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# Household Production and the Demand for Food and Other Inputs: U.S. Evidence

Wallace E. Huffman

The paper develops a new productive household model and a consistent household full-income/expenditure demand system for inputs and leisure of U.S. households. The demand system is fitted to U.S. annual aggregate data over the last half of the 20<sup>th</sup> century and findings include that the price and income elasticity of demand for food-at-home are roughly two times larger than for food-away-from-home and that food-at-home and away-from-home are substitutes. The price and income elasticity of demand for men's unpaid housework are twice as large as for women's unpaid housework and women's and men's unpaid housework are shown to be complements.

*Key words:* U.S. household sector, production, models of behavior, input demand system, food demand, time allocation, post-war II

## Introduction

Reid (1934) provided an early description of household production models, and her work is an important antecedent to Becker's formal modeling of the productive household. Becker (1965) is best known for the productive household model, in which a household is both a producing and a consuming unit. In his framework, households use inputs to produce commodities that are consumed directly and not sold in the market and maximize utility subject to the household's production function and human time and cash income constraints. Becker argues that these models provide significant new insights in demand theory relative to models where households are purely consuming units.

Mincer (1963) was the first to identify econometric model specification issues associated with classical demand analysis, including the relevant measure of income and set of prices to explain the demand for goods and services by households. However, food economic studies over the past four decades have largely overlooked these specification issues and biases arising from applying conventional as opposed to productive household models of demand (Blanciforti, Green, and King, 1986; Eales and Unnevehr, 1988; Moschini, Moro, and Green, 1994; Pashardes, 1993; Kastens and Brester, 1996; Stewart et al., 2005; Lewbel and Ng, 2005; Jorgenson and Slesnick, 2008).<sup>1</sup> Exceptions are Prochaska and Schrimper (1973), McCracken and Brandt (1987), and Hamermesh (2007).

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<sup>1</sup> Although LaFrance (2001) presents an abstract summary of productive household models, his paper does not illuminate the expected usefulness of these models. Moreover, his paper does not review the literature on food price and income elasticities nor present new estimates.

This paper examines the demand for inputs and leisure of U.S. households within a household production framework and reports new econometric estimates of the demand for food-at-home, food-away-from-home, and seven other input groups. The demand system is complete in that expenditures exhaust Becker's concept of full-income, which is the value of the time endowment of adult household members plus their nonlabor income. A U.S. aggregate data set created by the author for the second half of the twentieth century provides the opportunity to examine the demand for inputs by U.S. households during a period when relative prices, income, and the technology of household production were changing dramatically and the hours of women's housework and relative importance of food-at-home in total food consumption declined substantially.

This study provides one of the first sets of price and income elasticities for complete household demand system derived from a productive household model. The evidence for the U.S. aggregate household sector over the second half of the twentieth century include: The price and income elasticities of demand for food-at-home are roughly two times larger than for food-away-from-home. Likewise, the price and income elasticities of demand for men's unpaid housework are twice as large as for women's unpaid housework. Although input pairs are on average substitutes, women's and men's housework are complements, as are women's unpaid housework and household appliance services. The new price and income elasticities are in the spirit of Rogerson and Wallenius (2007); most relevant to macro-economic models and national policy analysis.

### **Food Demand and Productive Household Models**

Household production models have been fruitfully applied in a number of areas, including farm household decisions (Rosenzweig and Evenson, 1977; Huffman, 1980; Abdulai and Delgado, 1999; Chavas, Petrie, and Roth, 2005; Le, 2010), decisions on commuting and work trips (Odland, 1981; Small, 1982), decisions on children's education (Blau and Grossberg, 1992; Leibowitz, 2003), and child and human health outcomes (Rosenzweig and Schultz, 1983; Blau, Guilkey, and Popkin, 1996; Glewwe, 1999; Case, Fertig, and Paxson, 2005; Black, Devereux, and Salvanes, 2007; Huffman et al., 2010). However, in a review of the agricultural economics literature, only three papers reveal a concerted effort to incorporate household production theory into an empirical study of the demand for food (Prochaska and Schrimper, 1973; McCracken and Brandt, 1987; Hamermesh, 2007). Prochaska and Schrimper use cross sectional micro or household data to estimate household demand for food-away-from home. The authors 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 find that an increase in the homemakers' opportunity cost of time and comprehensive household income significantly increased 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 costs of time are omitted.

McCracken and Brandt (1987) analyze demand for food-away-from-home by major type of provider. They reference Lancaster's 1966 household production model, which is similar to Becker's model. In their empirical model, a variable for the opportunity cost of housework is included, consistent with Becker's model. However, they use household cash income, rather than non-labor income or full-income, as the income variable, which is inconsistent with Becker's model. Using household cross-sectional data for one year, they find a significant positive effect of the value of the homemakers' time on the demand for various types of food away from home.

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 household 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 effects of the husband's and wife's wage rates on the demand for food-at-home are negative, only the estimated coefficient for wife's wage is

significantly different from zero. In the 1985 data, Hamermesh (2007) finds 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 much smaller and weaker than in the 1985 data.

Other food demand studies that reference household production theory include Kinsey (1983), Keng and Lin (2005), Park and Capps (1997), and Sabates, Gould, and Villarreal (2001). 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 model is not consistent with Becker's theory. 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 frequently fit hedonic wage equations for individuals who are in the labor force and then use the predicted wage rate used to explain hours of market work, demand for children, and migration Card (1986); Tokle and Huffman (1991); Blundell and MaCurdy (1999); Huffman and Feridhanusetyawan (2007).

Keng and Lin (2005) find 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 proxy for opportunity cost of time, as a regressor in food demand equations. For example, Park and Capps (1997) find that the probability that a household purchases ready-to-eat or ready-to-cook meals increases with the education of household managers, but education is not included in the expenditure equation for ready-to-cook meals.

In new research at ERS, Andrews and Hamrick (2009) argue that "eating requires both income to purchase food and time to prepare and consume it." However, their focus is on income effects: "food spending tends to rise with a household's income. The opposite is true for time devoted to preparing food." Overall, few empirical studies of food demand have used a (consistent) productive household model framework.

### Household Production Models and Demand Analysis

Early research by labor economists added leisure to the set of goods that is consumed by households and the value of the human time endowment of a household's adult members to nonlabor income to obtain a new full-income budget constraint. Here, the household demand for leisure and purchased goods are explained by the price of time, price of purchased goods, and full-income (see Blundell and MaCurdy, 1999; Varian, 1992, pp. 95-113, 144-146). However, these models ignore the household production dimension.

The model of household production developed in this paper builds upon Becker's and Gronau's research, but also see Huffman (2011) for a review and some extensions of the Becker (1965) and Gronau (1977, 1986) productive household models. Households obtain utility from consuming two commodities ( $Z_1, Z_2$ ) and leisure ( $L$ ). For example, let's assume that  $Z_1$  is home-prepared meals and  $Z_2$  is other household produced commodities. The household has a strictly concave utility function:

$$(1) \quad U = Y(Z_1, Z_2, L; \tau),$$

where  $\tau$  is a taste parameter affecting the translation of  $Z_1$ ,  $Z_2$ , and  $L$  into utility, and is not the subject of current decisions (i.e., tastes are fixed). The household has a strictly convex transformation function (Chambers, 1988, pp. 260-261) where housework ( $t$ ) and purchased input ( $X$ ), including food and drink, are converted into commodities ( $Z_1$  and  $Z_2$ ), or  $G(Z_1, Z_2, t, X; \phi) = 0$ , which in asymmetric form is represented as:

$$(2) \quad Z_1 = F(Z_2, t, X; \phi), \partial Z_1 / \partial Z_2 < 0, \partial Z_1 / \partial t \geq 0, \partial Z_1 / \partial X \geq 0,$$

where  $\phi$  is an efficiency parameter, which is taken as fixed. Clearly, equation (2) permits joint production and does not impose constant returns to scale. Hence, it avoids two common criticisms of Becker (1965, 's) model (see Pollak and Wachter, 1975; Deaton and Muellbauer, 1980a).

The human time of adults in a household is an important resource, denoted by  $T$ , and it is allocated among leisure, housework, and wage work ( $h$ ):

$$(3) \quad T = L + t + h.^2$$

Cash income ( $I$ ) is generated by household members working for pay in the market ( $h$ ) at a wage ( $W$ ) and from interest and dividends on financial assets and unanticipated gifts ( $V$ ). Cash income is spent on  $X$ :

$$(4) \quad I = Wh + V = PX.$$

To simplify the analysis, we solve equation (3) for  $h = T - L - t$  and then substitute into equation (4) to obtain the full-income-expenditure constraint:

$$(5) \quad Y = WT + V = WL + Wt + PX.$$

At an interior solution the household selects  $t, X, L, Z_1$  and  $Z_2$  to maximize equation (1) subject to equations (2) and (5), which can be best visualized as:

$$(6) \quad \psi = U(Z_1, Z_2, L; \tau) + \lambda_1[Y - WL - Wt - PX] - \lambda_2[Z_1 - F(Z_2, t, X; \phi)].$$

From equation (6) the marginal conditions for an optimum are:

$$(7a) \quad \partial\psi/\partial t = -\lambda_1 W + \lambda_2 f_t = 0;$$

$$(7b) \quad \partial\psi/\partial X = -\lambda_1 P + \lambda_2 f_X = 0;$$

$$(7c) \quad \partial\psi/\partial L = U_L - \lambda_1 W = 0;$$

$$(7d) \quad \partial\psi/\partial Z_1 = U_{Z_1} - \lambda_2 = 0;$$

$$(7e) \quad \partial\psi/\partial Z_2 = U_{Z_2} - \lambda_2 f_{Z_2} = 0;$$

plus meeting the constraints of equations (2) and (5). In equations (7a)-(7e),  $U_i = \partial U/\partial i$  is the marginal utility of  $i = L, Z_1, Z_2$ , and  $f_l$  is the marginal product of  $l = t, X, Z_2$  in producing  $Z_1$ . The Lagrange multiplier  $\lambda_1$  is the marginal utility of full income, and  $\lambda_2$  is the marginal utility of  $Z_1$ . Hence, equation (7a) implies that  $(\lambda_2/\lambda_1)f_t = W$ , equation (7b) implies  $(\lambda_2/\lambda_1)f_X = P$ , equation (7c) implies that  $U_L/\lambda_1 = W$ , equation (7d) implies  $U_{Z_1} = \lambda_2$ , and equation (7e) implies  $U_{Z_2}/\lambda_2 = f_{Z_2}$ .

The solution to equations (7a)-(7d) plus constraints (2) and (5) provide the general form of the derived demand functions for inputs, leisure, and commodities:

$$(8) \quad Q^* = D_Q(W, P, Y, \tau, \phi), Q = t, X, L, Z_1, Z_2.$$

These demand equations differ from those of non-productive household demand equations—the technology of the household production function is embedded into these equations and inputs ( $t, X$ ) are distinguished from commodities  $Z_1$  and  $Z_2$ .  $Z_1, Z_2$ , and  $L$  yield utility directly. Full-income ( $Y$ ) and the price of time ( $W$ ) are key determinants of these demanded quantities. Although the derived demand functions for home-prepared meals ( $Z_1$ ) and for other commodities ( $Z_2$ ) exist, data are generally not available on them. However, the quantities  $t, X$ , and  $L$  are measurable, and therefore the derived demand equations for these variables can be investigated empirically. Moreover, expenditures on  $t, X$ , and  $L$  exhaust full-income. As with the estimation of any household demand system, the individual parameters of the utility function are not identified, and here the parameters of the production function are also not identified (Deaton and Muellbauer, 1980a).

<sup>2</sup> The model can be generalized by defining  $X, T, L, t$ , and  $h$  and their associated prices as vectors with more than one element. Of course  $T, L, t$ , and  $h$  must have the same dimension.

### The Data and Variables for 20<sup>th</sup> Century Households

The last half of the 20<sup>th</sup> century, which includes the post-World War II period, is an interesting period in which to examine the demand for inputs and leisure by U.S. households. This is a period in which resources that had been directed to war activities were re-directed to supplying other durable goods—new houses, household appliances, and cars to the household sector and tractors and machinery to the farm sector—and women’s labor returned to housework. Family size grew during the early part of the period as households caught up on disrupted fertility patterns (Huffman, 2008; Ramey and Francis, 2006). However, family sizes peaked by the late 1960s, and a new transition to smaller family sizes and less housework started. This released women’s time for other activities, especially market work; women’s labor force participation rates shot up. This transition in how women allocate their time was largely complete by the mid-to-late 1990s (Bryant, 1986; Goldin, 1986, 2000; Huffman, 2008).

Moreover, in 1948, U.S. households spend 18.3% of household disposable personal income on food-at-home and 3.9% on food-away-from-home. Over the next 50 years, the share of disposable personal income spent on food at home steadily declined to only 6.1% by the end of the period, while the share spent on food-away-from home increased slightly to 4.1%. The share of household disposable personal income spent on food-away-from-home over the subsequent decade, 1996 to 2006, increased by only 2 percentage points (Economic Research Service, 2011). Hence, during the second half of the 20<sup>th</sup> century the relative importance of food-at-home declined dramatically relative to food-away-from-home. In addition, major data series on the services of household durable goods are available from Jorgenson’s data starting in 1948. Hence, this study covers the 49 year period, 1948 to 1996, which is a relatively long time series, and it is a period in which the demand for food-at-home, food-way-from home, and women’s housework changed significantly.

### Empirical Definition of Groups

Nine demand groups are defined; eight for inputs and one for a residual category dominated by leisure. Nine is large enough to shed new light on the structure of household production as reflected in input demand equations but not so large as to degenerate into insignificant coefficient estimates. In contrast to almost all earlier consumer demand studies, capital inputs are defined as an annual flow of services and not purchases of durables. The use of capital services is consistent with Jorgenson and Slesnick (2008). Hence, in this study, housing, household appliances, transportation equipment, and recreation equipment are defined as capital services.

With household durable goods converted into services, a static empirical household demand system in the spirit of equation (8) is plausible. Households select (1) women’s (unpaid) housework, (2) men’s (unpaid) housework, (3) food-at-home, (4) food (and non-alcoholic beverage)-away-from-home, (5) housing services (for owner-occupied and rental housing), (6) services of household appliances (including imputed services from computers, furnishings owned and household utilities), (7) transportation services (imputed services of transportation capital owned, purchased transportation services, and fuel for transportation), (8) recreational services and entertainment (imputed services of recreation capital owned and recreation services purchased), and (9) “other inputs” (largely men’s and women’s leisure but also includes medical care and other purchased goods and services). From this point forward, I refer to these nine groups as “input groups.”

Table 1 presents a brief definition of all variables used in the empirical demand system; a summary of key details are presented below. Expenditures and chained (Tornqvist) price indexes for food-at-home and food produced and consumed on farms, food-away-from home, household utilities, transport services and fuel for transportation, entertainment and recreation services, and other non-durable-good consumption expenditures (including medical care) are taken from the data on personal consumption expenditures by type in the National Income and Product Accounts (NIPA) (Bureau of Economic Analysis, 2001). The Bureau of Economic Analysis (BEA) periodically

**Table 1. Definitions of Variables and Sample Means**

Variable Symbol	Definitions	Mean (Sd)
$w_1$	Expenditure share for women's (unpaid) housework	0.119 (0.020)
$w_2$	Expenditure share for men's (unpaid) housework	0.069 (0.006)
$w_3$	Expenditure share for food-at-home	0.052 (0.012)
$w_4$	Expenditure share for food-away-from-home	0.019 (0.001)
$w_5$	Expenditure share for housing services	0.048 (0.006)
$w_6$	Expenditure share for household appliance services	0.030 (0.002)
$w_7$	Expenditure share for transportation services	0.047 (0.004)
$w_8$	Expenditure share for recreation services and entertainment	0.025 (0.004)
$w_9$	Expenditure share for "other inputs" (including men's and women's leisure, medical care and other purchased consumer goods and services)	0.591 (0.020)
$p_1$	The price index of women's housework, or the opportunity wage	0.538 (0.411)
$p_2$	The price index of men's housework, or the opportunity wage	0.541 (0.395)
$p_3$	The price index of food-at-home	0.598 (0.355)
$p_4$	The price index for food-away-from-home	0.557 (0.386)
$p_5$	The price index of housing services	0.565 (0.369)
$p_6$	The price index for household appliance services	0.580 (0.333)
$p_7$	The price index for transportation services	0.611 (0.400)
$p_8$	The price index for recreation services and entertainment	0.660 (0.345)
$p_9$	The price index for "other inputs" (including men's and women's leisure, medical care and other purchased consumer goods and services)	0.552 (0.404)
P	The Stone price or cost of living index	0.556 (0.397)
Y/(N)	Average household full-income-expenditure per person	4,369.5 (4,127)
AGE < 5	Share of the resident population that is less than five years of age	0.090 (0.017)
AGE ≥ 65	Share of resident population that 65 years of age and older	0.104 (0.015)
Non-metro	Share of resident population living in non-metropolitan areas	0.132 (0.023)
S	The stock of patents of consumer goods	3,262.7 (335)
T	Trend	

revises these data. Although human time is an important household resource, several issues arise in measuring the allocation of time of adults. Each individual aged sixteen and older who is not in school, receives a time endowment at the start of each year of life, and this endowment is allocated to housework, labor market work, and leisure. The daily time endowment is re-scaled 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.<sup>3</sup> No evidence exists that time allocated to personal care by women or men is responsive to prices or to income, or even to trend (see Robinson and Godbey, 1997, p. 337). However, technical change associated with personal

<sup>3</sup> The (modified) time endowment is set as follows. For women and men aged sixteen to sixty-four who are not enrolled in school, the modified endowment is assumed to be fourteen and fifteen hours per day, respectively, based on Robinson and Godbey (1997, p. 337) and Juster and Stafford (1991, p. 477). 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 sixteen to sixty-four years of age reflects additional time spent recovering from illnesses. In national economy macro simulation/calibration models, Greenwood, Seshadri, and Yorukoglu (2005) use similar modified time endowments of roughly 100 hours per week. In deriving aggregate average hours of paid work and of unpaid housework, a distinction between the number of employed and not employed women and men is a major factor in the re-allocation of adult time over the study period (see Huffman, 2008).

care—soaps, shampoos, deodorants, shaving equipment—made steady improvement in the quality of personal hygiene possible, with a roughly unchanged amount of time spent on personal care.

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 laundry, and cleaning and straightening the house. However, considerable evidence exists that unpaid housework of women and men are not perfect substitutes; for example, child care and meal planning and preparation remain largely women’s housework and yard and car care and snow removal remain largely men’s housework (Becker, 1981; Gronau, 1977; Robinson and Godbey, 1997; Bianchi et al., 2000; Aguiar and Hurst, 2006). Hence, women’s and men’s unpaid housework are separate inputs.

Annual hours of unpaid housework for working and nonworking women and men aged sixteen to sixty-four who are not in school and for age sixty-five and over are derived from benchmark data.<sup>4</sup> Hours of work for pay were obtained from Bureau of Labor Statistics (various years) data files and these annual average hours of labor market work are consistent with the Census year estimates presented by McGrattan and Rogerson (2004). Leisure time is spent largely on entertainment, recreation, communications and social contacts, and 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. Data on commuting time are derived from information reported in Robinson and Godbey (1997).

Capital services are proportional to the stock of assets, including computers, but aggregation requires weighting stocks by rental prices rather than acquisition prices for assets. The rental price for each asset prepared by Jorgenson and associates 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. The price of housework and leisure is defined as the foregone hourly market wage following procedures in Smith and Ward (1985), with an adjustment downward in value for not-employed groups.

The price index for each of the nine major input groups is 1.0 in 1987, and for each of the aggregated input groups, the price  $p_i$ ,  $i = 1, \dots, 9$ , is also 1.0 in 1987. To be able to better see patterns over time in input prices, relative prices are computed by dividing each of the input price indexes ( $p_{it}$ ) by Stone’s price index  $P_t^*$  (Stone and Rowe, 1954) constructed across the nine input groups,  $\ln P_t^* = \sum_{i=1}^9 w_{it} \ln p_{it}$ , where  $w_{it}$  is the expenditure share. Now  $P_{1987}^*$  is 1.0 as well.

### Levels and Trends over the Last Half of the Twentieth Century

Over 1948–1996, full-income-expenditures per capita were \$3,668 in 1948 and \$10,085 in 1996, with a mean value of \$7,859 (all in 1987 dollars). Hence, the average annual rate of growth of full-income-based consumption expenditures per capita over the sample period was 2.06%, which is slightly lower than the 2.25% per year growth of real per capita personal consumption expenditures (BEA).

Table 1 reports mean expenditure shares over 1948 to 1996, and figure 1 displays the trends of eight of the nine aggregate expenditures shares (all but the share for “other inputs”). Full expenditure shares of the nine input groups are new and provide some interesting comparisons: women’s unpaid

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<sup>4</sup> The best data on hours of housework of women and men are from 1965 to 1996 (Juster and Stafford, 1991; Robinson and Godbey, 1997). Data from Bryant (1996) on married women are used to develop a benchmark value for average hours of housework of married women sixteen to sixty-four years of age in 1950 and these numbers are adjusted for changes in family size over 1950–1965 to link with the 1965 data (Huffman, 2008). These estimates of hours of housework over 1948 to 1965 are consistent with those of Ramey and Francis (2006, p. 46). Given that the demand system includes a time trend, and is estimated in first-difference form with an intercept term included, the estimated parameters of the demand system cannot be affected by the method of deriving time use in the early period.



housework, 11.9%; men's unpaid housework, 9.9%; food-at-home, 5.2%; food (and beverage)-away-from-home, 1.9%; housing services, 4.8%; household appliance services, 3.0%; transportation services, 4.7%; recreation services, 2.5%; and "other inputs," 59.1%.<sup>5</sup> Given that the "other input" category is dominated by women's and men's leisure time, roughly 85%, the U.S. household sector allocates a large share of full-income to leisure time, which is contrary to popular perceptions (also see Robinson and Godbey, 1997).

Expenditure shares have interesting trends over the study period. The full-income-expenditure share for women's unpaid housework is 16% in 1948 and displays a long-term negative trend with a slight reversal during the 1980s up to 1996. The net decline over a half-century is about 7 percentage points. The share for men's unpaid housework is 8% in 1948 and declines slowly to 1960, as major technical advances occurred in home heating equipment, and then remains largely unchanged over 1960 to 1975. However, these hours rose from 1975 to 1985, and then declined slightly. Hence, the net decline in men's housework over the whole period is about 1 percentage point. The size of the difference in the expenditure share for women's and men's unpaid housework has declined over the last half of the twentieth century.

The full-expenditure share for food-at-home is only 8% in 1948, and then declines steadily over the next half-century, ending at less than one-half this amount or 3.5%. The expenditure share for food-away-from-home is 2.0% at the beginning of the period, declining to 1.7% in early 1960s and then starting a long-term slow increase, ended the period at 2.2%. Hence, the share of full-income spent on food-away-from-home is roughly constant over 1948-1996, but the share spent on food-at-home declines significantly.

In 1948, the expenditure share for housing services is only 3.5. It rises slowly and steadily until 1970, remains essentially unchanged from 1970 to 1980, and then rises slowly and steadily until 1996. However, the net increase in housing services over the study period is only 2.3 percentage points. The expenditure share for household appliance services is 3.5% in 1948 and although it is a little higher in the 1950s than the 1970s, the net change over the half-century is negligible (see figure 1). The expenditure share spent for transportation services is 3.4% in 1948, rises steadily until 1965, but then essentially remains unchanged until 1975. Thereafter, it rises slowly and reaches 5% in 1996. The expenditure share for recreation services and entertainment is 2% in 1948, it trends downward slowly to the mid-70s, and then reverses course to 1996. It ends the century 1.3 percentage points higher than in 1948 (see figure 1). Hence, over the study period, expenditures on housing services, transportation services and recreation services and entertainment rise faster than on food-away-from-home.

To ease comparisons, relative input prices over the study period are rescaled to be 1.0 in 1948, and then logarithms of these relative input prices are graphed in figure 2 over 1948-1996. The price of women's unpaid housework rises dramatically over 1948 to 1980—a total increase of 30%—and, thereafter, it remains roughly unchanged. The price of men's unpaid housework rises about 27% over 1948 to 1972, then declines a little during the mid-70s to early 80s, and thereafter remains largely unchanged to 1996. Hence, a small decline in the price gap between women's and men's housework occurs over the study period. Consistent with rapid growth of U.S. agricultural productivity growth over 1948-1996 (Huffman and Evenson, 2006), the relative price of food-at-home has a strong trend downward, except for the world-food crisis years in the early 1970s, declining by about 60% over the half-century or a little more than one percent per year. The relative price of food-away-from-home declines 25% from 1948 to 1958 and remained unchanged to 1973, then rises 5% to 1980 and thereafter declining very slowly to the end of the period. However, the much larger labor cost

<sup>5</sup> Blanciforti, Green, and King (1986) use a related aggregate data set—the personal consumption expenditures from the U.S. Department of Commerce, 1947-1978, and split them into eleven commodity groups, including food. They aggregate food-at-home and food-away-from-home together, use a cash income measure of expenditures and report an average expenditures share for all food of 20.3%. An average of about 23% of all food expenditures during this period were for food-away-from-home. In the current study over 1948-1996, the mean expenditure share on food at home is 5.2% and 1.9% for food-away-from-home, which combined gives a mean share of is 7.1%. In addition to differences in time-period covered, differences arise from the cash versus full-income concepts.

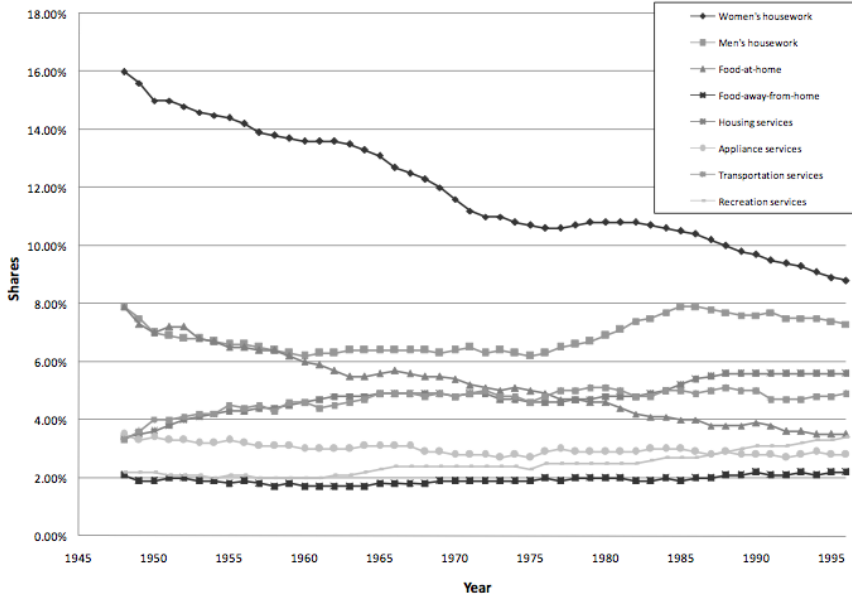


Figure 1. U.S. Household Full-Income-Expenditure Input Shares, 1948-1996

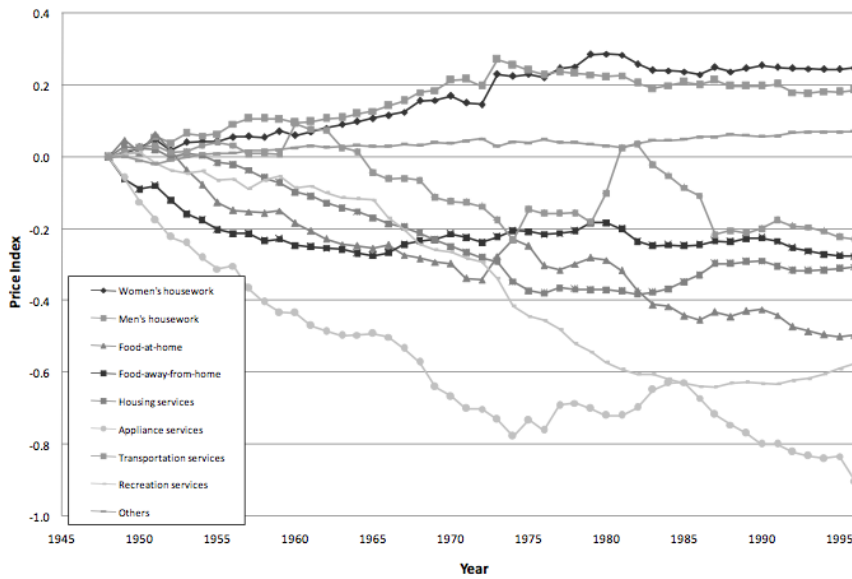


Figure 2. Prices of Inputs for U.S. Households Relative to the Stone Cost of Living Index, 1948-1996 (Proportional Change on Vertical Axis)

component to food-away-from-home than for food-at-home is a major factor in the differences in these price trends. The relative price of housing services declines steadily cumulating into a 45% decline over 1948 to 1975, and then reversed direction to increase slowly, ending 10% higher by 1996. The relative price of household appliance services declines dramatically at a compound rate of 2.5% per year over 1948 to 1975, moves irregularly but trends upward over 1975 to 1985, and then declines by 35% to 1996. Moreover, the net decline over the half-century is a dramatic 80%. The pattern for the relative price of transportation services is irregular over time and net price decline over the whole period is 20%. The relative price of recreation input rises from 1948 to 1958, declines steadily from 1958 to the mid-80s, and then rises slightly. The net decline over the period is, however, 20%. The relative price of "other inputs" rises slowly over the period.

In summary, full-income-expenditure shares and relative input prices constructed from aggregate data for women's housework, food-at-home, and housing services show substantial changes over the last half of the twentieth century but other shares change much less. Perhaps surmising is the finding that the share of full-expenditures spent on food-away-from-home changed very little over the second half of the twentieth century.

### The Econometric Model

Several well-known household demand systems can be made consistent with the economic model development here, including the linear expenditures model (Stone and Rowe, 1954), the Rotterdam model (Theil, 1965; Deaton, 1986), the translog model (Christensen, Jorgenson, and Lau, 1975) and the almost ideal demand system (Deaton and Muellbauer, 1980a). The last three have advantages of being so-called flexible demand systems.

Figures 1 and 2 display interesting patterns in aggregate expenditure shares and relative input prices over 1948-1996, and price and income elasticity estimates are important products of this study. An empirical demand system that has simplicity of form and style is at an advantage over more complex models, provided it performs well. Simplicity includes the ability (i) to explain the actual pattern in expenditures shares, (ii) to have algebraic forms for prices and total expenditures that are intuitively appealing (e.g., the logarithm of relative prices and real income per capita), (iii) to easily accommodate estimation, including restrictions for adding up, symmetry and homogeneity, and (iv) to provide good point estimates of the price and income elasticities of demand. One popular demand system that meets these criteria is the almost-ideal-demand system (AIDS), developed and applied by Deaton and Muellbauer (1980a,b) and Deaton (1986). Deaton and Muellbauer also chose to fit it in what has become known as the linear approximation of the AIDS (LA/AIDS). Although the LA/AIDS model loses some flexibility relative the nonlinear AIDS, Alston, Foster, and Green (1994) show in a small-commodity demand-system simulation-experiment that the LA/AIDS model performs well in estimating own-price and expenditure elasticities relative to the non-linear AIDS.<sup>6</sup>

The econometric LA/AIDS model for this study is written as:

$$(9) \quad w_{it} = \alpha_{i0} + \sum_{j=1}^9 \gamma_j \ln p_{jt} + \beta_i \ln(Y_t/P_t^*) + \sum_{s=1}^3 \delta_{is} D_{st} + \zeta_i S_t + \phi_i t + u_{it},$$

where  $w_{it}$  is the full-income-expenditure share for the  $i^{\text{th}}$  input group,  $i = 1, \dots, 9$ , in time period  $t = 1, \dots, 48$ ,  $p_{jt}$  is the price (index) of the  $j^{\text{th}}$  input group,  $j = 1, \dots, 9$ ,  $Y_t$  is full-income or expenditure,  $P_t^*$  is the Stone price index across the nine input groups, and  $D_{st}$  represents controls for heterogeneity in the population of the  $s^{\text{th}}$  type that enters through the taste parameter ( $\tau$ ) of the theoretical model.

<sup>6</sup> Variants of the translog demand system have been used by Lewbel and Ng (2005) and Jorgenson and Slesnick (2008). Brown and Lee (2007) use a Rotterdam model for beverages and Kastens and Brester (1996) use not only the Rotterdam model but also the AIDS and double log models for a seven commodity food demand system. See Piggott (2003) and Okrent and Alston (2010) for a comparison of more complex related demand systems.

$S_t$  is the stock of patents on consumer goods; an efficiency parameter ( $\phi$ ), and  $t$  represents a linear time trend.

With the LA/AIDS model, unit of measurement problems can arise when the translog price index denoted by  $\ln P_t$  is replaced with the Stone price index  $\ln(P_t^*) = \sum_{i=1}^9 w_{it} \ln(p_{it})$ . This substitution was first made by (Deaton and Muellbauer, 1980a), who showed that the difference between  $\exp(P_t)$  and  $\exp(P_t^*)$  is frequently very small. Moschini (1995) points out that the unit of measurement problem does not arise if the true price index  $P$  is approximated by to an index  $P^I$  that is invariant up to a multiplicative constant of  $P$ . Any one of the regular price indices is sufficient because they are invariant to changes in units of measurement. One obvious choice is the Tornqvist price index  $\ln(P_t^T) = 0.5 \sum_{i=1}^9 (w_{it} + w_{it-1}) \ln(p_{it}/p_{it-1})$ , which is a discrete approximation to the Divisia index. Another candidate is the loglinear analogue of the Paasche price index, labeled PS, and referred to as the “corrected” Stone index:  $\ln(P_t^S) = \sum_{i=1}^9 w_{it} \ln(p_{it}/p_{i0})$ . However, Moschini notes that in certain circumstance the “corrected” Stone price index is equivalent to employing the original Stone price index  $P^*$ . Specifically, this applies when the individual prices ( $p_{it}$ s) are themselves price indices of subcomponents (Moschini, 1995, p. 65). In the current study, the Tornqvist price index of disaggregate subcomponents is first created and then the Stone price index is computed across the nine input groups. This avoids a possible unit of measurement problem.<sup>7</sup>

Price endogeneity is a potential problem in estimating demand systems. First, consider the case of estimating the demand equation for one commodity. If the endogeneity is confined to one price and the equation is estimated by ordinary least squares, then the estimated coefficient of the endogenous price will be inconsistent (Wooldridge, 2002, p. 117-122). However, if one price is endogenous in a demand system with several prices where homogeneity, symmetry and adding up restrictions are imposed, the estimated coefficient of the endogenous price will be inconsistent, but the restrictions will spread the problem around to the other estimated price coefficients. If instead, all prices are endogenous, most likely all estimates of price coefficients will be inconsistent, but given the restrictions on the price coefficients, it is difficult to judge the consequences. For example, in an analysis of household purchases of vertically differentiated soft drinks from scanner data, Dhar, Gould, and Chavas (2003) provided evidence of significant price elasticity differences due to seemingly endogenous prices, but part of the noise in prices could be due to the well-known measurement error problem in unit values, which may exaggerate the importance of endogeneous prices. In a study of U.S. aggregate data on household expenditures on durables, non-durables and services over 1948-1978, Bronsard and Salvas-Bronsard (1984) found evidence of exogeneity but little impact on estimated price elasticities.<sup>8</sup>

In equation (9), the key parameters of LA/AIDS demand system are the  $\gamma$ 's,  $\beta$ 's,  $\delta$ 's, and  $\zeta$ 's. Consistent with the finding of Kastens and Brester (1996), equation (9) is estimated with traditional restrictions imposed— $\sum_i \alpha_i = 1$ ,  $\sum_i \gamma_{ij} = 0$ ,  $\sum_i \beta_i = 0$ —are needed for adding up,  $\sum_j \gamma_{ij} = 0$  are needed for price homogeneity, and  $\gamma_{ij} = \gamma_{ji}$  are needed for symmetry. These restrictions significantly reduces the number of coefficients to be estimated and have been shown to improve the out of sample period predictions (Kastens and Brester, 1996). Moreover, the constrained LA/AIDS has intuitive appeal because expenditures shares are explained by real full-expenditures and relative prices of the nine input groups.<sup>9</sup> In addition, the long-term trend in expenditure shares and relative prices are bounded.

Given the coefficient restrictions on the AIDS demand system 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 estimated input demand equations. Here, the ninth input category, which includes leisure, medical care and other purchased consumer goods and services, is omitted in estimation. It is

<sup>7</sup> Another alternative is when prices are scaled by their mean (Moschini, 1995). On a related note, estimation of an aggregate demand system can provide valuable information on price and income elasticities, even if it is not an exact aggregation of individual household decisions (e.g., see McGrattan and Rogerson, 2004).

<sup>8</sup> Further exploration of endogeneity of prices is left for future research.

<sup>9</sup> The NTLOG demand system of Lewbel and Ng (2005) and Jorgenson and Slesnick (2008) is unattractive in that expenditure shares are explained by the log of nominal prices divided by nominal total expenditures. Although this definition is consistent with a demand system, these normalized prices have no intuitive appeal.

of least direct interest to this study. Other authors have also assigned a good with a large expenditure share to the excluded category. For example, <sup>10</sup> exclude the expenditure share for leisure, which has a mean of 0.69, in estimating their household demand system.

Given equation (9), the full-income-expenditure elasticity of demand for the  $i^{\text{th}}$  input is:

$$(10) \quad \eta_{iE} = 1 + \beta_i/w_i, i = 1, \dots, n.$$

The compensated own-price elasticity for the  $i^{\text{th}}$  input is approximated by:

$$(11) \quad \zeta_{ii} = \gamma_{ii}/w_i + w_i - 1, i = 1, \dots, n,$$

and the compensated cross-price elasticity of demand for the  $i^{\text{th}}$  input and  $j^{\text{th}}$  input price is:

$$(12) \quad \zeta_{ij} = \gamma_{ij}/w_i + w_j, i, j = 1, \dots, n,$$

(Alston, Foster, and Green, 1994). They have also shown that the specification of price elasticities in equations (11) and (12) provide accurate estimates of the true price elasticities in one type of small scale (i.e., three commodities, simulation analysis).

Although expenditure-share-weighted full-income-expenditure elasticities must sum to unity, any individual income elasticity of demand for an input group 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. In this study, input groups are defined to be substitutes if they have a cross-price elasticity that is positive and complements if the cross-price elasticity is negative. Given the restrictions on the demand system and letting all input prices change by 1%, the expenditure-share-weighted compensated price elasticities for the  $i^{\text{th}}$  input are zero.

Heterogeneity of the U.S. populations or tastes is measured by (1) the share of the population that is five years of age and younger, or pre-school aged, (2) share of the population that is sixty-five years of age or older, who are retired, or near retirement, and (3) the share that reside in a non-metropolitan area. Hence, these variables control for the effects of a slowly changing age structure of the U.S. population and declining share living in non-metro areas. For example, a declining share of the population five years of age and under and share living in non-metro areas are expected to reduce the demand for women's housework.

In light of our productive household model and the technology parameter ( $\phi$ ) included in the theoretical model (see equations (2) and (8)), it is interesting to test for productivity change effects in the U.S. household sector over the study period. Moreover, this line of research follows Jorgenson and Stiroh (2000), who identify 37 sectors of the U.S. economy, including the "private household" sector and computed measures of multifactor productivity for all of them. Their methodology is growth accounting, and they admit that it is difficult to measure the output of the private household sector and for some other sectors, including the general government sector. Although they attribute zero multifactor productivity to the U.S. private household sector over 1958-1996, our productive household framework permits productivity change and data exist to test for effects on inputs demanded by households. This work builds on innovative research by Griliches (1990) and Huffman and Evenson (2006) using patent data. Patents are awarded for innovations or improvements in goods, and a technology proxy is created using data on patents of consumer goods consumer goods in twenty categories over 1922 to 1996. The flow of patents is converted into a stock variable  $S_t$  using trapezoidal shaped timing weights that sum to one and distributed over the twenty-six-year time period. Given the large contraction in the production of consumer goods during World War II, a dramatic reduction of patenting on consumer goods also occurred over 1941-1945. However, a dramatic recovery occurred in consumer-good patenting during the late 1940s and 1950s.<sup>11</sup> Moreover, this patent stock variable does not have a distinct linear trend.

<sup>10</sup> Jorgenson2008

<sup>11</sup> The patent stock  $S_t$  was sizeable in 1948, but had declined by 30% when it bottomed out in 1955. Then, it steadily increased, regaining its 1948 value only in 1976. Over 1976 to 1996, the average rate of increase of  $S_t$  was about 1% per year.

A trend and autocorrelation are included in the econometric model so as to improve the quality of the estimator for key parameters of a demand system. The time trend ( $t$ ) is included in equation (9) to “de-trend” the cost-shares and all of the other regressors and also pick up effects of any excluded variable that is highly correlated with trend, including for example a gradual shift in women’s skills from home production to market work (Wooldridge, 2002; Goldin, 1986, 2000; Kerkhofs and Kooreman, 2003; Borjas, 2005). They also insure that sample means of variables in the demand system are not trended, a necessary condition for a stationary time series (Enders, 2010), although expenditure shares (and relative prices) cannot have long-term linear trends.

For a household demand system where the data are annual and input groups are measured as services, including services of durable goods, a plausible specification is that the random disturbance term  $u_{it}$  follows a first-order autoregressive process:  $u_{it} = \rho u_{it-1} + \varepsilon_{it}$ ,  $\varepsilon_{it}$  having a zero mean (Enders, 2010; Deaton and Muellbauer, 1980a, p. 345-350). The reason is that economic shocks in the demand for leisure and household inputs in any year tend to spill over to the next year. This is especially true for services of durable goods. Economic shocks in one year tend to impact durable-good purchases and in turn the flow of services consumed in subsequent years. Moreover, Barten (1969) emphasizes that each of the equations within a demand system containing cross-equation restrictions must be transformed by the same value of  $\rho$ ; this is the reason for constraining  $\rho$  to a single value across equations.

### Fitting the Econometric Model and Interpreting the Results

A total of 93 different coefficients of the derived demand system are to be estimated in the LA/AIDS model after imposing symmetry, homogeneity and adding-up conditions and a single  $\rho$  value, and there are 48 observations per equation (or 384 total observations equations).

Estimation is undertaken with SAS ITSUR using Gauss, which is consistent, asymptotically efficient, and asymptotically equivalent to the maximum likelihood estimator (Barten, 1969; Berndt and Savin, 1975; Greene, 2003, pp. 340-350). The point estimate of  $\rho$  is 0.407 which is intermediate between the extremes of zero and one. The estimated coefficients (and price and income elasticities) are in some cases quite different from those obtained where  $\rho$  is constrained to be one, which is equivalent to a SUR estimate of the first-differenced version of equation (9). This outcome is consistent with the first-difference version of the demand system being a misspecification. Hence, modest correlation of residuals exists.

Table 2 reports the estimated coefficients of the aggregate demand system table 3 reports the estimated (aggregate) compensated price and full-income-expenditure demand elasticities, evaluated at the sample mean of the expenditure shares. Standard errors (and z-values) for these elasticities are computed in SAS using the delta method (Greene, 2003, p. 70). Five of the nine share equations have nonzero and significant trends, but all are small. The coefficient of trend is negative in the share equation for women’s and men’s unpaid housework, and food-at-home and positive in the share equation for recreation services and entertainment and for “other inputs,” which is consistent with figure 1. All household demand system studies place primary emphasis on the own-price and income/expenditure elasticities with cross-price elasticities being of secondary importance (e.g. Deaton and Muellbauer, 1980a,b; Blanciforti, Green, and King, 1986; Jorgenson and Slesnick, 2008). In the current study, own-price elasticities have large z-values, except for the food-away-from-home, and income/expenditure elasticities have large z-values, except for food-away-from-home, housing services and transportation services. All estimated own-price elasticities are negative and significantly different from zero at the 5% level, except for food-away-from-home. Their magnitudes are -0.545 for women’s unpaid housework, -0.964 for men’s unpaid housework, -0.643 for food-at-home, -0.375 for food-away-from-home, -0.728 for housing services, -0.647 for appliance services, -1.078 for transportation services, -0.369 for recreation services

**Table 2. ISUR-AR(1) Estimate of U.S. Household Demand System for Inputs: AIDS (Shares) 1948-1996 (z-values are in parentheses)<sup>a</sup>**

Variables	Women's housework (1)	Men's housework (2)	Food-at-home (3)	Food-away- from-home (4)	Housing services (5)	Appliance services (6)	Transportation services (7)	Recreation services and entertainment (8)
Constant	-0.583 (2.12)	-1.268 (4.34)	-0.168 (0.73)	0.083 (0.65)	0.516 (3.56)	0.033 (0.27)	0.517 (2.41)	-0.204 (1.83)
ln <i>p</i> <sub>1</sub>	0.040 (3.77)							
ln <i>p</i> <sub>2</sub>	-0.075 (7.60)	-0.002 (0.21)						
ln <i>p</i> <sub>3</sub>	-0.010 (1.72)	-0.012 (2.18)	0.016 (2.41)					
ln <i>p</i> <sub>4</sub>	-0.010 (1.87)	0.003 (0.59)	0.006 (1.64)	0.012 (1.93)				
ln <i>p</i> <sub>5</sub>	-0.004 (0.68)	0.016 (3.04)	-0.008 (2.17)	0.006 (1.52)	0.011 (1.74)			
ln <i>p</i> <sub>6</sub>	-0.009 (2.58)	-0.001 (0.33)	0.002 (1.61)	0.000 (0.11)	-0.010 (3.08)	0.010 (3.44)		
ln <i>p</i> <sub>7</sub>	0.015 (2.97)	0.024 (4.31)	-0.008 (1.78)	-0.004 (1.44)	-0.005 (1.63)	0.001 (0.21)	-0.006 (0.99)	
ln <i>p</i> <sub>8</sub>	-0.006 (1.48)	-0.014 (3.38)	0.002 (0.58)	0.001 (0.37)	0.003 (0.73)	0.003 (0.73)	-0.002 (0.76)	0.015 (3.53)
ln[Y/(P · N)]	0.031 (1.30)	0.086 (3.34)	0.013 (0.70)	-0.006 (0.62)	-0.041 (3.43)	-0.002 (0.23)	-0.028 (1.49)	0.016 (1.76)
AGE ≤ 5	0.443 (3.23)	0.133 (0.89)	0.093 (0.93)	-0.070 (1.13)	0.033 (0.41)	-0.003 (0.04)	-0.079 (0.72)	-0.051 (0.80)
AGE ≥ 65	0.359 (0.95)	0.153 (0.37)	-0.071 (0.27)	0.150 (1.07)	0.475 (2.68)	0.131 (0.87)	0.126 (0.39)	-0.081 (1.62)
Non-metro	-0.000 (0.10)	0.000 (0.48)	-0.001 (1.38)	-0.000 (0.57)	-0.001 (1.80)	0.001 (2.40)	0.000 (0.39)	0.000 (1.54)
ln(5)	0.036 (3.19)	0.029 (2.35)	0.008 (1.16)	0.000 (1.57)	0.000 (0.11)	0.001 (0.17)	-0.015 (1.67)	0.002 (0.58)
T	-0.002 (5.83)	-0.001 (1.72)	-0.001 (1.97)	0.000 (0.88)	0.000 (1.57)	0.000 (0.82)	0.000 (0.00)	0.001 (3.45)

Notes: <sup>a</sup> The AR(1) coefficient,  $\rho$ , is estimated jointly with the other coefficients in the demand system and its value is 0.407.

**Table 3. Estimates of Price and Income Elasticities: AIDS Model with Nine Input Groups, U.S. Aggregate Data, 1949-96**

Commodity/Input Groups (i)	Prices for input groups									Income/Expenditure Elasticities ( $\eta_{iE}$ )
	1	2	3	4	5	6	7	8	9	
1) Women's housework	-0.545 (6.11)	-0.559 (6.71)	0.028 (0.60)	0.061 (1.42)	0.002 (0.39)	-0.046 (1.57)	0.172 (4.07)	-0.029 (0.80)	1.078 (5.73)	1.262 (6.25)
2) Men's housework	-0.967 (6.77)	-0.964 (6.05)	-0.125 (1.54)	0.061 (0.86)	0.275 (3.68)	0.012 (0.22)	0.390 (4.90)	-0.179 (2.97)	1.496 (4.44)	2.246 (6.02)
3) Food-at-home	-0.064 (0.60)	-0.166 (1.54)	-0.643 (5.07)	0.133 (1.51)	-0.108 (1.51)	0.065 (1.12)	-0.099 (0.21)	0.059 (1.01)	0.825 (2.53)	1.257 (3.42)
4) Food-away-from-home	-0.377 (0.42)	0.218 (0.86)	0.357 (1.92)	-0.375 (1.19)	0.383 (1.74)	0.044 (0.34)	-0.135 (1.07)	0.095 (0.50)	-0.209 (0.36)	0.669 (1.26)
5) Housing services	0.044 (0.39)	0.396 (3.68)	-0.118 (1.51)	0.154 (1.74)	-0.728 (5.67)	-0.162 (2.60)	-0.061 (0.93)	0.084 (1.03)	0.390 (1.39)	0.133 (0.52)
6) Household appliance services	-0.182 (1.57)	0.028 (0.22)	0.111 (1.12)	0.028 (0.34)	-0.260 (2.60)	-0.647 (6.87)	0.065 (0.75)	0.108 (1.36)	0.750 (2.14)	0.923 (2.74)
7) Transportation services	0.440 (4.07)	0.575 (4.70)	-0.110 (1.21)	-0.056 (1.07)	-0.062 (1.93)	0.041 (0.75)	-1.078 (8.54)	-0.011 (1.24)	0.262 (0.82)	0.401 (1.00)
8) Recreation services and entertainment	-0.140 (0.80)	-0.498 (2.97)	0.123 (1.01)	0.074 (0.50)	0.163 (1.03)	0.136 (1.36)	-0.022 (1.24)	-0.369 (2.14)	0.539 (1.25)	1.642 (4.51)
9) "Other inputs"	0.217 (5.73)	0.174 (4.44)	0.072 (0.36)	-0.007 (0.36)	0.032 (1.39)	0.037 (2.14)	0.021 (0.82)	0.023 (1.25)	-0.570 (4.54)	0.885 (7.55)
(%) change in relative price/real income, 1948-1996	24.8	18.6	-49.6	-34.0	30.6	-90.1	-22.9	-57.5	7.1	102.1

Notes: Numbers in parentheses are z-values.



and entertainment and -0.570 for “other inputs.”<sup>12</sup> Hence, the negative and significant own-price elasticities are supportive of an aggregate demand system.

(Compensated) cross-price elasticities are on average positive—64% are positive, which shows the dominant role of substitutes (table 3). They, however, have on average smaller  $z$ -values than own price elasticities, but this is consistent with cross-price elasticities being second-order elasticities. Also, we know much less about their magnitudes. Women’s and men’s unpaid housework are strong complements, and appliance services and women’s unpaid housework are weak complements. Men’s unpaid housework and appliance services are weak substitutes. Transportation services and “other inputs” are strong substitutes for women’s and men’s unpaid housework. In addition to women’s unpaid housework, food-at-home and recreation services and entertainment are complements to men’s unpaid housework. Weak complements include food-at-home and housing services, and food-away-from-home and transportation services. In addition, food-at-home, appliance services and transportation services are complements with housing services.

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). For example, 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. Hence, negative cross-price elasticities seem plausible and account for about 35% of all cross-price elasticities, which is evidence supporting the LA/AIDS model.<sup>13</sup>

All input groups have positive full-expenditure elasticities; three are larger than one and the other six are less than one. Six of them have large  $z$ -values. The exact size of these expenditure elasticities are: women’s unpaid housework, 1.262; men’s housework, 2.246; food-at-home, 1.272; food-away-from-home, 0.669; housing services, 0.133; household appliance services, 0.923; transportation services, 0.401; recreation services and entertainment, 1.642; and “other inputs,” 0.885. Hence, women’s and men’s unpaid housework, food-at-home, and recreation services and entertainment are luxury goods, and the other inputs are necessities.

This set of full-income-expenditure elasticities is new and has considerable appeal, showing that men’s unpaid housework is more of a luxury input than for women’s unpaid housework. It may, however, be somewhat surprising that the expenditure elasticity of demand for food-at-home is higher than for food-away-from-home. Overall, the set of own- and cross-price and expenditure elasticities imply numerous margins where U.S. households on the whole have made adjustments over the last half of the twentieth century as prices and income have changed.

Next, consider the impact of demographic variables on input demand. A reduction in the share of the population five years of age and under reduces the demand for unpaid women’s and men’s housework and increases the demand for leisure—other effects being small and individually not significantly different from zero. An increase in the share of the population sixty-five years of age and older increases the demand for housing and reduces the demand for recreation services and entertainment and “other inputs.” A reduction in the share of the population living in non-metro areas increases the demand for food-at-home and housing services and reduces the demand for appliance services and “other inputs,” but these effects are small.

The estimated coefficients of the consumer patent stock in the input demand equations are non-zero, and some are significantly different from zero (at the 5% level). This evidence is interpreted as

<sup>12</sup> The estimate of the variance of price and income elasticities are computed directly treating the sample mean of expenditure shares as fixed. Now, the computation of the sample variance, standard errors and  $t$ - or  $z$ -values are straight forward, given the definition of these elasticities, and for the cross-price elasticities, the sample  $z_{ij} = z_{ji}, i \neq j$ . These computations were carried out in SAS with the “estimate” routine.

<sup>13</sup> However, given the restrictions of adding up, homogeneity and symmetry imposed on the demand system, no single price elasticity (income) elasticity is an island unto itself. For example, the summation of all compensated price elasticities for any single input is zero, and the summation of the share weighted expenditure elasticities is one. Hence, small  $t$ -values for any one cross-price elasticity (or income elasticity) should not get much attention.

supporting the hypothesis that productivity change in the U.S. household sector occurred over the study period, and it seems to contradict the economic accounting evidence provided by Jorgenson and Stiroh (2000) for this sector. In particular, an increase in the patent stock ( $S_t$ ) decreases the demand for transportation services and for “other inputs,” but increases the demand for women’s and men’s unpaid housework.

### Comparing Food Price and Income Elasticities

It is useful to compare the estimates of the own-price and expenditure (income) elasticity of demand for food-at-home (FAH) and away-from-home (FAFH) obtained in this study with others in the literature. Studies that estimate somewhat similar complete household demand systems using aggregate annual or quarterly data for the United States are chosen (table 4). The current study is the only one to use the household production framework, but other major differences between the current and other studies are the extent to which they control for population demographics, autocorrelation and trend. The earliest study by Blanciforti, Green, and King (1986) aggregate FAH and FAFH together into one commodity, and the other studies provide estimates of price and expenditure elasticities for both of these aggregates or for only FAFH (FAH being disaggregated into several subgroups and not reported here). In Blanciforti, Green, and King (1986), the own-price elasticity of demand for food is -0.51, while Piggott (2003) reports an estimate of the price elasticity for FAH of -0.22 and a much larger price elasticity for FAFH of -1.97. In comparison, my study provides price elasticities for these commodities of -0.64 and -0.38, which is a reversal of relative magnitudes. However, the Reed, Levedahl, and Hallahan (2005) and Okrent and Alston (2010) studies report estimates of the price elasticity of demand for FAH that are much closer to mine, -0.69 and -0.40, respectively. This leaves Piggott’s estimate as an outlier, and FAH may be more price elastic than FAFH.

In Blanciforti, Green, and King (1986), the expenditure/income elasticity of demand for food is 0.35. In Piggott (2003), the expenditure elasticity of demand for FAH is negative, -0.20, and very large positive for FAFH, 3.55. In contrast, my study provides estimates of these elasticities of 1.25 and 0.67, showing a reversal of relative size of the two expenditure elasticities. In the Reed, Levedahl, and Hallahan (2005) study the expenditure elasticity of demand for FAFH is 1.38, which is much smaller than for Piggott’s estimate, and the estimate by Okrent and Alston is even smaller, 0.53. Hence, even with major differences in methods, the Okrent and Alston expenditures elasticities of demand for FAFH is similar to my estimate. In addition, the expenditure elasticity of FAFH may in fact be smaller than for FAH. Overall, the largest divergence is between my estimate of the price elasticity of demand for FAH and those of Piggott. Perhaps, the specification of the demand for FAH is the place where the productive household model makes the largest difference in food price and income elasticity estimates.

### Conclusions

This paper develops and applies a productive household model to estimate the demand for food-at-home and away-from-home and seven other input groups. The LA/AIDS model is fitted to annual aggregate data for the U.S. household sector over the second half of the twentieth century, when major changes were occurring in relative prices, income, technologies and demographics.

All own-price elasticities are substantial, and one is price elastic. The largest five own-price elasticities in order from largest to smallest are transportation services, men’s unpaid housework, housing services, appliance services, and food-at-home. Hence, the demand for food-at-home is more price elastic than for food-away-from-home. Most input pairs are substitutes, including food-at-home and food-away-from home, but women’s and men’s unpaid housework are complements. The largest full-expenditure elasticities of demand are for men’s unpaid housework, women’s unpaid

**Table 4. Comparison of Price and Income Elasticity of Demand for Food in Annual (or Quarterly) Aggregate U.S. Data**

Study	Data years	Demand system	Controls for demographics, autocorrelation, trend	Elasticity					
				Own Price	FAH	FAFH	FAH	FAFH	Expenditure/Income
Blanciforti, Green, and King (1986, p. 30)	1948-1978	LA/AIDS-Cash Income	No	-0.51 <sup>a</sup>	-0.22	-1.97	-0.2	0.35 <sup>b</sup>	3.55
Piggott (2003, p. 9)	1968-1999	NonLA/AIDS-Cash Income <sup>c</sup>	No	-0.22	-0.22	-1.97	-0.2	-0.2	3.55
Reed, Levedahl, and Hallahan (2005, p. 35)	1982.1-2000.4	Semifx/AIDS-Cash Income	Autocorrelation only			-0.69			1.38
Okrent and Alston (2010, p. 102)	1960-2006	Generalized Rotterdam- Cash Income	Autocorrelation only			-0.4			0.53
This Study	1948-1996	LA/AIDS-Full Income	Yes	-0.64	-0.38	-0.38	1.26	1.26	0.67

Notes. <sup>a,b</sup>Food-at-home (FAH) and away-from-home (FAFH) area combined together into one commodity.

<sup>c</sup> Price and income elasticity estimates for 12 other functional forms are relatively similar, but results for a linear expenditure system are quite different.

housework, recreation services and entertainment, and food-at-home, and men and women's unpaid housework are luxury inputs. As somewhat of a surprise, the own-price and expenditure elasticity of demand for FAH are larger than for FAFH, and when compared to alternative estimates, the productive household model seems to provide a significantly better model of the demand for FAH than non-productive models of household behavior.

Over the study period, real full-income per capita was rising at an average of 2% per year. This real income growth implies large rightward shifts in aggregate demand for inputs with a income elasticity larger than one, e.g., men's and women's housework, recreation services and entertainment and food-at-home. Rightward shifts in demand due to income growth are smaller for other input groups. With women's and men's time endowments fixed and the demand for unpaid housework and leisure increasing as full-income increases, human time seems to be becoming more scarce (Linder, 1970; Robinson and Godbey, 1997).

The percentage change in relative prices and real full-income over 1948-1996 are presented at the bottom of table 3. The price and income elasticities of table 3 and these percentage changes permit a prediction and comparison of the growth in the aggregate demand for food-at-home and away-from-home over the study period. These changes boosted per capita demand for food-at-home by 175.0% and for food-away-from-home by 301.3%. Changes in the structure of the population reduced the demand for food-at-home by 26.9% but increasing the demand for food-away-from-home by 49.4%. However, unspecified factors represented by trend reduced the demand for food-at-home by an additional 94.4% (no effect on food-away-from-home). Hence, the prediction is of the net increase in demand for food-at-home due to these forces of 53.9% for food-at-home and of food-away-from-home by 350.7% over the study period. The increase in demand for food, recognition of the less healthy nature of food consumed away-from-home (Lin, Guthrie, and Frazao, 1999), and reduced energy needs set the stage for an emerging problem of excess per capita energy consumption and rising BMIs in the United States. (Huffman et al., 2010) extend this analysis and identify the effects of the price of food, price of time, income and other factors on the demand for calories and supply of obesity-related mortality in the U.S. and seventeen other developed countries (over 1970-2001).

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