THE ECONOMIC COST OF INEFFICIENT FOOD MANAGEMENT IN THE HOUSEHOLD

by

SARA LIPS

(Under the Direction of TRAVIS A. SMITH)

ABSTRACT

Each year billions of pounds of food available for human consumption goes unconsumed and ultimately discarded, with households responsible for the largest share of those food losses. Using nationally representative data from the 1977 National Food Consumption Survey on household food input usage and food consumption, a stochastic cost frontier is applied to estimate the cost incurred by households due to inefficiencies in food management and meal production. Using this method, it is found that the average U.S. household wastes about $2,009.67 annually, which sums to about $146.4 billion lost each year due to technical inefficiencies in the kitchen. Based on the results, inefficiencies are associated with race, income, education level, employment of female head, food shopping frequency, fresh food consumption, meals bought away from home, food storage, and joint food shopping and preparation habits.

INDEX WORDS: Food waste, household meal production, stochastic frontier, technical inefficiency

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SARA LIPS

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SARA LIPS

Major Professor: Travis A. Smith
Committee: Craig Landry
Chen Zhen

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
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CHAPTER 1

INTRODUCTION

The USDA estimates that each year roughly one-third, or 133 billion pounds, of food available for human consumption goes uneaten (Buzby, Wells, Hyman, 2014). Food waste represents 2.5% of U.S. energy consumption per year and the production of wasted food uses around 300 million barrels of oil and over 25% of the total freshwater consumed by agriculture annually (Weber, 2012; Hall et al, 2009). Less than 3% of food waste is recovered making food waste the single largest component going into municipal landfills, which are the third largest source of methane production in the United States (U.S. EPA, 2019). The USDA further estimates that households are responsible for two-thirds of food losses, about 90 billion pounds (Buzby, Wells, Hyman, 2014). Food disposal at the consumer level has a larger resource footprint than at any other point of the food chain because it has undergone more transport, storage, and often cooking.

Furthermore, reducing food waste has received attention as an important strategy to feed the growing population and address food insecurity. The USDA estimated 141 trillion calories, or 1,249 calories per capita per day, in the food supply went unconsumed (Buzby, Wells, Hyman, 2014). As population increases, food production will have to increase by approximately 70% by 2050 (UNFAO, 2009). Reducing food waste can help achieve this target by increasing the supply of food available for consumption and lowering prices. In the United States, 49 million people live in food insecure households, and one in seven people use food banks (Coleman-Jensen, Nord, and Singh, 2013; Weinfield, 2014). Preventing food waste may improve overall food security by diverting wholesome food that may have otherwise ended up in the landfill to help feed families in need. Due to the environmental and economic costs of food loss and the potential social benefits in reducing waste, the United Nations aims to halve food waste at the retail and consumers levels as one of the Sustainable Development Goals (UN, 2016). In September 2015, the first-ever national food loss and waste goal in the United States was launched by the USDA and EPA, also calling for 50% reductions by 2030.

Despite the large proportion of food waste occurring at the household-level, documented measures of consumer-level food waste have varied in value. In 2010, estimates of food waste cost ranged from $144 billion (ReFED) to $162 billion (USDA) to $165 billion (NRDC) (ReFED, 2016; Buzby et al, 2011; Gunders, 2012). This corresponds to an average family of four spending between $1,365 and $2,275 each year on wasted food (Bloom, 2010). Beyond these national-level studies, many recent publications rely on self-reporting to estimate food waste. However, self-reporting has been shown to be subject to serious underreporting biases. Recent research has compared the amount of self-reported food waste in diaries with waste-composition analysis for the same waste stream. These studies found that the amount of food waste reported in diaries is substantially lower, about 60% lower, than the amount resulting from the waste composition analysis (van Herpen et al, 2019; Quested, Easteal, and Ingel, 2013). This paper will attempt to address the discrepancies in estimates by providing a more precise measure using household-level data to directly estimate inefficient food usage in the household.

With the increasing cost and burden of food waste, it is important to identify what household factors and behaviors may exacerbate the problem. In this paper, determinants of inefficiency will be identified to explore what makes a household relatively more efficient. Much of the literature on drivers of household food waste rely on anecdotal evidence provided by stated preference analysis and surveys, rather than revealed preference or observational data. This is mainly due to a lack of adequate data, particularly at the household level. This paper fills the gap in the food waste literature by using household-level observational data and economic analysis to better understand what drives household inefficiency in meal production and food management activities.

According to a study funded by the NRDC, approximately 68% of all food discarded in the household was considered edible at some point before being thrown out (Hoover, 2017). This suggests that households are inefficient in meal production and food management activities. To calculate household meal production inefficiencies, this paper uses a stochastic frontier analysis, similar to Landry and Smith's 2018 working paper. However, this paper approaches household optimization using the "cost" frontier as opposed to the "production" frontier. The production frontier imposes the assumption that households attempt to maximize calories consumed given their budget and a set of inputs, in this example, household food stocks. The cost frontier assumes the household's objective is to minimize the costs of producing a set level of outputs given the prices of the inputs (Greene, 2008). In the case of household meal production, assuming households minimize costs, as opposed to maximizing calories, may be a more intuitive approach.

Measures of inefficiency is the extent to which households fail to achieve the minimum feasible cost. The USDA highlights the practical limit to how much food loss households could realistically prevent given technical factors (e.g., perishable nature of most foods, food safety, storage, and temperature considerations) and individual consumers' tastes, preferences, and food habits (e.g., throwing out milk left over in a bowl of cereal) (Buzby, Wells, Hyman, 2014). Acknowledging this is not a realistic expectation; households are instead measured against the cost frontier, which is estimated from the data. Technical inefficiency is then calculated for each household relative to this frontier to estimate cost of wasted at-home food inputs.

This paper observes measures of the U.S. diet at two levels—household food usage (food brought into the household and used) and food consumption (food actually eaten by individuals in the household)—to estimate household food waste. Using the stochastic cost frontier, inefficient households are identified as households that can consume the same number and quality of calories but for lower costs by reducing wasted edible food given the price of food inputs. Using the household inefficiency measure, it was found the average household in 1977 wasted $2,009.67 (or $1,181.95 at the median value) per year due to inefficiencies in the kitchen.[1] This adds up to between $86.1 billion and $146.4 billion lost each year due to technical inefficiency in household meal production.[2]

Results of this paper found household inefficiency decreases with educational attainment, frequency of shopping trips, and the proportion of fresh foods purchased. Furthermore, households below 185% of the poverty guidelines and households that jointly grocery shop experience lower inefficiency levels. Inefficiencies tend to be higher for households who consume more meals outside the home and who regularly use their freezer. Households who engage in joint meal preparation practices and households, where the female head is employed outside the household, also tend to be more inefficient.

Background

Along with the various measurements of food waste, there also exists an array of definitions. The USDA's Economic Research Service (ERS) defines food loss as "the amount of food postharvest that is available for human consumption but is not consumed for any reason" (Buzby,

[1] Values are from the 1977-78 National Food Consumption Survey; however, numbers correspond to the expected trend in food waste using USDA Loss-Adjusted Food Availability data. To date, there is no other nationally-representative survey data from the U.S. that records this information for the same observational units.

[2] The discrepancy between the two estimates is due to the skewness of the cost inefficiency distribution.

Wells, Hyman, 2014). Food loss may include natural shrinkage, loss from mold, pest or inadequate climate control, as well as food waste. Food waste is a component of food loss that occurs when an edible item goes unconsumed, such as plate waste by consumers (Buzby, Wells, Hyman, 2014). The Environmental Protection Agency's definition of food waste does not include recovered food for nonfood use, such as animal feed or fertilizer, and instead focuses on "the amount of food going to landfills from residences, commercial establishments, institutional sources, and industrial sources" (U.S. EPA, 2016). The ERS's definition only applies to edible and safe and nutritious food, whereas the EPA includes both edible and inedible parts of food (Bellemare et al, 2017). For the purpose of this study, household food waste is defined as edible food from the household food stock that is used but is ultimately not consumed. This includes food discarded due to spoilage before or after preparation, as well as leftovers that are not stored but thrown away.

Anecdotal evidence suggest that drivers of household food losses include lack of awareness and undervaluing food, confusion over date labels, spoilage, impulse and bulk purchases, poor planning, and over-preparation (Gunders, 2012). Perishables make up the majority of household food loss due to high volume consumption and the tendency to spoil. In terms of total mass, fresh fruits and vegetables account for the largest losses, followed closely by dairy and meat, poultry, and fish (Buzby et al, 2011). The UNFAO reports one of the major causes of food waste in recent years is that consumers spend a far smaller share of income on food (Sengupta, 2017). Recent studies show that affluent households waste more food than low income households because they can afford to, and there is a clear correlation between the proportion of income spent on food and the amount of food wasted (Stuart, 2009; Parfitt et al, 2010; Landry and Smith, 2019). Cheap, convenient food has promoted behaviors that undervalue fully utilizing purchases. Food sold in increasingly large package sizes and store promotions that encourage bulk or unnecessary products often lead to food spoilage and waste (Lyndhurst and WRAP, 2012). Lack of meal planning and shopping lists, inaccurate serving estimates, and impromptu restaurant meals can also lead to spoilage. Time constraints and inconvenience may exacerbate the problems listed above.

Although most households experience some level of food waste, the amount may vary among different groups. For example, age has been shown to be negatively correlated with the quantity of food wasted (Bishop and Megicks, 2019). Younger people (18-34) tend to waste more due to cooking, preparing, and serving too much, while older people (65+) seem to be better equipped in terms of skills and knowledge and have more disposable time to spend in the kitchen. From past qualitative reports, larger households tend to buy and prepare more food but waste less per capita than smaller households, most likely due to economies of scale (Bishop and Megicks, 2019). However, the presence of children in the household has been positively correlated with household food waste (Hoover, 2017). Educational attainment has been shown to be negatively correlated with meal production inefficiency, as well as distance to and frequency of major food shopping (Landry and Smith, 2018). Finally, joint meal preparation practices among household head(s) and other adults was shown to be correlated with inefficiency (Landry and Smith, 2018).

CHAPTER 2

DATA

This paper uses a nationally, representative dataset from the 1977-1978 Nationwide Food Consumption Survey (NFCS). R. Rizek, director of the Consumer Nutrition Division at the USDA, stated the purpose of the NFCS is "to measure the food and nutrient content of the diet and money value of food used by U.S. households" (National Research Council, 1984). The data was collected from approximately 15,000 U.S. households between April 1977 and March 1978. The NFC survey protocol involved a 7-day recall of food used by the household from food stocks including food that had been eaten, discarded, and fed to household pets as leftovers as reported by the person most knowledgeable and responsible for meal planning and preparations. The household food manager was then instructed to keep a 3-day diary of food consumption for all household members. This dataset is unique in that it collected both food usage and food consumption data concurrently for the same observational units.

One possible issue with the data is that the survey periods of food usage and food consumption only overlap on the last day of the food usage recall and the first day of the food diary (Batcher, 1983). This paper uses the assumption laid out by Landry and Smith that food usage and food consumption are generated by a common underlying household meal production process. There is potential for error reflecting differences in meal selection across sampling periods (i.e., initial food stock usage phase and subsequent meal production phase). A sample is selected in an attempt to minimize this error by using a sample of households that appear to be using and consuming consistent flows of at-home *edible* calories (Landry and Smith, 2019).

It should be noted that there are fundamental differences between food culture in the 1970s and present day, which may pose external validity concerns. Some areas that may cause differences in household food waste production include increased food intake, differences in composition of food intake, increased food away-from-home meals and calories, larger portion sizes, and the increase of women employed outside of the home. In the years between 1970 and 2010, Americans have begun to eat about 23% more calories and consume smaller proportions of fresh fruits and vegetables and a larger proportion of processed grains, fats, and sugars (Desilver, 2016). Additionally, the surface area of the average dinner plate has expanded by 36% (Wansink and Ittersum, 2007). Simultaneously, the share of women in the labor force has increased from about one-third to almost one-half thereby increasing the opportunity cost of time in meal production (Toossi and Morisi, 2017). Moreover, the consumption of foods prepared outside the home has steadily grown from one-sixth to almost one-third of an individual's daily dietary intake (Senguin et al, 2016). Alongside an increase in eating out, people spend less time in food preparation, with an approximate halving of time for women and a small increase for men (Smith, Ng, and Popkin, 2013).

Due to the reasons listed above, likely along with other drivers, food waste trends have been increasing over the past half century. According to the USDA Loss-Adjusted Food Availability data, between 1980 and 2010 food waste has more than doubled (from 57.395 tons/1000 people to 115.55 tons/1000 people) (USDA, 2018). Similarly, the EPA has reported increasing trends in food disposal in landfills; based on their reports, food waste has increased from 13 million tons in 1980 to over 35 million tons in 2010—a 275% increase (U.S. EPA, 2019). Despite the differences in food culture and trends in food waste generation, the data used in this report is unique as it is the only known nationally representative survey that collects food usage and intake for individual households concurrently. Thus, important conclusions from this data can be drawn that may apply to inefficiencies in household food waste in today's kitchens.

Sample

The NFC survey was conducted over 4 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 3 quarters, only half of household adults were included in the food consumption portion of the survey. In order to have complete information on both at-home food stock usage and at-home consumption for all household members, only the spring quarter is used in this study.

Additionally, observations were omitted based on previous studies of the NFCS (Batcher, 1983; Richards, Gao, and Patterson, 1998; Landry and Smith, 2018). From the initial 3,164 households surveyed in the spring quarter, the following households were excluded from the study: (*a)* 700 households that did not provide complete dietary intakes for every household member on all three days of the meal consumption survey; *(b)* 120 households in which no member consumed at least 10 meals from household food stock over the course of the one-week food usage survey; *(c)* 21 households that did not report how many guests were served meals from household food stocks; and *(d)* 13 households that had missing demographic information. Another 182 households are excluded due to a "mismatch" between food stock usage and food consumption data as described below. The final sample size is 2,128 households.

Food Usage

The first component of the NFC survey collected household food usage as reported from a 7-day recall by the household food manager. Food inputs include all food and beverages (excluding water) consumed from household food stocks by household members, boarders, roomers, employees, and guests. This includes all foods from the household that were consumed elsewhere, food fed to pets, and food thrown away before, during, or after preparation. Significant to this paper's objective, households 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 recall, but not yet consumed (e.g., leftovers) was not recorded. To exclude household food used by guests, food usage was adjusted by the ratio of meals consumed by non-household members to the total number of meals consumed following Batcher (1983).

Households reported detailed information on types of food inputs used from household stocks. Each food was assigned one of about 3,000 food codes that identify foods both by major food marketing group and subgroup and by food processing form, its variations, and the source of the food. Researchers at the USDA linked nutritional information to each food item using the 2005 Healthy Eating Index (HEI), which represents the healthfulness of food that the household used in the 7-day report. The HEI is calculated based on 12 total food groups and ranked according to the Dietary Guidelines. Total HEI is an aggregate measure of the quality of food consumed per 1,000 calories and does not reflect quantity consumed. Total HEI scores range from 0 to 100, where scores closer to 100 are considered healthier (Guenther et al, 2013).

Researchers at the USDA also adjusted each food item for the edible component. As this paper is only concerned with edible food waste, this minimizes the differences in made-from-scratch meals that potentially generate more inedible food waste than ready-to-eat meals. Calorie content is utilized as the main measure of food input quantity in this paper.

The survey also collected information on the monetary value (or cost) of food used out of household stocks. The value of each food item used is calculated using reported information on quantities, form, source, purchase and price, and information about quantity of food used. The sum of all food usage costs from household food stocks is used to form the stochastic frontier. Additionally, food prices were derived for defined subgroups, fresh and storable food products. Furthermore, households reported the total value of food purchased at away-from-home venues (e.g., restaurants, cafeterias, and fast food), however, food consumed away-from-home was not reported.

Food Intake

Following the 7-day household food usage recall, household members were also asked to recall the food eaten for the previous 24 hours. Questionnaires were left to be filled out for the subsequent and consecutive two 24-hour periods (days 2 and 3) for each household member. Interviewers returned to the households to collect and review the food records for completeness. Food intake reports were detailed to include a description of all food and beverages consumed, as well as quantities eaten, form ingested, and source of food. Respondents reported whether food consumed was eaten at-home or away-from-home and whether the food was obtained from household food supply or obtained outside the home. Because food usage only includes food from household food stocks, this paper focuses on food consumed from the household food supply to create a measure of household food waste. Thus, "at-home" consumption is defined as those food items consumed from household food stocks and consumed at or away-from-the-home.

Cost of Household Food Waste Proxy

Using Landry and Smith's definition, the quantity of at-home food waste ($\tilde{x}_h$) is proxied by 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:

$$\tilde{x}_h = x_h - z_h. \tag{2.1}$$

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

$$l_h = (x_h - z_h)/x_h. \tag{2.2}$$

As mentioned in previous sections, the data collection processes for food usage and consumption are not simultaneous, but rather consecutive (with one-day overlap). 182 households reported more at-home calorie consumption than usage $z_h > x_h$, which would imply negative waste. These households were excluded from the sample since they violate the 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 stock usage and meal production phases of data collection. This creates a sample that is more homogenous of at-home food usage and consumption flows. Measurement error in the calculation of food waste is also 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 (2.1). There is no way of knowing the magnitude or direction of any potential biases occurring, so the limitation is purely acknowledged before calculation.

To find a simple, non-econometric estimate of the total cost of unconsumed at-home calories $(\tilde{C}_h)$ to use as a baseline, the share of unconsumed at-home calories (l_h) is multiplied by the total cost of at-home food by the household (C_h):

$$\tilde{C}_h = l_h * C_h. \quad (2.3)$$

The household calculation can then be scaled up to an annual, nationally representative figure and then converted into 2010 dollars using census data and food CPI values for 1977 and 2010. Although this simple calculation has its flaws, it is used as an initial comparison between this older dataset and more recent measurements of household food waste costs to check the external validity of the data.

Summary Statistics

The mean percent of unconsumed edible at-home calories $(l_h * 100\%)$ is 43.07% (s.d.=19.55) with a minimum of 0.06% and a maximum of 96.02%. (Table 2.1*).* The density appears to be normally distributed, though slightly skewed to the left (Figure A.1). The sizeable spread of the measurement (i.e., a standard deviation of almost 20% with minimum and maximum values reaching the logical endpoints) most likely reflects the consecutive nature of collecting food stock usage information, followed by the collection of individual food consumption, and the relative short period of data collection.

The estimated average annual cost of unconsumed at-home calories $(\tilde{C}_h)$ is about $3,574.05 per household (converted to 2010-dollar equivalent) and the median household wastes about $2,719.45 per year on unconsumed at-home calories. Considering there were 72,870,000

Table 2.1: Sample Summary Statistics

	Mean	St. Dev.	Min	Max
Unconsumed kcal (%)	43.073	19.55	.06	96.02
Household Size	2.86	1.58	1	11
# of FAFH meals	7.05	15.11	0	250
Female employed outside HH	0.40	0.49	0	1
Age of Food Preparer	46.90	17.37	15	96
NH White	0.85	0.36	0	1
NH Black	0.10	0.30	0	1
Hispanic	0.04	0.19	0	1
Other race/ethnicity	0.01	0.11	0	1
Joint grocery shop	0.16	0.37	0	1
Joint food preparation	0.10	0.30	0	1
HH froze food	0.56	0.50	0	1
HH <185% poverty threshold (1977)	0.27	0.44	0	1
Meal Preparer: no HS grad	0.30	0.46	0	1
Meal Preparer: HS grad	0.37	0.48	0	1
Meal Preparer: some college	0.18	0.38	0	1
Meal Preparer: college grad+	0.15	0.35	0	1
Shop more than once per week	0.21	0.40	0	1
Shop once per week	0.50	0.50	0	1
Shop once per 2 weeks	0.21	0.41	0	1
Shop once per month	0.08	0.27	0	1
Shop less than one per month	0.003	0.06	0	1
Distance to grocery store	3.73	6.13	0	68
Share of fresh food kcal used (%)	48.49	13.78	8.51	94.63
Cost of food consumed at home	45.16	27.72	3.18	251.13
Price per 1000 fresh food kcals	9.78	3.04	3.13	35.21
Price per 1000 storable food kcals	7.92	3.89	0.66	65.23
Daily HH kcal consumed	4,221.76	2,914.97	187	23,206.67
HEI Score	49.55	10.53	21.80	84.62
Observations	2128			

Source: 1977-1978 Nationwide Food Consumption Survey (NFCS) *All numbers use sample weights.*

households in the U.S. in 1977, this means the annual amount of dollars wasted on unconsumed at-home calories at the median and mean in 2010-dollars is between about $198 billion and $260 billion, respectively. The estimates from this simple calculation are far higher than modern documented reports. Since there is no cost estimate of food waste from 1977, the USDA Loss-Adjusted Food Availability data is used to estimate a general trend between results from this dataset and recent measures (Figure A.3). From 1980 to 2010, the rate of food waste per 1000 people increases by 194%, while this data implies the cost of food waste decreases by 100% between 1977 and 2010 (USDA, 2018; Gunders, 2012). From this comparison it is clear that the simple calculation is flawed. The results derived from the cost frontier in this paper provides estimates that are consistent with expected trends. Finally, this calculated value is not related to efficiency, so it will differ from the modelled estimates in this study. This simple calculation implies households are perfectly efficient in food management, or measured against a perfectly efficient frontier, while the estimated model measures households against the minimum feasible cost frontier to determine inefficiency.

The remainder of Table 2.1 presents summary measures of covariates and other variables used as determinates of inefficiencies in the regression analysis. Demographically, the sample data appears to be representative of the United States in 1977, with 85.04% of the population identifying as non-Hispanic white, 10.05% non-Hispanic black, and 3.69% of Hispanic-origin. Comparatively, the U.S. Census Bureau reported 86.6% of the population as white, 11.6% as black, and 5.2% from Spanish origin in 1977. About 27% of the sample population were below 185% of the 1977 poverty level. The U.S. Census reported 16.7% of the population in 1977 was below 125% of the 1977 poverty level.

In terms of household structure, there were, on average, about 2.86 members, which is exactly the same number as reported in the 1977 Census. About 60% of households had a female head that was not employed outside the home. The average age of the household member responsible for prepping food was about 47 years old; the youngest household food prepper was 15, and the oldest 96. Roughly 30% of households had a food prepper that was not a high school graduate, 37% of food preppers had a high school diploma, and 33% with at least some college education.

In terms of food purchasing behavior, about 21% of households reported shopping for groceries more than once per week, 50% reported grocery shopping only once a week, 21% grocery shopped once every two weeks, and 7.8% shopped for groceries only once a month. The average distance to the household's grocery shopping location was 3.73 miles and the maximum distance was 68 miles. Roughly 16.5% of households had two or more members that jointly shopped for groceries and about 10% engaged in joint food prepping. Slightly over half of the sample (55.5%) had a freezer and regularly froze food. During the 3-day food consumption period, household members reported eating about 7 meals not from household food stocks combined. The maximum number of household meals eaten away from home was 250 and about 32.5% of households reported that all members consumed all of their meals from the household food stock.

The value of food used by household members from household food stocks over the 1-week period range from $3.18 to $251.13, with an average of $45.16. This measure cannot be cross-checked with the Consumer Expenditure survey because the CE did not start until 1982 and this measure is the value of food used, not bought. The price per 1000 edible calories of fresh food products range from $3.13 to $35.21, with an average of $9.78. The price per 1000 edible calorie for storable food products (canned, frozen, etc.) range from $0.66 to $65.23, with an average of $7.92. The average household ate approximately 4,221.76 calories per day from household food stocks with about half (48.5%) of calories consumed from fresh foods (dairy, meat and eggs, grains, fruit, and vegetables). The average HEI score of the 7-day food recall was 49.55, which ranged from 21.80 to 84.62 on a 100-point scale.

CHAPTER 3

METHODS

The goal of this paper is to measure inefficient food management at a household level in terms of dollars and further explain what factors may drive a higher level of inefficiency from one household to another. To achieve this, the cost frontier model is used, where the choice variables are the inputs in the household food production process (fresh and storable food products) and the objective is to minimize household at-home food costs, given the set amount of household calories consumed and HEI food quality score. By comparing households, this approach can identify which households can still consume the same number of calories and the same quality of calories but for lower costs by reducing inefficiencies caused by food waste (e.g., consuming less food than was used). Furthermore, this approach can calculate how much lower at-home food costs could be and what the key drivers of the current higher costs are.

Inefficiencies in the cost function can be measured through technical or allocative inefficiency. If the production process exhibits *technical inefficiency*, the household may improve its efficiency by obtaining the same number of calories using fewer inputs. If, by contrast, the same number of calories can be consumed by different combinations of inputs, then the household may also reduce the cost by improving *allocative inefficiency*. For the estimation process, technical inefficiency is used because it is a more straight-forward measure and, in application, it is expected that households can more easily reduce their food waste by simply purchasing less inputs and consuming larger proportions of food purchased.

It is assumed that each household is on the spectrum of technical inefficiency, where the household produces less than the maximum possible output, in other words, consumes less than it uses from household food stocks. In the context of household food waste, these assumptions, which focus on input overuse, are fairly intuitive. For an inefficient household in this setup, the additional cost must be due to the overuse of inputs, and cost saving will come from eliminating the excess usage of inputs. Households in this model are compared against the most technically efficient and feasible cost frontier, instead of perfect efficiency, as it is unrealistic to expect a household to produce zero waste.

The following specification implies that input prices and total food expenditure are exogenous, however, the two are theoretically endogenous. Total food expenditure, which is a function of at-home food input prices, is potentially endogenous not only due to its appearance on the right-hand side with input prices on the left-hand side, but also for the simple fact that it is a choice variable itself. Households may choose to optimize their budget by seeking out lower prices or lower quality food at various shopping locations to minimize cost (Landry and Smith, 2019). This limitation to the model is recognized and acknowledged, however, Landry and Smith find little evidence of endogeneity of prices and total expenditures using this data.

Specification

The following specification assumes the household's objective is to produce a given level of output (quantity and quality of calories) with the minimum possible cost and allows the household to be technically inefficient. The cost function C^* is defined as,

$$C^*(\boldsymbol{w}, y) = \sum_j \boldsymbol{w}_j \, x_j e^{-\eta}, \tag{3.1}$$

where x_j is the quantity of input *j* used and w_j is the price of input *j*. The input-oriented technical inefficiency ($\eta \geq 0$) measures the percentage by which all inputs are overused in producing output level *y*. The cost minimization problem for household *i* under input-oriented technical inefficiency specification is,

$$min_{\{x_j e^{-\eta}\}} \boldsymbol{w}'\boldsymbol{x}e^{-\eta} \; s.t. \; y = f(\boldsymbol{x}e^{-\eta}). \tag{3.2}$$

The frontier cost function yields the minimum cost given the vector of input prices $\boldsymbol{w}$ and the observed level of output *y* when inputs are adjusted for their efficiency. Here the minimum cost $\boldsymbol{w}'\boldsymbol{x}e^{-\eta}$ would be less than the actual cost $\boldsymbol{w}'\boldsymbol{x}$. Actual cost C^a can be related to unobserved minimum cost C^* as,

$$\ln C^a = \ln C^*(w, y) + \eta. \tag{3.3}$$

This relationship shows that log actual cost is increased by η because all the inputs are overused by η. The efficiency index of a household is calculated by the ratio of the minimum to actual cost:

$$\exp(-\eta) = \frac{C^*}{C^a}. \tag{3.4}$$

The ratio is bounded by 0 and 1, where higher values indicate higher levels of efficiency. Thus $100 * \eta$ is the percentage by which actual cost exceeds the minimum cost due to technical inefficiency.

The simple Cobb-Douglas specification to estimate the model, with an added noise term v to capture modelling errors, is,

$$\begin{aligned} \ln C_i^a &= \ln C^*(w_i, y_i) + v_i + \eta_i \\ &= \beta_0 + \beta_1 \ln w_{Fi} + \beta_2 \ln w_{Si} + \gamma_1 \ln y_{Ci} + \gamma_2 \ln y_{Hi} + v_i + \eta_i, \end{aligned} \tag{3.5}$$

where C^a is the actual cost of food used by the household from the household food stock during the 7-day food recall. Input prices, w_F and w_s, are the prices per edible calorie of fresh and storable food inputs, respectively. There are two outputs that are being measured in the model—quantity of food consumed, measured in household daily calories y_C, and quality of food consumed, measured by the HEI score y_H.

To add more flexibility to the model, the trans-log specification is also estimated as,

$$
\begin{aligned}
\ln C_i^a = {} & \beta_o + \beta_1 \ln w_{Fi} + \beta_2 \ln w_{Si} + \gamma_1 \ln y_{Ci} + \gamma_2 \ln y_{Hi} + \frac{1}{2}\beta_{11}(\ln w_{Fi})^2 + \frac{1}{2}\beta_{22}(\ln w_{si})^2 \\
& + \frac{1}{2}\gamma_{11}(\ln y_{Ci})^2 + \frac{1}{2}\gamma_{22}(\ln y_{Hi})^2 + \beta_{12}\ln w_{Fi}\ln w_{Si} + \beta_1\gamma_1 \ln w_{Fi}\ln y_{Ci} \\
& + \beta_1\gamma_2 \ln w_{Fi}\ln y_{Hi} + \beta_2\gamma_1 \ln w_{Si}\ln y_{Ci} + \beta_2\gamma_2 \ln w_{Si}\ln y_{Hi} + \gamma_{12}\ln y_{Ci}\ln y_{Hi} \\
& + v_i + \eta_i. \qquad (3.6)
\end{aligned}
$$

Because the cost function is homogenous of degree 1 in input prices, it should satisfy the additional parameter restrictions:

$$\sum_j \beta_j = 1\ , \quad \sum_j \beta_{jk} = 0\ \forall\, k, \quad \sum_j \beta_{jy} = 0. \qquad (3.7)$$

To impose the price homogeneity condition, C_i^a and input prices are normalized by dividing by an arbitrary choice of w_{ji}, in this case w_{Fi}. When the price homogeneity restrictions are imposed, the translog model is,

$$
\begin{aligned}
\ln\left(\frac{C_i^a}{w_{Fi}}\right) = {} & \beta_0 + \beta_2 \ln\left(\frac{w_{Si}}{w_{Fi}}\right) + \gamma_1 \ln y_{Ci} + \gamma_2 \ln y_{Hi} + \frac{1}{2}\beta_{22}\ln\left(\frac{w_{Si}}{w_{Fi}}\right)^2 + \frac{1}{2}\gamma_{11}(\ln y_{Ci})^2 \\
& + \frac{1}{2}\gamma_{22}(\ln y_{Hi})^2 + \beta_2\gamma_1 \ln\left(\frac{w_{Si}}{w_{Fi}}\right)\ln y_{Ci} + \beta_2\gamma_2 \ln\left(\frac{w_{Si}}{w_{Fi}}\right)\ln y_{Hi} + \gamma_{12}\ln y_{Ci}\ln y_{Hi} \\
& + v_i + \eta_i. \qquad (3.8)
\end{aligned}
$$

The parameter estimates from equations (3.5), (3.6), and (3.8) are reported and assessed based on their modelled fit using AIC, BIC, and log-likelihood score. Inefficiency terms from all 3 models are included, however, marginal effects, input cost shares, and output shadow prices are reported for the highest performing model, the translog model (3.6), only.

CHAPTER 4

RESULTS AND DISCUSSION

The parameter estimates from the cost function are not directly interpretable.[3] Instead, the inefficiency term and determinants of cost inefficiencies are used to evaluate the model results. Table 4.1 presents the inefficiency terms for all 3 model specifications, however, only the unrestricted translog models results are discussed. The average inefficiency level for household meal production is 20.8%. The median household had 16.33% inefficiency in the kitchen, the most efficient household had 4.61% inefficiency, and the least efficient household had 87.4%. Overall, the distribution of the inefficiency terms is skewed to the right, so the median may be a more reliable estimate (Figure A.2).

Inefficiencies are converted into 2010-dollar values by multiplying the inefficiency estimate by the household's reported value of food usage and then using the food CPI values from April 1977 and April 2010. The annual amount of dollars wasted due to technical inefficiency in household meal production at the mean and median is about $146.4 billion and $86.1 billion, respectively. This means that the average household wasted $2,009.67 (or $1,181.95 at the median value) per year due to inefficiencies in the kitchen.

Due to the skewness of inefficiency estimates, the mean estimate is on the lower range of contemporary household waste estimates. The median level is lower than modern measures, which could be due to the measurement of inefficiency instead of physical waste, which allows for some

[3] The coefficient estimates from the Cobb-Douglas, Unrestricted Translog, and Restricted Translog model are included in Table A.1. Although not used in the discussion, input cost shares and output shadow prices were calculated and included in Table A.2.

Table 4.1: Predicted Technical Inefficiencies

Model	Mean	S.D.	Min	Max	5^{th} pctl	Median	95^{th} pctl
Cobb-Douglas	.2107701	.1353495	.0444911	.8844222	.0817192	.1662551	.50293
Translog	.2080333	.1331095	.0460876	.8739771	.0817329	.163287	.4937188
Translog-H	.2119989	.1353833	.0504976	.8936846	.082836	.1664787	.5077195

Source: 1977-1978 Nationwide Food Consumption Survey (NFCS) *All analyses use sample weights.*
Note: Translog-H specifies the restricted Translog model with homogeneity constraints

amount of waste dependent on the estimated minimum cost frontier. Alternatively, and perhaps more realistically, the lower values may be a result of increasing food waste patterns that have been observed over the last 50 years. Indeed, this is consistent with the USDA and EPA food waste trends; food waste has more than doubled in the last quarter century (USDA, 2018; US EPA, 2019). Trends such as women's increased presence in the labor force, less leisure time, increases in portion sizes, or takeout meals could all contribute to greater inefficiencies in the kitchen and as a result, more food waste. (Figure A.3)

Thirteen determinants of inefficiency are used to predict what factors may cause a household to be less efficient than another and are shown in Table 4.2. Demographically, non-Hispanic white households have about 10.6% lower inefficiency levels (the majority of the sample) when compared to minority households. This is consistent with Landry and Smith's estimate from the production frontier perspective. Cultural factors, such as culinary skills and types of food inputs may be related to efficiency of the household. However, other research has found race/ethnicity, primary language spoken at home, and national origin were not related with amount of food wasted (Hoover, 2017). The NRDC's 2017 report remarked on the possible covariates related to race that may affect food wasted such as income, amount spent on groceries, household size, and number of meals bought outside the household. For example, a larger proportion of black households were

Table 4.2: Marginal Effects on Expected Technical Inefficiency

log(Household Size)	-0.0098
	(0.020)
# of FAFH meals consumed	0.0014***
	(0.000)
Female employed outside HH	0.0280*
	(0.016)
log(Age of Food Preparer)	-0.0267
	(0.022)
Non-Hispanic white	-0.1057***
	(0.021)
Joint grocery shop	-0.0637***
	(0.023)
Joint food preparation	0.0724***
	(0.026)
HH froze food	0.0514***
	(0.017)
HH <185% poverty threshold	-0.0360*
	(0.019)
Meal Preparer: no HS grad	0.0733***
	(0.023)
Meal Preparer: HS grad	0.0355**
	(0.018)
Shop more than once/week	-0.0607*
	(0.036)
Shop once per week	-0.0630*
	(0.033)
Shop once per 2 weeks	-0.0717**
	(0.034)
log(Distance to grocery store)	-0.0079
	(0.005)
Fresh food kcal	-0.0978*
	(0.058)

Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: 1977-1978 Nationwide Food Consumption Survey (NFCS) *All analyses use sample weights*
Note: results are derived from the unrestricted Translog specification

under 185% poverty guidelines and a smaller proportion of black households ate out compared to other ethnic groups. These impacts may be more apparent in 1970 minority households than they are in contemporary social environments. Households that are below 185% of the 1977 poverty guidelines are about 3.6% more efficient in the kitchen than higher income households. Early research showed no significant relation between income and amount of wasted food, but more recent studies indicated that wealthier households generate more food waste than low income households (Bishop and Megicks, 2019). Additionally, research has shown that there is a clear correlation between the proportion of income spent on food and the amount of food wasted (Stuart, 2009; Parfitt et al, 2010). This may be because as relative household income increases, households begin to place less value on food (Hoover, 2017).

Different aspects of households' structure were studied with respect to food inefficiencies. The size of the household was found to consistently have no effect on inefficiency. Previous reports have found that average amount of food waste increases with number of occupants, however, larger households waste less per capita due to economies of scale (Quested et al, 2013; Bishop and Megicks, 2019). Conversely, a number of studies have positively correlated presence of children in the household with the quantity of food wasted (Bishop and Megicks, 2017). These two forces on household size may have resulted in an insignificant marginal effect.[4]

Past research suggests age is negatively correlated with the quantity of food wasted in the household (Hoover, 2017; Gunders and Bloom, 2017; Landry and Smith, 2019; Bishop and Megicks, 2019; Quested et al, 2013). Younger people report wasting more due to cooking, preparing, and serving too much, while older people had a higher proportion of food being thrown away due to not being used in time. Older people seem to be better equipped in terms of skills and

[4] Result is robust to alternative definitions such as age category bins, presence and number of children, and number of adults.

knowledge and have more time to prepare excess food (Bishop and Megicks, 2019). In this study, age of the meal preparer was found to have a negative, albeit insignificant, effect on household inefficiency.[5]

Inefficiency in at-home meal production was found to decrease with education level. Meal preparers that have at least some college education have 3.6% lower inefficiency than those with only a high school diploma and 7.3% lower inefficiency than those with no high school education. This result is consistent with previous research that households, where at least one person has more than a high school education, waste less food per capita (total and edible) than other households (Hoover, 2017). Additionally, it was found that the degree of environmental concern with regards to food waste correlates with education level (Qi and Roe, 2016). Households, where the female head was employed outside the home, had 2.8% lower efficiency compared to households, where the female head was either not employed or employed in the home. This may be a result of less disposable time to spend shopping and preparing food for the household (Bava et al, 2008). People who are employed full-time reported feeling like they had less time to worry about food waste, and thus, full-time employment could have a negative effect on the amount of food wasted (Qi and Roe, 2016).

Household storage and purchasing decisions were also significant in determining the efficiency of the household. Households that consumed greater number of meals away from home experienced higher levels of inefficiency: an increase of 10 meals purchased away from home decreased efficiency by 1.4%. A study in New York City found that households with the maximum age of less than 35 were less likely to eat dinner out as "spur of the moment" compared to households over 35. For the households surveyed, under 35 households produced less food waste

[5] Retirement status was included as a variable with no significant effect found. Also, age of head of household, instead of age of food preparer, was used and results did not differ.

compared to households over 35 (Hoover, 2017). Based on the study in New York City, the planning of food away from home in advance, as opposed to spontaneous meals, may correspond with the amount of wasted food that a household produces, however, more research is needed to confirm this theory.

The storability of food used is important in the amount that is ultimately wasted. Households that consumed a greater proportion of fresh food have lower levels of inefficiencies compared to households that consumed less fresh food and more storable food. In terms of total mass, fresh foods account for the largest losses in food waste (Gunders, 2012). Despite this, a recent study found that policies that raise the price of processed food increase fresh food consumption, which resulted in a reduction of food waste (Hamilton and Richards, 2019). Households that consume greater amounts of fresh food may be more skilled at meal planning and food preparation and may have higher preferences and awareness for the environmental impact of food waste.

Furthermore, households that reported having and using their freezer experience higher levels of inefficiency, about 5% higher, compared to households that either do not have a freezer or do not use their freezer regularly. Bishop and Megicks found that storage space capacity is positively correlated with the amount of food wasted due to neglecting or forgetting some of the already purchased items that are out of sight. This result may appear to be misleading because inefficiency in this model is defined as food that was used but not yet consumed. Intuitively, households that own and regularly use its freezer can engage in more inefficient behavior with their food by freezing their produce or leftovers before spoilage, which would be included as an inefficiency in the model. These households may consume less than they use but will likely save their food from being wasted, resulting in a higher inefficiency but possibly less waste.

Shopping and preparation behaviors, jointly shopping for food inputs and jointly preparing meals, were examined for their influence on kitchen inefficiencies. These decisions could decrease inefficiencies if labor activities are complementary (e.g., gains from specialization or knowledge of food stocks), or increase inefficiencies through duplication of effort, difficulties in coordination, or crowding (Landry and Smith, 2019). The results suggest that jointly grocery shopping decreases inefficiency levels by 6.4%, while jointly preparing meals increases inefficiency levels by 7.2%. These results are consistent with the signs of Landry and Smith's production frontier inefficiency estimates. People, who do not check their food stocks prior to the shopping trip, are put in the position of estimating their inventory from memory when they make the purchase decisions in the store. However, earlier studies suggest the process of estimating inventories is biased and could lead to overstocking, which is an important contributor to food waste (Wansink, 2018; Bishop and Megicks, 2019). Shopping with a partner from the household may reduce bias and decrease the likelihood of underestimating household food stocks. In the UK, survey respondents reported that they often prepare proportions that are too large and that is a major source of their food waste (Bishop and Megicks, 2019). Jointly preparing food may exacerbate the issue of preparing more food than is required for the household.

Finally, the effects of food store proximity and shopping frequency were assessed. Pre-shopping planning, which consists of making shopping lists or planning their meals in advance, has been shown to have a negative influence on the amount of food waste generated at the household level (Bishop and Megicks, 2019). A priori, travel costs associated with shopping more frequently or travelling longer distances may induce better planning. Compared to households that go grocery shopping once a month or less, shopping more frequently decreases inefficiency levels. Households that grocery shop more frequently, holding distance travelled constant, may not need to plan as far in advance when going to the store. This may result in smaller purchases that are easier to manage (Landry and Smith, 2017). There was no significant difference between households living close to their grocery store compared to households with further distances to travel.

Robustness Check

Standard assumptions for the cost function include homogenous of degree 1 in input prices, as well as monotonic and concave in input prices and outputs (Kumbhakar, 2015). Three primary models were run with the exponential distribution using robust standard errors: a simple Cobb-Douglas model, a more flexible unrestricted translog model, and a restricted translog model with price homogeneity constraints. The three models were compared based on log-likelihood value, BIC, and AIC. In comparing model diagnostics, both AIC and BIC penalize for over specification, however, in general, BIC penalizes models with more parameters more than AIC does. When assessing model diagnostic values, smaller values of the negative log-likelihood value and smaller AIC and BIC values indicate the preferred model. The results from the diagnostic report can be found in the appendix (Table A.3).

The homogeneity parameter restrictions were tested using Wald tests of simple and composite linear hypotheses. When tested individually, every test failed to reject that the model is homogenous of degree 1 in input prices. However, when tested jointly, the test rejected the homogenous of degree 1 hypothesis. Despite this test, the unrestricted translog model outperformed restricted translog model when comparing AIC, BIC, and log-likelihood values and outperformed the Cobb-Douglas specification in AIC and log-likelihood values. Thus, the unrestricted translog model is used in all of the following tests, and its results are discussed above.

The monotonic condition requires cost to be nondecreasing in input prices and outputs. The condition was tested by evaluating the positivity of the estimated cost shares, as well as the partial derivatives for kcal and HEI outputs. Both cost shares, as well as the partial derivative of kcal passed the monotonic condition, however, 1490 out of 2128 observations violate the monotonicity condition for HEI score. The concavity condition requires that the Hessian matrix with respect to input prices is negative semidefinite, which is confirmed if all the eigenvalues are less than or equal to zero. After testing the condition, it was found that there were violations of the concavity condition as well. The monotonicity and concavity conditions are observation-specific, so they cannot be imposed by restricting the parameters alone. An estimation that would make the results align more with the theory is not straight forward, so these violations are noted and taken into consideration when model results are discussed.

Finally, the model was estimated separately using the respondents that were above 185% of the 1977 Poverty Level in one estimation and respondents below 185% of the Poverty Level in the second (Table A.4). The marginal effects of the determinants of inefficiency for the high-income group were largely the same as the full-sample results implying that the higher income respondents are driving the results. Low income respondents are mainly wasting food at the same rate regardless of shopping frequency, jointly shopping, or other observed behaviors. This is consistent with past research that food waste is a luxury good (Landy and Smith, 2019). Households that spend a larger proportion of total income on food may be more conscious of how the food is used and consumed, making sure that little is gone to waste. Households with higher income spend a far smaller share of income on food, which may encourage more carelessness in food management (Sengupta, 2017).

CHAPTER 5

CONCLUSIONS

Each year a nontrivial proportion of the U.S. food supply goes consumed (Buzby, Wells, Hyman, 2014; ReFED, 2016; Gunders, 2012). This paper found that U.S. households in 1977 wasted up to $146.4 billion each year due to inefficiencies in food management and meal production. This cost estimate can be used as a means of inducing households to engage in more efficient meal production and food management behaviors. Based on the results outlined in this report, inefficiencies decrease with education level and are lower for non-Hispanic white households as well as households below 185% of the poverty threshold. Eating more fresh food decreases inefficiency, while consuming more meals from outside the household food stock and use of the freezer increases inefficiency. Households, where the female is employed outside the household, experience higher inefficiency. Evidence was found that households, who shop with a partner, experience lower inefficiency whereas households, who jointly prepare foods, experience higher inefficiency in the kitchen. Finally, more frequent grocery shopping is associated with declining inefficiency levels.

This paper's results support policy recommendations and government issued advice to reduce household food waste through creating better meal planning, food preparation, and storage habits (USDA; U.S. EPA, 2018; U.S. FDA, 2019; Gunders and Bloom, 2017). More thorough grocery planning may be achieved through shopping with a partner by increasing combined knowledge of food stocks and decreasing the likelihood of overstocking (Gunders and Bloom, 2017; Bishop and Megicks, 2019). Additionally, shopping more frequently may allow households to plan ahead for shorter time horizons and discourage overstocking of perishable foods (Landry and Smith, 2017). The travel costs of shopping more frequently are important to take into consideration, especially for low income households that experience a limited budget and greater time constraints. However, based on the results from the high-income population, this suggestion may not be applicable to reducing food waste in low-income households. Overpreparation of food inputs is often cited as a cause of food waste and may be related to jointly preparing foods (Bishop and Megicks, 2019). If households do overprepare, it is important to practice efficient storage habits, such as use of the freezer, to divert leftovers from ultimately being discarded (USDA; U.S. EPA, 2018; U.S. FDA, 2019; Gunders and Bloom, 2017).

This paper presented a novel method to access the cost of household inefficiencies in food management and meal production that will add to the growing food waste literature. By relying on nationally-representative household data with food inputs and food consumption measured concurrently, this paper manages to bypass the subjective, self-reporting bias that many papers rely on (van Herpen et al, 2019; Quested, Easteal, and Ingel, 2013). The implications from the results contribute to the collective understanding of the drivers of food waste, however, repeating this study with modern data would provide insight on how food waste is changing with evolving household characteristics. One particular area of interest is disposable time in the household and its predictability. Trends of females in the labor force, fast food purchases, fresh food consumption, and time spent on food preparation, indicate that convenience in meal production may be increasingly demanded by the household (Bava et al, 2008; Toossi and Morisi, 2017; Senguin et al, 2016; Desilver, 2016; Smith, Ng, and Popkin, 2013). Based on the results in this paper, this may be contributing to more household food waste and higher costs incurred by the household. This study should be expanded to include contemporary data, as well as time use variables. However, no such data currently exists with both food input purchases and food consumption with the same observational units.

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APPENDIX

ADDITIONAL TABLES AND FIGURES

Table A.1: Coefficient Estimates: All Model Specifications

	Cobb-Douglas	Translog	Translog-H
Cost Frontier:			
Price per Fresh Food kcal	0.439***	1.012	1.363***
	(0.03)	(0.70)	(0.44)
Price per Storable Food kcal	0.293***	-0.356	-0.363
	(0.02)	(0.42)	(0.44)
Household Calories Consumed	0.779***	0.609*	0.270
	(0.02)	(0.35)	(0.33)
HEI Score-2010	-0.070*	2.066**	2.469**
	(0.04)	(1.04)	(1.05)
Fresh Food Price^2		0.062	-0.031
		(0.14)	(0.09)
Storable Food Price^2		-0.040	-0.031
		(0.11)	(0.09)
Fresh x Storable Food Price		-0.042	0.031
		(0.09)	(0.09)
Household Calories^2		0.062**	0.044
		(0.03)	(0.03)
Fresh Food Price x Household Calories		0.041	-0.051
		(0.05)	(0.03)
Storable Food Price x Household Calories		0.049	0.051
		(0.03)	(0.03)
HEI Score^2		-0.618***	-0.773***
		(0.24)	(0.25)
Fresh Food Price x HEI		-0.219	-0.077
		(0.13)	(0.09)
Storable Food Price x HEI		0.014	0.077
		(0.10)	(0.09)
HH Calories x HEI		-0.029	0.050
		(0.06)	(0.06)
Constant	-0.868***	-4.393	-3.130
	(0.22)	(2.77)	(2.67)

Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: 1977-1978 Nationwide Food Consumption Survey (NFCS) *Analytical Weight:* hhwgt
Note: Translog-H specifies the restricted Translog model with homogeneity constraints

Table A.1: Coefficient Estimates: All Model Specifications, *continued*

	Cobb-Douglas	Translog	Translog-H
Determinants of Inefficiency:			
log(Household Size)	-0.118	-0.076	-0.065
	(0.15)	(0.16)	(0.16)
# of FAFH meals consumed	0.011***	0.011***	0.009**
	(0.00)	(0.00)	(0.00)
Female employed outside HH	0.223*	0.218*	0.181
	(0.12)	(0.13)	(0.13)
log(Age of Food Preparer)	-0.175	-0.208	-0.260
	(0.17)	(0.17)	(0.17)
Non-Hispanic white	-0.807***	-0.823***	-0.808***
	(0.17)	(0.17)	(0.17)
Joint grocery shop	-0.548***	-0.496***	-0.512***
	(0.18)	(0.18)	(0.18)
Joint food preparation	0.554***	0.563***	0.582***
	(0.20)	(0.20)	(0.20)
HH froze food	0.397***	0.400***	0.413***
	(0.13)	(0.13)	(0.13)
HH <185% poverty threshold	-0.276*	-0.280*	-0.176
	(0.15)	(0.15)	(0.15)
Meal Preparer: no HS grad	0.585***	0.571***	0.746***
	(0.17)	(0.17)	(0.17)
Meal Preparer: HS grad	0.284**	0.277**	0.341**
	(0.14)	(0.14)	(0.14)
Shop more than once/week	-0.479*	-0.472*	-0.527**
	(0.27)	(0.27)	(0.26)
Shop once per week	-0.514**	-0.490*	-0.505**
	(0.25)	(0.25)	(0.24)
Shop once per 2 weeks	-0.553**	-0.558**	-0.524**
	(0.26)	(0.26)	(0.25)
log(Distance to grocery store)	-0.064	-0.062	-0.039
	(0.04)	(0.04)	(0.04)
Fresh food kcal	-0.753*	-0.761*	-0.866*
	(0.44)	(0.45)	(0.44)
Constant	-0.931	-0.876	-0.692
	(0.78)	(0.79)	(0.77)
Vsigma			
Constant	-2.848***	-2.845***	-2.810***
	(0.09)	(0.09)	(0.09)

Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: 1977-1978 Nationwide Food Consumption Survey (NFCS) *Analytical Weight:* hhwgt
Note: Translog-H specifies the restricted Translog model with homogeneity constraints

Table A.2: Cost Shares and Shadow Prices

Cost Share: Fresh Foods	0.4597***
	(0.031)
Cost Share: Processed Foods	0.3041***
	(0.021)
Shadow Price: Calories	0.7752***
	(0.017)
Shadow Price: HEI	2.5526***
	(0.932)

Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: 1977-1978 Nationwide Food Consumption Survey (NFCS) *All analyses use sample weights*
Note: results are derived from the unrestricted Translog specification

Table A.3: Model Diagnostics

Model	Log-Likelihood	df	AIC	BIC
Cobb-Douglas	-681.5921	23	1409.184	1537.304
Translog	-668.814	33	1403.628	1587.453
Translog-H	-707.7321	28	1471.464	1627.437

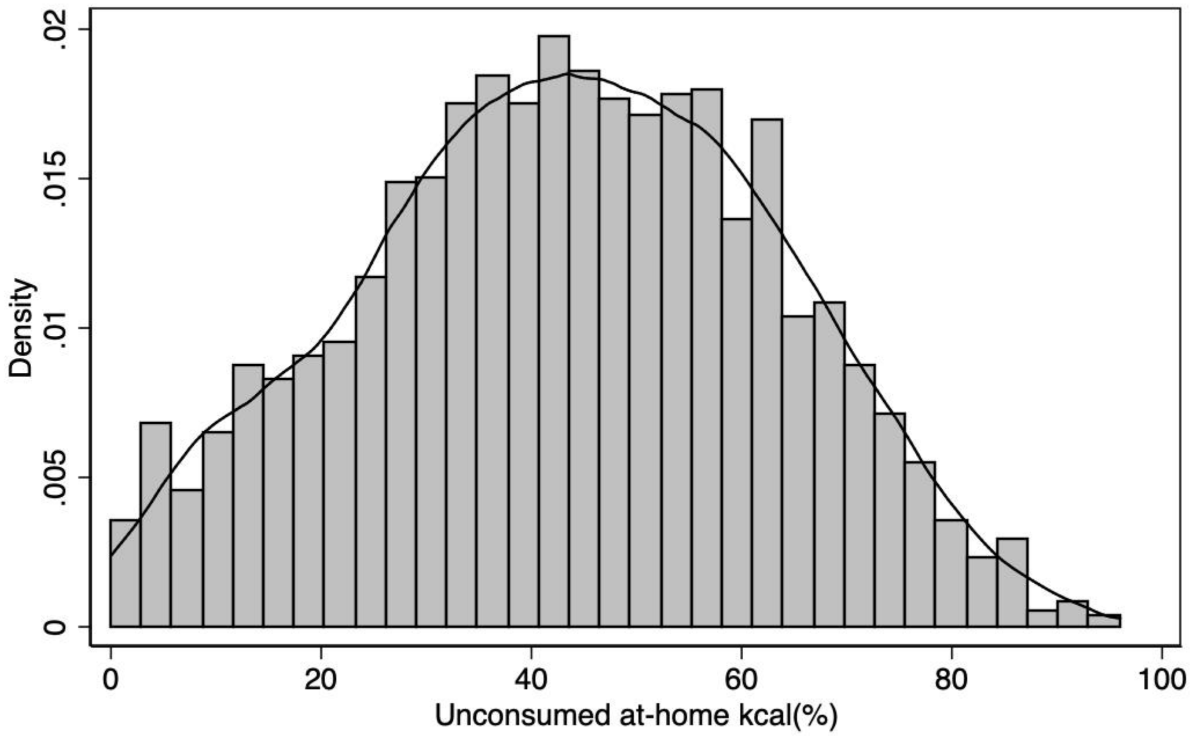
Source: 1977-1978 Nationwide Food Consumption Survey (NFCS) *All analyses use sample weights.*
Note: Translog-H specifies the restricted Translog model with homogeneity constraints

Table A.4: Marginal Effects by Household Income Group

	High-Income	Low-Income
log(Household Size)	-0.0000	-0.0244
	(0.024)	(0.034)
# of FAFH meals consumed	0.0015***	0.0006
	(0.000)	(0.002)
Female employed outside HH	0.0157	0.0529
	(0.018)	(0.033)
log(Age of Food Preparer)	0.0118	-0.1149***
	(0.026)	(0.040)
Non-Hispanic white	-0.0927***	-0.0947***
	(0.027)	(0.032)
Joint grocery shop	-0.0569**	-0.0613
	(0.026)	(0.049)
Joint food preparation	0.0659**	0.0773
	(0.027)	(0.061)
HH froze food	0.0657***	0.0221
	(0.020)	(0.030)
Meal Preparer: no HS grad	0.0736***	0.0399
	(0.025)	(0.046)
Meal Preparer: HS grad	0.0305	0.0097
	(0.019)	(0.045)
Shop more than once/week	-0.0889**	0.0216
	(0.043)	(0.056)
Shop once per week	-0.0789*	-0.0186
	(0.041)	(0.047)
Shop once per 2 weeks	-0.0917**	-0.0445
	(0.042)	(0.050)
log(Distance to grocery store)	-0.0126**	0.0015
	(0.006)	(0.010)
Fresh food kcal	-0.1689**	0.1525
	(0.066)	(0.110)
Observations	1418	522

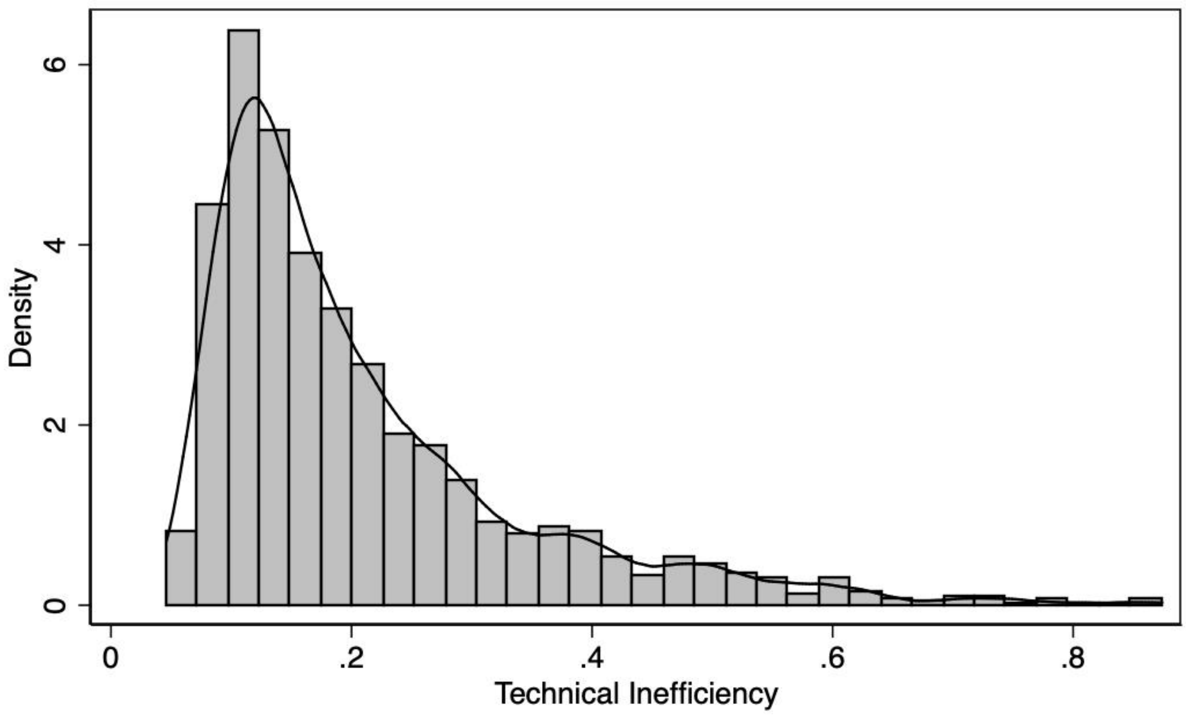
Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: 1977-1978 Nationwide Food Consumption Survey (NFCS) *All analyses use sample weights.*
Note: results are derived from the unrestricted Translog specification. "High-income" refers to households above 185% of the 1977 Poverty Level and "low-income" includes households below 185%.

Figure A.1: Distribution of Unconsumed Calories



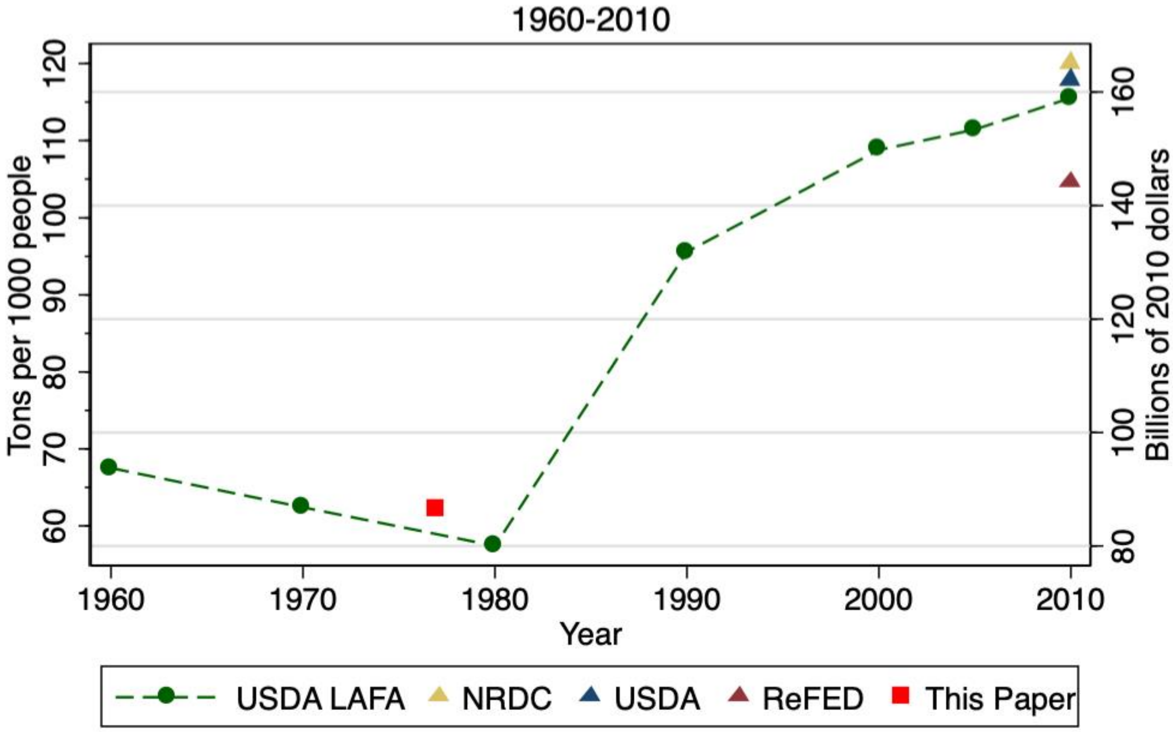
Source: 1977-1978 Nationwide Food Consumption Survey (NFCS)

Figure A.2: Distribution of Technical Inefficiency



Source: 1977-1978 Nationwide Food Consumption Survey (NFCS)

Figure A.3: Trends in Food Waste



Sources: USDA LAFA, 2018; Gunders, 2012; Buzby et al, 2011; ReFED, 2016
1977-1978 Nationwide Food Consumption Survey (NFCS)