Subsidizing Fruits and Vegetables by Income Group: A Two-Stage Budgeting Approach

Luyuan Niu and Michael Wohlgenant
Department of Agricultural and Resource Economics
North Carolina State University
Box 8109 NCSU
Raleigh, NC 27695

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Luyuan Niu and Michael Wohlgenant†

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Abstract

This paper investigates how a price subsidy affects demand for three fruit and vegetable products for two income groups of households. This study combines the results of conditional elasticity estimates from a previous study and develops a two-stage budgeting approach to estimate complete demand for fruits and vegetables using 1986 through 2010 quarterly CEX data. Precise standard errors are estimated by bootstrapping the entire two-stage estimation procedures. Results show that low-income households have larger total expenditure elasticities but smaller unconditional price elasticities than high-income households. Fruits and vegetables and all other goods are found to be net substitutes. Assuming that supplies for fruits and vegetables are perfectly elastic, a 10% price subsidy increases consumption of processed fruits and vegetables, fresh vegetables, and fresh fruits by 3.27% (10.68%), 3.29% (10.73%), and 3.50% (11.42%), respectively, for low-income (high-income) households, and only causes a small change in consumption of all other goods.

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† Niu and Wohlgenant, Department of Agricultural and Resource Economics, North Carolina State University
Email address: lniu@ncsu.edu and michael_wohlgenant@ncsu.edu

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1. Introduction

Average Americans eat fewer fruits and vegetables compared to dietary recommended intakes. The intakes of fruits and vegetables are only 42% and 59% of the recommended goal, although the intakes of solid fats and added sugars are nearly three times the recommended limit (2010 Dietary Guidelines for Americans). Lacking sufficient intake of fruits and vegetables may increase the risk of having many diseases such as heart disease, diabetes, high blood pressure, and obesity (Bazzano 2006 and Tohill et al. 2004), which are likely to cause huge economic burdens to both individuals and society. Cawley and Meyerhoefer (2012) show that obesity is estimated to raise annual medical costs by $2,741 (in 2005 dollars), while higher intake of fruits and vegetables is found to save up to more than $2,000 in annual and cumulative Medicare charges per person (Daviglus et al., 2005). [3]

A variety of policy questions are considered for improving individual's eating habits, including taxing high-calorie foods such as sugar-sweetened beverages (Zhen et al 2011) and subsidizing low-calorie and high nutrient foods such as fruits and vegetables. Many food policies and food assistance programs are aimed at encouraging low-income households to buy healthier food, where per capita fruit and vegetable consumption for low-income households is the lowest (Lin, 2005; Dong and Lin 2009). The Farm Bill provides policy makers with the opportunity to address agricultural policy and food issues. The last Farm Bill was passed in 2008 and expired in 2012.The nutrition assistance program comprises 65% of the Bill's funding, where the Supplemental Nutrition Assistance Program (SNAP, formerly known as the Food Stamp Program) is targeted at assisting low-income households to buy healthier food (Elliott and Raziano 2012). Moreover, the Farm Bill includes the Healthy Incentives Pilot (HIP) project that authorized $20 million to evaluate incentives provided to

[3] In Cawley and Meyerhoefer (2012), the authors limit the sample to adults between the ages of 20 and 64 with biological children between the ages of 11 years (132 months) and 20 years (240 months), and exclude pregnant women.

SNAP recipients at the point-of-sale to increase the purchase of fruits, vegetables, or other healthful food (U.S. Department of Agriculture, Food and Nutrition Service).

Several studies have already worked on the relevant policy issues. Okrent and Alston (2012) use an equilibrium displacement model to estimate and compare a range of obesity policies including taxing unhealthy foods such as fat and sugar and subsidizing fruits and vegetables at both farm and retail levels. Under the assumption that prices are exogenous, she found that a 10% subsidy on fruits and vegetables at the retail level increases an average adult's calorie consumption of these goods by 343 kcal per year, while the increase is only 16 kcal per year under the upward-sloping supply assumption. By comparison, subsidizing fruits and vegetables at the farm level would lead to a larger increase in calorie consumption. However, a tax on calories is shown to be the most efficient obesity policy.

Dong and Lin (2009) estimate the effects of a 10% price discount on purchases of fruits and vegetables at the retail level for low-income households using 2004 Nielsen Homescan data.[4] Under the case of exogenous prices, they show that at-home fruit consumption increases from 0.72 cups to 0.74–0.77 cups (that is, increase by 2.8–6.9%); at-home vegetable consumption increases from 1 cup to 1.03–1.07 cups (that is, increase by 3.0–7.0%). In comparison, total fruit consumption (including the consumption of food away from home) increases from 0.96 cups to 0.98–1.01 cups (that is, increase by 2.1–5.2%) and total vegetable consumption increases from 1.43 cups to 1.46–1.50 cups (that is, increase by 2.1–4.9%). The same dataset is also used in Dong and Leibtag (2010) to estimate the effects of two methods, coupons (10% off) and price discounts (10%), on lowering the cost of fruits and vegetables to promote fruit and vegetable consumption. They found that the effect from using coupons are larger than that from a pure price discount if consumers use coupons more than 30% of the time.

Lin et al. (2010) use three survey datasets to evaluate two strategies on diet improvements for food stamp recipients: subsidizing healthy food and increasing food stamp benefits. A 10% price subsidy on fruits increases at-home fruit consumption from 0.38 to 0.42 cup (10.5%) and a 10% price subsidy on vegetables increases at-home vegetable

[4] A low-income household in Dong and Lin (2009) is defined as the one in which the income is below or equal to 130 % of the federal poverty guidelines.

consumption from 0.94 to 1 cup (6.4%). Total consumption would increase from 0.89 to 0.97 cup (8.9%) for fruits and from 1.26 to 1.33 (5.6%) cups for vegetables. By comparison, a 10% increase in food expenditure increases at-home fruit consumption from 0.38 to 0.43 cup (13.2%) and at-home vegetable consumption from 0.94 to 1.04 cups (10.6%); it increases total fruit consumption from 0.89 to 0.97 cup (8.9%) and total vegetable consumption from 1.26 to 1.36 cup (7.9%).

The objective of this paper is to estimate unconditional price and total expenditure elasticities and use them to examine how a price subsidy on fruits and vegetables affects demand for three products of fruits and vegetables (processed fruits and vegetables, fresh vegetables and fresh fruits) for low-income households. Comparisons are also made between low-income and high-income households to evaluate the differences in demand for fruits and vegetables by income group. Compared to the literature, this paper uses a new methodology to estimate demand elasticities and investigates the effects of a price subsidy on the consumption of the three fruit and vegetable products instead of the aggregate fruit and vegetable consumption previously studied. This paper also investigates how a price subsidy on fruits and vegetables affects consumption of all other goods excluding fruits and vegetables.

This paper develops a two-stage budgeting approach to estimate complete demand for fruits and vegetables using 1986–2010 quarterly Consumer Expenditure Survey (CEX) data. Under the assumption of rational random behavior (Theil 1975; Theil 1976; and Theil 1980), the relative price version of the Rotterdam Model (Theil 1965; Theil 1975; and Barten 1966) is applied to estimate the composite demand system for a group of fruits and vegetables by using conditional elasticity estimates derived from the second chapter of Niu (2013). The unconditional demand elasticities are estimated by combining composite and conditional demand elasticities together. Precise standard errors are estimated by bootstrapping the entire two-stage estimation procedures.

Results show that low-income households have larger unconditional expenditure elasticities but smaller unconditional price elasticities than high-income households. For both income groups, all the fruits and vegetables are found to be net substitutes; fruits and vegetables and all other goods are also found to be net substitutes. Assuming that the supplies for fruits and vegetables are perfectly elastic, a 10% price subsidy increases consumption of processed fruits and vegetables, fresh vegetables, and fresh fruits by 3.27% (10.68%), 3.29% (10.73%), and 3.50% (11.42%), respectively, for low-income (high-income) households and only causes a small change in consumption of all other goods.

The remainder of the article is organized as follows. The next section describes the CEX data, how the variables are constructed, and the data's time series properties. The third section introduces the model, explains the methodology used in the estimation and gives the derivations of unconditional elasticities. Results of the demand estimation in addition to a policy application are shown in the fourth section. The final section summarizes and concludes the whole paper and presents some issues for further study.

2. Data

The paper uses the Diary Survey of CEX data from 1986 to 2010. The CEX is conducted by the Bureau Labor of Statistics (BLS) and used to maintain and support the Consumer Price Index (CPI). Although the CEX is available from 1980, nonfood composition has changed a lot from 1986. To make the data consistent, data between 1980 and 1985 are not used in this study.

The CEX represents a short panel. There are two observations for each household: One is collected in the first survey week and the other is collected in the second survey week.[5] The weekly expenditure series becomes a quarterly series by multiplying by the number of weeks in each quarter. Per capita quarterly data are calculated as the weighted average across all the observations in the same quarter, where weights, provided in the CEX for each observation, are used. It is noteworthy that weights may be different for the two observations from one household because each household represents a different number of households with similar characteristics.[6]

To study consumption patterns for different income groups of households, data are divided into two income groups: high-income and low-income. High-income (low-income) households are ones with annual disposable income larger than (lower than or equal to) 185% of the federal poverty guidelines (PG). Starting in 2004, CEX provides imputed income

[5] In this study, "CU" and "household" are used interchangeably.
[6] "U.S. Department of Labor, Bureau of Labor Statistics, Consumer Expenditure Survey, Diary Survey, 2006

values, which allows not-reported income values to be estimated. Specifically, CEX includes five derived imputations and their means in addition to the original income data. In 2004 and 2005, CEX deleted the original income data and recovered them from 2006. This study uses the not-imputed data from 1986 to 2010 except that means of the five imputed income values are used in 2004 and 2005 due to the deletion of original income data.[7] Income could be negative for self-employed households if they reported a business loss that was greater than the income they brought in. Thus, households with zero or negative income are grouped into the low-income group.

Because the purpose of this paper is to estimate the unconditional elasticities for the fruit and vegetable group, total expenditures are simply allocated over two broad groups: one is "fruits and vegetables" and the other is "all other goods." Given that there are no prices provided in the CEX, the nationwide CPI for fruits and vegetables is used. The quarterly CPI is derived from the monthly CPI reported on the BLS Web site. The aggregate CPI is available for fresh fruits and fresh vegetables during the whole sample period, but it is not available for processed fruits and vegetables before the year of 1998. Thus, the 1986–1997 CPI of processed fruits and vegetables needs to be derived. We know that

$$P_{FFV} w^{*}_{FFV} + P_{PFV} w^{*}_{PFV} = P_{FV} \quad (1)$$

where w^{*}_{FFV} and w^{*}_{PFV} are the expenditure shares of fresh fruits and vegetables and processed fruits and vegetables at base period, respectively; P_{FFV}, P_{PFV}, and P_{FV} are price indexes for fresh fruits and vegetables, processed fruits and vegetables, and all fruits and vegetables, respectively. Because the base period for P_{FFV} and P_{FV} is 1982–1984=100, w^{*}_{FFV} and w^{*}_{PFV} should be also in this period. However, no data are available for w^{*}_{FFV} and w^{*}_{PFV} because data from 1982 to 1984 are not used in this study. Considering the range of the dataset, the base period is changed to 1998. Thus, P_{PFV} can be calculated from the above equation as

$$P_{PFV} = \frac{P_{FV} - P_{FFV} w^{*}_{FFV}}{w^{*}_{PFV}} \quad (2)$$

Table 1 shows the descriptive sample statistics for both income groups of households. From the table we can see that, on average, the fruit and vegetable expenditures and other goods

[7] For more information about the imputation process and how to use these data, one can refer to "User's Guide to Income Imputation in the CE."

expenditures for high-income households are larger than low-income households. The budget shares of fruits and vegetables are larger and those of all other goods are lower for low-income households than those for high-income households. These comparisons show that high-income households allocate a smaller portion of expenditures on fruits and vegetables compared to low-income households, which is consistent with Engel's Law that the expenditures on food falls as income increases.

The group quantities are created by dividing the current expenditure by the group CPI. Because the CPI is a close approximation to the implicit price deflator, the quantities approximate constant dollar expenditures (Nelson 1991).

Test unit roots

Before proceeding to the model, the data's time series properties should be verified. First, the data are investigated to test if there are unit roots. The Augmented Dickey-Fuller (ADF) test (Fuller, 1976; Dickey and Fuller, 1981) is applied on the following variables: expenditure shares, price indexes, and quantity indexes for each commodity group. The latter two variables are in logarithm form.

Table 2 reports the ADF test statistics for the null hypothesis H_0: ρ=1 in the model

(3) $$X_t = \delta_0 + \delta_1 t + \rho X_{t-1} + \rho_1 \Delta X_{t-1} + ... + \rho_p \Delta X_{t-p} + \varepsilon_t ,$$

where X_t is the variable of interest, t is the time trend and ε_t is a white noise process. The test results show that the CPI of all other goods contains a unit root; both quantity indexes and total expenditures contain a unit root for low-income households. Given the data structure, the level-form demand system should not be used, although the differential demand model is appropriate for consistent estimating the demand systems.[8]

3. Model for Estimating Unconditional Elasticities for Fruits and Vegetables

In the literature, two demand systems are widely used by agricultural economists: the Almost Ideal Demand System (AIDS) model (Deaton and Muellbauer 1980a) and the Rotterdam Model. Beause the AIDS model is nonlinear in parameters, a linear approximate version of

[8] If the dependent variables, budget shares in this case, have a unit root and all the variables are cointegrated, then the error-corrected level-form demand system may be used.

AIDS (LA/AIDS) is often used in empirical work. There are many similar advantages between the LA/AIDS and the Rotterdam Model. They are both second-order locally flexible functional forms (Mountain 1988) and are both linear in parameters so are easily estimated and interpreted. Moreover, both models can be used to test economic restrictions with only linear restrictions on parameters. Brown, Lee, and Seale (1994) show that the two models are approximately equivalent in first difference form. By conducting a Monte Carlo study, Barnett and Seck (2008) compare the full AIDS model, the LA/AIDS model, and the Rotterdam Model model in terms of the ability to recover the true elasticities. They conclude that the Rotterdam Model and the AIDS perform much better than the LA/AIDS. The Rotterdam Model performs as well as the AIDS and often better when implementing exact aggregation within weakly separable utility function and building consistent aggregates. Alston and Chalfant (1993) use a statistical test and found the first-difference LA/AIDS model is rejected but the Model is not in an application to the meat demand. Thus, the Rotterdam Model is chosen for demand for fruits and vegetables as the first stage in a two-stage budgeting framework.

Assume that the consumer follows a two-stage budgeting procedure. The consumer's utility maximization problem can be decomposed into two stages. In the first stage, the consumer allocates total expenditures over two broader groups: fruits and vegetables and all other goods. In the second stage, the group expenditures of fruits and vegetables are allocated over three products of fruits and vegetables: fresh fruits, fresh vegetables, and processed fruits and vegetables. In the second chapter of Niu (2013), conditional demands were estimated, which represent the second stage demand estimates under two-stage budgeting.[9] This study focuses on estimating the first-stage composite demand model. Gorman (1959) shows that either strong separability or homothetic separability in addition to weak separability guarantees the consistency of two-stage budgeting and single-stage maximization, where strong separability is the least restrictive condition.[10] Because the

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[9] Niu (2013) develops an efficient GMM estimator to estimate a demand system for three products of fruits and vegetables (fresh fruits, fresh vegetables, and processed fruits and vegetables) with pseudo-panel data, where the model accounts for the unobserved group specific effects and addresses the correlation between demand equations. Cross-equation restrictions are also imposed according to the economic theory.

[10] Recall that the concept of the strong separability is the following: The preference $\mathrm{v}(\mathbf{q})$ is strongly separable if and only if $\mathrm{v}(\mathbf{q}) = \mathrm{F}[\mathrm{v}_1(\mathrm{q}_1) + \cdots + \mathrm{v}_G(\mathrm{q}_G)]$, where F function is monotonic.

relative price version of the Rotterdam Model under block-independent preferences imposes strong separability implicitly on its functional form, this model is used to estimate the composite demand for fruits and vegetables.

The relative price version of the Rotterdam Model for the composite good, fruits and vegetables in this context, can be written as

$$\bar{w}_{Gt}\Delta\log Q_{Gt} = b_G\Delta\log Q_t + \phi b_G(\Delta\log p'_{Gt} - \Delta\log p'_t)\,, \tag{4}$$

where $\bar{w}_{Gt} = \frac{1}{2}(w_{Gt} + w_{Gt-1})$ is the average value of budget share for group G, $\Delta\log Q_{Gt} = \sum_{k=1}^{3}\frac{\bar{w}_{it}}{\bar{w}_{Gt}}\Delta\log q_{kt}$ is the change in composite quantity of group G where $\Delta\log q_{kt}$ is the change in quantity of individual good k, $\Delta\log Q_t = \sum_{k=1}^{n}\bar{w}_{kt}\,\Delta\log q_{kt}$ is the Divisia quantity index representing the change in real total expenditure, the parameter b_G is the marginal budget share for group G with $\sum_G b_G = 1$, $\Delta\log p'_{Gt} = \sum_{k=1}^{3} b_k^G\Delta\log p_{kt}$ is the composite price index for group G, where $b_k^G = \frac{b_k}{b_G}$ is the conditional marginal budget share of good k given expenditure on group G and $\Delta\log p_{kt}$ is the change in price of individual good k, $\Delta\log p'_t = \sum_{k=1}^{n} b_k\Delta\log p_{kt}$ is the Frisch price index, used as the price deflator to transform the absolute prices into relative prices. Hence, the expenditure and own-price elasticities for the group are $e_G = \frac{b_G}{\bar{w}_G}$ and $e_{GG}^{*} = \frac{\phi b_G}{\bar{w}_G}$.

The corresponding conditional demand model for three products of fruits and vegetables can be obtained as

$$\bar{w}_{it}\Delta\log q_{it} = b_i^G\bar{w}_{Gt}\Delta\log Q_{Gt} + \sum_{k\in G}^{n} c_{ik}^G\Delta\log p_{kt}\,, \tag{5}$$

where $\bar{w}_{it}$, $\Delta\log q_{it}$, $\Delta\log p_{kt}$ and $\Delta\log Q_{Gt}$ have the same definitions as above, where the parameter c_{ik}^G is the conditional Slutsky coefficient. The equation (5) describes the demand for good i given the group expenditure of G ($\bar{w}_{Gt}\Delta\log Q_{Gt}$). Thus, the conditional expenditure and compensated price elasticities are $e_i^G = \frac{b_i^G\bar{w}_{Gt}}{\bar{w}_{it}} = \frac{e_i}{e_G}$ and $e_{ik}^{G*} = \frac{c_{ik}^G}{\bar{w}_{it}}$, respectively. The economic restrictions for (5) are

(6) $$\sum_{k \in G}^{n} c_{ik}^{G} = 0,\ c_{ik}^{G} = c_{ki}^{G}.$$ [11]

The conditional Slutsky matrix, [c_{ik}^{G}], is negative semi-definite, and symmetric with maximum rank $n_G - 1$.

To estimate the composite demand model (4), we need to know b_k^G and b_k. The conditional demand model (5) implies that the conditional expenditure e_k^G is equal to $\frac{b_k^G \bar{w}_{Gt}}{\bar{w}_{kt}}$, so $b_k^G = \frac{e_k^G \bar{w}_{kt}}{\bar{w}_{Gt}}$. Under the assumption of rational random behavior theory (Theil 1975; Theil 1976; Theil 1980), the error terms of the composite demand model and conditional demand model are independent. Hence, the estimated conditional elasticities in Niu (2013) are consistent by themselves with ones derived by estimating two-stage demand models simultaneously.[12] Hence, substitute the estimated conditional elasticities from the second chapter of Niu (2013) for e_k^G, then we know b_k^G and further $\Delta \log p'_{Gt}$ given $\bar{w}_{Gt}$ and $\bar{w}_{kt}$. Moreover, to identify the model, $\Delta \log p'_t$ also needs to be known. That is, all the weights, (all b_k's in its expression) need to be known. Because $b_k^G = \frac{b_k}{b_G}$, which implies $b_k = b_k^G b_G$, only b_k for k=1, 2, 3 in $\Delta \log p'_t$ can be estimated. However, we cannot estimate the b_k's outside the group G. Following Clements and Johnson (1983), the Frisch price index $\Delta \log p'_t$ can be approximated as

(7) $$\Delta \log p'_t \approx b_G \sum_{k=1}^{3} b_k^G \Delta \log p_{kt} + (1 - b_G) \Delta \log p_{ot}$$

where $\Delta \log p_{ot}$ is the CPI for all other goods excluding fruits and vegetables and can be calculated as

(8) $$\Delta \log p_{ot} = \frac{\Delta \log CPI_t - \sum_{k \in G} \bar{w}_{kt} \Delta \log p_{kt}}{1 - \bar{w}_{Gt}}$$

Substitute (7) in (4) and add an intercept and an error term, the estimating equation is the following

(9) $$\bar{w}_{Gt} \Delta \log Q_{Gt} = a_G + b_G \Delta \log Q_t + \phi b_G (1 - b_G)(\Delta \log p'_{Gt} - \Delta \log p_{ot}) + v_{Gt},$$

[11] Remember $\sum_{k \in G} b_k^G = 1$ holds automatically.

[12] For the details on the procedures of estimating two demand systems simultaneously, see Theil (1980) and Clements and Johnson (1983).

where a_G is the intercept to address the trend-related changes and v_G is the error term with a zero mean and a constant variance. To account for the serial correlation, first assume v_G follows an AR(1) process $v_{Gt} = \rho v_{Gt-1} + \varepsilon_{Gt}$, where ρ is the unknown parameters and is assumed to be same across equations (Berndt and Savin, 1975).[13] The quarterly seasonal dummies are also put into the model to account for any seasonal effects on demand for fruits and vegetables. The equation for all other goods is dropped to account for the singularity problem due to the restriction of additivity and its parameters are retrieved from the economic restrictions.

Substitute (5) (ignoring the intercept and error term at this moment) into (4) to eliminate $\bar{w}_{Gt}\Delta\log Q_{Gt}$ (which is approximately the change of real expenditures of group G). We then obtain

(10) $$\bar{w}_{it}\Delta\log q_{it} = b_i\Delta\log Q_t + \sum_{k=1}^{3} c_{ik}\Delta\log p_{kt} + c_{io}\Delta\log p_{ot}$$

where

(11) $$c_{ik} = c_{ik}^G + \phi b_G(1-b_G)b_i^G b_k^G \text{ and } c_{io} = -\phi b_G(1-b_G)b_i^G$$

are unconditional Slutsky coefficients. Recall $b_k^G = \frac{e_k^G \bar{w}_{Gt}}{\bar{w}_{kt}}$, and $c_{ik}^G = e_{ik}^G \bar{w}_{it}$. Thus, the unconditional expenditure elasticity for fruits and vegetables is $e_i = \frac{b_i}{\bar{w}_{it}}$ for $i \in G$; the unconditional compensated price elasticities are $e_{ik}^* = \frac{c_{ik}}{\bar{w}_{it}}$ for fruits and vegetables with i, k∈G, and $e_{io}^* = \frac{c_{io}}{\bar{w}_{it}}$ for the relationship between fruits and vegetables and all other goods. The unconditional uncompensated price elasticities can be derived using the Slutsky equation.

Recall that b_k^G's are "generated regressors" in the model, by which the variance of the parameter estimates are affected. There are many discussions on the methods of consistently estimating the variance in econometrics literature (e.g., Murphy and Topel (1985)). In this study, a bootstrapping method is applied. Recall the data structures used in the second chapter of Niu (2013) and in this study. Both samples are CEX data. However, the sample in the former case is from 1986 to 2010, while the sample in this study is from1996 to 2010. So

[13] During estimation, it is found that AR(2) is a preferred model. This issue will be revisited in the results section.

the samples overlap each other. This overlap needs to be handled during the bootstrapping so that the correlation among the parameters and error terms in the two models are addressed. That is also the reason why the variance derived only from the composite demand is not correct. In particular, 1000 new samples are randomly drawn from the original sample (allowing repeated sampling and keeping the same number of households). In each draw of a new sample, a subsample is created to repeat the estimation in Niu (2013), the results of which are combined to the whole sample to repeat the estimation in this study. In total, 1000 new sets of parameter estimates are generated, and the variance (standard deviation) of these estimates is the variance (standard error) of the parameter estimates in question.

4. Results

4.1 Model Estimates and Elasticities

Table 3 reports the conditional Slutsky coefficient c_{ik}^{G} and marginal budget share b_{k}^{G}, which are estimated based on the conditional demand elasticity estimates derived from Niu (2013). We can see that the estimates are very similar across income groups. Taking low-income households as an example, given group expenditures of fruits and vegetables, the allocation of an additional dollar spent on three fruit and vegetable products (b_{k}^{G}) are approximately 37 cents, 30 cents and 33 cents, for processed fruits and vegetables, fresh vegetables, and fresh fruits, respectively.

Table 4 shows the maximum likelihood estimates from estimating the composite demand equation (9). The intercept a_G is around zero meaning there is no evidence of trend-related changes such as taste changes in the model. Seasonal effects play an important role in demand for fruits and vegetables. Compared to the fourth quarter, households demand more fruits and vegetables in the other three quarters, where both high-income and low-income households demand the most in the second quarter. The estimates of the group marginal budget share (b_G) are positive as expected and different between the two income groups. The results indicate that when the total expenditure increases by $100, the expenditure on the group of fruits and vegetables increases by 24 cents for high-income households and by 45 cents for low-income households, respectively. Following the notation in the model section, the marginal budget shares of processed fruits and vegetables, fresh vegetables and fresh fruits are represented as b_1, b_2, and b_3, respectively. By the relationship $b_i = b_i^G b_G$, b_1, b_2, and b_3 are estimated as 8.63×10^{-4}, 7.05×10^{-4}, and 7.95×10^{-4} for high-income households, and 1.63×10^{-3}, 1.36×10^{-3}, and 1.46×10^{-3} for low-income households. This means that for high-income households, the allocation of an additional dollar income are 9 cents, 7 cents, and 8 cents for processed fruits and vegetables, fresh vegetables, and fresh fruits, respectively; for low-income households, the allocation of an additional dollar income are 16 cents, 14 cents, and 15 cents, respectively. Thus, we know that when income increases, low-income households would increase expenditure on fruits and vegetables more than high-income households. The money flexibility (i.e., the inverse of the income elasticity of the marginal utility of income) ϕ is negative as expected. High-income households have a higher ϕ (-7.728) in absolute value than low-income households (-1.862). This is consistent with the results found in Frisch (1959). The adjusted R^2 is 0.626 for high-income households and 0.383 for low-income households. Although the error term in (9) is assumed to follow an AR(1) process, the problem of serial correlation still exists in the model. So an AR(2) is used to ensure that no further serial correlation exists.

All the elasticities are evaluated at the mean budget shares. The group expenditure elasticities for fruits and vegetables (see Table 4) are positive and smaller than one, indicating fruits and vegetables are "normal goods" and "necessities," while the expenditure elasticities of all other goods are larger than one, indicating all other goods are "luxuries." Low-income households have larger group expenditure elasticities for fruits and vegetables (0.178) and all other goods (1.021) than high-income households (0.141 and 1.015, correspondingly) as expected, meaning low-income households are more responsive to total expenditure changes. By contrast, the group own-price compensated elasticities are negative as expected, and high-income households are more responsive to own-price changes than low-income households. The $[c_{ik}]$ matrix is also verified to satisfy the negativity condition.

Table 5 and

Table **6** report the estimated unconditional expenditure and price elasticities for three fruit and vegetable products and all other goods. All unconditional expenditure elasticities for fruits and vegetables are between zero and one, as expected. Low-income households have larger total expenditure elasticities than high-income households. As for price elasticities, no significant differences are found between uncompensated and compensated elasticities due to the small income effects. For high-income households, all fruits and vegetables are found to be unconditional gross and net complements. For low-income households, fresh fruits are found to be unconditional gross and net substitutes for processed fruits and vegetables and fresh vegetables, although the corresponding elasticities are not significant. High-income households have larger own-price elasticities than low-income households. Moreover, fruits and vegetables are found to be net substitutes for all other goods. Table 7 shows low-income households have larger unconditional total expenditure elasticities for both three products of fruits and vegetables and all other goods than high-income households.

4.2 A Price Subsidy on Consumption of Fruits and Vegetables

The unconditional elasticities derived above are used to evaluate the total effects of a price subsidy on consumption of three products of fruits and vegetables, especially for low-income households. Because data used here are at-home fruit and vegetable consumption, a price discount is considered to apply only to fruits and vegetables consumed at home. Assume the supplies of fruits and vegetables are perfectly elastic and other goods' prices remain unchanged. This assumption may overstate the consumption response to price changes.

For simplicity, rewrite equation (10) in terms of unconditional uncompensated price elasticities as

$$\Delta \log q_{it} = e_i \Delta \log y_t + \sum_{k=1}^{3} e_{ik} \Delta \log p_{kt} + e_{io} \Delta \log p_{ot}, \tag{12}$$

where $\Delta \log y_t$ is the change in total expenditures, e_i is unconditional expenditure elasticities of good i and e_{ik} and e_{io} are unconditional uncompensated price elasticities corresponding to the compensated definitions. Given a mean zero error term, Table 8 shows that a 10% price subsidy would increase low-income (high-income) households' consumption by 3.27% (10.68%) for processed fruits and vegetables, 3.29% (10.73%) for fresh vegetables, and 3.50% (11.42%) for fresh fruits. Because the demand elasticities of all other goods with respect to prices of fruits and vegetables are negative for low-income households and positive (not significant) for high-income households and their values are small, the quantity change in all other goods are only 0.17% and -0.02% for low-income and high-income households, respectively.

5. Conclusion and Directions for Future Work

This paper develops a two-stage budgeting methodology using the Rotterdam Model to estimate unconditional demand elasticities for fruits and vegetable using 1986–2010 CEX data. The demand system is separately estimated for low-income and high-income households. The estimates derived here are consistent with those derived in the literature. The estimated unconditional own-price elasticities are between -0.269 and -0.838, and the estimated unconditional total expenditure elasticities are between 0.138 and 0.186. Compared to high-income households, low-income households have larger total expenditure elasticities and smaller own-price elasticities. Fruits and vegetables and all other goods are found to be net substitutes for both the income groups of households.

The price subsidy on fruits and vegetables would increase consumption of fruits and vegetables by 3.27% to 3.50% for low-income households and by 10.68% to 11.42% for high-income households, which are also consistent with the literature. However, the subsidy's effects on consumption of all other goods are found to be very small.

Some related questions are worthy of exploring for further study. In particular, both composite demand system and conditional demand system (equations (4) and (5)) can be estimated simultaneously, allowing the correlation between the error terms of the two demand systems. The results can be considered as a test to the theory of rational random behavior (Clements and Johnson, 1983). In addition, the assumption of perfectly elastic supply curves of fruits and vegetable can be relaxed by allowing for upward-sloping supply curves for fruits and vegetables. Also, it would be interesting to disaggregate the group of "all other goods" and further explore what the effects are on both consumption of fruits and vegetables and unhealthy foods such as sugar-sweetened beverages if the revenue from taxing the unhealthy food is used to subsidize fruits and vegetables.

Table 1: Variables in the Model and Sample Statistics

Variable	High-Income Group (N=100) Mean	Std. Dev.	Min	Max	Low-Income Group (N=100) Mean	Std. Dev.	Min	Max
Group Frequency	1491.120	423.754	833.000	2299.000	1596.470	365.047	1070.000	2353.000
Quarterly Expenditure ($/per household)								
Total Expenditure	7861.760	1942.950	4411.790	11052.630	4285.450	943.971	2355.000	6537.780
Fruits and Vegetables	128.993	26.677	80.040	192.586	103.412	17.076	64.362	153.974
Other Goods	7732.760	1918.340	4327.530	10876.710	4182.040	929.704	2290.640	6398.900
Constant Dollar Expenditure ($/per household)								
PFV	0.476	0.046	0.395	0.589	0.388	0.055	0.257	0.470
FV	0.414	0.040	0.341	0.519	0.345	0.061	0.230	0.505
FF	0.437	0.067	0.307	0.593	0.349	0.069	0.221	0.512
Fruits and Vegetables	1.323	0.107	1.084	1.566	1.077	0.159	0.746	1.440
Other Goods	75.745	6.719	60.290	98.545	41.477	5.624	29.921	51.736
Price (1998=100)								
PFV	101.612	21.706	65.336	143.269	-	-	-	-
FV	97.851	28.481	48.764	146.691	-	-	-	-
FF	97.057	26.693	45.882	142.160	-	-	-	-
Fruits and Vegetables	99.046	25.214	54.558	143.099	-	-	-	-
Other Goods	101.116	19.945	67.083	134.381	-	-	-	-
Budget Share								
PFV	0.006	0.001	0.004	0.008	0.009	0.001	0.005	0.012
FV	0.005	0.000	0.004	0.007	0.008	0.001	0.006	0.012
FF	0.005	0.001	0.004	0.007	0.008	0.001	0.006	0.011
Fruits and Vegetables	0.017	0.002	0.013	0.021	0.025	0.003	0.018	0.035
Other Goods	0.983	0.002	0.979	0.987	0.975	0.003	0.965	0.982

Note: Prices are same for both income groups. PFV, FV, and FF denote processed fruits and vegetables, fresh vegetables, and fresh fruits, respectively.

Table 2: Test for Unit Roots

			High						Low					
Group Variable	Price Indexes		Expenditure Shares		Quantity Indexes		Total Expenditure		Expenditure Shares		Quantity Indexes		Total Expenditure	
	No. of Lags	ADF	No. of Lags	ADF	No. of Lags	ADF	No. of Lags	ADF	No. of Lags	ADF	No. of Lags	ADF	No. of Lags	ADF
Fruits and Vegetables	0	-3.71**	0	-5.60***	1	-5.15***	1	-3.85**	0	-5.80***	0	-5.86***	2	-2.06
Other Goods	2	-1.73	0	-5.25***	0	-7.04***			0	-7.04***	2	-2.57		

Note: ADF stands for Augmented Dickey-Fuller test. Price indexes and total expenditure are in logarithm form and deflated by CPI of all item. The critical values at 1%, 5%, and 10% significance levels (when sample size =100) are -4.04, -3.45, and -3.15 for ADF(t), respectively. ***and ** represents significance at the 1% and 5% level. The Lag Length is determined by the sequential t rule and Akaike information criterion (AIC); its upper bound is 12 using the rules in Schwert (1989).

Table 3: Conditional Slutsky Coefficients and Marginal Budget Shares

	High			Low		
	PFV	Fresh Vegetables	Fresh Fruits	PFV	Fresh Vegetables	Fresh Fruits
Conditional Slutsky Coefficient (c_{ik}^{G})						
PFV	-9.456E-04***	-1.236E-04	1.069E-03***	-1.415E-03***	-1.850E-04	1.600E-03***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Fresh Vegetables	-1.253E-04	-1.113E-03***	1.238E-03***	-1.901E-04	-1.689E-03***	1.879E-03***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fresh Fruits	1.143E-03***	1.307E-03***	-2.450E-03***	1.662E-03***	1.900E-03***	-3.562E-03***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Conditional Marginal Budget Share (b_{k}^{G})						
	0.367***	0.300***	0.338***	0.366***	0.304***	0.328***
	(0.015)	(0.013)	(0.015)	(0.015)	(0.013)	(0.015)

Note: *** denote significance at 1% level. PFV denotes processed fruits and vegetables. The numbers in the parentheses are standard errors.

Table 4: Composite Demand Estimates for Both Income Groups

	High		Low	
	Fruits and Vegetables G		Fruits and Vegetables G	
Variable	Coef.	Std. Err.	Coef.	Std. Err.
a_G	2.257E-05**	0.000	-1.811E-05	0.000
b_G	2.351E-03**	0.001	4.458E-03***	0.002
ΔQ1	3.795E-05	0.000	1.501E-04	0.000
ΔQ2	6.927E-04***	0.000	1.291E-03***	0.000
ΔQ3	3.706E-04**	0.000	9.742E-04***	0.000
Phi	-7.728	15.762	-1.862	4.699
ρ_1	-0.606***	0.096	-0.399***	0.092
ρ_2	-0.193**	0.086	-0.223***	0.071
e_G	0.141**	0.060	0.178***	0.069
e^*_{GG}	-1.088***	0.183	-0.332	0.292
Adj. R^2	0.626	-	0.383	-

Note: ** and *** denote significance at 5% and 1% level, respectively. PFV denotes processed fruits and vegetables. Model is corrected for second-order autocorrelation in error term, where the parameter estimates are ρ_1 and ρ_2.

Table 5: Uncompensated Price Elasticities

	High				Low			
	PFV	Fresh Vegetables	Fresh Fruits	Other Goods	PFV	Fresh Vegetables	Fresh Fruits	Other Goods
PFV	-0.541***	-0.339***	-0.189**	0.926***	-0.271**	-0.119	0.063	0.153
	(0.099)	(0.067)	(0.078)	(0.197)	(0.123)	(0.094)	(0.105)	(0.295)
Fresh Vegetables	-0.416***	-0.539***	-0.118*	0.930***	-0.145	-0.318***	0.135	0.154
	(0.082)	(0.070)	(0.071)	(0.188)	(0.114)	(0.099)	(0.104)	(0.296)
Fresh Fruits	-0.205**	-0.099	-0.838***	0.990***	0.083	0.135	-0.569***	0.164
	(0.093)	(0.068)	(0.098)	(0.200)	(0.126)	(0.103)	(0.112)	(0.305)
Other Goods	0.000	0.000	0.001	-8.839	-0.006**	-0.005**	-0.005**	-2.897
	(0.001)	(0.001)	(0.001)	(13.197)	(0.003)	(0.002)	(0.002)	(4.350)

Note: *, **, *** denote significance at 10%, 5%, and 1% level, respectively. PFV denotes processed fruits and vegetables. The numbers in the parentheses are standard errors.

Table 6: Compensated Price Elasticities

	High				Low			
	PFV	Fresh Vegetables	Fresh Fruits	Other Goods	PFV	Fresh Vegetables	Fresh Fruits	Other Goods
PFV	-0.540***	-0.338***	-0.188**	1.061***	-0.269**	-0.118	0.065	0.323
	(0.099)	(0.067)	(0.078)	(0.191)	(0.123)	(0.094)	(0.105)	(0.288)
Fresh Vegetables	-0.415***	-0.538***	-0.118*	1.066***	-0.144	-0.317***	0.136	0.325
	(0.082)	(0.070)	(0.071)	(0.180)	(0.114)	(0.099)	(0.104)	(0.289)
Fresh Fruits	-0.204**	-0.098	-0.837***	1.134***	0.085	0.137	-0.567***	0.346
	(0.093)	(0.068)	(0.098)	(0.194)	(0.126)	(0.103)	(0.112)	(0.298)
Other Goods	0.007***	0.006***	0.006***	-7.841	0.003	0.003	0.003	-1.901
	(0.001)	(0.001)	(0.001)	(16.030)	(0.003)	(0.002)	(0.002)	(4.817)

Note: *, **, *** denote significance at 10%, 5%, and 1% level, respectively. PFV denotes processed fruits and vegetables. The numbers in the parentheses are standard errors.

Table 7: Total Expenditure Elasticities

	High				Low			
	PFV	Fresh Vegetables	Fresh Fruits	Other Goods	PFV	Fresh Vegetables	Fresh Fruits	Other Goods
Elasticities	0.138**	0.138***	0.147**	1.015***	0.174**	0.175**	0.186***	1.021***
	(0.060)	(0.060)	(0.063)	(0.001)	(0.068)	(0.069)	(0.071)	(0.002)

Note: ** and *** denote significance at 5% and 1% level, respectively. PFV denotes processed fruits and vegetables. The numbers in the parentheses are standard errors.

Table 8: Average Effects of a 10% Price Subsidy on Consumption of Fruits and Vegetables and Other Goods

	High				Low			
	PFV	Fresh Vegetables	Fresh Fruits	Other Goods	PFV	Fresh Vegetables	Fresh Fruits	Other Goods
Percentage Change on Consumption	10.683%	10.731%	11.419%	-0.015%	3.272%	3.287%	3.497%	0.170%

Note: PFV denotes processed fruits and vegetables.

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