EDITED BY

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The Oxford Handbook *of* THE ECONOMICS OF FOOD CONSUMPTION AND POLICY

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INTRODUCTION

JAYSON L. LUSK, JUTTA ROOSEN, AND JASON F. SHOGREN

Throughout their history, humans' lives have been inextricably connected with the food they eat. All humans rely on food for sustenance and survival, but food has also shaped culture and civilization. Although much time was spent battling hunger and malnutrition, humans' proclivity for new and exotic goods such as spices or cane sugar made our ancestors willing to leave their homes seeking to trade with those in faraway lands. Given the historical importance of food and its link to culture, it is perhaps not surprising that food and agriculture are among the most regulated and romanticized industries in the modern world.

Historically, the challenge for humans has been to secure a sufficient supply of food to stave off hunger and starvation. As a result, much of the research on food and agriculture in the past century has focused on issues related to production efficiency, food supply, and farm profitability. While the problem of food availability has not been completely eradicated, people living in today's developed countries are as likely to suffer from problems of *over*consumption as from hunger or malnutrition. Today's food consumers not only have access to more food than ever before, they can also choose between a much wider variety and quality of foods than ever in the past; so much so that some psychologists claim consumers suffer from "choice overload."

As a result of these changes, farmers, agribusiness, policymakers, and academics have increasingly turned their attention away from the farm and toward the food consumer and to issues related to food consumption. Many recent developments have triggered greater interest in the economics of food consumption around the globe. Growing concerns about rising food prices and nutrition and have spurred speculation about the causes and consequences of expensive food. At the same time, consumer and environmental groups are demanding more from the food production system—sustainability, naturalness, reduced environmental impacts, and less use of genetic modification, growth hormones, pesticides, and so on. Technologies that have the potential to increase productivity and lower food prices are being spurned by some consumers and governments. Agricultural policies, which historically served to support farm incomes, are now being used to promote environmental objectives, protect consumers from unwanted food technologies, and identify origin of production. Perhaps at no time in the past has the food production system been confronted with such a confluence of challenges, and many, though not all, of the developments are a result of changes in consumer demand for food—demand for alternative production practices, increasing demand from developing countries, demand for new food products, demand for better nutrition, etc.

Although research on food demand and consumption has been active for several decades (e.g., see Unnevehr et al. 2010 for a historical account), there are presently few resources to which someone can turn as a basic reference on the economics of food consumption and policy that covers specificities of theories and methods related to the study of food consumers and covers issues in food demand and policy. This book is meant to fill that gap. Our hope is that it will serve as a useful reference guide to graduate students and academics working in the field of food economics and policy who are interested in the consumer end of the supply chain, and also to people employed in food and agricultural industries, special interest and activist groups, and policymakers.

The book is divided into three main parts: I, Theory and Methods; II, Food Policy; and III, Topics and Applications. The first section of the book contains eleven chapters covering the core theoretical and methodological approaches that are used in studying the economics of food consumption and policy. The focus of the chapters is on the application of the theories and methods to food consumption. There is no single unified theory of consumer demand. Rather, the literature consists of several competing and complementary theories, which are covered in Chapters 1 through 6. The chapters show how food consumers can be conceptualized as choosing quantities of goods (Chapter 1) or purchasing inputs from the market to produce goods and services of value (Chapter 2). Chapters 3 through 6 extend these foundational models to cases where consumers are uncertain about the quality or safety of food (Chapter 3), are less than perfectly rational (Chapter 4), and choose which good to buy given a good's characteristics (Chapters 5 and 6). While each of these chapters also discuss empirical implementation of the conceptual models, Chapters 7 and 8 delve more deeply into consumer research methods, focusing specifically on stated preference and experimental methods to determine product valuations of non-market goods or attributes. Chapters 9 through 11 cover topics related to the integration of models of consumer preference into market-level models involving interactions with firms and policymakers. Chapters 9 and 10 conceptualize consumer decision-making in light of the surge in product differentiation by firms. Chapter 11 provides a framework for assessing the economic effects of changes in consumer demand and food policy interventions on market prices and the welfare of food producers and consumers.

The second section of the book focuses specifically on policy issues related to food consumption. Several chapters in this section focus on the theory and conceptual issues relevant in food markets, such as product bans and labels, labeling, standards, political economy, and scientific uncertainty. Other chapters home in on policy issues of particular interest to the consumer end of the food supply chain such as food safety, nutrition, food security, and development.

The final section of the book turns attention to particular issues and topics related to the economics of food consumption and policy. These chapters are largely empirical and descriptive in nature, and are meant to serve as introductions to current topics. Several chapters discuss general trends in food consumption such as globalization, rising food prices, changes in away-from-home food consumption, and changes in food variety. The last section also contains chapters dealing with more specific food quality and food safety dimensions and with topics of emerging interest related to advertising, meat, environment, and ethics.

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PART I

THEORY AND METHODS

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CHAPTER 1

CONSTRAINED UTILITY MAXIMIZATION AND DEMAND SYSTEM ESTIMATION

NICHOLAS E. PIGGOTT AND
THOMAS L. MARSH

1 Introduction

The purpose of this chapter is to present an overview of constrained utility maximization and demand system analysis, targeting the applied economist examining issues of food demand. For completeness dual representations of the constrained utility maximization approach are presented, illustrating theoretical consistency between ordinary and inverse demand systems. An application of US food demand (food at home (FAH), food away from home (FAFH), and alcoholic beverages (ABs)) and relevant hypothesis tests are illustrated for both ordinary demand systems (quantity formation) and inverse demand systems (price formation). A comprehensive literature exists on the economics and econometrics of consumer demand analysis. Nonetheless, the central importance of the consumer to food markets continues to confront agricultural economists today. For example, demand systems are applied to estimate elasticities used in models for policy analysis (i.e., equilibrium displacement models, trade models), predict and forecast, test structural change, calculate welfare effects from price changes, and assess market effects from advertising, information, and food recalls. Consequently, the presentation of this chapter strives to strike a balance between theoretical rigor, empirical application, and implementation, which are important for quality research outcomes and effective policy recommendations.

The chapter is organized in the following manner. First, we provide an overview of the literature on consumer and demand system analysis with emphasis on complete food demand systems.[1] Second, we precent theoretical foundations, including the axioms of choice, constrained utility maximization, properties, and general demand restrictions. Third, we discuss dual functions, including the expenditure function, the indirect utility function, and the distance function. The first three dual approaches are standard tools of the applied demand system analyst. The distance function approach is less prevalent in the literature, but provides a theoretically consistent means to derive inverse demand relationships and to study consumer price formation. Fourth, we introduce welfare effects and integrability along with separability and aggregation. Fifth, we provide a review of functional forms. Sixth, we cover econometric issues that include estimation, inference and hypothesis testing, specification tests, and other empirical issues. Seventh, we provide an empirical example that focuses on FAH, FAFH, and ABs. Models of the almost ideal demand and inverse almost ideal demand systems are estimated and reported as well as some additional hypothesis tests and inferences regarding model performance. Finally, we provide concluding remarks.

1.1 Literature Review

This section highlights historical and broad contributions to neoclassical consumer demand analysis with focus on food and agricultural economics. More specific and targeted contributions are noted in the sections that follow.

The development of the linear expenditure model by Stone (1954) is often credited as one of the seminal papers in the demand system literature. This was followed by Barten's (1967) fundamental matrix equation, which was an important step in formalizing economic restrictions of consumer theory into a unified demand systems approach. Gorman's (1953, 1959, 1981) seminal work on preferences, separability, and aggregation laid a cornerstone for consumer demand theory. Barten (1977) reviewed some of the earlier demand system specification and estimation issues, while Pollak and Wales (1980, 1981, 1992) provided results on conditional demand models and incorporating demographic variables into demand systems. Deaton (1986) surveyed standard econometric issues of demand system estimation. Current demand system literature has focused on the rank of demand systems and functional specifications (see LaFrance and Pope 2008, 2009).[2]

[1] See LaFrance and Hanemann (1989) for development of incomplete demand systems. LaFrance (2001) provides a household production modeling framework for the applied economic analysis of consumption.

[2] Gorman (1981) demonstrated that in the case of exactly aggregable demand systems, integrability implies the matrix of Engle curve coefficients is at most rank 3. Full rank systems are those with rank equal to the columns of the coefficient matrix (Lewbel 1990). Barnett and Serletis (2008) provide a good discussion of demand system rank with examples.

Demand systems approaches have been pervasive in the agricultural economics literature, especially when examining the impact of prices, income, and other factors on food demand. For example, a significant amount of effort has been expended explaining changes in US food consumption and in particular identifying whether there has been structural change in demand. An incomplete list of such studies includes Chavas (1983), Moschini and Meilke (1984, 1989), Wohlgenant (1985), Dahlgran (1987), Eales and Unnevehr (1988, 1993), and Chalfant and Alston (1998). In addition, Holt and Goodwin (1997) investigated habit formation using US meat expenditures. Meanwhile, Capps and Love (2002) considered the use of electronic scanner data on fruit juices and drinks. Dhar, Chavas, and Gould (2003) explored branded products in the soft drink market using scanner data. Piggott (2003) examined US food demand using generalized PIGLOG models. A recent paper on the economic and econometric structure of food demand and nutrition is provided by LaFrance (2008).

Issues of advertising, health, and food safety effects on consumer demand have been examined using ordinary demand system approaches. Huang (1996) estimated nutrient elasticities in food demand. Brester and Schroeder (1995) examined the impacts of brand and generic advertising on meat demand in the US, while Piggott et al. (1996) investigated the impacts of advertising on meat demand in Australia. Kinnucan et al. (1997) investigated the effects of health and generic advertising on US meat demand. Piggott and Marsh (2004) examined the impact of public food safety information on meat demand. Marsh, Schroeder, and Mintert (2004) reported on the effect of product recalls on meat demand.

Relative to ordinary demand system approaches, which assume prices are fixed, inverse demand systems, which assume quantities are fixed, have received much less attention. Huang (1988) studied an inverse demand system for composite foods. Price formation has been previously studied for meat demand (Eales and Unnevehr 1994; Holt and Goodwin 1997; Holt 2002) and fish (Barten and Bettendorf 1989; Holt and Bishop 2002; Kristofersson and Rickertsen 2004, 2007). Alternatively, Moschini and Rizzi (2007) specified and estimated a system of mixed demand systems that allow adjustment of prices for some goods and of quantities for other goods to clear the market.[3]

Commonly used books on consumer demand analysis include (but are not limited to) Shephard (1970), Phlips (1974), Deaton and Muellbauer (1980b), Johnson, Hassan, and Green (1984), Theil and Clements (1987), Cornes (1992), Varian (1992), and Pollak and Wales (1992). These books provide a historical reference and neoclassical concepts of consumer demand with methods and applications to demand system analysis and duality theory. Other useful texts and readings include Chipman et al. (1971), Blackorby, Primont, and Russell (1978), Deaton (1981, 1986), Lancaster (1991), and Slottje (2009).

[3] Samuelson (1965) first analyzed mixed demand systems.

2 Preferences and Utility Maximization

In empirical analysis the existence of demand functions is often assumed with the anticipation that the law of demand and other properties may hold. Fortunately, microeconomic theory provides a set of fundamental assumptions on individual consumer preferences, often called the axioms of choice, which establish a theoretically consistent framework for demand system analysis. From the axioms of choice the existence of a utility function can be deduced, providing a convenient means to represent consumers' behavior. Furthermore, existence and properties of demand functions can be derived from constrained maximization with origins in the fundamental axioms on individual preferences.[4]

2.1 Axioms of Choice

Let X be a set of consumption bundles defined mathematically as a subset of a finite n-dimensional Euclidean space. The symbol $\succsim$ is used to mean "at least as preferred as" whereas $\succ$ is used to mean "strictly preferred to." Superscripts on vectors, for example, $\mathbf{x}^1$, will be used to distinguish different vectors. The axioms of choice are

Axiom 1. Reflexivity. For any bundle $\mathbf{x} \in X$, $\mathbf{x} \succsim \mathbf{x}$.
Axiom 2. Completeness. For any two bundles $\mathbf{x}^1 \in X$ and $\mathbf{x}^2 \in X$, either $\mathbf{x}^1 \succsim \mathbf{x}^2$ or $\mathbf{x}^2 \succsim \mathbf{x}^1$.
Axiom 3. Transitivity. Let $\mathbf{x}^1, \mathbf{x}^2, \mathbf{x}^3 \in X$. If $\mathbf{x}^1 \succsim \mathbf{x}^2$ and $\mathbf{x}^2 \succsim \mathbf{x}^3$, then $\mathbf{x}^1 \succsim \mathbf{x}^3$.
Axiom 4. Closure. For all $x \in X$, sets $\{\mathbf{x}^1 \in X : \mathbf{x}^1 \succsim \mathbf{x}\}$ and $\{\mathbf{x}^1 \in X : \mathbf{x} \succsim \mathbf{x}^1\}$ are closed.

The first axiom states that each bundle is as preferred as itself. The second axiom allows any two bundles to be compared. Axioms 1–4 are sufficient to allow representation of the preference ordering by a continuous, real-valued utility function $u(\mathbf{x})$.[5]

Axiom 5. Non-satiation. The utility function $u(\mathbf{x})$ is non-decreasing in each of its arguments and for all $\mathbf{x}$ in the choice set is increasing in at least one of its arguments.
Axiom 6. Convexity. If $\mathbf{x}^2 \succsim \mathbf{x}^1$, then for $0 \leq \lambda \leq 1$, $\lambda \mathbf{x}^2 + (1 - \lambda)\mathbf{x}^1 \succ \mathbf{x}^1$.

This axiom is a formal representation that indifference curves are convex to the origin, stating that the linear combination of $\mathbf{x}^1$ and $\mathbf{x}^2$ is as preferred as $\mathbf{x}^1$. From axioms 1–6 the utility function is non-decreasing, quasi-concave, and unique up to a strictly monotone function.[6]

[4] See Deaton and Muellbauer (1980b) and Cornes (1992) for additional introductory readings and references.

[5] See Blackorby, Primont, and Russell (1978).

[6] See Blackorby, Primont, and Russell (1978). Strict convexity rules out linear segments of indifference surfaces and facilitates the assumption of a second-order differentiable utility function in the optimization process. This assumption is useful in the application of duality theory.

The axioms of choice not only provide the logical and mathematical foundation for neoclassical consumer choice theory, but also provide means to justify constrained utility maximization. So should someone ask how an economist defends the use of a utility function, one answer is that it is equivalent to ranking preferences for bundles of goods.

2.2 The Primal Problem

The constrained utility maximization problem is represented by $\max_{x}\{u(\mathbf{x}) st\, \mathbf{p}'\mathbf{x} = m\}$ where u is a continuous, non-decreasing, and quasi-concave utility function, $\mathbf{x} = (x_1, \ldots, x_n)' > 0$ is a $(n \times 1)$ non-negative vector of goods, $\mathbf{p} = (p_1, \ldots, p_n)' > 0$ is a $(n \times 1)$ vector of given prices, and m is total fixed expenditure. The Lagrangian of the primal problem is $L = u(\mathbf{x}) + \lambda\left(m - \sum_{i=1}^{n} p_i x_i\right)$ with the first-order conditions yielding a system of n+1 partial differential equations $\frac{\partial L}{\partial x_i} = \frac{\partial u}{\partial x_i} - \lambda p_i = 0, i = 1, \ldots, n$ and $\frac{\partial L}{\partial \lambda} = m - \sum_{i=1}^{n} p_i x_i = 0$. Applying the Implicit Function Theorem, the utility-maximizing quantities demanded are $\mathbf{x} = \mathbf{x}(\mathbf{p}, m)$, which are the uncompensated (i.e., Marshallian) demand functions.[7] The Hotelling–Wold Identity $\frac{p_\ell}{m} = \frac{\partial u}{\partial x_\ell} / \sum_{j=1}^{n} x_j \frac{\partial u}{\partial x_j}$ provides the uncompensated system of inverse demand equations.

This set of demand functions satisfies the properties of homogeneity, aggregation, symmetry, and negativity (often termed the general demand restrictions). Both the derivative and elasticity form of these properties are provided ahead. Elasticity expressions are, for example, defined as $\varepsilon_{im} = \frac{\partial x_i}{\partial m}\frac{m}{x_i}$, which represents the total expenditure elasticity of demand for good i, and $\varepsilon_{ij} = \frac{\partial x_i}{\partial p_j}\frac{p_j}{x_i}$, which represents the price elasticity of demand for good i and price j. The ith share equation is $w_i = \frac{p_i x_i}{m}$. Applying Euler's Theorem (see Intriligator 1971; Silberberg 1978) with homogeneity of degree 0 in $\mathbf{p}$ and m gives rise to

$$0 = \sum_{j=1}^{n} \frac{\partial x_i}{\partial p_j} p_j + \frac{\partial x_i}{\partial m} m \Leftrightarrow \sum_{j=1}^{n} \varepsilon_{ij} + \varepsilon_{im} = 0.$$

Differentiating the budget constraint with respect to m yields Engle aggregation

$$\sum_{i=1}^{n} p_i \frac{\partial x_i(p, m)}{\partial m} = 1 \Leftrightarrow \sum_{i=1}^{n} w_i \varepsilon_{im} = 1.$$

Differentiating the budget constraint with respect to p_j yields Cournot aggregation

$$\sum_{i=1}^{n} p_i \frac{\partial x_i(p, m)}{\partial p_j} = -q_j \Leftrightarrow \sum_{i=1}^{n} w_i \varepsilon_{ij} = -w_j.$$

[7] If one does not assume an interior solution, then the first-order conditions can be derived by using the Kuhn–Tucker conditions (see Intriligator 1971).

From Young's Theorem, Slutsky symmetry can be derived as

$$\frac{\partial x_i}{\partial p_j} + x_j \frac{\partial x_i}{\partial m} = \frac{\partial x_j}{\partial p_i} + x_i \frac{\partial x_j}{\partial m}, i \neq j \Leftrightarrow w_i \varepsilon_{ij} + w_i w_j \varepsilon_{im} = w_j \varepsilon_{ji} + w_i w_j \varepsilon_{jm}, i \neq j.$$

From the Slutsky equation the standard price and income effects can be generated.[8] Compensated effects (and elasticities) can be derived from the substitution matrix as $\frac{\partial x_i^h}{\partial p_j} = \frac{\partial x_i}{\partial p_j} + x_j \frac{\partial x_i}{\partial \mathrm{m}} \Leftrightarrow \varepsilon_{ij}^h = \varepsilon_{ij} + w_j \varepsilon_{im}$, which is useful in classifying goods into substitutes ($\varepsilon_{ij}^h > 0, i \neq j$) and complements ($\varepsilon_{ij}^h < 0, i \neq j$). The matrix of compensated (i.e., Hicksian) demand functions is negative semi-definite, implying for each own-price effect the negativity condition of

$$\frac{\partial x_i^h}{\partial p_i} < 0, i = 1, \ldots, n.$$

Barten (1964, 1977) provides detailed derivations of general demand restrictions, including Barten's fundamental matrix equation, which concisely summarizes the above information. A set of parameters estimated from a demand system satisfying each of these restrictions is then fully consistent with the concept of constrained utility maximization.

3 Dual Functions

Duality involves transforming consumer preferences represented in one variable (e.g., quantity space for the utility function) to another variable, which can be more convenient for some theoretical or empirical problems. For example, in the expenditure function, preferences appear in price space as opposed to quantity space for the direct utility function. Below we provide an overview of the expenditure, indirect utility, and distance functions along with theoretical properties.[9]

3.1 Expenditure Function

The expenditure function is defined as the minimum expenditure of attaining utility level u at price $\mathbf{p}$. The dual expression can be defined as $e(\mathbf{p}, u) = \min_x \{\mathbf{p}'\boldsymbol{x} \; s.t. \; u(\mathbf{x}) = u\}$. The expenditure function is non-decreasing in $\mathbf{p}$, increasing in u, homogeneous of degree 1 in $\mathbf{p}$, and concave in $\mathbf{p}$. From Shephard's Lemma the compensated (i.e., Hicksian)

[8] Note that Engle aggregation, homogeneity, and symmetry imply Cournot aggregation, and are not independent relationships.

[9] See Blackorby, Primont, and Russell (1978) for a more rigorous presentation of duality theory and Deaton and Muellbauer (1980b), Varian (1992), and Cornes (1992) for additional introductory readings. Refer to Lusk et al. (2002) for some insights on the empirical properties of duality theory.

demand function arises from $\frac{\partial e(\mathbf{p},u)}{\partial p_j} = x_j^h(\mathbf{p}, u)$. The compensated demand functions are homogeneous of degree 0 in prices and satisfy the negativity condition.

3.2 Indirect Utility Function

The consumer's indirect utility function can be defined as

$$v(\mathbf{p}, m) = \max_x\{u(\mathbf{x})\ s.t.\ \mathbf{p}'\boldsymbol{x} = m\} = u(\mathbf{x}(\mathbf{p}, m))$$

The indirect utility function is non-increasing in $\mathbf{p}$, non-decreasing in m, homogeneous of degree 0 in $\mathbf{p}$ and m, and quasi-convex in $\mathbf{p}$. From Roy's Identity the uncompensated demand functions arise

$$\left(\frac{\partial v(\mathbf{p}, m)}{\partial p_j}\right) \Big/ \left(\frac{\partial v(\mathbf{p}, m)}{\partial m}\right) = -x_j$$

As above, the general demand restrictions of homogeneity, adding up, symmetry, and negativity hold. Alternatively, the uncompensated demand function can be obtained by the dual identity $x_j(\mathbf{p}, m) = x_j^h(\mathbf{p}, v(\mathbf{p}, m))$.

3.3 Distance Function

A less familiar dual function is the distance function from which inverse demand systems can be derived.[10] This is important in food demand analysis when quantities are predetermined. The standard consumer distance function can be defined by

$$d(\mathbf{x}, u) = \sup_{\tilde{d}}\left\{\tilde{d} > 0 | (\mathbf{x}/\tilde{d}) \in S(u), \forall u \in \mathbf{R}^1_+\right\}.$$

Here, u is a (1×1) scalar level of utility, $\mathbf{x} = (x_1, \ldots, x_n)'$ is a $(n \times 1)$ vector of predetermined goods, and $S(u)$ is the set of all vectors of goods $\mathbf{x} \in \mathbf{R}^n_+$ that can produce the utility level $u \in \mathbf{R}^1_+$. The underlying behavioral assumption is that the distance function represents a rescaling of all goods consistent with a target utility level u. Intuitively, d is the maximum value by which one could divide $\mathbf{x}$ and still realize u. The value d places $\mathbf{x}/d$ on the boundary of $S(u)$ and on a ray through $\mathbf{x}$.

Compensated inverse demand equations may be obtained by applying Gorman's Lemma $\frac{\partial d(\mathbf{x},u)}{\partial \mathbf{x}} = \tilde{\mathbf{p}}^h(\mathbf{x}, u)$, where $m = \sum_{i=1}^n p_i x_i$ and $\tilde{\mathbf{p}} = (\tilde{p}_1, \ldots, \tilde{p}_n)$ is a $(n \times 1)$ vector

[10] An even less familiar concept is the benefit function. Luenberger (1992) introduced the benefit function and Chambers, Chung, and Färe (1996) demonstrated that the benefit function is equivalent to a directional distance function. As pointed out by Luenberger (1992), the consumer distance function and the benefit function are distinctly different specifications. McLaren and Wong (2009) use the benefit function to specify and estimate price-dependent or inverse demand models.

of expenditure normalized prices or $\tilde{p}_i = p_i/m$.[11] The properties of a distance function are that it is homogeneous of degree 1, non-decreasing, and concave in quantities **x**, as well as non-increasing and quasi-concave in utility u (Shephard 1970; Cornes 1992). The Antonelli matrix $\frac{\partial^2 d(\mathbf{x},u)}{\partial\mathbf{x}\partial\mathbf{x}'}$ is negative semi-definite. Because the distance function is homogeneous of degree 1 in quantities, it follows that the compensated inverse demand function is homogeneous of degree 0 in quantities. Uncompensated inverse demand functions can be obtained by applying the dual identity $\tilde{\mathbf{p}}(\mathbf{x}) = \tilde{\mathbf{p}}^h(\mathbf{x}, u(\mathbf{x}))$.

The uncompensated price flexibilities are $f_{i\ell} = \frac{\partial \ln p_i(\mathbf{x};\mathbf{c})}{\partial \ln x_\ell}$. The compensated flexibilities $f_{i\ell}^h = \frac{\partial \ln p_i(\mathbf{x},u)}{\partial \ln x_\ell}$ can be recovered using the expression $f_{i\ell}^h = f_{i\ell}\text{-}f_i w_j$. Scale flexibilities $f_i = \frac{\partial \ln p_i(\lambda\mathbf{x})}{\partial \ln \lambda}$ can be derived by $\frac{\partial \ln p_i(\lambda\tilde{\mathbf{x}})}{\partial \ln \lambda} = \sum_{j=1}^n f_{ij}$ for any scalar λ (Anderson 1980). Conceptual and empirical properties exist between flexibilities and elasticities, which are discussed further in Huang (1994) and Lusk et al. (2002).

4 Aggregation and Separability

Consumers at any given time allocate resources between many goods (e.g., between foods or food groups, food/non-food goods, durable/non-durable goods, or current/future goods). It is important to find ways in which the consumer problem can be simplified, either by aggregation, so that whole categories can be dealt with as single units, or by separation, so that the problem can be dealt with in smaller, more manageable units, making it empirically tractable (Deaton and Muellbauer 1980b). Below we provide a brief introduction of aggregation and separability issues to set the stage for the empirical analysis later in this chapter.[12]

4.1 Aggregation

Aggregation can be thought of as the transition from the microeconomics of individual consumer behavior to the analysis of market demand. It is important to know what useful properties, if any, of the disaggregated model survive the aggregation process. Generally speaking, the aggregate demand function will possess no interesting properties other than homogeneity and continuity (Varian 1992: 155).

However, functional forms exist that can yield aggregate demand functions that are useful in economic analysis. Two forms of aggregation are exact linear aggregation and exact non-linear aggregation. An important role of aggregation theory is to provide

[11] If **x** is a bundle for which $u(\mathbf{x}) = u$ then $d(\mathbf{x}, u) = 1$, and the share form of the expression above is given by $\frac{\partial \ln d(\mathbf{x},u)}{\partial \ln \mathbf{x}} = \mathbf{w}(\mathbf{x}, u)$.

[12] See Blackorby, Davidson, and Schworm (1991) for a more rigorous presentation and Deaton and Muellbauer (1980b) and Cornes (1992) for additional readings.

necessary conditions under which it is possible to treat aggregate consumer behavior as if it were the outcome of the decisions of a single utility maximizing consumer.

Consider the aggregate demand function $x_i = x_i(\mathbf{p}, M) \equiv \sum_{h=1}^{H} x_{ih}(\mathbf{p}, m_h) = x_i(\mathbf{p}, m_1, \ldots, m_H)$, where there are $h = 1, \ldots, H$ consumers. Aggregate demand exists (theoretically) with an income for each consumer. In empirical work total income or the mean income level are more available but data may not be accessible for the income of each individual. Linear aggregation of income $M = \sum_{h=1}^{H} m_h \left(\Leftrightarrow \bar{M} = \frac{1}{H}\sum_{h=1}^{H} m_h\right)$ implies linearity of income for consumer demand. More formally $x_i(\mathbf{p}, M) \equiv \sum_{h=1}^{H} x_{ih}(\mathbf{p}, m_h)$ with $\mathrm{M} = \sum_{h=1}^{H} m_h$ if and only if $\frac{\partial x_{ih}}{\partial m_h} = \beta_i(\mathbf{p}) \forall h, i$. That is, this occurs if and only if the demand function is a linear function of income

$$x_i(\mathbf{p}, M) = \sum_{h=1}^{H} [\beta_i(\mathbf{p}) m_h + a_{ih}(\mathbf{p})] = \beta_i(\mathbf{p}) M + \alpha_i(\mathbf{p})$$

In effect, under exact linear aggregation, Engle curves are linear and the same slope for each individual. These restrictive conditions are not appealing for most empirical work.

Exact non-linear aggregation, wherein Engle curves are not necessarily linear, generalizes the above specification (see Deaton 1986). It requires only that demand for goods depends on prices and a representative level of expenditure, M, which itself can be a function of the distribution of expenditures and of prices. In this case, the market pattern of demand can be thought of as deriving from the behavior of a single representative individual endowed with total expenditure M and prices $\mathbf{p}$. A particularly relevant case for the applied economist occurs when the representative expenditure level is independent of prices and only depends on the distribution of expenditures. This case is known as the price-independent generalized linearity (PIGL). The logarithmic form is known as the PIGLOG, where the microexpenditure function is expressed as

$$\ln e(u, \mathbf{p}) = (1 - u) \ln a(\mathbf{p}) + u \ln b(\mathbf{p})$$

for function of prices $a(\mathbf{p})$ and $b(\mathbf{p})$. This gives rise to the almost ideal demand system, which is non-linear in expenditure, and is pervasive in the food demand literature. We illustrate this further as an application in the empirical section of this chapter. For recent extensions and further discussion of these issues, see Slottje (2009).

4.2 Separability

Separability is relevant because it has the potential to reduce the dimensionality of the consumer demand problem and allow a researcher to examine one aspect of a problem in relative isolation from others. For example, meat is often assumed separable from other foods. There are several historical forms of separability in the economic literature, including Hicksian separability and functional separability. Here we focus on functional separability.[13]

Alternative forms of separability inherit characteristics from the structure of the utility function. Consider, first, the concept of additive separability (Houthakker 1960). The utility function that is additively separable is expressed as $u(x) = f(x_1) + \ldots + f(x_n)$. This implies functional independence of the marginal utility of good i from the consumption of any other good, or

$$\frac{\partial u}{\partial x_i} = \frac{\partial f_i}{\partial x_i} \Rightarrow \frac{\partial^2 u}{\partial x_i \partial x_j} = \frac{\partial^2 f_i}{\partial x_i \partial x_j} = 0.$$

Is the additivity assumption ever defensible? Some argue it is for broad aggregates such as food, housing, or clothing, as opposed to individual commodities. However, most agree that the restrictive nature implied for the underlying preference structure limits its usefulness for food demand analysis.

A more general concept is weak separability, which has been applied in many empirical food demand studies. Suppose there exists a partition of m groups of goods (with n_m goods in group m), and consider two groups q and r (say, beverages and meats, respectively). Formally, weak separability arises when $u(x_{11}, \ldots, x_{1n_1}, x_{21}, \ldots, x_{2n_2}, \ldots, x_{m1}, \ldots, x_{mn_m}) = F(f_1(x_{11}, \ldots, x_{1n_1}), \ldots, f_m(x_{m1}, \ldots, x_{mn_m}))$ if and only if $\frac{\partial}{\partial x_{qk}}\left[\left(\frac{\partial u}{\partial x_{ri}}\right) / \left(\frac{\partial u}{\partial x_{rj}}\right)\right] = 0 \quad \forall\, r,\ i,\ j,\ k,\ q\,(q \neq r)$ and where $k \in \{1, \ldots, n_q\}$ and $i, j \in \{1, \ldots, n_r\}$. In other words, under weak separability, the ratio of marginal utilities from goods within one group (say, meats) is independent relative to the change in consumption of a good in another group (say, beverages). Goldman and Uzawa (1964) demonstrated that a direct result of weak separability is that price effects from outside a particular group of goods are translated through income effects. Alternative forms of separability that may be of interest to the applied economist are implicit and asymmetric separability.[14]

5 Integrability and Welfare Effects

The problem of integrability is summarized by the question "If $\mathbf{x}(\mathbf{p}, m)$ satisfies the general demand restrictions, can one integrate $\mathbf{x}(\mathbf{p}, m)$ back and recover the utility function?" As demonstrated above, in mathematical terminology, the first-order

[13] Hicksian separability occurs if prices of a group of goods change proportionately, then the corresponding group of goods can be aggregated into a single composite commodity having a single price for purposes of analyzing consumer demand. However, if prices of a group of goods do not change proportionately, then an alternative approach such as weak separability is needed.

[14] See Blackorby, Primont, and Russell (1978) and Moschini, Moro, and Green (1994) for more details related to weak and other forms of separability. To read more on two-stage budgeting and separability, see Deaton and Muellbauer (1980b).

conditions form a system of partial differential equations (PDEs). A necessary condition for a local solution to the system of PDEs is symmetry of cross-partial derivatives (i.e., satisfy mathematical integrability and path independence). Hence, economic integrability requires mathematical integrability (i.e., Slutsky symmetry) plus Engle aggregation, homogeneity, and curvature properties of $\mathbf{x} = h^m(\mathbf{p}, m)$. Therefore, recovering a utility, indirect utility, or expenditure function requires economic integrability (Hurwicz and Uzawa 1971; Silberberg 1978).

Integrability not only allows recovery of preference structure, but also provides the means to measure exact welfare changes.[15] Two standard measures of exact welfare are equivalent and compensating variation. Consider a consumer with an initial price vector and budget at $(\mathbf{p}^0, m^0)$. The idea is to obtain a measure of the welfare change implied by the move from $(\mathbf{p}^0, m^0)$ to $(\mathbf{p}^1, m^1)$. The equivalent variation associated with the move from $(\mathbf{p}^0, m^0)$ to $(\mathbf{p}^1, m^1)$ is defined as that amount of income that, if given to the consumer, would have exactly the same effect on his/her welfare as the move from $(\mathbf{p}^0, m^0)$ to $(\mathbf{p}^1, m^1)$. The equivalent variation can be represented by $EV^{01} = E(\mathbf{p}^0, u^1) - E(\mathbf{p}^1, u^1)$. For a single price change it can be represented by $EV^{01} = \int_{p_j^1}^{p_j^0} x_j^h(\mathbf{p}, u^1)\, dp_j$.

Compensating variation provides an answer to the following question: How much income would have to be taken away from the consumer in order to negate the effect of moving from $(\mathbf{p}^0, m^0)$ to $(\mathbf{p}^1, m^1)$? The compensating variation can be represented by $CV^{01} = E(\mathbf{p}^0, u^0) - E(\mathbf{p}^1, u^0)$. For a single price change it can be represented by $CV^{01} = \int_{p_j^1}^{p_j^0} x_j^h(\mathbf{p}, u^0)\, dp_j$. Approaches to estimate the magnitude and precision of welfare changes for single or multiple price changes are discussed in Vartia (1983) and Breslaw and Smith (1995).[16] See Just, Hueth, and Schmitz (2004) for further reading on applied welfare economics.

6 Functional Forms and Examples

Popular functional forms of ordinary demand systems include the translog model of Christensen, Jorgenson, and Lau (1975), the almost ideal (AI) demand system of Deaton and Muellbauer (1980a, b), and the normalized quadratic model (Diewert and Wales 1988). Differential demand systems were developed by Barten (1964) and Theil (1965), who provide alternative specifications of the Rotterdam model. Barnett (1979) provided theoretical foundations for the Rotterdam model. Several generalizations of these models include the AI translog model of Lewbel (1989), the generalized translog (Pollak and Wales 1980), the generalized AI (Bollino 1987), the globally flexible AI (Chalfant 1987), the generalized AI translog (Bollino and Violi 1990), the quadratic

15 See Diewert (2009) for exact index methods to approximate cost of living and welfare changes.

16 Kim (1997) provided information to estimate welfare impacts from quantity measurements. Holt and Bishop (2002) apply this approach to price formation of fish.

AI (Banks, Blundell, and Lewbel 1997), and the nested PIGLOG (Piggott 2003). LaFrance and Pope (2009) derived a generalized quadratic expenditure system. Functional forms of inverse demand systems include the inverse linear expenditure model, the inverse almost ideal (IAI) demand model of Eales and Unnevehr (1994), and inverse normalized quadratic model of Holt and Bishop (2002).

For illustrative purposes we include two duality examples. The first example uses the Cobb–Douglas functional form, which is a globally regular function with rank 1.[17] The second example uses the AI demand function, which is a locally flexible function of rank 2. Note that with the Cobb–Douglas specification, it is straightforward to derive the inverse uncompensated demand function directly from the uncompensated demand function. However, as shown below with the AI functional form, solving for the inverse demand function directly from the demand function is not always possible, further motivating the usefulness of duality relationships.

6.1 Duality Example I: The Cobb–Douglas Functional Form

A simple example demonstrating the dual relationships is the Cobb–Douglas functional form. Consider the utility function $u(\mathbf{x}) = \left(x_1^{\alpha_1} x_2^{\alpha_2}\right)$ with two goods where $\alpha_1 + \alpha_2 = 1$. Following standard relationships the following dual functions can be derived: (a) the indirect utility function $v(\mathbf{p}, M) = \left(\alpha_1 \frac{M}{p_1}\right)^{\alpha_1} \left(\alpha_2 \frac{M}{p_2}\right)^{\alpha_2}$ and (b) the expenditure function $e(\mathbf{p}, u) = \left(u \left(\frac{p_1}{\alpha_1}\right)^{\alpha_1} \left(\frac{p_2}{\alpha_2}\right)^{\alpha_2}\right)$. The distance function is $d(\mathbf{x}, u) = \left(\frac{(x_1)^{\alpha_1} (x_2)^{\alpha_2}}{u}\right)$. Further, and considering good 1 for convenience, applying Roy's Identity to the indirect utility function yields the uncompensated demand function $x_1^m = \alpha_1 \frac{M}{p_1}$. This demand system is homothetic with Engle curves through the origin and of rank 1.[18] The compensated demand function $x_1^h = \left(u \frac{p_1}{p_2} \frac{\alpha_2}{\alpha_1}\right)^{\alpha_1 - 1}$ (from Shephard's Lemma), uncompensated inverse demand function $p_1^m = \frac{\alpha_1 M}{(x_1)}$ (by the Hotelling–Wold Identity), and compensated inverse demand function $\tilde{p}_1^h = \frac{\alpha_1}{u} \left(\frac{(x_1)}{(x_2)}\right)^{\alpha_1 - 1}$ (from Gorman's Lemma). From the Hotelling–Wold Identity the uncompensated inverse share equation is given by $w_1^{im} = \left[\alpha_1 \left(\frac{x_i}{(x_i - c_i)}\right)\right] / \left[\sum_{j=1}^{n} \left[\alpha_1 \left(\frac{x_j}{(x_j - c_j)}\right)\right]\right]$ while the uncompensated share equation $w_1^m = \frac{p_1 c_1}{M} + \alpha_1 \frac{\overset{*}{M}}{M}$.[19]

[17] See Barnett and Serletis (2008) for discussion of global regularity versus flexible functional forms (arbitrary second-order approximation) and rank.

[18] This is a rank 1 demand system because it is comprised of a single term that is a function of price. See Barnett and Serletis (2008).

[19] This uncompensated inverse share expression is identical to equation (6) in Moschini and Vissa (1992) and derived in Marsh and Piggott (2010).

6.2 Duality Example II: The Almost Ideal Demand Function

Following Deaton and Meullbauer (1980a) the expenditure functions can be defined as $\ln e(\mathbf{p}, u) = (1 - u) \ln a(\mathbf{p}) + u \ln b(\mathbf{p})$. Applying Shephard's Lemma and substituting the indirect utility function yields the share expression $w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln (m/P)$ where $\ln P = \alpha_0 + \sum_{j=1}^{n} \alpha_j \ln p_j + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j$. This demand system is logarithmic in expenditure with two terms containing price functions and is of rank 2. Necessary demand conditions that lead to parameter restrictions are: $\sum_{i=1}^{n} \alpha_i = 1, \sum_{j=1}^{n} \gamma_{ij} = 0, \sum_{i=1}^{n} \beta_i = 0$ adding up; $\sum_{i=1}^{n} \gamma_{ij} = 0$ homogeneity; and $\gamma_{ij} = \gamma_{ji}$ symmetry.

Following Eales and Unnevehr (1994) the logarithmic distance function may be specified as $\ln d(\mathbf{x}, u) = (1 - u) \ln a(\mathbf{x}) + u \ln b(\mathbf{x})$. The IAI expenditure system is obtained by substituting in the equations $\ln a(\mathbf{x}) = \tilde{\alpha}_0 + \sum_{j=1}^{n} \tilde{\alpha}_j \ln x_j + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{\gamma}_{ij} \ln x_i \ln x_j$ and $\ln b(\mathbf{x}) = \tilde{\beta}_0 \prod_{i=1}^{n} x_i + \ln a(\mathbf{x})$. Applying Gorman's Lemma and substituting in the direct utility function $u(\mathbf{x}) = \ln a(\mathbf{x}) / (\ln a(\mathbf{x}) - \ln b(\mathbf{x}))$, which is obtained by inverting the distance function at $d(\mathbf{x}, u) = 1$. The share form of the inverse demand function is $w_i = \tilde{\alpha}_i + \sum_{j=1}^{n} \tilde{\gamma}_{ij} \ln x_j + \tilde{\beta}_i \ln Q$ where $\ln Q = \tilde{\alpha}_0 + \sum_{j=1}^{n} \tilde{\alpha}_j \ln x_j + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{\gamma}_{ij} \ln x_i \ln x_j$. Necessary demand conditions lead to parameter restrictions of the distance function specification as follows: $\sum_{i=1}^{n} \tilde{\alpha}_i = 1, \sum_{j=1}^{n} \tilde{\gamma}_{ij} = 0, \sum_{i=1}^{n} \tilde{\beta}_i = 0$ adding up; $\sum_{i=1}^{n} \tilde{\gamma}_{ij} = 0$ homogeneity; and $\tilde{\gamma}_{ij} = \tilde{\gamma}_{ji}$ symmetry.

7 Econometric Methods

There is an extensive literature on the empirical estimation of consumer demand models. Working (1926) provided a seminal paper entitled "What Do Statistical Demand Curves Show?" Stone's empirical application of the linear expenditure system arrived in 1954. Deaton (1986) provided an extensive review of demand system models and estimation issues. Lafrance (2008) provided a recent example of aggregate food demand analysis. A more current focus has been on microeconometric analysis, the analysis of individual-level data, which is now more available to the applied economist and is briefly discussed below (see Cameron and Trivedi 2005).

Consider a system with $i = 1, \ldots, N$ goods and $t = 1, \ldots, T$ time-series observations; this yields NT total observations. For estimation purposes, the demand system can be represented at time t by the non-linear specification $w_t = f_t(\beta, x_t) + \varepsilon_t$ where w_t is a vector of share equations, f is a differentiable non-linear function of unknown parameters β structuring the consumer's model, x_t is a vector of explanatory exogenous variables, and ε_t a vector of unknown residuals. Classical assumptions on the residual of the regression model are that $E(\varepsilon_t | x_t) = 0$ and $E(\varepsilon_t \varepsilon_t' | x_t) = \Omega$ is a finite contemporaneous correlation matrix. Here, the expected value of the residuals is 0 with constant variance exhibiting independence over time and correlation across equations. Standard estimators of this model, which are contingent on the properties of the residuals (and the maintained assumptions of the demand model), are least squares, maximum likelihood, and generalized method of moments. For example, the iterative seemingly unrelated regression model is commonly applied in the presence of contemporaneous correlation across equations. However, across competing estimators, trade-offs exist between less restrictive model assumptions and performance properties of the estimators. General discussion about, and specific references for, finite-sample (e.g., bias and efficiency) properties and large-sample (consistency and asymptotic efficiency) properties and distributions of these estimators can be found in Davidson and MacKinnon (1993), Mittelhammer (1996), Mittelhammer, Judge, and Miller (2000), and Greene (2008). In the share form of the system, the adding up constraint induces singularity in the covariance matrix Ω of the residual ε. This is addressed by omitting one of the goods from the estimation process, leaving $N-1$ goods and $(N-1)\times T$ remaining observations. Parameter estimates from the omitted equation are recovered through general demand restrictions.

Important econometric issues arise in estimation of demand systems, including identification, residual violations, and simultaneity. Working (1926) initially addressed issues of identification of demand and supply models. Hsiao (1983) provided a review of identification issues with insightful examples. Davidson and MacKinnon (1993) provided another good source for background on identification.

In empirical applications, contingent on the data-generating process, the residuals of the model could exhibit heteroskedastic disturbances, autoregressive disturbances, or combinations of these processes, which typically reduces efficiency (but does not affect consistency) of the estimator. Berndt and Savin (1975) developed the approach to estimation and hypothesis testing in singular equation systems with autoregressive disturbances. Given that the form of heteroskedasticity is known, then feasible least squares, iterated seemingly unrelated regression, maximum likelihood, and generalized methods of moments remain standard tools to consistently estimate systems of equations. White's heteroskedastic robust consistent covariance estimator and the Newey–White autoregressive–heteroskedastic consistent covariance estimator are often applied in practice if the form of heteroskedasticity is unknown (Greene 2008). For time-series data, unit root processes are feasible and require specific attention in demand system estimation (see Greene 2008). Balcombe (2004) applied cointegration methods to demand system analysis.

Simultaneity, on the other hand, in the regression model can arise and create bias and inconsistent parameter estimates, and the usual tests for these parameters are not appropriate (Judge et al. 1985; Thurman 1987). Here the model $w_t = f_t(\beta, x_t) + \varepsilon_t$ contains x_t, which is a vector of explanatory predetermined and endogenous variables. Hausman–Wu tests provide a general form of specification testing for endogeneity (Judge et al. 1985). In this situation, instrumental variable approaches are common estimators (Deaton 1986), as well as limited or full information maximum likelihood and generalized method of moments. Tests for weak instruments and overidentification restrictions are also standard tools and discussed in Greene (2008).

Hypothesis testing related to model parameters and specification is a crucial part of demand systems analysis. The standard Wald, Lagrange multiplier, and likelihood ratio test approaches for individual and joint hypotheses (e.g., symmetry) are covered in Engle (1984), as well as Mittelhammer (1996), Mittelhammer, Judge, and Miller (2000), Greene (2008), and Davidson and MacKinnon (1993). Bewley (1986) and Moschini, Moro, and Green (1994) provide adjusted likelihood ratio test approaches designed for tests in systems estimation. These hypothesis testing procedures can also be used to compare nested models by parameter restrictions. However, comparing performance of non-nested models is often of interest in practice. Non-nested hypothesis testing arises when, for example, competing models are not nested in the sense that one model cannot be made a special case of another by parameter restrictions. An introduction to non-nested testing is included in Davidson and MacKinnon (1993). Vuong (1989) provided a generalized likelihood test for non-nested models useful for testing between competing specifications of demand systems.

Other empirical research focused on hypothesis testing is relevant to the applied economist. McGuirk et al. (1995) provided an overview of system misspecification testing and structural change related to meat demand. Moschini, Moro, and Green (1994), Eales and Unnevehr (1988), and Eales and Wessells (1999) test for separability in food products. Useful non-parametric tests for normality and independence are described in Mittelhammer (1996, ch. 10).

The availability of more disaggregate data has refocused some traditional issues and introduced other econometric issues into the forefront of demand system estimation. For example, Dhar, Chavas, and Gould (2003) examined brand-level scanner data and tested for simultaneity and separability. Furthermore, missing observations that are latent in nature remain pervasive in disaggregate data often adding an additional layer of censoring complexity to systems estimators (Yen and Lin 2006). Spatial processes have recently received attention in systems estimation of disaggregate data. These topics are rich areas of future research.

8 Empirical Application

This section highlights how different approaches and methods can impact results in practice. That is, researchers' empirical application of demand systems is fraught with auxiliary hypotheses of specification choices that can impact results. This reality of empirical work is unavoidable and presents significant challenges to researchers. Space limitation precludes a thorough and complete analysis of all of the challenges involved. We limit our attention to examination of a single data set that involves annual US food-at-home (FAH), food-away-from-home (FAFH), and alcoholic beverages (AB) consumption over the period 1978–2007. This offers the novel opportunity to explore price formation for FAH, FAFH, and AB, which has not been published as far as we are aware. Furthermore, we investigate an important modeling choice involving food demand that confronts agricultural economists. Specifically, we investigate whether a system of inverse demands, where prices are a function of quantities providing an alternative and fully dual approach to ordinary demand system, is a more appropriate way to model food demand consistently with the idea that food quantities are exogenous (supply is inelastic) and it is price that must adjust to establish a market clearing equilibrium. The possibility of demand models that specify prices as a function of quantities is motivated by the perishability of the many foods now consumed and the increasing prevalence of consumption of food away from home which tends to be freshly prepared with a limited shelf life. To evaluate this question we employ a novel straightforward example of estimating the IAI demand system (Eales and Unnevehr 1994) and the AI demand system (Deaton and Muellbauer 1980a) using the same data set and then proceed to make comparisons of each of the models' statistical performance based on econometric criteria and also qualitative assessments of the estimated economic effects in an effort to identify definitively an empirically preferred approach.

8.1 The Inverse Almost Ideal (IAI) Demand System

The share form of the IAI demand system can be expressed as

$$w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \ln x_j + \beta_i \ln Q$$

where

$$\ln Q = \alpha_0 + \sum_{j=1}^{n} \alpha_j \ln x_j + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln x_i \ln x_j$$

and variables w_i = expenditure share of food $i (w_i = \frac{p_i x_i}{M})$, x_i = quantity demanded of food i, p_i = price of food i, and parameters are to be estimated as $\alpha_0, \alpha_\mathrm{i}, \gamma_{ij}$, and β_i (Eales and Unnevehr 1994). Necessary demand conditions that lead to parameter restrictions of the distance function specification are as follows:

$$\sum_{i=1}^{n} \alpha_i = 1, \sum_{j=1}^{n} \gamma_{ij} = 0, \sum_{i=1}^{n} \beta_i = 0 \text{ adding up}$$

$$\sum_{i=1}^{n} \gamma_{ij} = 0 \text{ homogeneity}$$

$$\tilde{\gamma}_{ij} = \tilde{\gamma}_{ji} \text{ symmetry}$$

Price and scale flexibilities are defined by

$$\frac{\partial \ln p_i(\mathbf{x})}{\partial \ln x_\ell} = \frac{1}{w_i}\left[\gamma_{i\ell} + \beta_i\left(\alpha_\ell + \sum_{j=1}^{n}\gamma_{j\ell}\ \ln(x_j)\right)\right] - \delta_{i\ell}$$

$$\frac{\partial \ln p_i(\lambda\tilde{\mathbf{x}})}{\partial \ln \lambda} = -1 + \beta_i/w_i,$$

where the last equality simplifies due to imposition of general demand restrictions with reference vector $\tilde{\mathbf{x}}$

8.2 The Almost Ideal (AI) Demand System

The share form of AI demand function can be derived as

$$w_i = \alpha_i + \sum_{j=1}^{n}\gamma_{ij}\ \ln\ p_j + \beta_i\ \ln\ P$$

where

$$\ln\ P = \alpha_0 + \sum_{j=1}^{n}\alpha_j\ \ln\ p_j + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\gamma_{ij}\ \ln\ p_i\ \ln\ p_j,$$

and w_i= expenditure share of food $i(w_i = \frac{p_i x_i}{M})$, p_i = price of food i, x_i = quantity demanded of food i, and parameters are to be estimated as $\alpha_0, \alpha_i,\ \gamma_{ij},$ and β_i (Deaton and Muellbauer 1980a). Necessary demand conditions that lead to parameter restrictions of the expenditure function specification are as follows:

$$\sum_{i=1}^{n}\alpha_i = 1, \quad \sum_{j=1}^{n}\gamma_{ij} = 0, \quad \sum_{i=1}^{n}\beta_i = 0 \ \text{ adding up}$$

$$\sum_{i=1}^{n}\gamma_{ij} = 0 \text{ homogeneity}$$

$$\gamma_{ij} = \gamma_{ji} \text{ symmetry.}$$

Price and expenditures elasticities are defined by

$$\frac{\partial \ln q_i(\mathbf{p})}{\partial \ln p_\ell} = \frac{1}{w_i}\left[\gamma_{i\ell} - \beta_i\left(\alpha_\ell + \sum_{j=1}^{n}\gamma_{j\ell}\ \ln(p_j)\right)\right] - \delta_{i\ell}$$

$$\frac{\partial \ln q_i(\mathbf{p})}{\partial \ln M} = -1 + \beta_i / w_i$$

8.3 Empirical Results

The IAI and AI models are applied to aggregate annual time-series data for food demand in the United States over the period 1978–2007 (thirty years). Expenditures on food are maintained to be weakly separable from expenditure on all other goods. The annual consumer expenditure data are from the United States Department of Agriculture measuring FAFH, FAH, and AB. Per capita expenditure series were derived by dividing expenditures by US population data from the Census Bureau. Per capita consumption series were then constructed by dividing the expenditure data by the appropriate price index, which is from the Bureau of Labor Statistics.

The summary statistics are shown in Table 1.1, which reveals that US consumers, over the past thirty years, spent an average of $2,665 per person annually on food. These expenditures were allocated on average as follows: 39.4 percent on FAFH, 48.5 percent on FAH, and 12 percent on AB. However, these average expenditure shares mask an important trend that FAFH expenditures have become more prominent, while FAH expenditures have been declining, with expenditures on AB remaining relatively stable. These trends are made clear in Figure 1.1, which reveals that if these trends continue then FAFH will soon account for the largest component of US consumers' food budget. Piggott (2003) makes the point that there has been an abundant literature investigating factors responsible for these changes and the growing importance of FAFH. A large part of

Table 1.1 Summary statistics of annual data, 1978–2007 (30 observations)

Variables	Average	Standard deviation	Minimum	Maximum
FAFH expenditure ($/capita)	1,073.770	400.830	430.870	1,840.180
FAH expenditure($/capita)	1,271.880	333.359	687.507	1,932.630
Alcoholic beverages ($/capita)	319.555	102.139	162.691	538.209
Total expenditures ($/capita)	2,665.200	834.276	1,281.070	4,311.020
FAFH price index	139.385	38.271	68.300	206.659
FAH price index	138.178	36.560	73.800	201.245
Alcoholic beverages price index	141.944	39.409	74.100	207.026
Share FAFH	0.394	0.031	0.336	0.428
Share FAH	0.485	0.028	0.447	0.537
Share alcoholic beverages	0.120	0.006	0.110	0.128

Sources: Food expenditures are from Economic Research Service, US Department of Agriculture, <http://www.ers.usda.gov/briefing/CPIFoodAndExpenditures/Data/table1.htm>; price data are from US Bureau of Labor Statistics <http://data.bls.gov/PDQ/outside.jsp?survey=cu>; population data are from US Census Bureau <http://www.census.gov/popest/archives/1990s/popclockest.txt>, <http://www.census.gov/popest/states/NST-ann-est2007.html>.

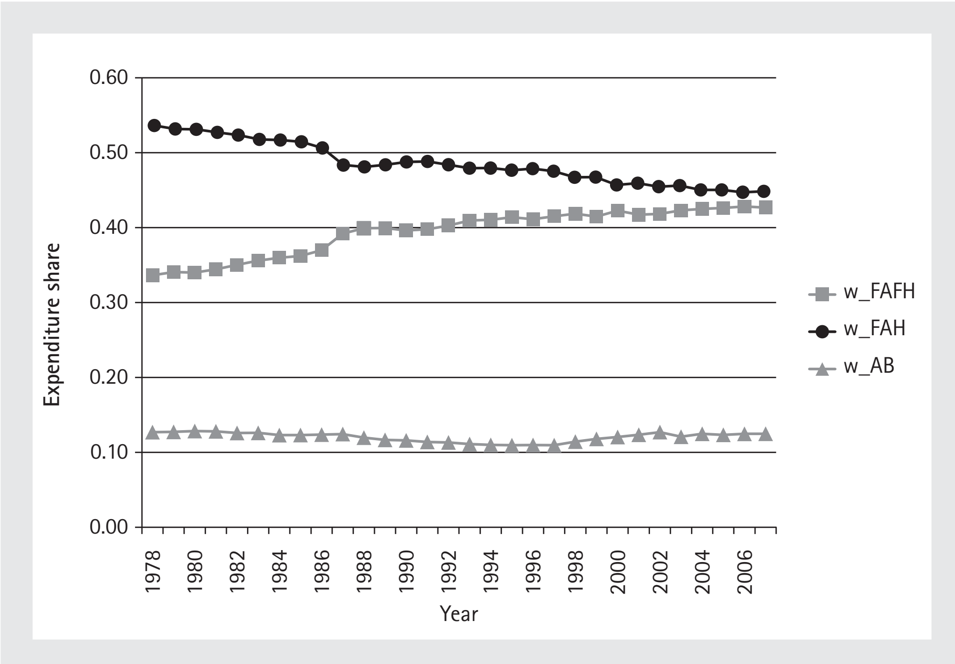

FIGURE 1 US expenditure shares of FAH, FAFH, and AB, 1978–2007

this literature has been concerned with utilizing cross-sectional data such as panel data and assessing the impact of household demographics and change in the workforce participation etc. A viable alternative approach following Piggott (2003) is to employ aggregate time-series data applied to theoretical consistent complete demand systems. Of particular interest in this chapter is to examine the empirical question of whether a system of inverse demands, where prices are a function of quantities providing an alternative and fully dual approach to the ordinary demand system, is a more appropriate way to model food demand consistently with the idea that food quantities are exogenous (supply is inelastic) and it is price that must adjust to establish a market clearing equilibrium.

8.4 Some Estimation Issues

The IAI and AI models are estimated as separable complete systems of equations including FAFH, FAH, and AB using iterated non-linear estimation techniques in SAS (proc model and ITSUR). Because of the singular nature of the share system, one of the equations must be deleted in estimation (AB). General demand restrictions of homogeneity, symmetry, and aggregation are imposed and treated as maintained hypotheses. Both the IAI and AI models include the difficult-to-estimate α_0 parameter, which can cause convergence issues owing to difficulties in identifying values of this parameter.

This problem is well known in the literature and the common ad-hoc fix is to set this parameter to zero. In an effort to estimate this parameter, an estimation strategy employed was first to estimate each model with α_0=0 to generate starting values for the unrestricted model, where α_0 is unrestricted. This strategy was successful, allowing us to identify and estimate α_0 in both models with convergence at 1.0E-5.

8.5 Parameter Estimates

The estimated parameters for the IAI and AI models are reported in Table 1.2. Inspecting the statistical significance of individual parameter estimates provides some insight into the potential relative goodness of fit of each model. It is noteworthy that in both models the parameter α_0 was not individually statistically different from zero at the 5 percent level, providing some support to previous work that has imposed this parameter to zero to facilitate estimation. The IAI model has five of the eight estimated parameters being individually statistically significantly different from zero at the 5 percent level compared with only two parameters in the AI model being individually statistically significantly different from zero at the 5 percent level. Further evidence that the IAI model might be a statistically better fit is reflected in the value of the maximized log-likelihood values of 272.6 for the IAI model compared with 208.7 for the AI model. Finally, the individual R^2 for the estimated FAH and FAFH are 0.97 in the IAI model, compared with the lesser 0.74 and 0.83 respectively for the AI model. Thus, based on a larger number of individually statistically significant parameters, a larger maximized likelihood value, and larger R^2 for each equation, the estimated

Table 1.2 Estimated coefficients for the inverse almost ideal (IAI) and almost ideal (AI) models

	IAI model	AI model
α_0	−470.037 (412.500)	43.949 (28.693)
α_{FAH}	62.906 (36.271)	20.992 (13.062)
α_{FAFH}	−54.617 (29.956)	−20.166 (13.264)
β_{FAH}	0.134* (0.042)	0.502* (0.067)
β_{FAFH}	−0.117* (0.041)	−0.504* (0.052)
$\gamma_{FAH,FAH}$	−8.214* (2.452)	10.444 (6.095)
$\gamma_{FAH,FAFH}$	7.229* (1.940)	−10.454 (6.118)
$\gamma_{FAFH,FAFH}$	−6.282* (1.611)	10.443 (6.181)
LL	272.622	208.663
R^2_{FAH}	0.977	0.737
R^2_{FAFH}	0.972	0.829

Notes: Figures in parentheses are the estimated standard errors.
* denotes a coefficient that is statistically significantly different from zero at 5% level. LL is the maximized likelihood value.

parameter results suggest that the IAI might be a more statistically appropriate model compared with the AI model in explaining expenditure shares over the period 1978–2007.

8.6 Flexibility and Elasticity Estimates

Another criterion for evaluating competing models is to compare estimated economic effects (flexibilities and elasticities) and their reasonableness with prior beliefs and their consistency with theory. Table 1.3 provides a comparison of the estimated flexibilities and elasticities for the IAI model and the AI model. For the IAI model all of the uncompensated own-price flexibilities are negative, as are the scale flexibilities. A 1 percent increase in the quantity of FAH consumed is associated with a 0.379 percent decline in the price of FAH. Interestingly, a 1 percent increase in the quantity of FAFH consumed is associated with a 0.687 percent decline in the price of FAFH, revealing a much more elastic response compared with FAH. A 1 percent increase in the quantity of AB is associated with a 0.311 percent decline in the price of AB. Scale

Table 1.3 Estimated flexibilities for the IAI model and elasticities for the AI model

	Flexibilities IAI model				Elasticities AI model		
			Uncompensated				
	P_{FAH}	P_{FAFH}	P_{AB}		Q_{FAH}	Q_{FAFH}	Q_{AB}
Q_{FAH}	−0.379	−0.252	−0.028	P_{FAH}	−1.296	−0.786	−0.197
Q_{FAFH}	−0.403	−0.687	−0.152	P_{FAFH}	0.301	−0.464	0.204
Q_{AB}	−0.265	−0.558	−0.311	P_{AB}	−0.145	0.311	−1.176
			Compensated				
	P_{FAH}	P_{FAFH}	P_{AB}		Q_{FAH}	Q_{FAFH}	Q_{AB}
Q_{FAH}	−0.118	0.067	0.051	P_{FAH}	−0.400	0.323	0.077
Q_{FAFH}	0.088	−0.085	−0.003	P_{FAFH}	0.283	−0.482	0.199
Q_{AB}	0.182	−0.008	−0.174	P_{AB}	0.253	0.801	−1.054
			Scale or expenditure				
		Scale				Expenditure	
	P_{FAH}	P_{FAFH}	P_{AB}		Q_{FAH}	Q_{FAFH}	Q_{AB}
	−0.659	−1.243	−1.134		2.279	−0.040	1.011
		Measures of consistency with theory (percent compensated < 0)					
	P_{FAH}	P_{FAFH}	P_{AB}		Q_{FAH}	Q_{FAFH}	Q_{AB}
	70.0	66.7	100.0		86.7	90.0	100.0
			Percent NSD				
	66.7			86.7			

Notes: Reported estimates are the respective means from flexibilities and elasticities calculated over the sample. Measures of consistency with theory involve checking the negativity of uncompensated and compensated flexibilities at every data point and the negative semi-definiteness (NSD) of the substitution matrix.

flexibilities indicate that scale of consumption increases of 1 percent would lead to declines in FAH price of 0.659 percent, FAFH price of 1.2 percent, and AB price of 1.134 percent. These flexibilities seem reasonable and plausible. Checking their consistency with underlying theory reveals that the compensated own-price flexibilities of FAH and FAFH are only consistent with the negativity condition at 70 and 66.7 percent of observations, respectively. Furthermore, the Antonelli substitution effects were found to be consistent with negative semi-definiteness at 66.7 percent of observations (failing during the period at the beginning of the sample, 1978–88).

For the AI model all of uncompensated own-price elasticities are negative and two of the expenditure elasticities (FAH and AB) are positive, with the other (FAFH) being borderline negative. A 1 percent increase in the price of FAH is associated with a 1.296 percent decline in the quantity demanded of FAH. Interestingly, a 1 percent increase in the price of FAFH is associated with a 0.464 percent decline in the quantity demanded for FAFH, revealing a much more inelastic demand response. A 1 percent increase in the price of AB is associated with a 1.176 percent decline in the quantity demanded of AB. Expenditure elasticities convey that FAH is a luxury good (2.279), FAFH is borderline inferior (−0.04), and AB is a borderline luxury good (1.011). Checking their consistency with underlying theory reveals that the compensated own-price flexibilities of FAH and FAFH are consistent with the negativity condition at 86.7 and 90 percent of observations, respectively. Furthermore, the Hicksian substitution effects were found to be consistent with negative semi-definiteness at 86.7 percent of observations (failing during the period at the beginning of the sample 1978–81). In sum, both models' estimated effects seem mostly plausible, with the caveat that neither model is fully consistent with theory owing to problems being consistent with negativity of flexibilities and elasticities (FAH and FAFH) as well as the magnitudes of expenditure elasticities—with the AI model being inconsistently slightly less than the IAI model.

8.7 In-Sample Non-Nested Tests

Since the IAI and AI models have the same set of dependent variables, it is possible to test whether the IAI model rejects the AI model using a non-nested test framework developed by Vuong (1989). Testing the IAI model against the AI model, if the null hypothesis is true the average value of the log-likelihood should be zero and the test statistic should be close to zero. Alternatively, if the test statistic is positive and statistically significantly different from zero ($Z_{0.05} = 1.96$), then the IAI model rejects the AI model. We calculated the Vuong test with the IAI against the AI and the test statistic was found to be 8.725 (Table 1.4), providing strong statistical support for the IAI model with the AI being rejected. This result echoes the other statistical results favoring the in-sample performance of the IAI model over the AI model.

Table 1.4 Statistical inferences for the IAI model versus the AI model, non-nested test (Vuong statistic = 8.725) (out-of-sample one-period-ahead forecasting performance)

Criteria	IAI model	AI model
$tr(\Omega)$	0.00170	0.01478
$\|\Omega\|$	7.07E-08	5.05E-06

Note: See Piggott (2003: 11) for methods used in calculating Ω.

8.8 Out-of-Sample Non-Nested Tests

Since both the IAI and AI models have the same set of dependent variables, it is also possible to evaluate each model's respective out-of-sample forecast accuracy. Owing to the small sample on hand, and to conserve degrees of freedom, each model is evaluated on its ability to make *one*-period-ahead forecasts using the approach of Piggott (2003). This approach leads to two different statistics being calculated that utilize all of the information contained in the forecast error vector generated by the one-period-ahead forecast errors at each observation. The first statistic, $tr(\Omega)$, which is the trace of the estimated covariance of one-period-ahead forecast errors, is equivalent to the sum of squared forecast errors (SSFE) for the two equations estimated. Table 1.4 reveals, based on this criterion, that the IAI model (0.00170) outperformed the AI model (0.01478) with markedly smaller one-period-ahead forecast errors. The second statistic, $|\Omega|$, which is the determinant of the covariance of forecast errors, is favorably impacted if there is correlation between forecast errors. Table 1.4 reveals, based on this criterion, that the IAI model (7.07E-08) once again outperformed the AI model (5.05E-06) with smaller one-period-ahead forecast errors. Thus, there appears to be further support for the IAI model over the AI model based on the criterion of out-of-sample one-period-ahead forecast prediction performance.

9 Conclusion

The constrained utility maximization model provides the basis for ordinary demand system estimation and has been the mainstay for food demand analysis in the agricultural economics literature. Duality theory provides alternative approaches to both ordinary and inverse demand system approaches. In particular, the distance function approach allows applied researchers the opportunity to specify inverse demand systems to study consumer price formation. An overview of the literature was presented with the intention of balancing theoretical concepts and empirical application.

We provide a straightforward illustrative example of US food demand (food at home, food away from home, and alcoholic beverages) using aggregate annual time-series data in the United States over the period 1978–2007. Applying a standard AI demand model and IAI demand model, we find that the price formation model dominates the quantity formation model in both in- and out-of-sample testing. A plausible explanation is motivated by the perishability properties of the many foods now consumed and the increasing prevalence of consumption of food away from home, which tends to be freshly prepared with a limited shelf life. This result calls for a more complete examination of the less commonly employed inverse demand systems in agricultural economics to establish its performance compared to the mainstay ordinary demand systems over a broader range of empirical applications to food demands and more general functional forms. Rationalizing this empirical question of the auxiliary hypothesis of specification choices as to whether an ordinary or inverse demand system is most appropriate for a particular application is left for future work, with the question of inverse models being more appropriate for demand analysis remaining open for further careful scrutiny.

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CHAPTER 2

HOUSEHOLD PRODUCTION THEORY AND MODELS

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1 Introduction

Becker (1976) is best known for modeling household decisions and resource allocation in a model where a household is both a producing and a consuming unit. Output that is produced by the household is consumed directly and not sold in the market. Becker claimed the productive household model was a major advance in understanding household behavior relative to models that treated households as purely consuming units (e.g., see Varian 1992: 94–113). Margaret Reid (1934) provided an early description of household production behavior, and her work is an important antecedent to Becker's formal modeling of the productive household. And in the early 1960s Mincer (1963) became convinced of serious misspecification of empirical household demand functions for food, transportation services, and domestic services; the opportunity cost of the homemaker's or traveler's time and household non-labor- (or full-)income were omitted variables. He also showed that using cash income as an explanatory variable was inappropriate because it reflected a variety of household decisions, including a decision on how many hours to work for pay. Food economic studies over the past four decades have largely overlooked the potential of household production theory and models in demand analysis.

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This chapter first presents a brief review of empirical studies of food demand, especially linkages to household production theory and models. However, the main objectives of the chapter are: (1) to present several types of microeconomic models of household decision-making and highlight their implications for empirical food demand studies and (2) to present an empirical application of insights gained from household production theory for a household input demand system fitted to unique data on the US household sector over the post-Second World War period, 1948–96.[1] Finally, I address how future food demand studies might build a stronger bridge to the models of household behavior including a production function and resource of human time of adult household members. The chapter focuses on household production theory and models for non-agricultural households largely in developed countries.[2]

Relative to neoclassical demand functions, the models of productive household behavior that are developed in this chapter include the opportunity cost of time of adults, full-income budget constraint, and technical efficiency or technical change in household production as determinants of the demand for food and other inputs. An important dimension of these models is that time spent shopping, preparing and eating food has a cost even though there is not a direct cash outlay and that individuals who have a higher opportunity cost of time find ways to substitute toward less human time intensive means of household production.

The remainder of the chapter is organized into four major sections.

2 A Brief Review of Demand Theory and Empirical Studies of Food Demand

Although LaFrance (2001) presents an abstract restatement of neoclassical demand theory and the theory of demand with household production, he does not present a review of the empirical food demand literature, empirical applications, or estimates of household demand systems. Looking more broadly, I uncovered two papers that make a concerted effort to incorporate household production theory into an empirical study of the demand for food. These papers are by Prochaska and Schrimper (1973) and Hamermesh (2007). Prochaska and Schrimper use cross-sectional micro- or household data to estimate the demand by households for food away from home. The authors

[1] In contrast to Becker's and Gronau's perspective on household decision-making, there is a sizable literature that applies game theory or bargaining theory to two-adult household decision-making, for example, see Blundell and MaCurdy (1999) and Browning, Chiappori, and Lechene (2009).

[2] For those who are interested in a conceptual model of agricultural household decision-making where decisions are made on inputs for farm production and for household production, see Huffman and Orazem (2007: 2286–92), or agricultural household models that incorporate a time constraint and multiple job holding of household members, see Huffman (1991; 2001: 344–7) and Strauss (1986a). Empirical studies of food demand by agricultural households include Strauss (1986b) and Pitt and Rosenzweig (1986).

include a measure of the opportunity cost of time of the homemaker or opportunity wage and a comprehensive measure of household income, computed as the annual value of the homemaker's time endowment evaluated at the market wage plus household non-labor income. They found that an increase in the homemakers' opportunity cost of time and comprehensive household income significantly increased the demand for food away from home. They also show that significant specification bias would have occurred in the estimated coefficients of the included variables if the opportunity cost of time had been excluded or ignored.[3]

A recent study by Hamermesh (2007) builds on household production theory in his empirical study of demand for food at home and away from home and time allocated to eating by married couples in 1985 and 2003. Key explanatory variables are husband's and wife's wage rates and a household's non-labor income. He finds that a higher wage rate for the husband and wife increases the demand for food away from home significantly. Although the estimated effect of the husband's and wife's wage rates on the demand for food at home is negative, only the estimated coefficient for wife's wage is significantly different from zero. In the 1985 data, he found that non-labor income has a significant positive effect on the demand for food at home but a negative effect on the demand for food away from home. However, in the 2003 data, income effects are reduced and much weaker than in the 1985 data.

Other food demand studies that incorporate household production theory are by Kinsey (1983), Park and Capps (1997), Sabates, Gould, and Villarreal (2001), Keng and Lin (2005).

Although Kinsey (1983) lays out a Beckerian model of household production in a study of the demand for households' purchases of food away from home, her empirical analysis she does not follow through. For example, she claims that the wage rates of working women do not vary much and then excludes women's price of time from a household's demand for food away from home. In contrast, labor economists have made a working individual's wage the target of frequent empirical investigations, and predicted wage rates are regularly included in models explaining labor supply, demand for children, and migration (Tokle and Huffman 1991; Blundell and MaCurdy 1999; Card 1999; Huffman and Feridhanusetyawan 2007).

Keng and Lin (2005) show that as women's labor market earnings increase, their household's demand for food away from home increases. In addition, a few other studies have included the education of the household manager, a rough proxy for her opportunity cost of time, as a regressor in food demand equations. For example, Park and Capps (1997) found that the probability a household purchases ready-to-eat or ready-to-cook meals increases with the education of the household manager, but education was not included in the expenditure equation for ready-to-cook meals.

[3] Chen et al. (2002) did not find a statistically significant effect of an individual's wage on the demand for particular nutrients—riboflavin, fatty acids, and oleic acids—in the National Health and Nutrition Examination Survey (NHANES) data set.

In new research at the ERS, Andrews and Hamrick (2009) argue that "eating requires both income to purchase food and time to prepare and consume it." Their focus is on income effects: "food spending tends to rise with a household's income. However, the opposite is true for time devoted to preparing food." Their research does not focus on price effects. In conclusion, there is not an abundance of evidence that productive household theory has been integrated into econometric studies of food demand.

3 A Neoclassical Model of Household Decisions to Allocate Human Time and Cash Income

Early models of labor supply decisions of household members made small advances in neoclassical demand theory by adding leisure time to the list of goods that a household consumes and by adding a new type of resource constraint—adult human time endowments that were allocated between leisure and work for pay (Varian 1992: 95–113, 144–6; Blundell and MaCurdy 1999). This model provides an important benchmark by incorporating the opportunity cost of time into household decision-making, but it does not go so far as adding a household production function. To see this, assume that the household consumes and obtains utility from leisure (L) and two purchased goods—food (X_1) and non-food goods and services (X_2)—and utility can be summarized by a strictly concave utility function

$$U = U(L, X_1, X_2; \tau). \tag{1}$$

In (1) τ is a taste parameter, affecting the translation of leisure and purchased goods into utility.

The household receives a time endowment each time period, e.g., year, and it is allocated between leisure (L) and hours of work for pay (h):

$$T = L + h. \tag{2}$$

The household receives cash income (I^C) from members working for a wage (W) and from interest, dividends, and unanticipated gifts (V), and this income is allocated to purchasing X_1 and X_2 such that

$$I^C = W \cdot h + V = P_1X_1 + P_2X_2. \tag{3}$$

Although a household might choose to allocate all physical time to leisure and spend only V on X_1 and X_2, most households choose to forgo some leisure and to allocate this time to wage work, in order to purchase larger quantities of X_1 and X_2. Under these conditions, I can rearrange equation (2) to obtain $h = T - L$. Substitute this relationship into equation (3) and rearrange to obtain Beckerian (Becker 1976) full income (F) constraint

$$F = W \cdot T + V = W \cdot L + P_1 X_1 + P_2 X_2. \tag{4}$$

Note that full income is received from the value of the time endowment at the wage rate (W) plus non-labor income (V), and hence, it does not vary with hours of work. Moreover, full income received is spent on leisure and purchases of food and non-food goods and services.

At this interior solution, the household chooses L, X_1, and X_2 to maximize equation (1) subject to equation (4) with a Lagrange multiplier (λ), which is the marginal utility of full income. These first-order conditions for the household's decision problem are

$$L\colon U_L = \lambda W \tag{5a}$$

$$X_i\colon U_{X_i} = \lambda P_i,\ i = 1, 2 \tag{5b}$$

$$\lambda\colon W \cdot T + V - W \cdot L - P_1 X_1 - P_2 X_2 = 0 \tag{5c}$$

Equations (5a)–(5c) can be solved jointly to obtain the general form of the household's demand functions for leisure, food, and non-food goods and services:

$$L^* = D_L(\mathrm{W}, P_1, P_2, V, \tau) = D_L(\mathrm{W}, P_1, P_2, F, \tau) \tag{5a}$$

$$X_i^* = D_{X_i}(\mathrm{W}, P_1, P_2, V, \tau) = D_{X_i}(\mathrm{W}, P_1, P_2, F, \tau),\ i = 1, 2.^4 \qquad (5b)-(5c)$$

Clearly, the demands for leisure, food purchases, and non-food purchases are determined by the wage rate, which is the price of leisure at an interior solution, the price of purchased food (P_1), the price of non-food purchases (P_2), income (V or F), and tastes (τ). The income effect on demand can be represented either by non-labor income (V) or as full income (F), given that W, which is the opportunity cost of time, is held constant in either case. Given the optimal choice of leisure and the time constraint (2), obtain the general form of the labor supply equation

$$h^* = T - L^* = S_h(W, P_1, P_2, V, \tau) = S_h(W, P_1, P_2, F, \tau). \tag{6}$$

Hence, hours of work or labor supply are determined by exactly the same set of variables as those that determine the demand for leisure, food purchases, and non-food purchases.

In this model of household demand for food (X_1), there is a major difference in cross-price effects owing to an increase in P_2, which eliminates some consumption opportunities, and W, which increases consumption opportunities. The reason for this difference is that the household starts each period with a positive time endowment for

[4] Although T is a determinant of demand, it is a constant that does not vary across household so it can be suppressed in the specification of the demand (and supply) functions.

each adult (T), which rises in value whenever the wage rate increases, but does not hold inventories of X_2. Hence, the Marshallian or money income constant own- and cross-price elasticities of demand for food (X_1) are

$$\partial X_1/\partial P_1 = (\partial X_1/\partial P_1)_{\bar{U}} - X_1 \partial X_1/\partial F \qquad (7a)$$

$$\partial X_1/\partial P_2 = (\partial X_1/\partial P_2)_{\bar{U}} - X_2 \partial X_1/\partial F \qquad (7b)$$

$$\partial X_1/\partial W = (\partial X_1/\partial W)_{\bar{U}} + (T-L)\partial X_1/\partial F \qquad (7c)$$

where $(\partial X_1/\partial Y)_{\bar{U}}$ is the utility constant (Hicksian) effect of a change in price $\{P_1, P_2, W\}$ on the demand for food, and $T-L$ (= $h>0$) at an interior solution.

Another notable difference in the demand for food in this model relative to one where decisions on time use are ignored is that the opportunity cost of time, as represented by the wage rate (W), is an additional determinant of demand. A less notable difference is that V (or F) represents the pure income effect on quantity demanded in place of cash income (I). Hence, econometric food demand studies that ignore household expenditures on leisure and the price of time of household members will suffer from misspecification bias including omitted variable bias.[5]

4 Models of Consumption that Incorporate Household Production Theory

The unique feature of adding the household production function to the theory of household decision-making is that it becomes possible to bring the theory of the firm to bear on household decisions, including the demand for food and supply of labor (Becker 1976).

4.1 A Becker-Type Model

In Becker's model household production (Michael and Becker 1973; Becker 1976), a household consumes only commodities that it produces, and the production of each commodity requires an input of human time of one or more household members and an input/good purchased in the market. To gain further insights, assume that a household consumes and obtains utility from two commodities, e.g., Z_1 is home-prepared meals, and Z_2 is a non-food commodity such as washed and ironed clothing,

[5] As we shall see in the next section, it is hard to justify a household utility function that is separable in leisure and other goods consumed.

or clean and organized interior of the house. Household utility is summarized by a strictly concave utility function

$$U = U(Z_1, Z_2; \tau) \tag{8}$$

where τ is a taste parameter. Each commodity Z_i is produced using a purchased input, X_i, and housework of one or more household member, t_i. For example, X_1 refers to standard food purchased at the grocery store, and X_2 might be soap, water, and utilities for heating water, or drying and ironing clothing. However, to simplify the analysis further, assume each production function is strictly concave and exhibits constant returns to scale in the two variable inputs, but there are neither fixed costs of production nor joint production between Z_1 and Z_2:

$$Z_i = G_i(X_i, t_i; \varphi_i), \text{i} = 1, 2, \tag{9a)-(9b}$$

where φ_i is a technology or efficiency parameter. The household has a time constraint. It receives a time endowment each time period, e.g., year, which is allocated between housework (t_1 + t_2) and hours of work for pay (h):

$$T = t_1 + t_2 + h. \tag{10}$$

The household has a cash income constraint (I), which it receives as cash income from members working for a wage (W) and from income on financial assets (interest and dividends) and unanticipated gifts (V), and this cash income is allocated to purchasing X_1 and X_2

$$I = W \cdot h + V = P_1X_1 + P_2X_2. \tag{11}$$

In this model, I first examine household decision-making in the input space, i.e., to choose inputs so as to maximize utility (8), subject to the production technology, physical time, and cash income constraint. Moreover, if the household allocates physical time to work in the market at wage rate (W), the physical time (10) and cash income constraints (11) can be combined into one full-income constraint

$$F = W \cdot T + V = P_1X_1 + Wt_1 + P_2X_2 + W \cdot t_2. \tag{12}$$

In addition, one method of incorporating the technology constraint is by substitution (9a) and (9b) into (8). The new constrained optimization with Lagrange multiplier λ (marginal utility of full income) becomes

$$\psi = U[G_1(X_1, t_1; \varphi_1), G_2(X_2, t_2; \varphi_2); \tau] + \lambda[W \cdot T + V - P_1X_1 - \text{W} \cdot t_1 - P_2X_2 - W \cdot t_2]. \tag{13}$$

The first-order conditions for an interior solution is

$$X_i\text{: } U_{Z_i} G_{iX_i} - \lambda P_i = 0, i = 1, 2 \tag{14a}$$

$$t_i\text{: } U_{Z_i} G_{it_i} - \lambda W = 0, i = 1, 2 \tag{14b}$$

$$\lambda: W \cdot T + V - W \cdot L - P_1X_1 - P_2X_2 = 0, \tag{14c}$$

where U_{Z_i} is the marginal utility of commodity Z_i, G_{iXi} is the marginal product of input X_i in producing Z_i, and G_{it_i} is the marginal product of input t_i in producing Z_i. A notable feature of these first-order conditions in (14a) and (14b) is that for a household to maximize utility subject to its technology and resource constraints, it must produce Z_1 and Z_2 at minimum cost

$$MC_{Z_i} = W/G_{iX_i} = P_i/G_{it_i} = \pi_i(W, P_i, \phi)i, i = 1, 2. \tag{15}$$

$MC_{Z_i} = \pi_i(W, P_i, \phi_i)$ is the marginal cost of Z_i, which depends on the opportunity cost of time (W), the price of purchased input (P_i), and the technology or efficiency parameter (φ_i). Moreover, with fixed input prices to the household and constant returns to scale in producing the Z_is, the marginal cost of producing each Z_i is unchanged with a proportional rescaling, e.g., doubling of both variable inputs.

From equations (14a)–(14c), solve for the following general form of the implicit demand functions for the inputs in this model

$$X_i^* = D_{x_i}(P_1, P_2, W, V, \phi_1, \phi_2, \tau) = D_{X_i}(P_1, P_2, W, F, \phi_1, \phi_2, \tau), i = 1, 2 \tag{16a}$$

$$t_i^* = D_{t_i}(P_1, P_2, W, V, \phi_1, \phi_2, \tau) = D_{t_i}(P_1, P_2, W, F, \phi_1, \phi_2, \tau), i = 1, 2 \tag{16b}$$

And, hence, the general form of the demand equations for housework and supply of labor can be derived as follows:

$$t_p^* = t_1^* + t_2^* = D_{t_p}(P_1, P_2, W, V, \phi_1, \phi_2, \tau) = D_{t_p}(P_1, P_2, W, F, \phi, 1\phi_2, \tau) \tag{17a}$$

$$h^* = T - t_1^* - t_2^* = S_H(P_1, P_2, W, V, \phi_1, \phi_2, \tau) = S_H(P_1, P_2, W, F, \phi_1, \phi_2, \tau). \tag{17b}$$

Moreover, the demand for purchased inputs, such as food, housework, and labor supply, are all a function of the prices (P_is) of purchased inputs for home production (such as meat and fish; potatoes, pasta, bread; tomatoes, lettuce, cucumbers; and milk and eggs), price of housework (W), non-labor or full income (V or F), the technology or efficiency parameters (φ_1 and φ_2), and the taste parameter (τ).[6] Hence, with the household production model the education of the homemaker can be connected to the efficiency of household production (φ_i) and not be forced into an association of tastes with education. Many labor economists accept that a homemaker's education or skill may raise the productivity of household production time (Becker 1976; Michael and Becker 1973).

[6] In contrast, if we assume the technology of household production is represented by a joint production function, $G(Z_1, Z_2, X_1, X_2, t_p, \varphi) = 0$, with Zs as commodities (outputs); Xs and t_p as inputs, and efficiency parameter φ, where $G(\cdot, \varphi)$ is convex in outputs, decreasing in inputs, and strictly increasing in φ, then we obtain roughly the same implicit input demand functions as in (16a) and (17a) and supply function as in (17b).

Given the above results, the household's decision problem is stated in the commodity or Z-space. I now define the full-income constraint in terms of the quantity and marginal cost of the Z_is

$$F = \pi_1 Z_1 + \pi_2 Z_2. \tag{18}$$

Now, assume that the household chooses the Z_is so as to maximize utility (8) subject to the full-income constraint in (18) and obtain the following first-order conditions for an interior solution:

$$Z_i\colon U_{Z_i} - \lambda\pi_i = 0,\ i = 1, 2 \qquad (19a)-(19b)$$

$$\lambda\colon F - \pi_1 Z_1 - \pi_2 Z_2 = 0. \qquad (19c)$$

Equations (19a)–(19c) can be solved jointly for the implicit demand functions for the commodities (Z_is)

$$Z_i = D_{Z_i}(\pi_1, \pi_2, F, \tau),\ i = 1, 2. \tag{20}$$

Hence, the demand for Z_i is determined by the marginal cost of the two commodities, full income available for spending ($F = W \cdot T + V$), and the taste parameter (τ). Moreover, under the assumptions that the household faces fixed input prices and constant returns to scale in the production of both commodities, the iso-cost line or slope of the budget constraint of the household in commodity or Z-space is a straight line.

An example can help shed new light on insights gained by adding household production to demand theory. Consider two alternative meat dishes for dinner, one consisting of pork loin in the form of boneless pork chops cooked on the stove top and the second consisting of a pork loin baked in the stove's oven. Hence, X_i is pounds of pork loin and t_i is the amount of the cook's time required in overseeing cooking the loin. Let's assume that two pounds of loin are prepared in both cooking processes, but it takes twenty minutes of the cook's time to fry the pork chops and 1.5 hours to roast the loin, including basting the loin roast. Hence, I have defined fixed-proportions input–output technology where $X_i = a_i Z_i$ and $t_i = b_i Z_i$ so that $\pi_i = a_i P_i + b_i W$, $i = 1, 2$. Now let P_i be \$5.00 for two pounds of pork loin (either as quarter-pound cut chops or as a two pound roast).

Now first assume that the opportunity cost, or price of the cook's time, is initially the minimum wage, roughly \$8 per hour. Then the marginal cost of two pounds of fried pork chops is π_1 = \$5.00 + \$2.67 = \$7.67. In contrast, the marginal cost of two pounds of roasted pork loin is π_2 = \$5.00 + \$12.00 = \$17.00. Although the "grocery store cost of the pork loin" is identical in these two cases, the marginal cost of ready-to-eat pork loin is roughly twice as much when it comes prepared as a loin roast as compared to fried chops. Hence, when the cost of the cook's time is factored into the decision, the absolute and relative cost of cooked chops versus a cooked loin roast changes dramatically.[7]

7 Although the cook may be able to engage in a secondary activity such as watching TV or monitoring children, the main point is that cooking the roast, including basting it, requires the presence of the cook.

Second, let us now assume that the price of the cook's time is three times higher or \$24 per hour (which is roughly equivalent to annual full-time earnings of \$48,000 per year). The marginal cost of two pounds of fried pork chops is now $\pi_1' = \$5.00 + \$8.00 = \$13.00$, and of two pounds of ready-to-eat pork loin roast is $\pi_2' = \$5.00 + \$36.00 = \$41.00$. Hence, even though the grocery store cost of the pork loin remains unchanged in our second example, the marginal cost of two pounds of cooked pork loin roast is more than three times as expensive as is two pounds of fried pork chops. Hence, the difference in the marginal cost of cooked pork loin roast compared to fried pork chops has increased significantly from the first example. Furthermore, this logic can be used to explain why wealthy households tend to consume expensive easy-to-prepare cuts of meat rather than cheap time-consuming-to-prepare ones. When the cost of the cook's time tripled, the marginal cost of the time-intensive pork loin roast increases relative to the marginal cost of the fried pork chops—from 17/6.67 = 2.55 in the first example to 41/13 = 3.15 in the second example. Hence, as the price of the cook's time increases, the marginal cost of cook's time-intensive pork meals increases relative to those that are less intensive in cook's time—fried pork chops. Viewed another way, as women have obtained more education and entered the labor force, which increases the opportunity cost of their time, cook's-time intensive meal preparation has become less attractive. Given that meals prepared at home are on average more nutritious than meals eaten away from home, this change has a negative impact on the production of good health (Lin, Frazão, and Guthrie 1999). See application at the end of this section.

A second factor that weighs against pork loin roasts is that the minimum size is about two pounds, which would feed a relatively large household (or a dinner party), and as average household sizes declined over the 1950s and 1960s, households are more likely to be too small to make roasting a loin economical and fried pork chops become more likely. However, frying pork chops in cooking oil, which means adding oil and calories per ounce of prepared meat, is widely recognized as a less healthful means of preparing loin than the more time-intensive oven roasting.[8] Given that women continue to be the main meal planners and preparers, these examples show how rising opportunity cost of women's time has tipped the scale toward less healthy meal preparation for household's members (Kerkhofs and Kooreman 2003; Lin, Frazão, and Guthrie 1999; Robinson and Godbey 1997).

After replacing fixed- for variable-proportions production technology, additional insights from the Becker model of household production are obtained. To do this, continue with the two-commodity–two-input model. Moreover, assume that $X = X_1 + X_2$, i.e., the purchased inputs are perfect substitutes, and continue with total time in housework allocated between t_1 and t_2. In addition, assume that commodity Z_2 is relatively time-intensive to produce, and the prices of the purchased component of

[8] Basting liquid for pork loin roasts consists of some vegetable oil, but also wine and spices. However, a much smaller share of the loin comes in direct contact with the oil than in fried pork chops, which reduces oil uptake.

production of each Z (P_is) is fixed to the household. Given the assumption of constant returns to scale in the production of both commodities, all of the information about production of each commodity can be represented on a unit isoquant, i.e., $Z_i = 1$. Total production involves only rescaling the information in the unit isoquant model.

Consider panel A in Figure 2.1, where the initial iso-cost line C_0C_0' with slope (−W/P) is drawn tangent to the one-unit isoquant for Z_1 and Z_2 at *a* and *b*. Because I will focus on the implications of an increase in the wage rate, I will measure cost in term of units of X, which is unchanged in our example. Hence, in the initial situation, the cost of one unit of Z_1 and Z_2 is $0C_0$ in units of X. An increase in the wage rate from W to W' while minimizing cost causes a substitution effect away from time (t_i) toward the purchased input component (X_i) and the marginal cost of both Zs increases in units of X—to $0C_{11}$ for Z_1 and to $0C_{12}$ for Z_2. However, the marginal cost of Z_2, which is relatively time-intensive, rises relative to the marginal cost of Z_1.

Next, consider the effect of an increase in the wage rate (W) in commodity or Z-space. The initial budget constraint is R_0R_0' with tangency to U_0 at *a* and with optimal quantities of Z_1^0 and Z_2^0 in Figure 2.1, panel B. I have already shown that when the wage rate increases, the marginal cost or price of the time-intensive commodity Z_2 increases relative to the marginal cost of the less time-intensive commodity Z_1 (Figure 2.1, panel A).[9] The new relative marginal cost or price line for the Zs is R_1R_1' tangent to U_0 at point *b* in Figure 2.1, panel B. Given that the production of both Zs uses purchased inputs and housework, the household will experience a net increase in consumption opportunities as a result of the increase in the wage rate and a new budget constraint of R_2R_2'. Hence, the increase in consumption opportunities is represented by the area $R_1R_2R_2'R_1'$, and the household can now move to any point between *j* and *l* on R_2R_2'. Even with a pure substitution effect away from the housework-intensive commodity Z_2 as the wage increases, the consumption of Z_2 will actually increase. This occurs when the new optimum is between *j* and *k* on R_2R_2'. However, if the new optimum is located between *k* and *l* on R_2R_2', the quantity demanded of Z_2 will decline. In addition, there is a high probability that the consumption of Z_1 will increase.

Becker's model of household production has been criticized because of his assumption of constant returns to scale in producing each commodity (the Zs) and the assumption of no joint production in producing the Zs, for example see Pollak and Wachter (1975). However, these assumptions are only needed to obtain a straight-line iso-cost constraint or budget constraint, which implies that household preferences and the budget constraint are independent.

Additional insights can be obtained by considering the following model of joint production. Assume the household obtains utility directly from consuming Z_1, which is produced using X_1 and t_1, as in equation (9a), but t_1 also provides utility (or disutility) directly to the household. For example, time cleaning the house or doing the laundry

[9] This is an application of the Lerner–Pearce Diagram from international trade theory (Lerner 1952; Deardorff 2002).

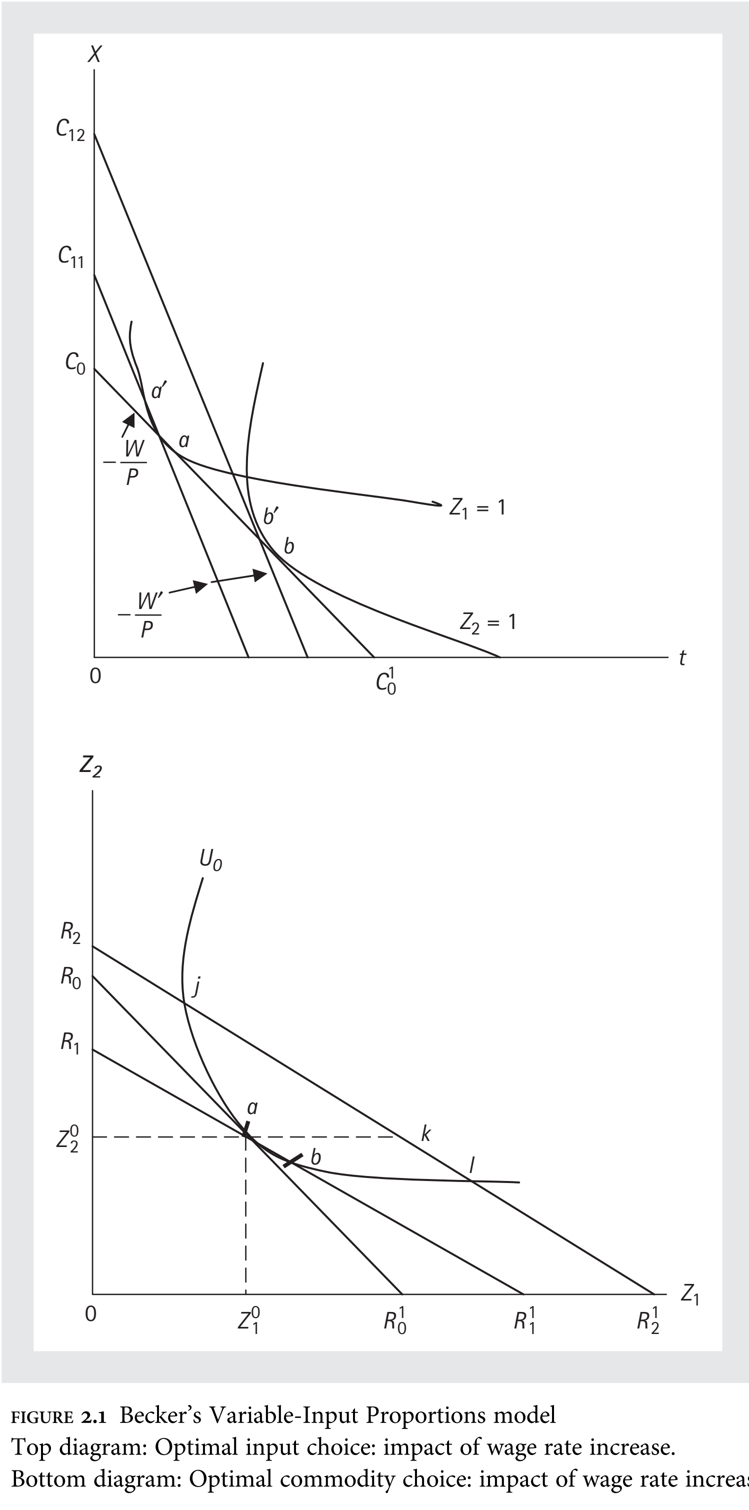

FIGURE 2.1 Becker's Variable-Input Proportions model
Top diagram: Optimal input choice: impact of wage rate increase.
Bottom diagram: Optimal commodity choice: impact of wage rate increase.

may directly lower utility but time gardening may directly raise utility, irrespective of the utility obtained from the product produced. Hence, the household's strictly concave utility function can be written as

$$U = U(Z_1, t_1; \tau). \tag{21}$$

The household's time constraint is

$$T = t_1 + h, \tag{22}$$

and the full-income budget constraint is

$$W \cdot T + V - P_1 X_1 - \mathrm{W} \cdot t_1 = 0. \tag{23}$$

The household now chooses X_1 and t_1 so as to maximize (21) subject to the technology of producing Z_1 and the full-income constraint

$$\psi = U[G_1(X_1, t_1; \varphi_1), t_1; \tau] + \lambda[W \cdot T + V - P_1 X_1 - \mathrm{W} \cdot t_1]. \tag{24}$$

The first-order conditions at an interior solution are

$$X_1 \colon U_{Z_1} G_{1X_1} - \lambda P_1 = 0 \tag{25a}$$

$$t_1 \colon U_{Z_1} G_{1t_1} + U_{t_1} - \lambda W = 0 \tag{25b}$$

$$\lambda \colon W \cdot T + V - P_1 X_1 - \mathrm{W} \cdot t_1 = 0 \tag{25c}$$

where U_{t_1} represents only the direct contribution of t_1 to utility. Rearranging equations (25a) and (25b) provides important information about optimal input combinations for producing Z_1

$$G_{1t_1} / G_{1X_1} = (W - U_{t_1}/\lambda)/P_1. \tag{26}$$

First, if t_1 does not directly enter the household utility, i.e., $U_{t_1} = 0$, then obtain the standard result for producing Z_1^0 at cost minimization, or point *a* in Figure 2.2. If, instead, the household obtains positive utility directly from housework, e.g., the homemaker enjoys cooking or gardening, then the direct impact of housework on utility is positive, $U_{t_1} > 0$, and the optimal input combination will be at point *b* in Figure 2.2, which implies that more time will be devoted to cooking or gardening than when pure cost minimization reigns. In contrast, if the household obtains negative utility directly from housework, e.g., the homemaker dislikes cleaning the house and doing the laundry, then the direct effect of housework on utility is negative, $U_{t_1} < 0$, and the optimal input combination will be at point *c* in Figure 2.2, which implies that less time will be devoted to cleaning or doing the laundry than when cost minimization reigns. Clearly, this substitution toward more X_1 in producing Z_1^0 could include hiring a home cleaning service or taking clothing to a commercial laundry for washing and ironing.

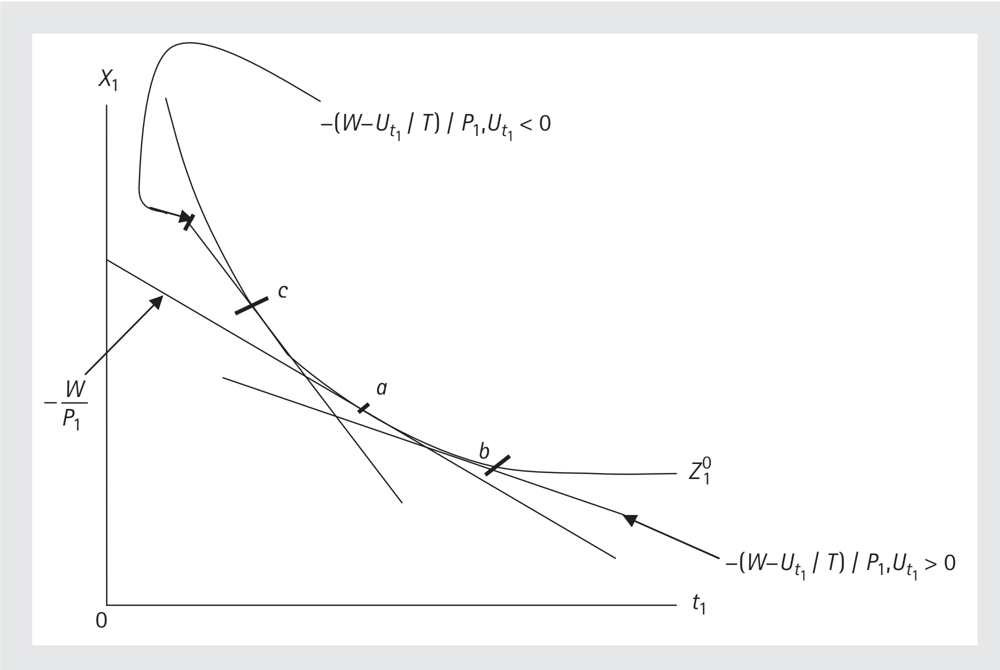

FIGURE 2.2 Effects of "joint" production on Optimal Input Proportions for commodity Z_1

4.2 A Gronau-Type Model

The most notable feature of the Gronau model of household production is that home-produced and purchased goods are perfect substitutes, but this could also be one of its shortcomings (Gronau 1977, 1986). Assume a household consumes and obtains utility from two goods, leisure (L) and a good X, say meals, which can be produced at home, denoted as X_1, or purchased in the market, denoted as X_2. In Gronau's framework, these goods are assumed to be perfect substitutes, where the household only values total X rather than individual quantities of home-produced and purchased X

$$X = X_1 + X_2. \tag{27}$$

Also, the household has a strictly concave utility function

$$U = U(L, X; \tau) \tag{28}$$

And, for simplicity, assume that the household's production function for X_1 is strictly concave in one variable input, housework (h_1):

$$X_1 = G_1(h_1; \varphi) \tag{29}$$

where φ is a technology or efficiency parameter. The household faces a time constraint, receiving an endowment T each period that is allocated to leisure (L), housework (h_1), and wage work (h_2):

$$T = L + h_1 + h_2. \tag{30}$$

The household has cash income from wage work (h_2) and non-labor income (V), which it allocates to X_2:

$$\text{I} = W \cdot h_2 + V = P_2 X_2. \tag{31}$$

Equation (30) can be solved for h_2 and substituted into equation (31) to obtain the household's full-income constraint:

$$F = W \cdot T + V = W \cdot L + W \cdot h_1 + P_2 X_2. \tag{32}$$

Equation (29) can be substituted into (27), which in turn is substituted into (28), and h_1 and X_2 can be chosen to maximize the modified utility function subject to the full-income constraint

$$\psi = U[L, G_1(h_1; \varphi) + X_2; \tau] + \lambda(W \cdot T + V - W \cdot L - W \cdot h_1 - P_2 X_2). \tag{33}$$

The first-order conditions for an interior solution are

$$L\text{: } U_L - \lambda W = 0 \tag{34a}$$

$$h_i\text{: } U_X G_{1h1} - \lambda W = 0 \tag{34b}$$

$$X_2\text{: } U_X - \lambda P_2 = 0 \tag{34c}$$

$$\lambda\text{: } W \cdot T + V - WL - W \cdot h_1 - P_2 X_2 = 0 \tag{34d}$$

Combining equations (34b) and (34c), obtain the result that X_1 should be produced under the standard one-variable input profit-maximizing condition, $P_2 G_{1h_1} = W$,and the general form of the optimal quantity of housework demanded, t_1, and supply of X_1 is given by

$$h_1^* = D_{t_1}(W, P_2, \phi) \tag{35a}$$

$$X_1^* = G_1(h_1^*; \phi) = S_{X_1}(W, P_2, \phi). \tag{35b}$$

Conditions (34a), (34c), and (34d) can be solved jointly for the following demand functions for L^* and X_2^*:

$$L^* = D_L(W, P_2, V, \tau, \varphi) = D_L(W, P_2, F, \tau, \varphi) \tag{36a}$$

$$X_2^* = D_{X_2}(W, P_2, V, \tau, \phi) = D_{X_2}(W, P_2, F, \tau, \phi) \tag{36b}$$

Rearranging the time constraint (30) and using the information in equations (35a) and (36a), obtain the general form of the household's labor supply equation

$$h_2 = T - L^* - h_1^* = \text{S}_{h_2}(W, P, V, \tau, \varphi) = \text{S}_{h_2}(W, P, F, \tau, \varphi). \tag{37}$$

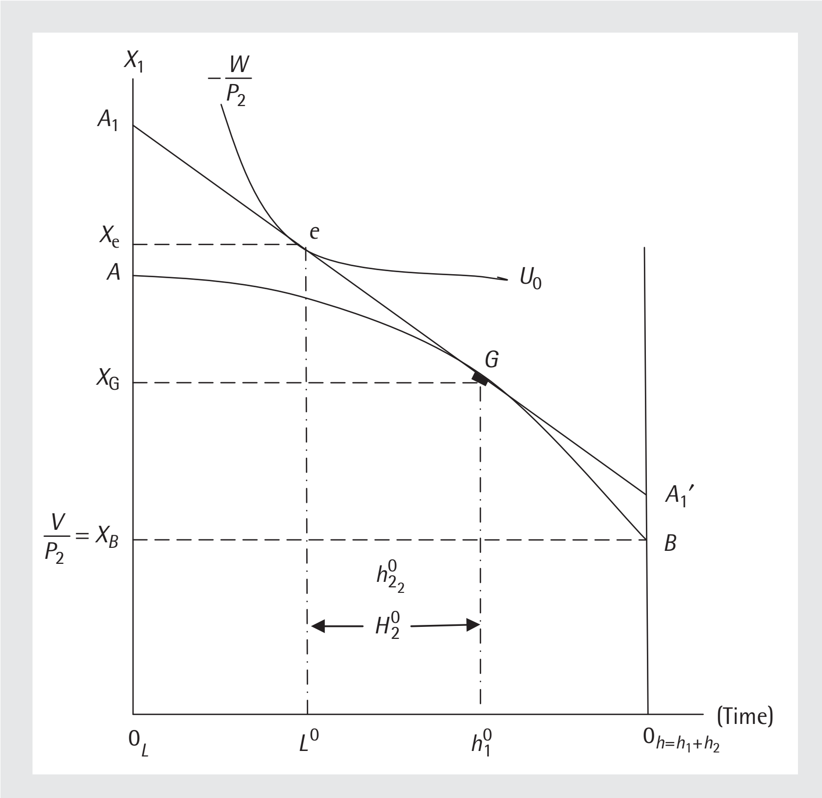

FIGURE 2.3 Optimal resource allocation in Gronau's model

Figure 2.3 displays a graphic representation of the optimal resource allocation at an interior solution for the Gronau model of household production. Units of X are on the vertical axis and units of time are on the horizontal axis, but the maximum length of this axis is T, which is reflected by the erection of a vertical line at this amount of human time. The household can purchase X_B units of X from its non-labor income (V). At point B on the vertical axis T, the household considers how best to allocate a unit of time: to produce X directly or to work for a wage and purchase the added X from earnings. The boundary of the technology and resource constraints facing the household are represented by A_1GB0_h in Figure 2.3. Moreover, Figure 2.3 is drawn such that at point B, the marginal product of housework in producing $X(G_{1h_1})$ is greater than the real wage (W/P_2), so it is optimal for the household to allocate time to housework rather than wage work along the production relationship as the segment AGB. At point G optimal housework is h_1^0. This results in the quantity $X_B - X_G$ of home-produced goods. Additional forgone leisure should be allocated to wage work since the figure for the marginal product of housework in producing X is lower than the real wage. The household's utility maximum (U_0) occurs at e, with $X_e - X_G$ of X purchased from earnings. In the figure, the optimal amount of leisure is L^0 and of wage work is $h_2^0 = L^0 - h_1^0$.

An usual prediction of this model is that if non-labor income (V) increases, the household will optimally keep the quantity of home-produced goods (X_1) unchanged, but allocate the additional income to purchase units of X in the market (X_2) and leisure (L). However, if P_2 increases, this reduces the real wage rate (W/P_2) and unambiguously increases the amount of time allocated to and quantity of home goods produced. The net impact on leisure, hours of work, and total quantity of X consumed will be determined by resulting substitution and income effects. In this model, it is also obvious that an increase in the efficiency of producing X_1 at all h, e.g., owing to better information or training in home production, will increase the amount of time allocated to and production of home goods (X_1).

4.3 Application of Household Production Theory to Health with Food as an Input

Of considerable interest is the household's production of good health, especially as it is related to obesity and associated health problems (Finkelstein, Fiebelkorn, and Wang 2003; Huffman et al. 2010). Inputs in the health production function include food, which is a source of protein, energy, vitamins, minerals, fiber; leisure time; and medical care. However, food intake also frequently yields utility directly because food texture and taste give satisfaction and eating and drinking together are a major part of satisfaction-yielding social interaction.

Let's assume a household has a strictly concave utility function

$$U = U(H, X, C, LP, LO; H_e, Z) \tag{38}$$

where utility U depends on the current health status of the household members (H); consumption of food and drink (X) and other purchased goods (C) (excluding purchased health care); and physically active leisure (LP) and other leisure time (LO). The variable H_e represents early health status, e.g., genetic potential for good/bad health or sometimes summarized by health status at birth such as birth weight (Fogel 1994). Z denotes fixed observables, such as education, gender, and race/ethnicity of adults. Current health, other purchased goods, and other leisure time (H, C, and LO) are assumed to be positive "goods," i.e., a marginal increase in any one of them directly Increases household utility (U_H, U_C, $U_{LO}>0$) and, hence, better (current) adult health status increases household utility, as do higher consumption of other purchased goods and more time allocated to sedentary leisure, e.g., TV viewing, surfing the Web. However, time allocated to vigorous physically active leisure may directly reduce utility, i.e., adults find this activity unpleasant or uncomfortable and then $U_{LP} < 0$.

Let's assume the household's production function for adult health status is

$$H = H(LP, X, I; H_e, Z, \varphi), \tag{39}$$

where $H(\cdot)$ is a strictly concave function and I is a vector of purchased health inputs or medical care. The parameter φ summarizes unobservable factors which affect the efficiency of current production of health status, e.g., genetic predisposition for good/bad health such as obesity. In the health production function, I expect $H_{LP}, H_I > 0$, or, holding other factors constant, additional time allocated to physically active leisure (*LP*) or a larger quantity of purchased health care (*I*) produces more good health. Although many adults may obtain disutility from vigorous physically active leisure, the fact that its marginal product in health production is positive can result in a combined direct and indirect effect on marginal utility ($U^S_{LP} = U_H H_{LP} + U_{LP} > 0$) if the positive first term on the right in this equation ($U_H H_{LP}$) outweighs a negative second term (U_{LP}).

The marginal product of food in health production (H_X) is expected to be positive for some foods (i.e., $H_X > 0$) and perhaps negative for others (i.e., $H_X < 0$). For example, fresh fruits and vegetables, which are high in fiber, vitamins, and minerals, are expected to have a positive marginal product on health output, but the marginal product might be negative for processed fruits and vegetables, which frequently contain "added sugar" and sometimes contain "added salt and fat" and less fiber and fewer vitamins and minerals than fresh produce. All meats and fish contain protein, which is essential for cell reproduction and growth, but they also contain fat. Since fats are very calorie-dense, they can contribute to excess energy intake and obesity. Also, some fats (low-density ones) detract from cardiovascular health and others (high-density ones) are neutral or positive to cardiovascular health. But some fat is needed to make fresh vegetables more palatable and to dissolve essential vitamins. Also, fat makes some other foods taste "good," which implies that the direct effect of *X* on utility is positive, or $U_X > 0$. If a type of food has a negative marginal product in the production of good health, the combined marginal effect of *X* on utility may still be positive, provided that $U^S_X = U_H H_X + UX > 0$, or the first term on the right of this equation ($U_H H_X$) is outweighed by a positive second term on the right (U_X).

Assume the household has two adults and their time constraint consists of a time endowment (*T*) which is allocated among work for pay (*R*), physically active leisure (*LP*), and other leisure (*LO*): $T = R + LP + LO$. Let P_x, P_1, P_C denote the price vectors corresponding to *X*, *I*, and *C*, respectively, *W* denotes the wage rate or opportunity cost of time of an adult, *V* denotes household non-labor income, then household cash income constraint $WR + V$ is spent on *X*, *I*, and *C* such that $WR + V = P_X X + P_I I + P_C C$. Now the household's decision is to choose *LP*, *LO*, *R*, *X*, *I*, and *C* to maximize household utility subject to staying within the human time and cash income constraints

$$\begin{aligned} \max_{LP,LO,R,X,I,C} \quad & u = U(H(LP, X, I; H_e, Z, \varphi),\ X, C,\ LP, LO; H_e, Z) \\ s.t. \quad & P_X \cdot X + P_I \cdot I + P_C \cdot C = WR + V \\ & R + LP + LO = T, R \geq 0, LP \geq 0, LO \geq 0 \end{aligned} \tag{40}$$

where the first constraint is the household's cash income constraint and the second constraint is the household's time constraint. The Lagrangian for the constrained utility maximization is

$$\begin{aligned}\Phi &= U(H(LP, X, I; H_e, Z, \varphi),\ X, C,\ LP, LO; H_e, Z) \\ &\quad + \lambda(WR + V - P_X \cdot X - P_I \cdot I - P_C \cdot C) + \mu(T - R - LP - LO)\end{aligned} \tag{41}$$

where λ and μ are the Lagrange multipliers, indicating the marginal utility of cash income ($WR + V$) and marginal utility of the time endowment (T), respectively.

The first-order conditions for an optimum, including Kuhn–Tucker conditions on LP and R, are

$$\begin{array}{llll} LP: & U_H \cdot H_{LP} + U_{LP} - \mu^* \leq 0 & (LP^* \cdot U_H \cdot H_{LP} + U_{LP} - \mu^*) = 0 & LP^* \geq 0 \\ R: & \lambda^* \cdot W - \mu^* \leq 0 & R^* (\lambda^* \cdot W - \mu^*) = 0 & R^* \geq 0 \\ LO: & U_{Lo} = \mu^* & & \\ X: & U_H \cdot H_X + U_X = \lambda^* P_X & & \\ I: & U_H \cdot H_I = \lambda^* P_I & & \\ C: & U_c = \lambda^* P_c & & \\ \lambda: & P_x \cdot X^* + P_I \cdot I^* + P_c \cdot C^* = WR^* + V & & \\ \mu: & R^* + LP^* + LO^* = T & & \end{array}$$

where $U_H = \partial U/\partial H$, $U_{LP} = \partial U/\partial LP$, $U_C = \partial U/\partial C$, $U_{LO} = \partial U/\partial LO$, $UX = \partial U/\partial X$, $H_{LP} = \partial H/\partial LP$, and $H_X = \partial H/\partial X$ and $H_I = \partial H/\partial I$ represent partial derivatives.

These immediately above first-order conditions can be solved jointly for an interior solution (where the opportunity cost of time is W) to obtain the implicit household optimal demand function for LP, LO, X, I, and C:

$$\begin{aligned} LP^* &= LP(W, P_X, P_I, P_C, V, H_e, Z, \varphi) \\ LO^* &= LO(W, P_X, P_I, P_C, V, H_e, Z, \varphi) \\ X^* &= X(W, P_X, P_I, P_C, V, H_e, Z, \varphi) \\ I^* &= I(W, P_X, P_I, P_C, V, H_e, Z, \varphi) \\ C^* &= C(W, P_X, P_I, P_C, V, H_e, Z, \varphi). \end{aligned} \tag{42}$$

Now upon substituting the equations in (42) into the health production function (39), obtain the general form of the household's health supply (and demand) function for (current) adult health:

$$H^* = H(LP^*, X^*, I^*; H_e, Z, \varphi) = H(W, P_X, P_I, P_C, V, H_e, Z, \varphi). \tag{43}$$

A notable feature of (43) is that it contains the same set of explanatory variables as those in the system of household demand equations (42). See Chen and Huffman (2009) for application of this model to adults' decisions to participate in physical activity and to be a healthy weight (not obese).

5 An Empirical Application: Demand for Food at Home and Other Household Inputs

To illustrate more vividly the empirical implications of household production theory and models for household demand studies, I consider the demand for inputs by the US sector over the post-Second World War period. The methodology that I follow is best described as a hybrid version of Becker's and Gronau's productive household models in which there are two classes of unpaid human time—unpaid housework and leisure—and where purchased and home-produced goods are not perfect substitutes. Following Jorgenson and Stiroh (1999), Jorgenson (2001) and Jorgenson and Slesnick (2008), inputs are defined as flows, and, hence, the input from housing, household appliances, transportation equipment, and recreation equipment is capital services and not the durable goods themselves.[10]

The immediate post-Second World War period is interesting because it was a time when the war effort that had been directed to producing tanks, planes, ships, guns, and ammunition was redirected to supplying durable goods—new houses, household appliances, and cars—to the household sector and tractors and machinery for the farm sector. Moreover, major series on the services of household durable goods available from Jorgenson start in 1948. My period of analysis ends in 1996, which is almost a half-century in length, and is a date when the transition of women from housework to market work had been largely completed (Goldin 1986).

After translating durable goods into services, it is now plausible to specify a static household input demand system that is in the spirit of equations (16a) and (17a), where leisure time is one of the t_is. Over the post-Second World War period, major changes in households included less time allocated by women to preparing meals and meal clean-up at home and more meals consumed away from home. Frequently, workday lunches are purchased and eaten at school or work and weekend dinners are eaten in restaurants. When meals are at home, ready-to-eat food is frequently purchased at fast-food restaurants, grocery delis, and restaurants, and taken home to be eaten. Advances in household appliances now provide microwave ovens with timers and electric and gas ranges with thermostatically controlled burners, and ovens give temperature control with little supervision, which may lead to higher-quality home-produced meals. These appliances are technically advanced relative to the coal, wood, kerosene, and LP gas burning cooking stoves of the late 1940s (Bryant 1986).[11]

[10] Although capital services are proportional to the stock of consumer durables, proper aggregation requires weighting the stocks by rental prices rather than asset acquisition prices (Jorgenson, Gollop, and Fraumeni 1987). Moreover, the rental price for each asset incorporates the rate of return, the depreciation rate, and the rate of change in the acquisition price.

[11] An alternative perspective of these input demand functions is that they represent demand functions for goods and services that yield utility directly to households (Pollak and Wachter 1975).

5.1 Specific Input Groups

Nine empirical input categories are distinguished for the aggregate household sector and indexes of price and quantity are constructed for each of them. Table 2.1 contains a brief definition of all variables used in the empirical demand system. A very brief summary of some key details about the input categories is discussed here, but greater details are available in Huffman (2008). As indicated above, households' durable goods are converted into service flows, and personal consumption expenditures on non-durables are used in constructing measures of non-durable goods or inputs. Also, considerable evidence exists that unpaid housework of women and men are not perfect substitutes, ranging from child care and meal planning and preparation where women's work dominates effort to yard and car care and snow removal where men's work dominates effort (Gronau 1977; Becker 1981; Robinson and Godbey 1997; Bianchi et al. 2000; Aguiar and Hurst 2006, tables 2 and 3). Hence, men's and women's time are treated as different inputs.

Table 2.1 Definitions of variables and sample means

Variable	Definitions	Sample mean
w_1	Expenditure share for women's (unpaid) housework	0.119
w_2	Expenditure share for men's (unpaid) housework	0.069
w_3	Expenditure share for food at home	0.052
w_4	Expenditure share for purchased housework-substitute services	0.015
w_5	Expenditure share for housing services	0.048
w_6	Expenditure share for household appliance services	0.030
w_7	Expenditure share for transportation services	0.047
w_8	Expenditure share for recreation services and entertainment	0.025
w_9	Expenditure share for "other inputs" (men's and women's leisure and other consumer goods and services)	0.595
AGE < 5	Share of resident population that is less than 5 years of age	0.090
AGE ≥ 65	Share of resident population that is 65 years of age and older	0.104
Non-metro	Share of resident population living in non-metropolitan areas	0.132
Consumer patents	Stock of patents of consumer goods, trapezoid weights over 26 years	3,262.7
F/(N)	Average household full-income expenditure per person	4,369.5
P_1	Price of women's housework, or opportunity wage	0.528
P_2	Price of men's housework, or opportunity wage	0.541
P_3	Price index for food at home	0.598
P_4	Price index for purchased housework-substitute services	0.512
P_5	Price index for housing services	0.565
P_6	Price index for household appliance services	0.580
P_7	Price index for transportation services	0.611
P_8	Price index for recreation services and entertainment	0.660
P_9	Price index for "other inputs" (e.g., men's and women's leisure and other consumer goods and services)	0.552
P	Stone price or cost of living index	0.556

The choice of exactly nine input groups is subjective. This is a large enough number to provide large amounts of information about the structure of US household production and it is near the maximum number of input categories can be supported in an econometric model with the data at hand. The complete set of input categories is: (i) women's (unpaid) housework, (ii) men's (unpaid) housework, (iii) food at home, (iv) purchased housework-substitute services (e.g., domestic services, laundry and dry-cleaning services, and food away from home), (v) housing services (for owner-occupied and rental housing), (vi) services of household appliances (including imputed services from computers, furnishings owned, and household utilities), (vii) transportation services (imputed services of transportation capital owned, purchased transportation services, and fuel for transportation), (viii) recreational services and entertainment (imputed services of recreation capital owned and recreation services purchased), and (ix) other goods and services (largely men's and women's leisure) and other purchased services.[12] Hence, in this empirical framework, unpaid housework and "other" inputs, which are largely leisure time, are distinct input categories.[13]

For this study, the daily time endowment of adults is rescaled from twenty-four hours to a modified time endowment of fourteen or fifteen hours per day, by excluding time allocated to sleeping, eating, and other personal care. No evidence exists that time allocated to personal care by women and men is responsive to prices or income, or even to trend (see Robinson and Godbey 1997: 337).[14] Moreover, Ramey, and Francis (2005) and Greenwood, Seshadri, and Yorukoglu (2005) use similar modified time endowments of roughly 100 hours per week in developing national economy macro simulation/calibration models.

Each individual aged 16 and older who is not in school is assumed to allocate his/her modified time endowment among unpaid housework, labor market work, including commuting, and leisure. Housework is defined as time allocated primarily to: food preparation and clean-up; house, yard, and car care; care of clothing and linens; care of family members; and shopping and management. Thus, housework in this study is considerably broader than "core housework"—cooking, cleaning and washing dishes, doing the laundry, and cleaning and straightening the house. Labor market work includes work for pay and commuting time to work. Time allocated to leisure or free time is time allocated primarily to social organizations, entertainment, recreation, and

[12] Some might suggest that food away from home be treated as a separate input category, but for the early part of the study period its share was quite small. See Prochaska and Schrimper (1973) for evidence.

[13] Only one price exists for men's and one for women's time, and hence, it is not possible to include leisure time as a separate input. However, men's and women's leisure does account for more than 85 percent of the "other input" category. Jorgenson and Slesnick (2008) use a household demand system consisting of four groups (non-durables, capital services, consumer services, and leisure). In particular, they do not distinguish between unpaid housework and true leisure and label the aggregate of the two "leisure."

[14] However, technical change associated with showering/bathing—soaps, shampoos, deodorants, shaving equipment—has made it possible for steady increases in the quality of personal hygiene, with a roughly unchanged amount of time spent on personal care.

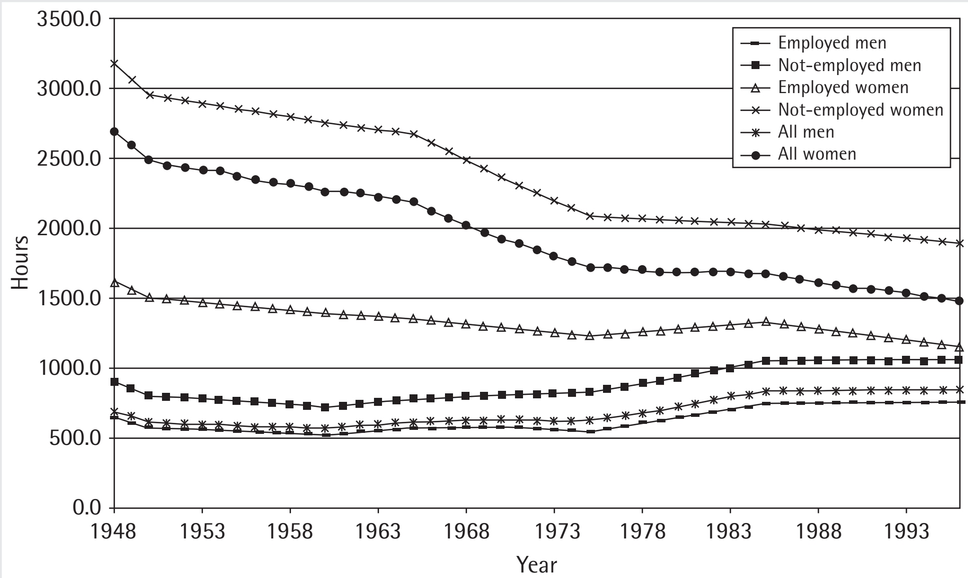

FIGURE 2.4 Average annual hours of unpaid household work of employed and not employed men and women, 16–64 years of age: 1948–96

communications.[15] However, it is defined residually for each individual as his/her allocatable time endowment less hours of housework and hours of labor market work.

The (modified) time endowment is set as follows. For women and men aged 16 to 64 who are not enrolled in school, the modified endowment is assumed to be fourteen and fifteen hours per day, respectively. The size of these modified time endowments is based on information presented in Robinson and Godbey (1997: 337) and Juster and Stafford (1991: 477), showing that women spend a little more time on sleep and personal care than men. For women and men who are 65 years of age and older, the modified time endowment is thirteen and fourteen hours, respectively. The small reduction relative to individuals 16–64 years of age reflects that additional time is spent recovering from illnesses.[16] In deriving aggregate average hours of paid work and of unpaid housework, a distinction is made between the number of employed and not employed women and men because these numbers have changed dramatically over time, which is a major factor in reallocation of adult time (see Figure 2.4 and Huffman 2008 for more details).

[15] In empirical research, Juster and Stafford (1985, 1991) also distinguish between time allocated to housework and leisure. For the purposes of my study, it is important to maintain these distinctions for the primary uses of non-market time.

[16] All computations dealing with time use assume a 365-day and fifty-two-week year.

Annual hours of unpaid housework for working and non-working women and men aged 16–64, who are not in school, and for age 65 and over were derived from benchmark data. Hours of work for pay were obtained from US Department of Labor data files.[17] Data on commuting time were derived from information reported in Robinson and Godbey (1997). Hours of women's and men's leisure are computed as the adjusted time endowment less hours of unpaid housework, and hours of work for pay, including time for commuting to work. Among men and women aged 16–64 who are not in school, women on average have slightly less leisure time than men, but for men and women, the average amount of leisure time rose over 1948 to 1975, and then decreased a little.

The price of time allocated to housework and leisure is defined as the forgone market wage following procedures in Smith and Ward (1985) where an adjustment downward occurs in the wage for the not-employed groups. An average nominal wage rate over working and not-working men (and women) is constructed as the weighted average of the average nominal wage rate for employed and not-employed men (and women), which is an index number solution to the aggregate problem. See Huffman (2008) for details.

Consumers purchase non-durable goods and services for consumption and acquire consumer durables in order to obtain a flow of services to use in household production. Capital services are proportional to the stock of assets, including computers, but aggregation requires weighting the stocks by rental prices rather than acquisition prices for assets. The rental price for each asset incorporates the rate of return, the depreciation rate, and the rate of decline in the acquisition price. The Bureau of Economic Analysis (BEA) provides data on purchases of twelve types of consumer durable goods used in the construction of service measures for household durable goods.

Input price indexes are Tornqvist indexes (Diewert 1976; Deaton and Muellbauer 1980a: 174–5). The Tornqvist index permits substitution to occur within major input categories as relative prices of subcomponents change. The overall price index for the nine-input group making full expenditures is, however, the Stone price or cost of living index (Stone 1954).

5.2 Mean Values and Long-Term Trends over the Post-Second World War Period

Mean full-income expenditure per capita over the study period is $4,369 in 1987 dollars. The mean expenditure share on women's unpaid housework is 0.119, men's unpaid housework is 0.069, food at home is 0.052, purchased housework-substitute services is 0.015, housing services is 0.030, household appliance services is 0.030, transportation

[17] The derived annual average hours of labor market work are consistent with the census year estimates presented by McGrattan and Rogerson (2004).

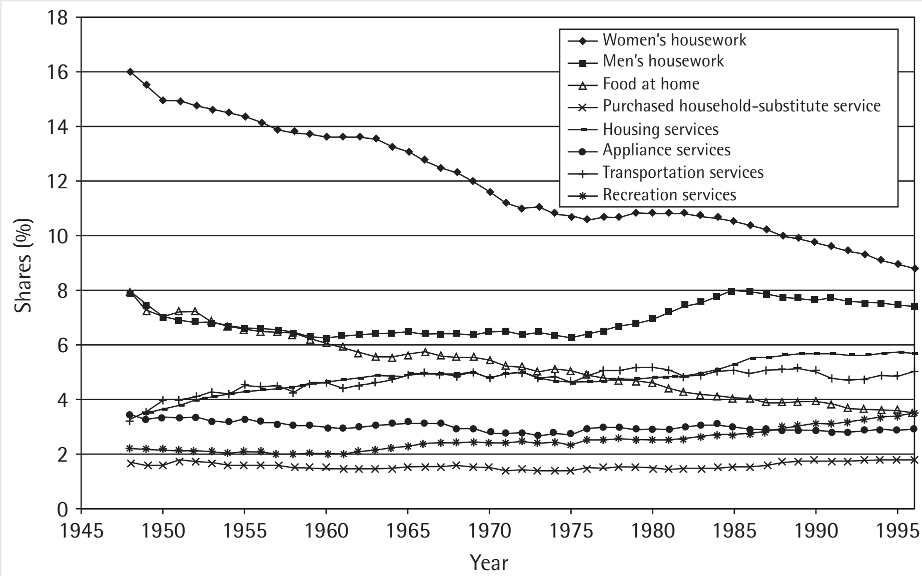

FIGURE 2.5 US household full income expenditure input shares, 1948–96

services is 0.047, recreation services and expenditures is 0.025, and "other inputs" is 0.595. Given that the other input category is dominated by leisure, the US household sector allocates a large share of full-income to leisure time, which is contrary to popular perceptions (Robinson and Godbey 1997).

Using the modified time endowment, full-income expenditures per capita in 1987 dollars were $3,668 in 1948 and $10,085 in 1996, with a mean value of $7,859. Hence, the average annual rate of growth of full-income-based consumption per capita over the sample period was 2.06 percent, slightly lower than the 2.25 percent per year growth of real per capita personal consumption expenditures in the National Income and Product Accounts (BEA). Evidence on the level and trend in eight of the nine expenditure shares (but excluding the share for "other inputs") from the aggregate data over 1948–96 are displayed in Figure 2.5.

The full-income expenditure share for women's housework is 16 percent in 1948 and displays a long-term negative trend with a slight reversal during the 1980s. The net decline over a half-century is about 7 percentage points. The share for men's housework is 8 percent in 1948 and declines slowly to 1960, as major technical advances are made in home heating equipment, and then shows almost no change from 1960 to 1975. However, it rose from 1975 to 1985, and then declined slightly. The net decline over the half-century was about 1 percentage point. Hence, during the post-Second World War period there has been a significant narrowing of the differential in the (unpaid) housework cost shares for men and women.

The full-income expenditure share for food at home was 8 percent in 1948, and then declined steadily over the half-century, ending at 3.5 percent. The expenditure share for purchased housework-substitute services (laundry and dry-cleaning services, domestic services, and food away from home) was about 1.7 percent in 1948, declined slowly until the mid-1970s, and then rose slightly, ending essentially where it started. Although some may have the conception that the expenditure share on this item has risen dramatically over the sample period, it has not changed. A major factor was the steady technical advance in fabrics used in making clothing, making them easier to care for, along with wages of domestic servants and restaurant workers, which have remained low owing to the immigration of low-skilled workers since 1980 relative to all US workers.

Turning to full-income expenditure shares for inputs, the share of housing services was only 3.5 percent in 1948, which is roughly one-tenth its share using cash personal income rather than full income as the budget constraint. It rose slowly and steadily until 1970, remained essentially unchanged from 1970 to 1980, and then rose slowly and steadily until 1996. The net change is an increase of 2.3 percentage points. Although the share of full-income expenditure allocated to food at home was larger in 1948 than for housing services, this was reversed by 1980, and in 1996 the share spent on housing was about twice as large as for food at home. The share for household appliance services rose initially, with the massive investment in new housing during the late 1940s and 1950s, displayed a slow decline to the mid-1970s, and thereafter rose very slowly. However, the net change over the half-century was negligible (see Figure 2.5). The share spent on transportation services was 3.4 percent in 1948, rose steadily until 1965, but then essentially remained unchanged until 1975. From 1975 to 1996 it rose slowly, reaching 5 percent in 1996. The share spent on recreation services and entertainment was 2 percent in 1948, had a slight negative trend until the mid-1970s, and then reversed course with a slow increase until 1996, ending the century 1.3 percentage points higher than at the beginning (see Figure 2.5).

In summary, some of the nine full-income expenditure shares show major changes over the last half-century—women's housework, food at home, and transportation services—but the others are relatively stable over time. When unpaid housework and leisure are excluded from the expenditure system, very different expenditure shares result. Deaton and Muellbauer (1980a), Jorgenson and Slesnick (1990), and Moschini (1998) also present expenditure shares using aggregate data with traditional measures of household consumption.

The relative input prices (derived as the nominal input price deflated by the Stone price or cost of living index (Stone 1954) for all nine input groups, 1948 to 1996, are displayed in Figure 2.6. They show dramatic changes over the study period.[18] A distinguishing feature of these new input prices is the dramatic change in the relative price of women's unpaid housework, which rose steadily from 1948 until 1980 by a total

[18] The excluded share is for the residual group labeled "other goods and services," which rose significantly over the post-Second World War period.

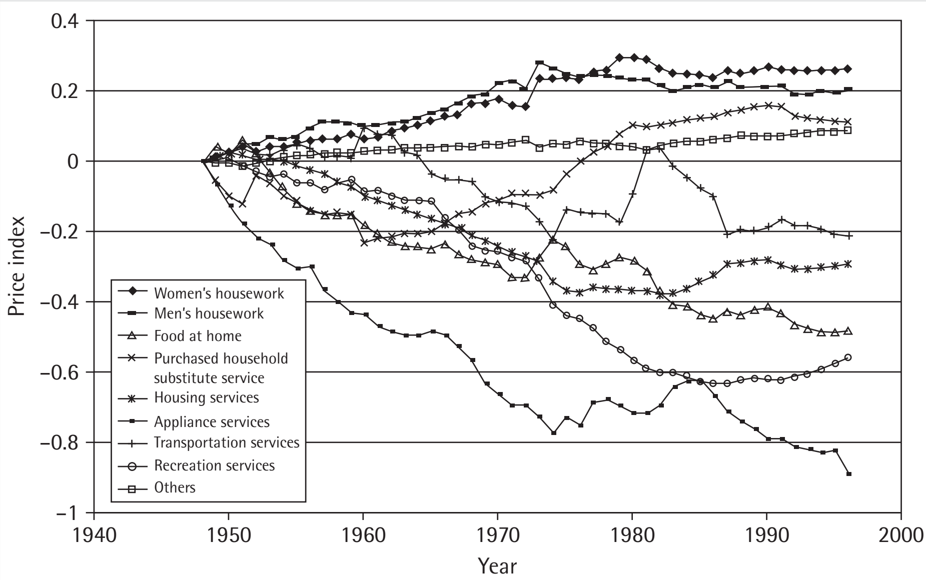

FIGURE 2.6 Prices of inputs for US households relative to the Stone cost of living index, 1948–96

of 30 percent and thereafter remained roughly unchanged. The relative price of men's unpaid housework rose about 27 percent over 1948 to 1972, then declined a little during the mid-1970s to early 1980s, and then remained largely unchanged to 1996. Hence, there was a small decline in gap between the prices of women's and men's housework over the study period.

The relative price of food at home had a strong negative trend, except for the world food crisis years in the early 1970s, declining by about 60 percent over the last half-century or a little more than 1 percent per year. The relative price of purchased housework-substitute services declined slowly over 1948 to 1967, rose slowly over 1967 to 1991, and then leveled off to 1996. The net result in the last half-century was an increase of about 10 percent (see Figure 2.5). The relative price of housing services declined steadily, cumulating into a 45 percent decline from 1948 to 1975, and then reversed its trend to increase slowly and be 10 percent higher in 1996. The relative price of household appliance services declined dramatically at a compound rate of 2.5 percent per year over 1948 to 1975, moved irregularly but trending upward over 1975 to 1985, and then declined by 35 percent to 1996. Moreover, the net decline over the half-century was a dramatic 80 percent. The relative price of transportation services moved in an irregular pattern over time and had a net decline over the whole period of 20 percent. The relative price of recreation input rose from 1948 to 1958, declined steadily from 1958 to the mid-1980s, and then rose slightly. The net decline over a half-century was, however, 20 percent. The relative price of "other inputs" rose very slowly over the half-century (see Figure 2.5). Thus, over 1948 to 1996, the data on expenditure shares and input prices show significant variation that is useful in estimating a complete household input demand system.

5.3 The Econometric Model

Among possible flexible function forms for the aggregate input demand system, I chose the almost ideal (AI) demand system by Deaton and Muellbauer (1980b) and Deaton (1986), which has cost shares as the dependent variables. In particular, the version is sometimes referred to as the linear approximation (LA) of the AI demand system (LA/AI), which has several major advantages, e.g., see Alston, Foster, and Green (1994), and has also been used by Hausman (1996) and Huffman and Johnson (2004). The econometric model is

$$w_{it} = \alpha_{i0} + \sum_{s=1}^{S} \delta_{is} D_{st} + \sum_{j=1}^{k} \gamma_{ij} \log p_{jt} + \beta_i \log\left[F_t/P(p_t)\right] + \varphi_i t + u_{it}, \tag{44}$$

where w_{it} is the full-income expenditure share for the ith input, $i = 1, \ldots, n$, in time period $t = 1, \ldots, T$, D_{st} are translating or equivalency variables, $p_{jt}$is the price of the jth household input, F_t is full-income or expenditure, $P(p_t)$ is the Stone price index across the n input categories, which avoids inherent non-linearities, t is a linear time trend, and u_{it} is a random disturbance term that represents random shocks to the demand for input i in year t (Deaton and Muellbauer 1980a: 75–8; Wooldridge 2002: 251–8). The time trend is included to "detrend" the cost shares and all of the other regressors and also pick up any excluded variable that is highly correlated with trend, including gradual shift in women's skills from home production to market skills (Goldin 1986; Wooldridge 2002; Kerkhofs and Kooreman 2003; Borjas 2005).

In equation (44), the primary interest is in the αs, γs, and βs, which are key parameters of the LA/AI demand system. α_{i0} is a time-invariant unobserved effect for input i. The γs and βs are related to price and income elasticities, and symmetry, homogeneity, and adding up restrictions are imposed across the system of input demand equations (Deaton and Muellbauer 1980a: 76). Given the above restrictions and that expenditure shares sum to one, one of the share equations can be omitted in the estimation and its parameters can be recovered from the other ($n-1$) estimated input demand equations. The ninth input category is omitted in my estimation.

The full-income expenditure elasticity of demand for the ith input is

$$\eta_{iE} = 1 + \beta_i/w_i, \; i = 1, \ldots, n. \tag{45}$$

The Hicksian compensated own-price elasticity for the ith input is

$$\xi_{ii} = \gamma_{ii}/w_i + w_i - 1, i = 1, \ldots, n, \tag{46}$$

and the compensated cross-price elasticity of demand for the ith input and jth input price is

$$\xi_{ij} = \gamma_{ij}/w_i + w_j, i, j = 1, \ldots, n. \tag{47}$$

The specification of price elasticities in (46) and (47) has been shown in a simulation analysis by Alston, Foster, and Green (1994) to provide accurate estimates of the true price elasticities. Furthermore, the price and income elasticities that are to be calculated in this study using aggregate data are macro- rather than micro-estimates, and Rogerson and Wallenius (2007) emphasize that these macro-price and income elasticities are most appropriate for aggregate policy analysis.

Although expenditures share weighted full-income expenditure elasticities must sum to unity, any individual income elasticity of demand for an input can be positive, negative, or zero. However, for the compensated own-price elasticity of demand to be consistent with demand theory, it must be negative. Inputs are denoted as substitutes if they have a cross-price elasticity that is positive and as complements when the cross-price elasticity is negative. Given the restrictions on the demand system and letting all input prices change by 1 percent, the expenditure share weighted compensated price elasticities for the ith input is zero.

Equation (44) has two random unobserved terms (α_{i0} and u_{it}) and α_{i0} may be correlated with regressors in a demand equation and u_{it}. If the system were estimated in *level form*, this could, in principle, bias all the estimated coefficients. The additive disturbance term u_{it} in equation (44) satisfies the usual stochastic assumptions (having a zero mean, finite variance, first-order autoregressive process over time, and contemporaneous correlation across share equations). Under the hypothesis of a first-order autocorrelation and fitting a system of demand equations with cross-equation symmetry conditions, Barten (1969) emphasized that each of the equations within the system must be transformed by the same value of ρ but estimates of ρ were found to be close to one. Hence, the demand system was expressed in first-difference form for estimation. The differenced (n – 1) expenditure share equations were estimated with all restrictions imposed. In this version of the model, intercept terms become the coefficient of the linear time trend in equation (44).

The eight differenced input demand equations are configured as a stacked system of difference equations having the form of the seemingly unrelated regression (SUR) model, including contemporaneous cross-equation correlation of disturbances (Greene 2003: 340–50). The iterative feasible generalized least squares estimator is consistent, asymptotically efficient, and asymptotically equivalent to the maximum likelihood estimator (Barten 1969). The estimation is conducted using the iterative seemingly unrelated regression (ISUR) procedure in the software package Statistical Analysis System (SAS).

In addition to prices and income, the input demand system (44) contains demographic variables representing important dimensions of the structure of the population—the *D*s. These translating variables are the share of the US resident civilian population that is (a) 5 years of age and younger, or pre-school age, (b) 65 years of age or older, who are retired or contemplating retirement, (c) residing in a non-metropolitan or rural area. I also allowed for the possibility of disembodied technical change to occur. Following Griliches (1990), I construct a proxy variable that is, the stock of patents of consumer goods, using trapezoidal weights (see Huffman and Evenson 2006 for a discussion of this type of weighting pattern). Also, see Huffman (2008) for more details.

5.4 The Empirical Results and their Interpretation

The nine aggregate full-income expenditure shares are the dependent variables, and they are explained econometrically by nine relative input prices: real full-income expenditures per capita; share of the population under age 5, over age 65, and living in non-metropolitan areas; and the consumer goods' patent stock and trend. The differenced versions of equation (44) is fitted to data covering forty-nine years, 1948–96, subject to symmetry and homogeneity and adding up conditions, to estimate a total of eighty-four unknown parameters of the demand system by the ISUR model.

Estimated coefficients of the LA/AI household demand system are reported in Table 2.2, and the estimated (macro) compensated price and full-income expenditure demand elasticities (equations (45)–(47)), evaluated at the sample means of the relevant variables, are reported in Table 2.3. The impacts of per capita real full-income expenditure, demographic characteristics, and own-price effects are estimated relatively precisely. The impacts of cross-price effects are estimated less precisely, but this is to be expected because they represent price effects that are of secondary importance and about which less prior information exists. Surprisingly, the coefficients of the consumer patent stock variable are non-zero, and some are significantly different from zero, which is evidence of technical change in the demand system for input in household production.

The estimated intercept terms of the first-differenced LA/AI demand system are the coefficients of the linear trend in the input demand equations (Table 2.2). Hence, a positive trend exists for the demand for women's unpaid housework, food at home, purchased housework-substitute services, housing services, appliance services, and transportation services. A negative trend exists in the demand for men's unpaid housework, recreation services and entertainment, and "other inputs."

For price and income expenditure elasticities, the associated z-values are computed for taking the respective shares as given. The Hicksian-compensated macro own-price elasticity for all nine input groups is negative, statistically significant at the 1 percent level and plausible, at -0.493 for women's unpaid housework, -0.489 for men's unpaid housework, -0.553 for food at home, -0.757 for housing services, -0.887 for appliance services, −1.087 for transportation services, −0.628 for recreation services and entertainment, and −0.338 for "other inputs." Hence, the negative and statistically significant macro own-price elasticities are supportive of an aggregate demand system being estimated that mirrors some of the properties of a microeconomic demand system.

It is an empirical question as to whether women's and men's unpaid housework are substitutes or complements. The empirical results in Table 2.3 provide evidence that women's and men's housework are complements, having a macro compensated cross-price elasticity of −0.16, which is significantly different from zero at the 5 percent level. Given the restriction on estimated coefficients that the summation across all compensated price elasticities for women's housework is zero (Deaton and Muellbauer 1980a: 43–4), the other seven input categories as a group are on average a substitute for women's housework. The average size of this compensated cross-price elasticity must be 0.09 (and cannot be zero). In fact, row 1 in Table 2.3 provides evidence that all seven of these other input categories are substitutes for women's housework.

One likely explanation for women's and men's unpaid housework being complements is that women and men perform different types of housework and that these tasks complement rather than substitute for one another (Robinson and Godbey 1997). Within married couples, housework continues to be specialized by gender. Women have continued over recent decades to perform core housework—traditionally "female" tasks like cooking and cleaning—while men perform yard, car, and external house care and maintenance. Unattached men can, however, purchase services in the market that replace women's core unpaid housework, and unattached women can purchase services in the market to replace men's unpaid housework associated with a yard, car, and exterior house care and maintenance.

Although purchased housework-substitute services and appliance services are substitutes for women's unpaid housework, as anticipated, they are also substitutes for men's unpaid housework (see Table 2.3). The respective macro cross-price elasticities between these two input categories are, in fact, much larger for men's unpaid housework than women's unpaid housework. Hence, the evidence is that this input category is a "better" substitute for men's than women's unpaid housework. Not too surprisingly, food at home and recreation services and entertainment are complements to men's housework and the other four major input categories are substitutes.

Housing and transportation services are shown to be complements to food at home, where both are inputs to produce a commodity defined as a family enjoying meals at home. Food at home, purchased housework-substitute services, and household appliance services are complements for housing. For appliance services, all of the other input groups are substitutes, except for housing services. Food at home, housing services, and transportation services are complements (and "other inputs" are substitutes) for recreation services and entertainment. However, the strongest substitute for recreation services and entertainment is the "other inputs." The compensated cross-price elasticity is one and significantly different from zero at the 1 percent level. Hence, I interpret this result to mean that a strong substitution effect exists between the "goods" component of recreation and entertainment and the "own-time" component.

The cross-price elasticities among the nine input groups imply numerous margins where "other inputs" have been substituted for women's and men's unpaid housework as the relative price of time rose in the post-Second World War period (see Figure 2.6). The results suggest that food at home and women's unpaid housework are substitutes but food at home and men's housework are complements. Purchased housework-substitute services and men's unpaid housework are shown to be strong substitutes, but purchased housework-substitute services and women's unpaid housework are weak substitutes.

The macro full-income expenditure elasticity of demand for women's housework is 0.713, for men's housework is 1.136, for food at home is 0.793, for purchased housework-substitute services is −0.420, for housing services is 0.480, for household appliance services is 0.392, for transportation services is 1.151, for recreation services and entertainment is 1.579, and for "other inputs" is 1.133. Hence, transportation services, recreation services and entertainment, and "other inputs" are luxury goods, having macro full-income expenditure elasticities greater than one. Women's unpaid housework, food at home, housing services, and household appliance services are normal inputs and have positive macro income elasticities that are less than one. Only purchased housework-substitute services are inferior, having negative macro expenditure elasticity, but this elasticity is not significantly different from zero at the 5 percent level.[19] Although the full-income expenditure elasticity for purchased housework-substitute services is essentially zero, readers can easily confuse price and income effects here. Changes in the use of this input category over the post-Second World War period is largely due to rising prices of unpaid housework and not due to rising real income.

On the whole, this set of macro full-income expenditure elasticities has considerable appeal. Looking at the post-Second World War period up to 1996, our results suggest relatively large rightward shifts in aggregate demand for normal inputs as full income has risen. This increase occurred for men's unpaid housework, household sector transportation services, recreation services and entertainment, and "other inputs." With the macro full-income expenditure elasticities of demand for both men's and women's unpaid housework being positive and their time endowment being fixed, rising non-labor income is a factor tending to make human time more scarce over time (Linder 1970; Robinson and Godbey 1997).[20]

The generally significant estimated coefficients of the consumer patent stock in the demand system supports the hypothesis of technical change in the US household sector over the post-Second World War period. The precise impact on input demand for each input category is obtained by evaluating δ_j/w_j at the sample mean of the expenditure

[19] However, the coefficients are estimated with restrictions so that one coefficient cannot be changed without an offsetting change in one or more other coefficients.

[20] If the wage elasticities of demand for men's and women's leisure are the same and they equal the own-price elasticity of demand for "other inputs," then the implied compensated own-wage elasticity of labor supply for women is approximately 1.98 and for men is 0.83.

Table 2.2 ISUR estimate of US household demand system for inputs: almost ideal demand system (shares) 1948–96 (asymptotic standard errors in parentheses)[a]

Variables	Women's housework (1)	Men's housework (2)	Food at home (3)	Purchased housework-substitute services (4)	Housing services (5)	Appliance services (6)	Transportation services (7)	Recreation services and entertainment (8)
Constant	0.287 (0.305)	−0.300 (0.236)	0.066 (0.264)	0.254 (0.147)	0.348 (0.129)	0.180 (0.156)	0.131 (0.236)	−0.177 (0.120)
AGE ≤5	0.424 (0.157)	0.184 (0.125)	0.118 (0.144)	−0.008 (0.087)	0.062 (0.080)	0.073 (0.093)	−0.026 (0.146)	−0.053 (0.075)
AGE ≥65	−0.360 (0.282)	−0.161 (0.223)	−0.240 (0.261)	0.229 (0.146)	0.311 (0.131)	0.025 (0.155)	−0.024 (0.243)	0.021 (0.122)
Non-metro	−0.056 (0.04)	0.007 (0.03)	−0.065 (0.04)	−0.007 (0.02)	−0.040 (0.02)	0.042 (0.03)	0.030 (0.0005)	0.034 (0.0002)
ln (Consumer patents)	0.035 (0.014)	0.032 (0.011)	0.019 (0.013)	0.002 (0.007)	−0.002 (0.006)	0.009 (0.008)	−0.021 (0.014)	0.002 (0.01)
ln[F/(N)]	−0.034 (0.027)	0.009 (0.021)	−0.011 (0.023)	−0.022 (0.013)	−0.025 (0.012)	−0.018 (0.013)	0.007 (0.021)	0.014 (0.011)
$\ln P_1$	0.046 (0.014)							
$\ln P_2$	−0.028 (0.010)	0.030 (0.011)						
$\ln P_3$	0.007 (0.007)	−0.012 (0.006)	0.021 (0.008)					
$\ln P_4$	0.003 (0.006)	0.015 (0.005)	0.004 (0.004)	0.002 (0.005)				
$\ln P_5$	0.003 (0.006)	0.008 (0.006)	−0.008 (0.004)	−0.004 (0.004)	0.009 (0.007)			
$\ln P_6$	0.003 (0.005)	0.004 (0.004)	−0.001 (0.004)	0.004 (0.003)	−0.009 (0.003)	0.002 (0.004)		
$\ln P_7$	0.005 (0.005)	0.002 (0.004)	−0.003 (0.005)	−0.003 (0.003)	0.007 (0.003)	−0.001 (0.003)	−0.006 (0.006)	
$\ln P_8$	−0.002 (0.005)	−0.008 (0.005)	−0.000 (0.003)	0.008 (0.003)	−0.007 (0.004)	−0.000 (0.003)	−0.003 (0.002)	0.009 (0.004)
R^2	0.996	0.969	0.989	0.707	0.990	0.832	0.874	0.981

[a]System estimated as first-differences to induce stationarity of the time-series.

Table 2.3 Estimates of price and income elasticities: almost ideal demand system model with nine input groups, US aggregate data, 1950–96 (z-values are in parentheses)

Commodity–input groups (i)	Prices (j)									Income/ expenditure elasticity
	1	2	3	4	5	6	7	8	9	
	Compensated (e_{ij}^*)									
(1) Women's housework	−0.493 (4.29)	−0.164 (1.99)	0.110 (1.81)	0.043 (0.90)	0.070 (1.29)	0.053 (1.30)	0.085 (1.95)	0.007 (0.15)	0.289 (1.68)	0.713 (3.16)
(2) Men's housework	−0.283 (1.99)	−0.489 (3.14)	−0.116 (1.35)	0.229 (3.11)	0.166 (1.93)	0.087 (1.45)	0.077 (1.22)	−0.085 (1.21)	0.414 (1.73)	1.136 (3.75)
(3) Food at home	0.253 (1.81)	−0.154 (1.35)	−0.553 (3.71)	0.098 (1.23)	−0.109 (1.50)	0.002 (0.03)	−0.015 (0.17)	0.016 (0.24)	0.463 (1.44)	0.793 (1.81)
(4) Purchased housework-substitute services	0.330 (0.90)	1.019 (3.11)	0.328 (1.23)	−0.882 (2.79)	−0.184 (0.77)	0.295 (1.51)	−0.139 (0.75)	0.075 (0.36)	−0.841 (1.22)	−0.420 (0.51)
(5) Housing services	0.173 (1.29)	0.238 (1.93)	−0.119 (1.50)	−0.060 (0.77)	−0.757 (5.28)	−0.159 (2.56)	−0.093 (1.71)	−0.113 (1.32)	0.888 (4.16)	0.480 (1.99)
(6) Household appliance services	0.211 (1.30)	0.202 (1.45)	0.004 (0.03)	0.153 (1.51)	−0.255 (2.56)	−0.887 (7.45)	0.008 (0.08)	0.024 (0.28)	0.541 (1.51)	0.392 (0.88)
(7) Transportation services	0.217 (1.95)	0.113 (1.22)	−0.017 (0.17)	−0.046 (0.76)	−0.095 (1.71)	0.005 (0.08)	−1.087 (8.92)	−0.029 (0.56)	0.937 (3.37)	1.151 (2.63)
(8) Recreation services and entertainment	0.032 (0.15)	−0.236 (1.21)	0.034 (0.24)	0.047 (0.36)	−0.219 (1.32)	0.029 (0.28)	−0.055 (0.56)	−0.628 (3.56)	0.997 (2.64)	1.579 (3.71)
(9) "Other inputs"	0.058 (1.68)	0.048 (1.73)	0.040 (1.44)	−0.022 (1.22)	0.071 (4.16)	0.027 (1.51)	0.074 (3.37)	0.041 (2.64)	−0.338 (3.48)	1.133 (10.08)

share w_j. These results suggest that technical change in the household sector reduced the demand for women's housework relative to housing services, transportation services, and "other inputs," and increased the demand for women's unpaid housework relative to food at home and men's unpaid housework. No significant change in the demand for women's housework relative to purchased housework-substitute services, appliance services, or recreation services occurs.

The impacts of a change in the share of the population that is age 5 or less is 2.3 times larger for women's unpaid housework than for men's unpaid housework, and the impact of a change in the share of the population 65 years of age and older is 2.2 times larger on women's unpaid housework than on men's unpaid housework. Hence, the demand for women's unpaid housework is more responsive to the changing age structure of the US population than is men's housework.

6 Conclusions

Advances in household production theory and models have made almost no inroads to the study of food demand over the past fifty years. With three exceptions, food demand studies have not even adopted the slight advance in neoclassical consumer demand that occurs when one recognizes that the household has a major resource consisting of the time endowment of adult households. This means that food demand studies have continued to omit the price of time (of adult household members, especially of the homemaker) in food demand equations and to use a household's cash income rather non-labor income or full income in these equations. The tradition has been to focus on the household's cash income constraint, and how cash income is allocated to purchased goods and services, but to ignore the fact that these decisions are made jointly with adult time allocation decisions on work versus leisure. Also, the cash income constraint in traditional demand models includes labor market earnings, which results from households' decisions on time allocated to work for pay versus other activities. This means that cash income reflects a mixture of price and income effects and that estimates of the income elasticity of demand for food in these studies are invariably biased. More generally, because the price of time is omitted from these food demand equations, there are further biases in estimated price and income elasticities obtained in a demand system.

The adoption of the productive household models makes it possible to incorporate the economics of production theory into household consumption decisions. This means that commodities are in general produced at minimum cost, or the household is on the frontier of a multiple-output–multiple-input relationship. In some cases it is useful to assume that no joint production occurs in the household, but a more realistic assumption is that the household represents an institution where joint production is pervasive. For example, an adult is simultaneously preparing a meal, supervising children, and listening to the news. Moreover, with the household production model, we can associate the education of the homemakers with the efficiency of household production, and thereby free ourselves from the assumption of neoclassical models that education primarily changes tastes.

Using key concepts from household production theory, I have developed an empirical application that is a demand system for inputs used by households, and it has been fitted to data for the US household sector over the post-Second World War period. The data on expenditure shares and relative input prices show dramatic changes over time; for example, the share of women's unpaid time in consumption expenditures has fallen by 8 percentage points. The relative price of a number of inputs has changed substantially; for example, the price of household appliance services declined by 75 percent over the first twenty-five years of the study period and the price of food at home declined by 50 percent over the forty-nine-year study period. Moreover, the empirical estimate of a complete input demand system for the US household sector has provided new and interesting estimates of own-price and cross-price elasticities and full-income expenditure elasticities of demand for food at home and for eight other input groups.

The results provide estimates of the compensated own-price demand elasticities for inputs ranked from highest to lowest; these are: transportation services, appliance services, purchased services that substitute for unpaid housework, housing services, recreation services, food at home, women's unpaid housework, men's unpaid housework, and "other inputs." The results also provide evidence that food at home and women's unpaid housework are substitutes but food at home and men's unpaid housework are complements. Purchased services that substitute for unpaid housework and men's unpaid housework are shown to be strong substitutes, but purchased services and women's unpaid housework are weak substitutes. The full-income expenditure elasticities of demand for inputs ranked from highest to lowest are: recreation services, transportation services, "other inputs," men's unpaid housework, food at home, women's unpaid housework, appliance services, and purchased services that substitute for unpaid housework.

These new macro price and income elasticities show that productive household theory can be effectively applied to the measurement of inputs, to the specification of a household sector complete input demand system, and to estimation of a new type of demand system. Moreover, my results provide evidence that the compensated price elasticity of demand for food at home is relative large, and that food at home and women's housework are substitutes but food at home and men's housework are complements. Also, food at home and purchased housework-substitute services, which include food away from home, are substitutes. In addition, the compensated price elasticity of demand for services that are a substitute for unpaid housework is relatively large. Two surprising results are that the full-income expenditure elasticity of demand for food is relatively large but for services that substitute for unpaid housework, i.e., purchased housework-substitute services, is small and not significantly different from zero.

For those who are interested in recent annual data on time use, the American Time Use Survey, which was initiated by the US Department of Labor in 2003, may be a useful source of data.

This chapter has laid a foundation that can be a bridge between household production theory and future studies of the demand for food and other inputs.

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