained from the health and demand equation estimates. Vector e_1 is derived using conventional matrix methods.

Health and Nutrition Policy Alternatives

The system of equations (7.4) is used to analyze the effects of four health and nutrition policies. Each policy corresponds to a particular exogenous variable. The first policy is food price subsidies which involve changes in price vector **P**. Changes in total household expenditures Y are achieved by means of direct cash transfers. The third policy is construction of sewer facilities which affect input vector **Z**. The final policy is expenditures on public education which also affect **Z**. It is assumed that the principal constraint on primary and secondary education in the sample households is the inability pay school expenses. Consequently, education is a government policy variable where public expenditures for tuition and fees result in increased education.

Each of these policies has been discussed elsewhere including Kennedy and Alderman (1987), Pinstrup-Anderson (1985), and Mateus (1983) (food price subsidies); Reutlinger and Selowsky (1976) and Pinstrup-Anderson (1978) (direct transfers); Cornia (1990) (sewer facilities); Psacharopoulos and Woodhall (1985) (education). It should be noted that effects such as the impact of improved health and education on household income are not considered.

Comparative Static Results

The health and demand equation estimates from Chapters 4 and 6 are used to complete matrices $\mathbf{J}_{ee}$ and $\mathbf{J}_{l}$. Some of the coefficients in the health functions (7.2) and (7.3) were modified so that all marginal effects in the system are measured in identical units. Recall that the food inputs in the health equations are measured on an adult equivalent basis while the demand equations are specified on a per capita basis. The food coefficients in the health functions are converted to a per capita basis by multiplying the relevant coefficients in (7.2) and (7.3) by the ratio of household size over household adult equivalents at the sample means.[17] A second modification is needed on the health risk function because equation (7.3) measures the marginal impact of all inputs on health variance θ^2 while the demand equations depend on the standard deviation of health θ. Therefore, the coefficients in equation (7.3) are modified to show the marginal impact of all inputs on θ at the sample means.[18]

The marginal health effects of sewer construction and parental education in the health equations also require special explanation. The impact of sewer provision on health is the impact of a public sewer for a household with no sewer access, yielding a change in $\overline{H}$ and θ^2 of 1.5 and -7.07, respectively. The marginal impact of education on expected health and health variance is the total combined effects of the father and mother's primary and secondary education.

A summary of all endogenous and exogenous variables in the system of equations (7.4) is provided in Table 7.1. Table 7.2 shows the comparative static effects of a change in total expenditures, food prices, sewer access and parental education. The comparative

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[17] The average household size is 6.7 and the average number of adult equivalents is 5.2. Thus, all coefficients on the food inputs are multiplied by (6.7/5.2)=1.29.

[18] By the implicit function theorem, if $\partial\theta^2/\partial z_l=\Gamma$ then $\partial\theta/\partial z_l=[\Gamma/(2\theta)]$.

Table 7.1. Summary of variables included in the system of health and demand equations (7.4).

Variable	Mean	Description
Endogenous Variables		
Consumption:		
Meat	23.9	Per capita consumption of meat and fish (index).
Dairy	14.8	Per capita consumption of dairy products and eggs (index).
Cereal	37.7	Per capita consumption of cereals (index).
Vegetables	15.1	Per capita consumption of vegetables, fruits, and legumes (index).
Tubers	7.6	Per capita consumption of tubers (index).
NonFood	73.8	Per consumption of nonfood items (index).
Expected health	23.8	Expected days healthy per month per person.
Health risk	3.1	Standard deviation of the household's days healthy per month per person.
Exogenous Policy Variables		
Prices:		
Meat	1.39	Price index of meat product and fish (July 1985=1).
Dairy	1.23	Price index of dairy products and eggs (July 1985=1).
Cereals	1.16	Price index of bread and cereals (July 1985=1).
Vegetables	1.55	Price index of vegetables, fruits, and legumes (July 1985=1).
Tubers	1.72	Price index of tubers (July 1985=1).
Nonfood	1.22	Price index of nonfood items (July 1985=1).
Total Expenditures	262.1	Per capita monthly expenditures (in Intis)
Parental education	0.45	Proportion of households where neither parent has a primary education.
Sewer access	0.12	Proportion of households with no sewer system.

Table 7.2. Comparative static effects on consumption and health for a change in total expenditures, food prices, parental education, and sewer provision.

Exogenous Variables:

Endogenous Variables	Sewer access	Parental education	Total expenses	Price of:				
				Meat	Dairy	Cereals	Vegetables	Tubers
Consumption:								
Meat	1.8	3.5	0.13	-26.1	0.1	3.0	0.3	-1.1
Dairy	-0.9	-1.8	0.06	-1.7	-21.0	8.8	0.7	0.4
Cereals	-0.2	-0.5	0.06	5.4	0.3	-12.3	-7.0	0.5
Vegetables	-0.2	-0.3	0.05	2.3	0.1	-6.6	-5.5	0.3
Tubers	0.0	0.0	0.01	0.0	0.0	3.4	0.0	-3.9
Nonfood	4.5	8.7	0.37	-4.7	0.1	-28.8	0.7	-2.8
Health:								
Expected health	1.4	2.7	0.0	2.6	0.3	-1.3	-1.0	-0.6
Health risk	-1.2	-2.4	-0.01	1.3	-0.04	-1.0	-0.2	0.8

static effects are converted to elasticity form in Table 7.3. For sewer access and parental education the elasticities in Table 7.3 are the percent change (0-1) in consumption and health at the sample mean.

Discussion of Comparative Static Effects

Table 7.3 shows a wide range of health and consumption effects for changes in the exogenous variables. First, the effects of sewer access and parental education are very similar. Both programs have a positive effect on expected health and a negative effect on health risk, although the percent changes in expected health are not especially large. In addition, neither program has a substantial impact on consumption.

Changes in total expenditures have a substantial impact on consumption for all commodities. These elasticities resemble the estimated expenditure elasticities from Chapter 6 with minor differences arising from health and consumption interactions in the system of equations. Also note that the effect of total expenditures on expected health is negligible while an increase in total expenditures causes a sharp decline in health risk.

The effects of price changes on health are mixed. An increase in the price of meat causes an increase in expected health and an increase in health risk. For cereals and vegetables a price increase causes a decline in both expected health and health risk. A price increase for tubers causes a large increase in health risk and a small decline in expected health. The health effects of dairy price are negligible. Further note that the price elasticities of demand for the system resemble their counterparts in Chapter 6.

Table 7.3. Comparative static effects on consumption and health for a change in total expenditures, food prices, parental education, and sewer access, in elasticity form.

Exogenous Variables:

Endogenous Variables	Sewer access	Parental education	Total expenses	Price of: Meat	Dairy	Cereals	Vegetables	Tubers
Consumption:								
Meat	0.07	0.15	1.43	-1.51	0.0	0.14	0.02	-0.08
Dairy	-0.06	-0.12	1.11	-0.16	-1.75	0.69	0.07	0.04
Cereals	-0.01	-0.01	0.43	0.20	0.01	-0.38	-0.29	0.02
Vegetables	-0.01	-0.02	0.82	0.21	0.01	-0.51	-0.57	0.03
Tubers	0.0	0.0	0.36	0.0	0.0	0.52	0.0	-0.88
Nonfood	0.06	0.12	1.30	-0.09	0.0	-0.45	0.01	0.06
Health:								
Expected health	0.06	0.11	0.0	0.15	0.02	-0.06	-0.06	-0.04
Health risk	-0.40	-0.78	-0.50	0.58	-0.02	-0.39	-0.09	0.42

One conclusion from Table 7.3 is that the effects of expected health and health risk on consumption are not sufficiently large to affect policy decisions. That is, the price and expenditure elasticities of demand for the system resemble the elasticities obtained directly from the demand equation estimates in Chapter 6. However, this result does not exclude a role for health risk in policy decisions. Table 7.3 shows that most policy variables have a large impact on health risk. Given that health risk negatively affects expected utility and household welfare (Chapter 3), the impact of the policy variables on health risk also needs to be considered. Specifically, policies that produce a decrease in health risk and also improve food consumption and health should be given high priority.

Cost of Program Alternatives

While Table 7.3 reveals the effect of policy variables on consumption and health there is no indication to the cost effectiveness of each policy. A convenient method for evaluating cost effectiveness is to compare the health and consumption benefits per dollar of program expenditures. The per dollar benefits can thus identify which program achieves a given health or consumption improvement for the least amount of public expenditures. This result is especially important for health and food policies designed to achieve a given level of consumption or health improvement among subsistence households.

The total costs of each policy are obtained from several sources. For direct transfers the program cost is simply the transfer amount. For food price subsidies the costs are derived from the initial consumption levels and the comparative static effects in Table

7.2. That is, the subsidy costs are post-subsidy consumption levels multiplied by the subsidy amount. Approximate costs of sewer and education programs in Lima are taken from previous studies. Esrey, Feachem, and Hughes (1985) estimate the annual cost of urban sewer construction and maintenance in developing countries at $26 per person (1982 dollars). Education costs are taken from Jimenez (1986) who estimates that the marginal cost of educating one child in Bolivia in primary and secondary school is $67 and $117 per year, respectively (1975 dollars).

The above information is used to compute the present value cost of supporting each program over one person's lifetime. Thus, the costs of a transfer program are the total cost of all transfers for one person's lifetime, discounted to a present value basis. Similar treatment is given to the annual per person costs of food subsidies and sewer programs.

Computing the per person cost of parental education requires special consideration due to the "public" nature of education benefits within households. Recall from Chapter 4 that the husband and wife's education affected the expected health and health variance of the entire household. First, the total annual costs of six years primary education are discounted to a present value basis. Four years of (discounted) secondary education costs are then added to this figure yielding the present value cost of educating one child. The present value cost of educating one child is then multiplied by two and divided by the average family size in Lima (6.7). This step is necessary because the costs of educating two children (one male and one female) yield health and consumption benefits for themselves and their entire (future) household.

However, it should be emphasized that the benefits of education programs are long term while the benefits of the other programs occur almost immediately. No adjustment is made for this difference in the analysis. Instead, it is useful to distinguish short term policies (subsidies, transfers, and sewer construction) from education programs whose benefits are long term.

Each program's cost per person is given in Table 7.4. The specific cash transfer considered is 10 percent of total (real) expenditures per capita at the sample mean. The food subsidies are a 10 percent reduction in the price of each commodity. These costs are converted to 1985 US dollars using the intis/dollar exchange rate (IMF). For the sewer and education costs the estimates in Esrey et al. and Jimenez are converted to 1985 dollars using the US consumer price index (IMF).

Cost Effectiveness of Program Alternatives

The cost effectiveness of each program is compared by computing the impact on food consumption, expected health, and health risk for one person per dollar of program expenditures. It would ideal if current nutrient intake levels were known so that the nutritional impact of each policy could be calculated. It would then be possible to identify the policy that corrects critical nutrient deficiencies for the least cost. Unfortunately, this information is not available in the data. An alternative procedure is to convert the

Table 7.4. Present value costs per person of various program alternatives, in 1985 US dollars.

	Program:									
			Education:			Subsidy for:				
Category	Sewer	Transfer	Primary	Second.	Total	Meat	Dairy	Cereals	Vegetables	Tubers
Annual Cost	29.0	24.0	133.6	234.2		4.1	2.3	4.9	2.7	1.5
Total present value cost for one person[a]			582.0	419.0	1001.0					
Present value cost for one persons' lifetime[a]	288.8[b]	239.6[b]			300.6[c]	40.7[b]	22.9[b]	48.5[b]	26.4[b]	15.1[b]

a = annual discount rate is 10 percent.
b = discounted for the life of the individual (60 years).
c = per person costs multiplied by two and divided by average family size.

expenditure survey data into approximate kilogram equivalents for each food category. While this procedure does not yield nutrient intake levels it provides a rough idea of the consumption level of various commodities.

Mean consumption levels in kilograms are estimated from mean expenditures (in intis) divided by a representative price (in intis/kg) for each category. "Representative" prices for each category are created from 12 month averages from July 1985 to June 1986 for various commodities in Lima:[19] The cereals and bread price is the average price of rice, bread, and noodles. The meat and fish price is the average price of pork, beef, poultry, and fish. For dairy products and eggs the price/kg is the average price of eggs and fluid milk. The price of vegetables, fruits, and legumes is the average price of tomatoes, oranges, and lentils. Finally, the price of tubers is proxied by the average price of yellow and white potatoes. The corresponding mean consumption levels in kilograms are shown in Table 7.5. The mean daily consumption for all foods using the above procedure is 0.51 kg per person.

Table 7.6 gives the per dollar changes in food consumption and health for the four policy alternatives. Nutrition benefits of each program are measured by the change in one person's consumption, in kg per month ($\times 10^3$), for every dollar spent over the person's lifetime. The health benefits are the percent change in one person's expected health and

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[19] Unpublished prices of food commodities were provided by the Instituto Nacional de Estadistica e Informatica (INEI) in Lima.

Table 7.5. Mean consumption levels per person for each food category, in kilograms per month per person.

Category	Consumption (kg/person-month)
Cereals and bread	6.64
Meat and fish	1.42
Dairy products and eggs	2.19
Vegetables, fruits, and legumes	2.15
Tubers	2.95
Total	15.35

health risk ($\times 10^3$) per dollar of expenditures over the person's lifetime.

Table 7.6 reveals that the largest per dollar improvements in expected health occur for education, sewer provision, and vegetable and tuber subsidies. Direct transfers and subsidies for cereals, dairy, and meat have small or negative effects on expected health. Almost all policies negatively affect health risk, with the largest per dollar effects coming from education programs and tuber subsidies.

The per dollar increases in food consumption greatly vary for each policy. The consumption effects of sewer and education programs are negligible. Cash transfers have a relatively small per dollar impact on food consumption. The largest consumption increases per dollar occur for dairy, tuber, and vegetable subsidies.

Differences in the per dollar health benefits of each policy are primarily due to the effects of the health inputs in the health functions. Recall from Chapter 4 that a mother's education substantially increases expected health and lowers health risk. Similar effects

Table 7.6. Per dollar benefits for one person for various policy alternatives, measured in changes in food consumption (kilograms per month × 10^3) and percent change in expected health and health risk (× 10^3).

Policy								
	Sewer	Education	Transfer	Subsidy: Meat	Dairy	Cereals	Vegetables	Tubers
Food Consumption: (kg per month × 10^3)								
Meat	0.36	0.69	0.72	5.27	-0.02	-0.42	-0.09	0.75
Dairy	-0.47	-0.90	0.87	0.87	16.76	-3.12	-0.57	-0.63
Cereals	-0.15	-0.27	1.02	-3.26	-0.31	5.18	7.22	-1.10
Vegetables	-0.08	-0.14	0.63	-1.11	-0.10	2.25	4.61	-0.42
Tubers	0.0	0.0	0.38	0.0	0.0	-2.36	0.0	17.29
Total	-0.34	-0.62	3.62	1.77	16.32	1.53	11.17	15.89
Health: (percent change × 10^3)								
Expected health	20.1	38.2	-0.1	-37.1	-7.0	12.7	24.1	26.6
Health risk	-137.1	-258.3	-17.9	-142.1	-7.1	80.5	35.7	-281.7

occur in households with public sewer access. Hence, public expenditures on these programs produce large per dollar health benefits. The health benefits of cash transfers are relatively small because the corresponding increases in food consumption are divided between items which have both positive and negative effects on health.

For the food subsidies, a combination of the price elasticities of demand and the health function coefficients determine the per dollar health benefits. Hence, even though cereal consumption produces a large increase in expected health a subsidy for cereals does not yield large gains in expected health because of its small price elasticity. On the other hand, the large price elasticity for meat amplifies the negative impact on expected health caused by a meat price subsidy. The large per dollar effects of a tuber subsidy on both expected health and health risk occur from the moderate sized coefficients on tubers in the health functions and because the price elasticity of demand for tubers is reasonably large.

The per dollar consumption effects of the subsidies mainly depend on the price elasticities. For example, the high price elasticity for dairy products yields a large per dollar consumption benefit. Another important factor is the initial consumption level in kilograms. Even though meats have a high price elasticity the quantity consumed is small so that a subsidy yields only small kilogram increases in meat consumption. This effect also explains the large per dollar consumption increase for a tuber subsidy. Both the price elasticity and initial consumption level for tubers are moderate.

Policy Recommendation for Lima

The results in Table 7.6 identify several policy alternatives for improving health and nutrition among low-income households in Lima. First, it is clear that direct cash transfers are not an effective policy alternative. Direct transfers yield minimal food consumption benefits per dollar of expenditures and no meaningful health benefits. Price subsidies for meat and cereals can also be ruled out because of their small impact on consumption and their small or negative health effects.

The best option among the remaining policies depends on the specific health and nutrition needs in the population. If health conditions are poor despite adequate food consumption the optimal policies are sewer and education programs. In particular, education provides an especially large per dollar increase in expected health. However, because the benefits of education are long run a combination of sewer and education programs might be preferred. On the other hand, if food consumption levels are inadequate the dairy, vegetable, and tuber subsidies are attractive. The choice of which commodity to subsidize would depend on current nutrient intake levels since the composition of these items is very different. Another point worth considering is that tuber and vegetable subsidies also produce large increases in expected health. Thus, to ensure a balanced increase in nutrient intake plus improved health a combined subsidy for all three commodities might be appropriate.

It is also useful to focus on the health risk effects of each policy. In Chapter 3 it was explained that health risk negatively affects expected utility. The magnitude of this effect can not be identified from the linear demand equations. In general, however, welfare in the target households can be improved by choosing policies that reduce health risk. The impact on health risk should especially be considered for two or more policies that yield similar effects on expected health and consumption. For example, tuber and vegetable subsidies yield similar per dollar effects on consumption and expected health. However, because a tuber subsidy also yields a sharp decline in health risk tuber subsidies should be given higher priority. The large per dollar declines in health risk also increase the attractiveness of education programs.

Summary

The demand and health equations from earlier chapters are analyzed for their policy implications. Writing these equations as a simultaneous system permits the full effects of changes in exogenous policy variables to be analyzed. The results suggest that the effects of expected health and health risk on consumption do not affect the estimated demand elasticities in Chapter 6. However, because the food inputs affect expected health and health risk it is possible to identify the health effects of changes in total expenditures and food prices.

The most cost efficient policies for improving health are education and sanitation programs and subsidies for tubers and vegetables. The largest per dollar increases in food consumption occur for dairy, vegetable, and tuber subsidies. The optimal policy choice depends on the current health and nutrition conditions in Lima. However, the negative impact of education programs and tuber subsidies on health risk suggest that these programs be given high priority.

CHAPTER 8: SUMMARY AND CONCLUSIONS

This study examines two issues related to health uncertainty and food consumption in developing countries. The first topic is the impact of health uncertainty on food consumption. The second area is the effects of food consumption on household health.

The effects of food consumption on health are addressed by means of an estimated health production function for low-income households in Lima, Peru. The health function is similar to recent studies except that the possibility of heteroscedasticity is considered. There is strong evidence that the food and nonfood inputs in the health function affect the variance of health or health risk. In particular, a mother's education and household access to sewer facilities greatly reduce health risk. Females, children, and the elderly have a higher level of health risk than adult males. Consumption of food commodities such as meat and tubers lower health risk while cereals and miscellaneous foods increase health risk.

The health function is then estimated using generalized least squares to account for heteroscedasticity. Estimates of this function also show strong effects for the food and nonfood inputs. Consumption of cereals and tubers positively affect health status while meats and other commodities have an insignificant or negative impact. The mother's education and public sewer access positively affect health. In addition, women and children generally have poorer health than adult males. These results are consistent with previous studies.

The issue of health uncertainty and food demand is explored by means of an expected utility model. The model employed is a function of food and nonfood consumption, expected health status, and health risk. The function suggests that when household's maximize expected utility the demand equations for food and nonfood depend on expected health and health risk. However, the sign of these effects can not be predicted.

Demand equations containing expected health and health risk are estimated for the sample households in Lima. The estimated health equations provide estimates of each household's expected health and health risk for this exercise. It is shown that both expected health and health risk significantly affect food demand. These effects greatly vary for different commodities. Expected health has a positive impact on the demand for cereals and vegetables and a negative impact on dairy consumption. Health risk also positively affects cereal and vegetable demand but negatively affects the demand for meat and nonfood. The size of these effects are moderate for the observed range of expected health and health risk in the sample households. That is, for one standard deviation above and below the sample mean of expected health and health risk the corresponding change in food demand is roughly 10 percent.

However, these effects are not large enough to dramatically alter the demand elasticities used for policy design. After accounting for the simultaneous interactions between health and food consumption, the price and expenditure elasticities of demand resemble their counterparts from the demand equations. A related result is that health policy variables such as sewer construction and public education do not dramatically affect food consumption.

The importance of health risk in policy decisions lies in the effect of health risk on household welfare. Using the estimated health and demand equations, several policy alternatives are compared for their per dollar benefits on food consumption, expected health, and health risk. Consumer subsidies for dairy products, vegetables, and tubers provide substantial increases in food consumption. In addition, expenditures on sewer construction and education lead to substantial increases in expected health. Yet, only tuber subsidies and public education programs provide substantial reductions in health risk. Given that decreases in health risk lead to improved household welfare, policymakers should give priority to education programs and tuber price subsidies as tools for improving expected health and food consumption. Each of these policies will provide additional gains in household welfare by lowering health risk.

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APPENDIX A: OVERVIEW OF THE SICKNESS IMPACT PROFILE

The Sickness Impact Profile: Categories and Selected Items (Bergner et al., 1981).

Dimension	Category	Selected Items
Independent Categories	Sleep and Rest (SR)	I sit during much of the day. I sleep or nap during the day.
	Eating (E)	I am eating no food at all, nutrition is taken through tubes of intravenous fluids. I am eating special or different food.
	Work (W)	I am not working at all. I often act irritable toward my work associates.
	Home Management (HM)	I am not doing any of the maintenance or repair work around the house that I usually do. I am not doing heavy work around the house.
	Recreation and Pastimes (RP)	I am going out for entertainment less. I am not doing any of my usual physical recreation or activities.
I. Physical	Ambulation (A)	I walk shorter distances or stop to rest often. I do not walk at all.
	Mobility (M)	I stay within one room. I stay away from home only for brief periods of time.
	Body Care and Movement (BCM)	I do not bathe myself at all, but am bathed by someone else. I am very clumsy in body movements.
II.Psychosocial	Social Interaction (SI)	I am doing fewer social activities with groups of people. I isolate myself as much as I can from the rest of the family.
	Alertness	I have difficulty reasoning and solving

Behavior (AB)	problems, for example, making plans, making decisions, learning new things. I sometimes behave as if I were confused or disoriented in place or time, for example, where I am, who is around, directions, what day it is.
Emotional Behavior (EB)	I laugh or cry suddenly. I act irritable and impatient with myself, for example, talk badly about myself, swear at myself, blame myself for things that happen.
Communication (C)	I am having trouble writing or typing. I do not speak clearly when I am under stress.

APPENDIX B: DERIVATION OF THE EXPECTED UTILITY FUNCTION

The expected utility function $\bar{U}(F,C,\bar{H},\theta)$ can be obtained by treating the marginal expected utilities

$$\begin{aligned}
\frac{\partial \bar{U}}{\partial F} &= \bar{U}_F = \alpha_F + \alpha_{FF}F + \alpha_{F\bar{H}}\bar{H} + \alpha_{FC}C + \alpha_{\theta F}\theta \\
\frac{\partial \bar{U}}{\partial C} &= \bar{U}_C = \alpha_C + \alpha_{CC}C + \alpha_{C\bar{H}}\bar{H} + \alpha_{FC}F + \alpha_{\theta C}\theta \\
\frac{\partial \bar{U}}{\partial \bar{H}} &= \bar{U}_{\bar{H}} = \alpha_{\bar{H}} + \alpha_{\bar{H}\bar{H}}\bar{H} + \alpha_{C\bar{H}}C + \alpha_{F\bar{H}}F + \alpha_{\theta\bar{H}}\theta \\
\frac{\partial \bar{U}}{\partial \theta} &= \bar{U}_\theta = \alpha_\theta + \alpha_{\theta\theta}\theta + \alpha_{\theta C}C + \alpha_{\theta F}F + \alpha_{\theta\bar{H}}\bar{H}
\end{aligned} \tag{B.6}$$

as an exact differential and integrating along a broken line from points (0,0,0,0) to $(F,C,\bar{H},\theta)$ (Taylor, 1955, p. 471). First integrate $\bar{U}_F$ from (0,0,0,0) to (F,0,0,0)

$$\beta_F = \int_0^F (\alpha_F + \alpha_{FF}q)\,dq \tag{B.7}$$

where q denotes an integration dummy variable. Next integrate $\bar{U}_C$ from (F,0,0,0) to (F,C,0,0)

$$\beta_C = \int_0^C (\alpha_C + \alpha_{CC}q + \alpha_{FC}F)\,dq \tag{B.8}$$

Similarly, integrate $\bar{U}_{\bar{H}}$ from (F,C,0,0) to (F,C,H,0)

$$\beta_{\bar{H}}=\int_{0}^{H}(\alpha_{\bar{H}}+\alpha_{\bar{H}\bar{H}}q+\alpha_{\bar{H}F}F+\alpha_{C\bar{H}}C)dq \tag{B.9}$$

Finally, integrate $\bar{U}_{\theta}$ from (F,C,$\bar{H}$,0) to (F,C,$\bar{H}$,θ)

$$\beta_{\theta}=\int_{0}^{\theta}(\alpha_{\theta}+\alpha_{\theta\theta}q+\alpha_{\theta C}C+\alpha_{0F}F+\alpha_{0H}H)dq \tag{B.10}$$

The expected utility function is $\bar{U}(F,C,\bar{H},\theta)=\beta_F+\beta_C+\beta_H+\beta_0$. Without repeating the intermediate steps

$$\begin{aligned}\bar{U}(F,C,\bar{H},\theta)=&\alpha_0+\alpha_F F+\alpha_C C+\alpha_{\bar{H}}\bar{H}+\alpha_0\theta+\frac{\alpha_{FF}}{2}F^2+\frac{\alpha_{CC}}{2}C^2+\frac{\alpha_{\bar{H}\bar{H}}}{2}\bar{H}^2+\frac{\alpha_{\theta\theta}}{2}\theta^2\\&+\alpha_{FC}FC+\alpha_{F\bar{H}}F\bar{H}+\alpha_{C\bar{H}}C\bar{H}+\alpha_{0\bar{H}}\theta\bar{H}+\alpha_{0F}\theta F+\alpha_{\theta C}\theta C\end{aligned} \tag{B.11}$$

where α_0 is the sum of the integration constants from β_F, β_C, β_H, and β_0.

APPENDIX C: CURVATURE PROPERTIES OF THE EXPECTED UTILITY FUNCTION

Tobin (1958, 1965) analyzed the case where expected utility depends on the mean and standard deviation of wealth. He shows that diminishing marginal utility of wealth in the original utility function yields indifference curves between expected wealth and its standard deviation that are upward sloping and convex (placing standard deviation on the horizontal axis).

Tobin's methods can be applied to utility function $U(F,C,H)=U(F,C,\bar{H}+\theta v)$ and its expectation $\bar{U}(F,C,\bar{H},\theta)$. First consider any combination of health risk θ and good $n=F,C,\bar{H}$ that yield an equivalent expected utility. For example, suppose that (F^0,θ^0) and (F^1,θ^1) lie on the same indifference curve. If utility function $U(F,C,H)$ shows diminishing marginal utility of health then the following holds because of Jensen's Inequality

$$\frac{1}{2}U(F^0,C,\bar{H}+\theta^0 v)+\frac{1}{2}U(F^1,C,\bar{H}+\theta^1 v)<U\left(\frac{F^0+F^1}{2},C,\bar{H}+\left(\frac{\theta^0+\theta^1}{2}\right)v\right) \qquad \textbf{(C.1)}$$

Taking the expectation of both sides of (C.1) yields

$$\frac{1}{2}\bar{U}(F^0,C,\bar{H},\theta^0)+\frac{1}{2}\bar{U}(F^1,C,\bar{H},\theta^1)<\bar{U}\left(\frac{F^0+F^1}{2},C,\bar{H},\frac{\theta^0+\theta^1}{2}\right) \qquad \textbf{(C.2)}$$

Because (F^0,θ^0) and (F^1,θ^1) yield the same level of expected utility it follows that

$$\bar{U}(F^0,C,\bar{H},\theta^0),\ \bar{U}(F^1,C,\bar{H},\theta^1)<\bar{U}\left(\frac{F^0+F^1}{2},C,\bar{H},\frac{\theta^0+\theta^1}{2}\right) \qquad \textbf{(C.3)}$$

Hence, the midpoint of (F^0,θ^0) and (F^1,θ^1) lies on a higher indifference curve so that the indifference curve containing (F^0,θ^0) and (F^1,θ^1) is convex. Identical results are obtained by substituting C or $\overline{H}$ in place of F.

APPENDIX D: RESTRICTIONS IMPOSED ON THE EXAMPLE UTILITY FUNCTIONS

The optimization problem used to derive the example expected utility functions is

$$\max_{F,C,\bar{H},z} \ \bar{U}(F,C,\bar{H},\theta)=\alpha_0+\alpha_F F+\alpha_C C+\alpha_{\bar{H}}\bar{H}+\alpha_0\theta+\frac{\alpha_{FF}}{2}F^2+\frac{\alpha_{CC}}{2}C^2+\frac{\alpha_{\bar{H}\bar{H}}}{2}\bar{H}^2+\frac{\alpha_{\theta\theta}}{2}\theta^2$$

$$+\alpha_{FC}FC+\alpha_{F\bar{H}}F\bar{H}+\alpha_{C\bar{H}}C\bar{H}+\alpha_{\theta\bar{H}}\theta\bar{H}+\alpha_{\theta C}\theta C+\alpha_{\theta F}\theta F$$

$$s.t. \ Y=P_F F+P_C C+P_{\bar{H}}\bar{H}+P_z z, \quad \theta=\phi_0+\phi_1 z \tag{D.1}$$

or

$$\max_{F,C,\bar{H},z} \ \mathcal{L}=\alpha_0+\alpha_F F+\alpha_C C+\alpha_{\bar{H}}\bar{H}+\alpha_0(\phi_0+\phi_1 z)+\frac{\alpha_{FF}}{2}F^2+\frac{\alpha_{CC}}{2}C^2+\frac{\alpha_{HH}}{2}\bar{H}^2$$

$$+\frac{\alpha_{\theta\theta}}{2}(\phi_0+\phi_1 z)^2+\alpha_{FC}FC+\alpha_{F\bar{H}}F\bar{H}+\alpha_{C\bar{H}}C\bar{H}+\alpha_{\theta\bar{H}}(\phi_0+\phi_1 z)\bar{H} \tag{D.2}$$

$$+\alpha_{\theta C}(\phi_0+\phi_1 z)C+\alpha_{\theta F}(\phi_0+\phi_1 z)F+\mu(Y-P_F F-P_C C-P_{\bar{H}}\bar{H}-P_z z)$$

which yields demand equations $F(Y,P_F,P_C,P_{\bar{H}},P_z)$, $C(Y,P_F,P_C,P_H,P_z)$, $\bar{H}(Y,P_F,P_C,P_{\bar{H}},P_z)$, and $z(Y,P_F,P_C,P_{\bar{H}},P_z)$. The corresponding expenditure elasticities of demand are

$$\epsilon_{FY}=\frac{\partial F(.)}{\partial Y}\frac{Y}{F}, \quad \epsilon_{CY}=\frac{\partial C(.)}{\partial Y}\frac{Y}{C}$$

$$\epsilon_{HY}=\frac{\partial \bar{H}(.)}{\partial Y}\frac{Y}{\bar{H}}, \quad \epsilon_{zY}=\frac{\partial z(.)}{\partial Y}\frac{Y}{z} \tag{D.3}$$

The elasticity of substitution between goods i and j, $i,j=F,C,\bar{H},\theta$, $i\neq j$, is

$$\omega_{ij}=\frac{\bar{U}_i\bar{U}_i(\bar{U}_i i+\bar{U}_j j)}{ij(2\bar{U}_i\bar{U}_j\alpha_{ij}-\bar{U}_i^2\alpha_{jj}-\bar{U}_j^2\alpha_{ii})} \qquad \textbf{(D.4)}$$

where $\bar{U}_i$ and $\bar{U}_j$ are the marginal expected utilities from expected utility function (3.4)

$$\begin{aligned}
\frac{\partial\bar{U}}{\partial F}&=\bar{U}_F=\alpha_F+\alpha_{FF}F+\alpha_{F\bar{H}}\bar{H}+\alpha_{FC}C+\alpha_{\theta F}\theta\\
\frac{\partial\bar{U}}{\partial C}&=\bar{U}_C=\alpha_C+\alpha_{CC}C+\alpha_{C\bar{H}}\bar{H}+\alpha_{FC}F+\alpha_{\theta C}\theta\\
\frac{\partial\bar{U}}{\partial\bar{H}}&=\bar{U}_{\bar{H}}=\alpha_H+\alpha_{\bar{H}\bar{H}}\bar{H}+\alpha_{CH}C+\alpha_{FH}F+\alpha_{\theta H}\theta\\
\frac{\partial\bar{U}}{\partial\theta}&=\bar{U}_\theta=\alpha_\theta+\alpha_{\theta\theta}\theta+\alpha_{\theta C}C+\alpha_{\theta F}F+\alpha_{\theta H}\bar{H}
\end{aligned} \qquad \textbf{(D.5)}$$

Finally, the value of Lagrange multiplier μ from (D.2) is the marginal expected utility of expenditures, $\partial\bar{U}/\partial Y=\mu(Y,P_F,P_C,P_{\bar{H}},P_z)$. All fourteen restrictions used to derive the α parameters are summarized in Table D.1.

Table D.1. Restrictions used to derive the expected functions.

Category	Formula
Demand[a]	$F(Y,P_F,P_C,P_{\bar{H}},P_z)$, $C(Y,P_F,P_C,P_{\bar{H}},P_z)$, $\bar{H}(Y,P_F,P_C,P_{\bar{H}},P_z)$
Expenditures Elasticities[a]	ϵ_{FY}, ϵ_{CY}, $\epsilon_{\bar{H}Y}$
Substitution elasticities	ω_{FH}, ω_{CH}, ω_{0F}, ω_{0C}, ω_{0H}, ω_{FC}
Scale and curvature of the expected utility function	$\bar{U}(F,C,\bar{H},\theta)$, $\partial\bar{U}/\partial Y=\mu(Y,P_F,P_C,P_{\bar{H}},P_z)$

a=The demand equation and expenditure elasticity for z are omitted. From the budget constraint in (D.2) the demand equation and expenditure elasticity for z is determined from the demand equations for F, C, and $\bar{H}$.

Values for prices, consumption, and health variables are chosen to yield reasonable expenditure shares and to coincide with mean data values from Lima, Peru. The resulting expenditure shares for F, C, $\bar{H}$, and z are 0.57, 0.31, 0.08, and 0.03, respectively. Values for ϕ_0 and ϕ_1 are chosen to yield a unitary elastic health risk function, $\theta=\phi_0+\phi_1 z$. This additional information is summarized in Table D.2.

Table D.2. Values of additional variables and parameters in the example expected utility functions.

Variable	Value
P_F	1.3
P_C	1.2
$P_{\bar{H}}$	1.0
P_z	10.0
$\bar{H}$	24.0
θ	3.0
ϕ_0	6.0
ϕ_1	-3.0
Total expenditures	286.5

A Newton alogrithm is then used to solve for the α parameters given the restrictions in Table D.1.

APPENDIX E: OBTAINING INSTRUMENTAL VARIABLES FOR HOUSEHOLD FOOD CONSUMPTION

The instrumental variables procedure for the indices of total household food consumption is described in Chapter 4. Table E.1 summarizes variables used in the instrumental variable equations not already described in Chapter 4. In Table E.2 a description of the binary district variables used for Metropolitan Lima is given. Table E.3 shows the estimated regressions used to create instruments of total household food consumption.

Table E.1. Variables used to predict total household food consumption.

Variable	Mean	Std.Dev.	Description
Total Household Food Consumption:			
Meat	157.8	124.3	Index of total meat and fish consumption.
Dairy	92.9	69.1	Index of total dairy and egg consumption.
Cereals	250.8	130.0	Index of total cereal consumption.
Vegetables	98.8	66.9	Index of total vegetable, fruit, and legume consumption.
Tubers	50.3	42.6	Index of total tuber consumption.
Other Food	222.2	145.0	Index of total consumption of other foods.
Household Composition:			
Members under 3	0.69	0.82	Total members under age 3.
Members between 3 and 10	1.45	1.23	Total members between 3 and 10.
Male members between 10 to 18	0.64	0.91	Total male members between 10 and 18.
Female members between 10 to 18	0.72	0.94	Total female members between 10 and 18.
Male members between 18 to 60	1.55	1.01	Total male members between 18 and 60.
Female members between 18 to 60	1.42	0.85	Total female members between 18 and 60.
Male members over 60	0.12	0.33	Total male members over 60.
Female members over 60	0.07	0.25	Total female members over 60.
Other:			
Total (real) expenditures	1361.8	663.8	Total household expenses (in intis) deflated by the consumer price index, July 1985=1.
Dist1-Dist35	..		Binary variable indicating the household's location in Metropolitan Lima (see Table E.2).

Table E.2. List of all districts in Metropolitan Lima

Variable	District Name
Dist1	Callao
Dist2	La Perla
Dist3	Bellavista
Dist4	Carmen de la Legua
Dist5	Ventanilla
Dist6	Puente Piedra
Dist7	Carabayllo
Dist8	Comas
Dist9	Independencia
Dist1	an Martin de Porres
Dist11	San Miguel
Dist12	Magdelena del Mar
Dist13	Pueblo Libre
Dist14	Brena
Dist15	Jesus Maria
Dist16	Lince
Dist17	San Isidro
Dist18	La Victoria
Dist19	Lima
Dist20	Rimac
Dist21	San Juan de Lurigancho
Dist22	El Agustino
Dist23	San Luis
Dist24	Ate
Dist25	Lurigancho
Dist26	Santiago de Surco
Dist27	San Borja
Dist28	Surquillo
Dist29	Miraflores
Dist30	Barranco
Dist31	Chorrillos
Dist32	San Juan de Miraflores
Dist33	Villa M. del Triunfo
Dist34	Villa El Salvador
Dist35	Lurin

Table E.3. First stage regressions used to predict total household food consumption, method=ordinary least squares.

Dependent Variable=Total household consumption of:

Variable	Meat	Dairy	Cereals	Vegs.	Tubers	Other food
Members under 3						
	22.78	6.78	10.74	10.36	7.21	4.02
	(2.42)	(1.32)	(1.40)	(2.04)	(1.92)	(0.37)
Members 3 to 10						
	-9.15	-2.21	26.34	6.41	6.72	6.00
	(-1.34)	(-0.59)	(4.75)	(1.74)	(2.47)	(0.76)
Male members 10 to 18						
	-2.11	-6.35	16.21	-3.37	-0.50	-19.44
	(-0.25)	(-1.40)	(2.41)	(-0.76)	(-0.15)	(-2.03)
Female members 10 to 18						
	-3.40	-7.16	13.36	-0.55	4.57	0.52
	(-0.43)	(-1.65)	(2.07)	(-0.13)	(1.45)	(-0.06)
Male members 18 to 60						
	10.17	7.27	25.34	10.72	7.02	1.19
	(1.12)	(1.46)	(3.41)	(2.18)	(1.93)	(0.11)
Female members 18 to 60						
	-13.94	-6.13	13.34	-0.18	4.93	-18.58
	(-1.33)	(-1.07)	(1.57)	(-0.03)	(1.19)	(-1.54)
Males members over 60						
	-2.42	8.15	26.69	0.48	7.29	-2.35
	(-0.10)	(0.60)	(1.33)	(0.04)	(0.74)	(-0.08)
Female members over 60						
	-30.74	-9.63	-0.43	-15.66	4.12	55.31
	(-0.95)	(-0.54)	(-0.02)	(-0.89)	(0.32)	(1.47)
Husband's educ - primary						
	22.01	8.02	-25.31	1.50	-6.55	37.45
	(1.22)	(0.81)	(-1.73)	(0.15)	(-0.91	(1.80)
Husband's educ - secondary						
	3.55	8.32	22.57	3.42	-7.40	-33.22
	(0.16)	(0.71)	(1.29)	(0.29)	(-0.86	(-1.33)
Wife's educ. - primary						
	8.99	14.27	-18.11	10.46	-5.00	-48.04
	(0.45)	(1.31)	(-1.12)	(0.97)	(-0.63	(-2.09)

Wife's educ - secondary						
	2.81	0.09	-9.46	-12.88	3.84	-17.58
	(0.11)	(0.01)	(-0.44)	(-0.89)	(0.36)	(-0.57)
Sewer system - septic tank						
	11.57	6.43	-23.42	-29.30	-2.72	-8.13
	(0.28)	(0.29)	(-0.70)	(-1.32)	(-0.17)	(-0.17)
Sewer system - cesspool						
	6.11	-3.74	25.45	-19.01	6.27	11.47
	(0.29)	(-0.32)	(1.46)	(-1.65)	(0.74)	(0.46)
Sewer system - none						
	-19.98	0.97	13.65	10.09	7.57	1.39
	(-0.86)	(0.00)	(0.72)	(0.80)	(0.82)	(-0.05)
Tot Exp	0.12	0.03	0.13	0.06	0.06	0.21
	(2.95)	(1.32)	(3.81)	(2.75)	(3.43)	(4.34)
$(\text{Tot Exp})^2$	2.3×10^{-6}	1.2×10^{-5}	-1.1×10^{-5}	-2.4×10^{-6}	-1.2×10^{-5}	-1.7×10^{-5}
	(0.20)	(1.90)	(-1.23)	(-0.39)	(-2.71)	(-1.31)
Aug	72.79	20.44	82.96	-8.54	11.49	39.22
	(2.00)	(1.02)	(2.79)	(-0.43)	(0.79)	(0.93)
Sept	36.64	27.39	36.75	20.21	14.32	29.36
	(1.29)	(1.76)	(1.59)	(1.32)	(1.27)	(0.89)
Oct	31.19	-6.37	36.14	25.04	-9.07	107.72
	(1.00)	(-0.37)	(1.41)	(1.48)	(-0.72)	(2.97)
Nov	81.51	23.08	43.06	33.97	-15.45	29.42
	(1.81)	(.94)	(1.18)	(1.40)	(-0.86)	(0.57)
Dec	25.74	14.45	-0.61	45.40	-9.58	66.07
	(0.72)	(0.73)	(-0.02)	(2.34)	(-0.67)	(1.59)
Jan	16.74	-8.49	78.43	29.84	-4.73	31.27
	(0.41)	(-0.38)	(2.39)	(1.37)	(-0.30)	(0.67)
Feb	20.47	8.71	29.51	5.39	-12.21	139.60
	(0.65)	(0.50)	(1.14)	(0.32)	(-0.97)	(3.81)
Mar	33.05	27.90	41.99	12.66	-13.65	71.08
	(1.04)	(1.61)	(1.63)	(0.74)	(-1.08)	(1.94)
April	10.64	-3.05	38.48	22.27	16.71	55.83
	(0.27)	(-0.14)	(1.22)	(1.06)	(1.08)	(1.24)
May	22.20	-26.94	41.68	-25.73	-39.76	20.61
	(0.56)	(-1.24)	(1.29)	(-1.21)	(-2.52)	(0.45)
June	-0.09	5.19	61.40	-9.73	-16.73	96.63
	(-0.00)	(0.19)	(1.49)	(-0.36)	(-0.83)	(1.65)

Dist2	-306.66	13.25	33.78	81.18	34.06	53.00
	(-2.65)	(0.21)	(0.36)	(1.30)	(0.74)	(0.40)
Dist3	-58.37	40.65	-67.07	-15.17	32.07	115.58
	(-0.69)	(0.88)	(-0.97)	(-0.33)	(0.95)	(1.18)
Dist4	-96.55	-62.54	13.92	13.92	26.60	27.60
	(-1.54)	(-1.82)	(0.27)	(0.41)	(1.06)	(0.40)
Dist6	-87.87	-57.24	-82.16	-24.50	42.36	91.44
	(-1.22)	(-1.45)	(-1.40)	(-0.63)	(1.47)	(1.09)
Dist7	-257.69	-112.10	42.77	7.90	23.08	204.96
	(-2.46)	(-1.96)	(0.50)	(0.14)	(0.55)	(1.69)
Dist8	-63.32	-21.56	-88.15	-1.55	23.75	58.08
	(-1.94)	(-1.21)	(-3.32)	(-0.09)	(1.83)	(1.54)
Dist9	-60.93	-7.96	-72.63	45.05	47.03	-0.03
	(-1.11)	(-0.26)	(-1.62)	(1.52)	(2.15)	(-0.00)
Dist10	-43.79	-45.67	-58.10	14.63	35.89	134.73
	(-1.06)	(-2.03)	(-1.74)	(-0.66)	(2.19)	(2.84)
Dist12	37.83	-186.12	-102.98	143.96	38.45	100.76
	(0.35)	(-3.15)	(-1.17)	(2.48)	(0.90)	(0.81)
Dist13	-90.46	-3.88	-106.01	109.35	-4.64	-84.63
	(-0.90)	(0.07)	(-1.29)	(2.01)	(-0.12)	(-0.72)
Dist14	-51.73	-33.48	-18.05	3.39	67.31	98.78
	(-.88)	(-1.05)	(-0.38)	(0.11)	(2.89)	(1.46)
Dist15	-70.28	-56.53	-65.78	8.75	69.55	13.38
	(-0.62)	(-0.91)	(-0.71)	(0.14)	(1.53)	(0.10)
Dist16	-64.36	-237.85	-230.32	-200.50	68.72	230.86
	(-0.52)	(-3.49)	(-2.28)	(-2.99)	(1.39)	(1.60)
Dist18	-60.18	-44.70	-40.42	-13.03	31.15	79.26
	(-1.56)	(-2.13)	(-1.29)	(-0.63)	(2.03)	(1.78)
Dist19	-79.82	-38.71	-49.33	-1.33	31.44	78.82
	(-2.38)	(-2.11)	(1.81)	(-0.07)	(2.36)	(2.04)
Dist20	-49.53	-66.08	-11.31	30.44	40.85	64.14
	(-0.76)	(-1.86)	(-0.21)	(0.87)	(1.58)	(0.86)
Dist21	-63.32	-33.26	-51.15	-0.12	40.24	43.84
	(-1.82)	(-1.74)	(-1.80)	(-0.01)	(2.90)	(1.09)
Dist22	13.66	-30.84	-24.70	28.66	42.66	25.80
	(0.35)	(-1.43)	(-0.77)	(1.35)	(2.72)	(0.57)
Dist23	-40.45	-83.45	14.20	-18.26	2.11	-23.17
	(-0.40)	(-1.49)	(0.29)	(-0.33)	(0.05)	(-0.20)
Dist24	33.13	-53.38	-66.19	20.31	29.60	-37.49
	(0.50)	(-1.48)	(-1.24)	(0.57)	(1.13)	(-0.49)

Dist25	-62.85	-45.41	-59.79	41.10	38.92	12.60
	(-1.48)	(-1.96)	(-1.74)	(1.80)	(2.31)	(0.26)
Dist26	-26.44	13.68	-9.03	15.58	18.90	15.32
	(-0.55)	(0.52)	(-0.23)	(0.60)	(0.98)	(0.28)
Dist28	3.74	-12.04	-99.09	39.38	15.96	15.00
	(0.05)	(-0.29)	(-1.59)	(0.96)	(0.52)	(0.17)
Dist29	-91.23	-42.23	-139.67	24.30	37.39	145.39
	(-0.84)	(-0.72)	(-1.59)	(0.42)	(0.87)	(1.17)
Dist31	-57.09	-22.34	-50.22	0.85	38.43	-0.44
	(-1.47)	(-1.05)	(-1.59)	(0.04)	(2.49)	(-0.01)
Dist32	-79.39	-26.37	-47.31	8.65	28.64	71.05
	(-2.09)	(-1.27)	(-1.54)	(0.42)	(1.90)	(1.62)
Dist33	-81.61	-30.54	-98.16	28.10	38.73	153.60
	(-1.75)	(-1.20)	(2.59)	(1.12)	(2.09)	(2.85)
Dist34	-66.00	-22.12	-32.78	-0.90	41.13	19.67
	(-1.40)	(-0.86)	(-0.86)	(-0.04)	(2.20)	(0.36)
Constant	8.53	42.40	-1.93	-30.42	-58.70	-102.92
	(.17)	(1.51)	(-0.05)	(1.10)	(-2.87)	(-1.74)
R^2	0.58	0.59	0.74	0.58	0.43	0.59
Correlation Coefficient between actual and predicted values						
	0.76	0.77	0.86	0.76	0.66	0.77

No households were located in districts 5, 11, 17, 27, 30, or 35.
Numbers in parentheses are t-ratios
Sewer system - public is the "base" sewer system.
Dist1 is the "base" district.
July is the "base" month.