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Featured Article

Demand for Household Food Waste

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Abstract *We estimate the demand for food waste within the household using observational data of food stock usage and meal consumption, the net of which forms a proxy for unconsumed food. We find that food waste is a luxury good with an expenditure elasticity ranging from 1.1 to 1.4. The wasting of food is also rather responsive to price: our own-price elasticity estimates range from -1.9 to -1.3. We further find differences in the demand for food waste related to household membership structure, human capital, joint preparation of meals within the household, and geographic location.*

Key words: Food waste, household food production, demand estimation.

JEL codes: D12, Q18.

According to the USDA, roughly one-third of the U.S. food supply goes unconsumed (Buzby, Wells, and Hyman 2014). The USDA further estimates that two-thirds of this discarded food occurs within the household, while the remaining one-third occurs at the processing, shipping, and retail levels (Buzby, Wells, and Hyman 2014). Within the household, Hoover (2017) recently found that an average of 68% of discarded food in three major U.S. cities was edible, with only a small fraction (11%) being viewed as questionably edible (e.g., potato peels, apple skins, and broccoli stalks). Many countries, including the United States, have adopted the United Nations Sustainable Development Goal that aims to halve food waste at all points in the supply chain (United Nations 2015). As such, policymakers have recognized the subsequent calls to action, spurring many local politicians and managers to seek policy prescriptions, with a particular focus on households.

The economic justification for policy intervention is based upon market failure arguments. Unconsumed food poses a potential economic burden to society in the form of foregone resources such as energy, water, and land (Hall et al. 2009; Cuéllar and Webber 2010; Kummu et al. 2012; Birney et al. 2017), as well as negative externalities such as greenhouse gas emissions

(Heller and Koeleian 2015). Of course, these arguments are predicated upon the idea that such externalities are not already embedded in the price of food. Aside from externality concerns, more efficient management of household food resources would reduce the excess demand for food, thereby lowering food prices and increasing consumer welfare (Rutten 2013). Moreover, lower food prices would lead to an increase in the number of food secure households in the United States (Gregory and Coleman-Jensen 2013).

Household food waste includes the following: spoiled meats, fruits, and vegetables; prepared foods and ingredients that have expired (or appear no longer suitable for consumption); unconsumed leftovers; plate waste; and any other willful disposal of previously or otherwise edible foodstuffs (Buzby, Wells, and Hyman 2014). Hoover (2017) finds that 76% of households believe they throw out less food than the average American household. While most households feel guilty about wasting food (Qi and Roe 2016; Hoover 2017), most think that there is little they can do to reduce their own waste of food. This suggests that households tend to see themselves as reasonably efficient in their meal production and food management activities. Food waste, however, can be influenced by difficulties in forecasting household meal demand over the planning period (e.g., shopping for ingredients today in anticipation of household preferences in the near future), uncertainty of the availability of household labor time or other ingredients necessary for meal production, mistakes in meal production or food storage, or other sources of uncertainty or difficulties in managing and processing food stocks. Indeed, nearly 70% of households see some level of food waste as a necessary part of meal production and food management (Qi and Roe 2016). As such, households exhibit "demand" for a particular level of food waste in order to manage risk and uncertainty, account for potential mistakes, and deal with other food stock management constraints and complexities (e.g., budget non-convexities, diet optimism, hyperbolic discounting).

We explore the demand for food waste in response to changes in food prices and household resources (i.e., expenditures dedicated to food purchases), controlling for household characteristics and other factors that could be policy-relevant. We pose a simple economic model that conforms to the basics of consumer demand theory, and we use novel data on household food stock usage and consumption, the net of which forms our proxy for "food waste."

While our data are not current (they are from 1977–78), they represent the only extant nationally representative information that can be used to create a food waste proxy and estimate associated demand parameters. Our objectives are the following: to assess whether we can estimate a demand model for household food waste; explore the extent to which food waste responds to price, expenditures, and household characteristics; evaluate covariate effects in light of microeconomic theory; and provide insight into future data collection and analyses.

Much of the literature on household food waste focuses on consumer attitudes, awareness, and perceptions (e.g., Neff, Spiker, and Truant 2015; Qi and Roe 2016) or investigates the role of information provisions, such as the effects of date labelling on individual perceptions and consumption intentions (e.g., Wilson et al. 2017). These studies use stated preference analysis, rather than revealed preference or observational data. Stated preference studies are useful for exploring latent attitudes and perceptions of food waste and understanding how consumers might respond to policy interventions. Revealed preference studies are equally important insofar as they uncover actual behaviors in response to potential policy levers such as changes in food prices or access to food waste diversion strategies such as composting.

We contribute to the empirical literature by using household reports of food input usage and meal consumption (revealed preference data), the net of which forms our proxy for food waste. One of the advantages of constructing a proxy for food waste in this manner is to circumvent the inherent difficulties in capturing and measuring food waste before it enters the refuse stream (e.g., Hoover 2017), which can be expensive and time consuming, or relying on self-reports of food waste, which may be particularly susceptible to the Hawthorne effect and/or social desirability bias.[1] Ellison, Muth, and Golan (forthcoming) further discuss contemporaneous data collection issues such as the usage of digital photography via phone apps (Roe et al. 2018).

We find that at-home food waste is a luxury good with an income (expenditure) elasticity ranging from 1.10 to 1.44, depending upon the specification and identifying assumptions; our preferred estimate is 1.33. We also find that the demand for wasting at-home food inputs is rather responsive to price: our own-price elasticity estimates range from -1.90 to -1.34, with -1.50 being our preferred estimate. These elasticity estimates in and of themselves are, to our knowledge, the first to be estimated using observational data of actual food input and meal consumption choices in the United States. Such estimates grounded in observational data (i.e., revealed preferences) are important for policymaking as they reflect actual choices in the market rather than hypotheticals from stated-preference data.

Data

We utilize a unique, nationally representative dataset—the 1977–78 Nationwide Food Consumption Survey (NFCS). The NFC survey protocol involved collection of household food usage from food stocks over a one-week period, followed by a three-day period of information on food consumption for all household members. We are not aware of another nationally representative survey of U.S. households that has collected both food input usage and meal consumption data concurrently for the same observational units.

One issue with the data is that the survey periods of food stock usage and meal consumption do not align perfectly: the only overlap is on the last day of food stock usage and the first day of food consumption (Batcher 1983). Since the data are collected in such close proximity, however, we assume that they are generated by a common underlying household meal production process. Nevertheless, there is some potential for error reflecting differences in meal selection across sampling periods (i.e., the initial food stock usage phase and the subsequent meal production phase).[2] We attempt to

[1]For example, Williams et al. (2012) asked Swedish households to keep food waste diaries and noted that the average waste level was nearly 60% that of previous studies. These authors attribute this to social desirability bias: wasting food may be viewed as socially unacceptable, which in turn is reflected in self-reports. In the data section, we discuss the shortcomings of our self-reported data.

[2]We note that food-away-from-home expenditure and consumption was less common in 1977 than one typically sees in modern meal selection data; just under 17% of household calories are consumed away from home and 60% of households report zero expenditure on food-away-from-home over the one-week food usage survey. This implies that most errors in the data would likely relate to meal selection for at-

minimize such potential errors by using a sample of households that appear to be using and consuming consistent flows of at-home *edible* calories. We briefly describe the data here, but point the interested reader to Batcher (1983) for additional details.

Sample Selection

The NFC survey was conducted over four consecutive quarters, starting in the spring (April- June) of 1977. The spring quarter was the only time period in which food consumption data was collected for all household members; in the following three quarters, adults were subsampled from households for the food consumption portion. As such, we only use the spring quarter because this is the only time period in which we have complete information on both at-home food stock usage and at-home consumption for all household members.

From the initial 3,164 households surveyed in the spring quarter, we follow previous studies of the NFCS (Batcher 1983; Richards, Gao, and Patterson 1998; Landry and Smith 2018) by excluding the following: (*a*) 700 households that did not provide complete dietary intakes for all members; (*b*) 120 households that had no member consuming at least 10 meals from home over the course of the food usage survey; (*c*) 21 households that did not report how many guests were served meals from household food stocks; and (*d*) 16 households that had missing demographic information. Another 193 households are excluded due to a "mismatch" between food stock usage and food consumption data (as we describe in detail below). The final sample size is 2,113 households.

Food Inputs Used from Household Stocks

The first component of the survey was to collect household food input usage, as reported by the household food manager. Food inputs included all foods and beverages (excluding water) that were used from household stocks by household members, boarders, roomers, employees, and guests. This includes food inputs consumed outside the home, food fed to pets, and food thrown away at any point during food preparation. Importantly, households also report food inputs that were thrown away due to spoilage or other causes, and thus never used in preparation. Households did not report food given away or sold to people outside the household, or food fed to animals raised for commercial purposes. Finally, food that was bought or prepared during the one-week period but not yet consumed (e.g., leftovers) was not recorded. We adjust food input usage by the ratio of meals consumed by non-household-members to total meals consumed following Batcher (1983).

Households reported detailed information pertaining to the types of food inputs used from household stocks. For example, we know the types of meats, produce, and dairy products used in preparing home-produced meals over a one-week period. Researchers at the USDA then linked nutritional information to each food item and adjusted for the edible

home production that might be related to waste generation (e.g., ready-to-eat meals versus made-from-scratch meals) rather than food-at versus away-from-home (e.g., eating at home during the collection of food stock usage data and eating away from home during the collection of information on meal consumption).

component.[3] We utilize the calorie content as our main measure of food input quantity.[4]

The survey also collected information on the value (or cost) of foods used out of household stocks. Moreover, households reported the total value of food purchased at away-from-home venues (e.g., restaurants, cafeterias, and fast food). The sum of the costs associated with food usage (at and away from home) will form our expenditure constraint.

Food Consumed by the Household

The individual food consumption component of the survey (in most cases) immediately followed the one-week household food usage component (with a one-day overlap). An in-person 24 hour recall was conducted for all individuals in the household on day 1. Questionnaires were left at the household to be filled out for the subsequent and consecutive two 24-hour periods (days 2 and 3). Interviewers returned to the households to pick up and review the questionnaires for completeness. This component of the survey asks if the food item was consumed from the household food supply and either eaten at-home or away-from-the-home, or obtained and eaten away-from-home. Thus, we define "at-home" consumption as those food items consumed from household food stocks and consumed at or away-from-the-home.

Household Food Waste Proxy

Our proxy for the quantity of at-home food waste ($\tilde{x}_h$) is simply the difference between calories used out of household food stocks (x_h) and at-home calories consumed by the household (z_h), normalized on a per-day basis,

$$\tilde{x}_h = x_h - z_h. \tag{1}$$

Tautologically, this implies that the share of at-home calories that go unconsumed (i.e., lost or wasted) (l_h) is

$$l_h = (x_h - z_h)/x_h. \tag{2}$$

As mentioned above, data collection processes for food usage and consumption are not simultaneous, but rather consecutive (with one day of overlap). For 194 households, we have reports of more at-home calorie consumption than usage $z_h > x_h$, which would imply negative waste. We removed these households since they violate our assumption that the food usage data and food consumption data are generated from a common underlying data-generating process with consistent choices in both the food

[3] *For example, if a household used a banana, the reported calorie content pertains to the edible portion. This helps minimize the differences in made-from-scratch meals that potentially generate more inedible food waste than ready-to-eat meals. We are only concerned with the edible portions.*

[4] *We considered using the weight (in pounds) of food inputs. Our results remain substantively the same, although elasticity estimates are larger. The problem with using weight in pounds is that households were instructed to not record the usage of water in food preparation and cooking. Thus, the consumption of products with added water (e.g., coffee, rice, pasta, etc.) will be much higher than the corresponding inputs. Batcher (1983) notes similar problems using pounds rather than nutrients.*

stock usage and meal production phases of data collection. This creates a sample that is more homogenous in terms of at-home food usage and consumption flows.

We recognize that measurement error is possible. If misreporting of food usage and consumption is biased with the same magnitude and direction (e.g., not reporting alcohol) then the biases virtually cancel in equation (1). If, however, input usage is accurately measured, for example, but food consumption is subject to errors that vary with regressors (e.g, household structure), our regression estimates would be inconsistent. On the other hand, if food input usage and meal consumption are subject to random measurement error, OLS regression coefficients should be consistent and (under fairly general conditions) unbiased. We have no way of knowing which situation is the truth, and merely point out this limitation. As discussed below, we do use an instrumental variables approach to address potential endogeneity in our main regressors of price and expenditure.

Summary Measures

The mean percent of unconsumed edible at-home calories ($l_h \times 100\%$) is 42.47% (s.d. = 19.53) with a minimum of 0.02% and a maximum of 96.02% (see table 1). Figure 1 shows the density, which appears approximately normally distributed, though slightly skewed to the left.[5] The substantial spread in our measurement (i.e., a standard deviation of nearly 20% with minimums and maximums reaching the logical endpoints) most likely reflects (*a*) the consecutive nature of collecting food stock usage information, followed by the collection of individual food consumption, and (*b*) the relative short period of data collection. Nevertheless, a noisy measure of our dependent variable should yield valid estimates, but will carry larger standard errors.

Our average measure of at-home food waste is on the upper end of existing estimates (e.g., those stated in the introduction), although not unreasonable. In particular, the estimate from Hall et al. (2009) is roughly 34 ± 6% in 1977–78, which in turn is slightly higher than the ERS-USDA estimate of 23% food loss rate in 1974 (Buzby, Wells, and Hyman 2014). These are the only two estimates of food waste (in a caloric metric) during our study period that we are aware of, and are themselves estimates. One main difference is that the Hall et al. (2009) and Buzby, Wells, and Hyman (2014) estimates include at-home and away-from-home food waste. It is not clear to us at which venue individuals wasted more food during this time period. Nevertheless, our simple calculation using the NFCS data appears to be in line with the existing literature.

The remainder of table 1 presents summary measures of our covariates and other variables used in the regression analysis. Demographically, the sample appears to be representative of the United States in 1977–78, with 85% non-Hispanic white, 10% non-Hispanic Black, and about 4% Hispanic.[6] The average age of the household head was about 49 years. Roughly 26% of household heads had no high school education, 34% with a high school

[5]*The mean at-home food usage was just under 7,752 kcal per day per household, while the average per-day at-home consumption was 4,280 kcal per household. The loss ratio from these two means (44.78%) does not equal the mean of loss ratios. It is a well-known statistical fact that the ratio of two means will in general not equal the mean of ratios.*

[6]*U.S. Census reports 86.6% white households and 11.6 % black households, with no reference to Hispanic origin (U.S. Bureau of the Census 1978).*

Table 1 Sample Summary Statistics

Variable	Mean	St. Dev.
Unconsumed kcal (percent)	42.41	19.45
Non-Hisp white	0.85	0.36
Non-Hisp black	0.10	0.30
Hispanic	0.04	0.19
Other race/ethnicity	0.01	0.11
Age of household head	48.66	17.32
Middle school only	0.13	0.34
No high school grad.	0.13	0.33
HS grad	0.34	0.47
Some college	0.19	0.39
College 4+ yrs	0.21	0.41
Urban household	0.71	0.46
New England	0.06	0.25
Mid-Atlantic	0.18	0.39
East North Central	0.18	0.39
West North Central	0.09	0.28
South Atlantic	0.14	0.35
East South Central	0.07	0.26
West South Central	0.09	0.29
Mountain	0.05	0.21
Household Size	2.86	1.59
Dual head, no kids	0.34	0.47
Single head with kids	0.07	0.26
Dual head with kids	0.36	0.48
Number of infants <1yr	0.04	0.19
Number of toddlers 1–4 yr	0.18	0.47
Number of kids 5–12 yr	0.38	0.78
Number of teens 13–18 yr	0.34	0.76
Number of adults	1.92	0.70
Annual household income (1976)	12,506.43	10,593.92
Weekly FAH and FAFH input costs ($1977)	54.25	35.20
Price $ per 1,000 edible kcal used ($1977)	0.87	0.27
Joint food prep	0.10	0.30
Joint food shopping	0.17	0.37
Observations	2113	

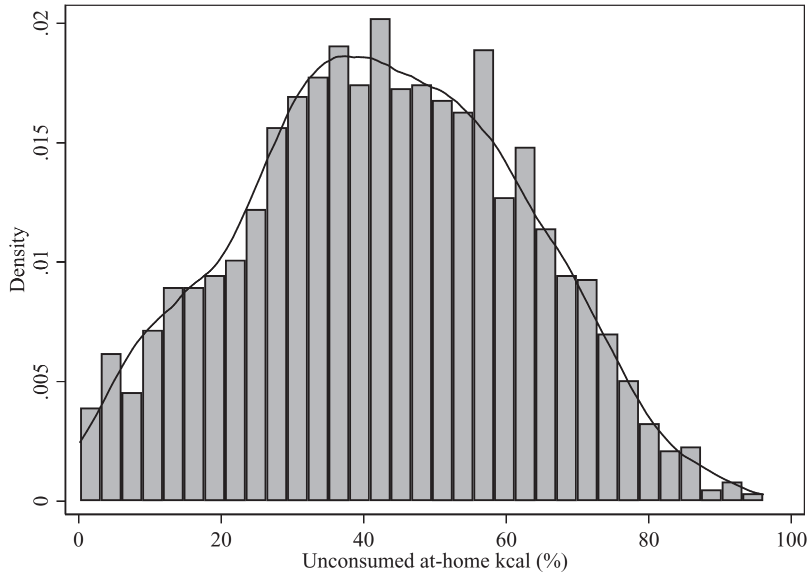
education and 40% with at least some college education. The geographic spread, as well as the percentage of urban households (71%) also appears in line with the U.S. Census data from the time period. The average household before-tax income in 1976 was about $12,500, which is slightly lower than census reports of $14,922 (U.S. Bureau of the Census 1978).[7]

In terms of household structure, there were, on average, 2.86 members, which is on par with census data, indicating 2.9 household members (U.S. Bureau of the Census 1978). About 70% of households were dual-headed, and about half of these had children aged 18 or younger. The remaining 30% was split between single-headed households with kids (7%) and without children (23%). In terms of the ages of children, 4% of households had an infant under 12 months.

[7]As explained below, income will be our instrumental variable for the cost of food input usage. Where annual income from the previous year is missing, we use reports of income in the previous month.

Figure 1 Distribution of the percentage of unconsumed calories

Source: 1977-78 Nationwide Food Consumption Survey (NFCS)



The value of food used by household members (both at-home and away-from-home) over the one-week period ranged from \$3.18 to \$381.45, with an average of \$54.25.[8] The price per 1,000 edible calories of at-home food stock usage ranged from \$0.20 to \$2.98, with an average of \$0.87. A small fraction of households engage in joint food preparation (10%) and joint food shopping (17%) by multiple adults within the household.

Empirical Approach

Our empirical approach is to allow at-home food waste to enter the household utility function. This allows us to analyze the demand for food waste in terms of the demand for unconsumed food inputs ($\tilde{x}_h$). Specifically, we use a simplified version of the household production model of food waste described in the previous literature (Höjgård, Jansson, and Rabinowicz 2013; Lusk and Ellison 2017; Landry and Smith 2018). In very brief terms, this model posits that households purchase market goods such as groceries x_h at prices p_h and combine them with other inputs (culinary capital) and labor time to produce a vector of consumable goods, such as at-home meals z_h, which in turn give rise to utility. We make several simplifying assumptions to the full structural model of Landry and Smith (2018) for tractability, as well as due to data limitations.

First, we assume utility is separable in food and all other goods. We do this because our data are food-focused and do not provide enough information for all other goods. Second, notice that equation (1) implies a linear relationship between food input calories x_h and at-home consumption calories z_h. Given the inefficiencies in transforming inputs into outputs, we expect

[8] *This number is difficult to compare to the "gold-standard" Consumer Expenditure (CE) Survey because (a) the CE did not start until 1982, and (b) our measure is the value of food used, not bought.*

the rate of transformation to be less than one, and we expect demand for food waste to reduce this transformation coefficient. In other words, given some amount of food used out of the household's stocks, a fraction of it is wasted, which we defined in equation (2) as l_h. Lusk and Ellison (2017) make a similar assumption, and this corresponds to the Gorman-Lancaster "linear characteristics" household production model (Gorman 1956; Lancaster 1966).[9] These first two assumptions allow us to analyze demands in terms of wasted food inputs $\tilde{x}_h$ as a function of input prices p_h and total food expenditures I.

Finally, we do not have information of amounts of food bought away-from-home, only the amounts consumed and the total expenditure. Therefore, we must assume that wasted calories from away-from-home venues do not enter the utility function due to missing information. As mentioned above, 60% of households have zero food-away-from-home expenditure, and the average share of calorie consumption from away-from-home venues is 17%.

Specification

By allowing preferences to take the price-independent, generalized logarithmic (PIGLOG) form (Muellbauer 1976), our main specification is the Working-Leser model. Specifically, this specification relates the share of the food budget spent on at-home food inputs to its price and total food expenditure. Thus, the traditional approach to analyzing food input demand would be to estimate

$$s_h = \frac{p_h x_h}{I} = \alpha_1 + \beta_1 \log(I) + \gamma_1 \log(p_h) + D'\delta_1 \tag{3}$$

where s_h is the share of food expenditures on at-home food inputs, I is total expenditure on food inputs (home and away), p_h is the price per kcal of at-home food inputs and D includes household composition, demographic, geography, and other control variables. In the appendix (see table A.2), we report results from equation (3) to show that the demand for food inputs for at-home meal production conforms to intuition: food inputs are necessary goods and are moderately own-price inelastic (table A.3).

We can incorporate a simple Lancasterian production technology (Lancaster 1966) by applying the loss factor from equation (2) to shares to obtain the share of food inputs that are lost/wasted, which written in full form is

$$\tilde{s}_h = \frac{p_h l_h x_h}{p_h x_h + p_a x_a} = \frac{p_h \tilde{x}_h}{I} = \alpha_2 + \beta_2 \log(I) + \gamma_2 \log(p_h) + D'\delta_2 \tag{4}$$

where $p_h x_h$ and $p_a x_a$ are the total values of food used from home and out of the home, respectively. Below, we discuss the fact that we do not observe away-from-home prices, p_a.

[9] *The linear characteristics model assumes that household meal production exhibits constant returns to scale. Landry and Smith (2018) found using the NFCS sample, which is nearly identical to the one used in this study, that constant returns to scale exist. However, when they allow scale economies to shift by household size, smaller households of size 1–4 exhibit decreasing returns to scale. In our application, we control for household size.*

The advantage of the Working-Leser specification is that it conforms to utility-maximization under the assumption of constant returns to scale and separability, and we can calculate expenditure and own-price elasticities that are consistent with consumer theory.[10] As a robustness check, we also estimate the reduced-form, double-log specification

$$\log(\tilde{x}_h) = \alpha_3 + \beta_3 \log(I) + \gamma_3 \log(p_h) + D'\delta_3 \tag{5}$$

for which the estimated parameters β_3 and γ_3 are direct estimates of income and own-price elasticity, respectively.

Identification

We have several potential threats to identification for key determinants of food waste. First, total food expenditure I, which is the sum of at- and away-from-home food inputs, is potentially endogenous not only due to its appearance on the left-hand side as the denominator of budget shares, but also for the simple fact that it is a choice variable itself. We follow the standard demand analysis practice and use the household's pre-tax income from 1976 as an instrumental variable.[11]

Our measure of food input price is calculated as a unit value: the total value of food used over the previous week divided by its quantity in calories. Thus, our measure of price is also potentially endogenous due to its derivation from a choice variable (i.e., food usage). Moreover, unobservable factors related to food preferences could be partially correlated with quality choices and thus unit prices paid (Deaton 1988). We use Hausman-type price instruments (Hausman 1997), which employs the average per-unit price paid within neighboring markets as an IV. In our data, we know the geographic division, which is a control variable in our equation of interest. Each geographic region is further disaggregated into "substrata".[12] Thus, within a geographic region we use the average price within all substratum $s \neq t$ as an instrument for prices paid by households in stratum t.

Finally, we do not have a measure of food-away-from home prices, which would complete our simple food demand system. We cannot calculate a unit value because (*a*) we do not have purchase quantities and (*b*) nearly 60% of our sample report zero purchases. Thus, we face a potential omitted variable problem. Our primary concern arises with the correlation of away-from-home prices with both food-at-home prices and total food expenditure. Since we are instrumenting for these two variables, a secondary concern is the partial correlation with other regressors. We thus discuss the remaining parameter estimates while recognizing some degree of possible inconsistency. We note that excluding food-away-from home prices may be less problematic in terms of policy intervention at the consumer level if waste

[10]Expenditure elasticity is calculated as $1 + (\hat{\beta}_2/\bar{\bar{s}}_h)$. Own-price elasticity is calculated as $-1 + (\hat{\gamma}_2/\bar{\bar{s}}_h)$. In both cases, we use the sample means for $\bar{\bar{s}}_h$.

[11]The argument for income as a valid instrument follows from the weak separability assumption: short-run food input and consumption decisions are separable from labor decisions that generate income. For example, see Blundell, Browning, and Crawford (2003).

[12]The documentation does not give further information with regard to how these substratum were defined, only that they exist within the geographic division.

from such venues is more in the hands of the retail owners rather than the restaurants' patrons.

The strength of our instrumental variables is evidenced by their statistical significance, expected sign, and strong first-stage results (table A.1). That is, last-year's income is positively related to the dollar value of foods used as inputs. The local food price has a negative sign, which is expected: unit-prices reflect household-specific product quality (Deaton 1988) so that when regional market prices rise, households substitute toward lower quality food. Finally, we can see that the first-stage F-statistics are well above the conventional value of 10 (Stock and Yogo 2005).

Results

We report coefficient estimates from equation (4) in table 2. We can see that at-home food waste demand is positively correlated with food input expenditure and negatively correlated with at-home food input prices, as expected. These coefficient estimates are converted to elasticities in table 3. With regard to food expenditures, we find consistent evidence that food waste can be categorized as a luxury, with elasticity estimates ranging from 1.10 to 1.44. The demand for at-home food waste is also rather price elastic, with estimates ranging from -1.35 to -1.90.

Despite the fact that we have good reasons to believe that unit-prices and total expenditure are endogenous, in no case can we reject the null hypothesis that the OLS estimates are significantly different than the IV estimates using Wooldridge's (1995) robust F-test and score test (see table 2).[13] If price and expenditure are exogenous, then two-stage least squares (2SLS) IV estimates are still consistent. If, however, they are endogenous, despite our statistical tests, then OLS is inconsistent. We again emphasize that our instruments have good first-stage properties (table A.1). One potential reason for rejecting the endogeneity test is that our covariates are controlling for a substantial portion of the correlation between the endogenous variables and relevant omitted variables. It is for these reasons that we place emphasis on the OLS estimates, which yield approximate price and income elasticity estimates of -1.5 and 1.3, respectively. We note that these estimates fall within the range of IV estimates and do not change the overall conclusion that food waste is a luxury good and is price elastic.[14]

We further find that household membership structure matters: the demand for food waste decreases with household size in general, which we interpret as a reflection of scale or scope economies in which quantity or diversity of meals serves to decrease the demand for unconsumed food. This mirrors the results of Landry and Smith (2018), who find that larger households tend to be more efficient in meal production. Human capital

[13] *Wooldridge's (1995) test extends the more commonly-used Durbin and Wu-Hausman tests by using a robust covariance matrix. Thus, Wooldridge's test is more conservative. Nevertheless, we still cannot reject the null using either the Durbin or Wu-Hausman tests.*

[14] *As a robustness check, we also estimated a reduced-form specification by redefining the dependent variable as the natural log of the quantity of kilo-calories wasted, but kept the same regressors (i.e., a double-log specification). Results appear in appendix table A.4 and are roughly consistent with the Working-Leser model: OLS price and expenditure elasticity estimates are -1.61 and 1.30, respectively. IV estimates, noting that the first stage is identical to the Working-Leser model, yield price elasticity estimates ranging from -2.11 to -1.50, and expenditure elasticities from 1.14 to 1.51. We also fail to reject the endogeneity tests for this specification.*

Table 2 Coefficient Estimates: Working-Leser Specification

Dep. Var. = at-home food waste budget share	**OLS**	**IV-1**	**IV-2**	**IV-3**
log(weekly FAH and FAFH input costs)	0.12***	0.04	0.15***	0.16
log(price $ per 1000 edible kcal used)	−0.18***	−0.13**	−0.33***	−0.34*
log(household size)	−0.20***	−0.13	−0.24***	−0.25*
Joint food prep	0.03**	0.03**	0.03**	0.03**
Joint food shopping	−0.03**	−0.03**	−0.03**	−0.02*
Urban household	−0.02*	−0.01	−0.00	−0.00
Age of household head	0.00	0.00	0.00	0.00
Age-squared	−0.00	−0.00	−0.00	−0.00
Middle school only	0.05***	0.05**	0.04	0.04*
No high school grad	0.05***	0.05***	0.03	0.03
HS grad	0.02	0.01	0.01	0.01
Some college	0.00	0.00	−0.00	−0.00
New England	−0.00	−0.00	0.00	0.00
Mid-Atlantic	0.02	0.02	0.03	0.03
East North Central	−0.01	−0.01	−0.02	−0.02
West North Central	−0.01	−0.00	−0.02	−0.02
South Atlantic	0.01	0.01	0.01	0.01
East South Central	0.03	0.04*	0.01	0.01
West South Central	0.02	0.03	0.01	0.01
Mountain	−0.00	0.00	−0.02	−0.02
Non-Hisp black	0.05***	0.05***	0.03*	0.03
Hispanic	0.06**	0.06**	0.05**	0.05**
Other race/ethnicity	0.04	0.03	0.05	0.05
Dual head, no kids	−0.04***	−0.02	−0.05***	−0.05
Single head with kids	0.01	0.01	0.00	−0.00
Dual head with kids	−0.02	−0.01	−0.03	−0.04
Number of infants <1yr	0.07***	0.06***	0.08***	0.08***
Number of toddlers 1-4yr =1	−0.00	−0.01	−0.00	0.00
Number of toddlers 1-4yr ≥ 2	0.05*	0.04	0.05*	0.05*
Number of kid 5-12yr =1	−0.00	−0.00	−0.00	0.00
Number of kid 5-12yr ≥ 2	0.04**	0.03	0.04**	0.04*
Number of teens 13-18 yr =1	−0.00	0.00	−0.01	−0.01
Number of teens 13-18 yr ≥ 2	0.01	0.01	−0.00	−0.00
Constant	0.02	0.24	−0.09	−0.12
Observations	2113	2113	2113	2113
R-squared	0.193	0.160	0.164	0.160
Expenditure IV		X		X
Price IV			X	X
Wooldridge (1995) Exog. Tests				
Robust Score		0.827	1.565	3.094
Robust Score *p*-value		0.363	0.211	0.213
Robust *F*-stat		0.722	1.426	1.382
Robust *F*-stat *p*-value		0.396	0.233	0.251

Note: *Asterisks represent the following:*
**= $p < 0.1$, **= $p < 0.05$, and ***= $p < 0.01$. Robust standard errors appear in parentheses. The instrumental variable (IV) for expenditure is the previous year's (1976) before-tax income. The IV for price is the average per-unit price paid within neighboring markets.*

(i.e., educational attainment) reduces the demand for food waste, as expected, most likely through efficiency gains. We also find that joint meal preparation amongst two or more adults in the household increases food

Table 3 At-Home Food Waste Elasticities: Working-Leser Specification

Variable	OLS	IV-1	IV-2	IV-3
Expenditure	1.33***	1.10***	1.40***	1.44***
	(0.03)	(0.27)	(0.07)	(0.38)
Price	−1.49***	−1.35***	−1.88***	−1.90***
	(0.05)	(0.17)	(0.34)	(0.47)
Expenditure IV		X		X
Price IV			X	X
Observations	2113	2113	2113	2113

Note*: Asterisks represent the following:*
$^{*}= p < 0.1$, $^{**}= p < 0.05$, and $^{***}= p < 0.01$. The instrumental variable (IV) for expenditure is the previous year's (1976) before-tax income. The IV for price is the average per-unit price paid within neighboring markets.

waste demand, consistent with the idea of structural complexity or the potential for coordination problems in the meal production process. Unlike Landry and Smith (2018), we find that food waste demand increases with recent changes in household structure, such as introduction of an infant, and in the presence of 2 or more children aged 5–12. Finally, we also find geographic differences in the demand for food waste, which to our knowledge has not been empirically documented in the United States. Specifically, our results suggest that the western states demand the least amount of food waste, with states residing in the southeast and northeast along the Appalachian Mountains demanding the most.[15] We find that urban areas tend to demand less food waste, which may be a product of food access and is consistent with Landry, Smith, and Turner (2017).

Overall, we find compelling evidence of significant relationships between the wasting of food inputs and food price, food expenditures, measure of household structure, skills, tastes, and location. While these data are forty years old, they nonetheless provide some initial empirical insight into price and income effects and permit testing and exploration of hypotheses related to household food waste. Through model formulation and testing, we discover some of the advantages and limitations of using survey and revealed-preference data to analyze household food waste.

Discussion and Conclusion

By several measures, a nontrivial share of food within the U.S. food supply chain goes unconsumed (Hall et al. 2009; Buzby, Wells, and Hyman 2014; U.S. Environmental Protection Agency 2018). A majority of this wasted food is generated at the household level (Buzby, Wells, and Hyman 2014). While policymakers explore various options to curb this trend, little is known about how households might respond to economic incentives using revealed preference data. Previous stated preference literature has demonstrated that households, by and large, feel guilty about wasting food, but also feel that some level of food waste within the household is simply

[15]*We performed a joint F-test for signifcance across regions, and reject the null of equality at a p-value of 0.095.*

unavoidable and a necessary part of meal production and food management (Qi and Roe 2016; Hoover 2017). This implies that households "demand" some level of food waste as an inventory management good.

Our empirical analysis utilizes information from the 1977–78 Nationwide Food Consumption Survey (NFCS), a nationally representative dataset that collected detailed data on food input usage from household food stocks and meal consumption by all household members. We find a negative relationship between the demand for at-home food waste and food input prices, with price elasticities ranging from -1.90 to -1.35; our preferred estimate is -1.50. This suggests that household food waste is responsive to food prices, and thus price instruments may have an effect on food waste.

We find that the wasting of food within the household can be viewed as a luxury good, with expenditure elasticities ranging from 1.10 to 1.44; our preferred estimate is 1.33. This result reflects the two pathways by which income affects food waste demand in the household production model. The first is the traditional pathway via a resource constraint: as households become richer, they purchase more food and are perhaps less concerned about it going to waste. The second pathway reflects larger opportunity costs of time for wealthier households and/or greater time constraints for less wealthy households. That is, the lack of available time for meal production and/or its higher opportunity cost could lead to increased demand for household food waste. Our data did not provide sufficient information on time usage and opportunity costs, and future research should strive to incorporate time.

How might researchers and policymakers use such elasticity estimates? First, any market-based policy would benefit from a better understanding of how households respond to economic incentives. The taxing of food inputs has been explored in Katare et al. (2017) as one mechanism. Food taxes are quite regressive given the necessary nature of food and would most likely lead to increases in food insecurity (Gregory and Coleman-Jensen 2013). Moreover, targeting food inputs that are associated with greater levels of food waste (e.g., fresh fruits and vegetables) would distort food choice and could induce health effects via changes in nutrition in unintended ways.

Alternative policy mechanisms exist that alter incentives so that households internalize the external effects of wasting food. For example, social sanctions (i.e., the idea that individuals alter behavior through social norms) via public awareness and informational campaigns are one such mechanism that have been used against littering, drunk driving, and drug abuse (e.g., Cialdini, Reno, and Kallgren 1990; Miguel and Gugerty 2005).[16] Some cities, such as Seattle and San Fransisco, have moved towards mandatory sorting of food scraps and compostable paper: this shifts the burden to the consumer in the form of time costs in sorting while mitigating anaerobic rotting in landfills. However, if sorting out food scraps engenders disutility, the loss in household welfare must be appropriately weighed against any benefits.

Alternatively, providing households with information on prevention measures (e.g., better meal planning or "just-in-time" shopping), diversion measures (e.g., composting), or reuse of potentially edible portions (e.g., broccoli stalks for soup) may have more efficacy in that such policies employ a positive frame. That is, as compared to taxes and social sanctions,

[16]Quantity instruments such as tradable food waste permits, are less feasible due to difficultlies in enforcement, public resistance, and sizable transaction costs.

such policies encourage households to take actions to do something good for the environment, while potentially stretching the household food budget. Here again, we must note that these policies do involve additional time costs for the household.

One open question remains: How have the elasticities likely changed in the past 40 years? While it is difficult to predict how elasticities might change over time due to their inherent dependency upon preferences, changes in constraints, and evolution of technology, some previous literature does exist. For example, Beatty and LaFrance (2005) find increasing income elasticities for several food nutrients from 1919 to 2000, though all remain necessities. For luxury commodities, the trend is less clear. Increasing labor participation among women and increasing demand on household time (e.g., longer commutes, more traffic congestion in urban centers), may have further restricted time availability for household meal production, which could increase demand for household food waste with income. Recognizing a greater scarcity of time, however, households may substitute to less labor-intensive meals or a greater reliance on food-away-from-home. Nonetheless, we do know that food waste is increasing, and to the extent that the value of food waste is increasing in its share of the food budget, we may expect expenditure elasticities to fall. Compiling aggregate data on input usage and consumption over many years (as done in Beatty and LaFrance 2005) may be a fruitful path forward in answering this question and others.

Our calculation of food waste as the net of food input usage and consumption may be of practical importance for future data collection. The United States has long-running surveys of food input purchases (e.g., the Consumer Expenditure Survey) and food consumption (e.g., the National Health and Nutrition Examination Survey-NHANES), but no such data currently exists with both components for the same observational units. Either one of these surveys could elicit questions pertaining to the missing piece of information. For example, NHANES fields a module called the Flexible Consumer Behavior Survey (FCBS), which allows for policy-relevant questions to be added on a rolling basis. Given the wealth of consumption data in NHANES, the addition of input usage information could be harnessed to create food waste measures like the one in this study. Finally, we note the use of emerging technologies in monitoring food waste: Roe et al. (2018) have recently demonstrated the usage of phone apps to measure plate waste. Such apps could be used in conjunction with food stock usage and meal preparation to increase the accuracy of data collection and reduce the burden on respondents.

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Supplementary Material

Supplementary material is available online at *Applied Economic Perspectives and Policy* online.

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