FOOD-DEMAND RESPONSIVENESS IN BANGLADESH: AN ECONOMETRIC INVESTIGATION

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ABSTRACT

The primary objective of this study is to investigate the food-demand responsiveness in Bangladesh. More specifically, applying the Stone Price Index to an Almost Ideal Demand System (AIDS), this paper estimates income (i.e.; expenditure) and price elasticities of demand for ten composite food products in Bangladesh; namely, Cereals, Fish, Meat, Pulses, Edible oil, Milk, Vegetables, Fruits, Spices, and Other foods. The study utilizes data from the Household Income and Expenditure Surveys including the most recent one of 2016, undertaken by the Bangladesh Bureau of Statistics.

An empirically based demand system can numerically inform a variety of simulation models in projecting future food demands in Bangladesh. As such, the up-to-date estimates of demand responsiveness are expected to help Bangladeshi policymakers understand the impact of some exogenous price and/or income ‘shocks’ as well as in formulating pragmatic and effective food and agricultural policies, fiscal and financial stimulus packages, among many others.

The results reported and analyzed in this paper seem to suggest that, in Bangladesh, a representative household regards Fish, Meat, Fruits, and Spices as luxury food products, each with an estimated expenditure elasticity value of greater than unity. This implies that as the economy of Bangladesh keeps on growing, leading to an ever higher *per capita* household income, the economy will likely witness some structural shift in food demand—in particular, households will increasingly spend a higher proportion of its food budget on the protein-rich, more balanced food basket involving fish, meat, fruits and spices.

However, all composite food products are estimated to be price inelastic regardless of the household being compensated and uncompensated for any price hike. Furthermore, the estimated cross-price elasticities appear to suggest no strong substitution happening across various product groups, lending support to the hypothesis of ‘separability in consumption’ at a reasonably high level of commodity aggregation. Comparing with the previously estimated elasticities available in the literature, the new estimates for the composite food products (except for Meat) seem to fall within the historical range of estimated values.

Keywords: AIDS model, Food demands in Bangladesh, Own- and cross-price elasticities, Expenditure elasticities, Separability, Generalized Composite Commodity Theorem, Commodity aggregation.

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1. MOTIVATION FOR THE STUDY

The main objective of this paper is to investigate the food-demand responsiveness in Bangladesh by econometrically estimating food-demand elasticities for Bangladesh using an Almost Ideal Demand System (AIDS) with the application of the Stone Price Index, and analyzing these estimates. With the updated estimates of food demand system, policymakers in Bangladesh would be well informed to tweak relevant policies and/or design evidence-based policy reforms. An empirically based demand system can also quantitatively inform various simulation models in projecting future food demands and food policy analyses for Bangladesh. As such, an ancillary objective of this study is to generate various elasticity estimates so as to provide a robust empirical basis for a structural model of the economy of Bangladesh called NUDGE (Ahammad 2020a, 2020b).

Maintaining food security is a critical, politically sensitive policy goal for successive governments in Bangladesh. At the 1996 World Food Summit, it was agreed that food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life (FAO 1996). In this regard, Bangladesh has made considerable progress in mitigating national food insecurity by increasing annual rice production and reducing the incidence of poverty over the years (Ahammad 2022). Among all the agricultural and food commodities, rice is by far the leading staple and paddy rice is the main agricultural crop accounting for about 75 percent of the total cropped area and over 80 percent of the total irrigated area in Bangladesh (BBS 2022). However, other food commodities such as wheat, pulses, vegetables, fish, meat, and fruits are essential for a household’s healthy and balanced food basket.

In a comparative analysis on food security across different countries, Chen and Lu (2018) showed that, in cereals production until 2008, Bangladesh failed in meeting its national needs. They found that the production of cereals had improved in Bangladesh during 2009-2013. However, increases in cereals production were not accompanied by significant increases in the availability and intake of other foods, which is likely to lead to a dietary imbalance. This might reflect insufficient domestic production of non-cereal foods such as oilseeds, pulses, fruits, meat, milk, spices and eggs as well as, on average, households’ low levels of income, poor food preferences, and lack of nutritional knowledge (Bose and Dey 2007).

Moreover, the affordability of food is a crucial component of assuring food (and nutritional) security. Activist public policy makers often embark on managing food prices and food affordability by a plethora of measures including agricultural input subsidies, government food procurement and food distribution systems as well as imposing trade restrictions. The design of such policies must be underpinned by empirical estimates for consumers’ responsiveness to prices and income changes; and critically, by robust and recently estimated set of values for price and income (or expenditure) elasticities. In the past, many studies estimated food demand elasticities in Bangladesh. However, to craft pragmatic and credible food policies, elasticity estimates must be based on most recent data and must be econometrically robust. This study utilizes the data and information from the Bangladesh Bureau of Statistics' Households Income and Expenditure Surveys (HIES) including those from the most recent 2016 HIES (BBS 2019), to estimate the food-demand system in Bangladesh. Such estimates can help project future food demands in Bangladesh given the changing size and structure of its population (and also of a representative household) in globally integrated food markets. With inherent future uncertainties and food market volatilities, an empirically based food-demand system is instrumental in enabling economy-wide models like NUDGE to simulate some credible alternative future food scenarios.

2. LITERATURE REVIEW

An extensive array of studies exists that has focused on estimating households' demand systems and their underlying elasticities. To estimate elasticities for food items, some aggregation over the lower-level food commodities is needed as all the lower-level food items cannot be specified individually and estimated owing to the dearth of relevant data. As such, one of the most problematic aspects in estimating food systems relates to assuring consistency in the aggregation of commodities (Davis 2003). Two theoretically defensible solutions have been applied for almost half a century: The Hicks-Leontief composite commodity theorem (Hicks 1939; Leontief 1936); and the separability theorem (Leontief 1947; Sono 1961). Much later, Lewbel (1996) proposed a generalization of the Hicks-Leontief composite commodity theorem, which was appealing for its various properties (discussed further in the methodology section of this paper). Indeed, many studies have since been conducted applying the generalized composite commodity theorem (GCCT) for testing the consistency in aggregation over food products (see, for example, Reed et al. 2005; and Wang 1997).

The GCCT holds under many widely used empirical models such as the homothetic utility function (Varian 1992), Almost Ideal Demand System (AIDS; Deaton and Muellbauer 1980), and Translog demand system (Jorgenson et al. 1982). In this study, an AIDS model has been chosen for estimation. (The justification for the choice of a particular form of AIDS model has been explained in Section 3.2 of the paper; and some additional details on GCCT are provided in Appendix.)

A suit of Almost Ideal Demand Systems (AIDS) have been used widely in different studies for demand estimation (see, for example, Buse and Chan 2000; Davis et al. 2000; Verbeke and Ward 2001; Asche et al. 2005; Jabarin 2005; Reed et al. 2005; Petersen 2006; Grant et al. 2010; Aziz et al. 2011; Ngui et al. 2011; Carletto et al. 2013; Basarir 2013; Nirmali and Edirisinghe 2015; and Akram 2020). With the country focus of this study being Bangladesh, it may be noted that there are only a limited number of empirical studies on food demand in Bangladesh (see, for example, Alamgir and Berlage 1973; Mahmud 1979; Chowdhury 1982; Pitt 1983; Ahmed and Shams 1994; Huq et al. 2004; Wadud 2006; Awal et al. 2008; Huq and Arshad 2010; Rahman 2020; and Shadat 2022). Some of these studies used a single equation model to estimate the demand elasticities of different food items. Although useful for gaining some sense of price and income (or expenditure) elasticities of different food and/or non-food items, most of the studies are fairly dated or based on a single HIES dataset. To inform future policies, decision makers need up-to-date and robust estimates. The availability of more recent methodology and data provided such an opportunity.

What follows is a review of some selected studies that investigated the food demand systems for Bangladesh, together with a few on other South Asian countries (viz. India, Pakistan, and Sri Lanka). Table 1 lists the key features of the studies reviewed. As can be seen, these studies used the AIDS framework, Exact Affine Stone Index (EASI; Lewbel and Pendakur 2009), or Quadratic Almost Ideal Demand System (QUAIDS; Banks et al. 1997).

Huq and Arshad (2010) tried to identify the magnitude of food demand which they believed would help in demand projection by estimating the demand elasticities for different food items in Bangladesh by using the Linear Approximate Almost Ideal Demand System (LA-AIDS; see section 3.2 for further details) with corrected Stone Price Index while using BBS' Household Income and Expenditure Survey (HIES) data for 1983-84, 1988-89, 1991-92, 1995-96, 2000, 2005. They used nine types of food items for their study and found that the *compensated* and the *uncompensated* demand for all food items were price inelastic, and also limited substitution across food groups characterized by low cross-price elasticities.

Rahman (2020) estimated the EASI demand model using 2000, 2005, 2010, and 2016 Household Income and Expenditure Survey (HIES) data of the Bangladesh Bureau of Statistics (BBS). By accounting for potential pre-commitments, he utilized the generalized EASI (GEASI) demand model to estimate the demand elasticities of different major food items in Bangladesh. The GEASI demand model has the same properties as the AIDS model plus some additional benefits. Rahman also performed a consumer welfare analysis for 14 different food items. While attempting to forecast rice production and consumption to figure out the deficit or surplus production in Bangladesh in the short run and also for the long run to 2049-50, he found that there might be a deficit in rice production both in the short run and in the long run. Once used the double exponential approach, Rahman also found some contradictory estimates such that there might be surplus both in the short run and in the long run. Moreover, his estimated deficits or surpluses were not too large to influence the price of rice considerably.

Shadat (2022) used QUAIDS for estimating the food demand elasticities nationally, by residence (distinguishing rural from urban households) as well as by poverty level (extreme poor, poor and non-poor) using the BBS 2016 HIES dataset. QUAIDS (Banks et al. 1997) is a simple generalization of the popular liner AIDS model, which incorporates a quadratic income term that allows more flexible Engle curves without sacrificing the theoretical consistency and integrability. Shadat (2022) considered nine food bundles; namely, Rice, Other food grains, Pulses, Fish, Eggs, Meat, Vegetables, Fruits, and Other foods. He found that, nationally, with the estimated expenditure elasticities greater than one Fish, Meat, Fruits are luxury food bundles. Nationally, the expenditure elasticity for Rice was estimated to be the lowest. Furthermore, the compensated and uncompensated price-elasticities for his food bundles except for Other food grains, were estimated to be less than unity.

For Sri Lanka, Nirmali and Edirisinghe (2015) also used a linear approximation of the strict Almost Ideal Demand System (LA-AIDS) and the Seemingly Unrelated Regression Procedure (SURE) on the 2006-07 household income and expenditure survey (by the Department of Census and Statistics in Sri Lanka) to estimate the food demand elasticities, price changes and calorie availability of households. A Seemingly Unrelated Regression (SURE) method was used because it takes the correlation of errors into account. They found all the food items inelastic. According to them, price increases in the future would have some discernible impact on households' food security. According to their study, the calorie availability of the household declined with most of the food products and in the light of expected food price increases in the world.

For Pakistan, Akram (2020) also estimated the Quadratic Almost Ideal Demand System (QUAIDS) on Household Integrated Income and Consumption Survey (HIICS) 2015-16 data to analyze the household food demand in Pakistan. He found there are some extraneous factors such as households' locality, dependency ratio, house ownership, age, and household-head's education had a significant impact on food demand. Akram suggested various government policies such as the 'Naya Pakistan Housing project' and advocated for linking it with government's efforts for poverty reduction and meeting Pakistan's Sustainable Development Goals (SDGs).

Aziz et al. (2011) also used the Linear Approximate Almost Ideal Demand System (LA-AIDS) for estimating the rural-urban income as well as own-price elasticities across a range of consumption quintiles for Pakistan, using the data from the Federal Bureau of Statistics (FBS) for the year of 2007-08. Because of the spatial variations in data, regional prices were estimated to use as the proxies for the food prices by using household survey data. They have used nine types of food items while making two groups: 1st quantile as the poor group and 5th quantile as the upper class having a high rate of consumption expenditure share. It is found that the expenditure and price elasticities for selected food groups were relatively high in Pakistan, and also, the expenditure elasticities were all positive. They also suggested that the findings of the empirical analysis of price and expenditure elasticities could be used in the projections for future food consumption in Pakistan. Their results also indicated that income-oriented policies were fundamental to achieving better nutrition as well as reducing the unbalanced dietary problems in Pakistan.

For India, Kumar et al. (2011) tried to explain the food demand by using a set of demand elasticities corresponding to major food commodities, which were estimated using multi-stage budgeting with the Quadratic Almost Ideal Demand System (QUAIDS) model, and another alternative model, the Food Characteristic Demand System (FCDS) based on the Indian National Sample Survey (NSS) household data for 1983, 1987-88, 1993-94, 1990-00, and 2004-05. The Quadratic Almost Ideal Demand System (QUAIDS) with a multistage budgeting framework is an extended version of the AIDS model. QUAIDS gives away the assumption of linearity in the expenditure function as well as accounts for the zero-consumption influence while estimating the income elasticity of demand. Their modified model assumes a non-linear relationship between income and consumption. The Food Characteristic Demand System

(FCDS) was first introduced by Bouis (1996); and is claimed to be easily used for those households who spend a high proportion of their total income on food, and a large share of their total food expenditure on a low-cost-calorie staple, to avoid going hungry. Kumar and others used 11 types of food items for this analysis while they categorized the income group as very poor, moderately poor, non-poor lower, and non-poor higher. The analysis suggested that an increase in food price inflation might not adversely affect the demand for staple food. However, the high-value food commodities were likely to be affected negatively.

Table 1: Some salient features of selected South Asian studies on the food demand system

Author(s) and the year of publication	Model used	Country focus	Elasticities by commodity		Overall comments and limitations of the study
			Food items	Expenditure elasticities	
Huq and Arshad (2010)	LA-AIDS	Bangladesh	Cereals	0.51	Almost all the food items are price elastic except cereal, pulse, and vegetables.
			Pulses	0.72	
			Edible oils	**1.77**	
			Vegetables	0.50	
			Fish	**1.29**	
			Meat	**2.46**	
			Fruits	**1.97**	
			Milk	**1.87**	
			Spices	**1.59**	
Rahman (2020)	GEASI & EASI	Bangladesh	Cereals	0.99	Most of the food items are price inelastic.
			Pulses	**1.03**	
			Fruits	**2.23**	
			Vegetables	0.89	
			Milk	**2.53**	
			Eggs	0.86	
			Oils	0.83	
			Beef & Mutton	**1.72**	
			Chicken	**1.35**	
Shadat (2022)	QUAIDS	Bangladesh	Rice	0.57	Nationally, all food items except for Other food grains are price inelastic.
			Other food grains	0.95	
			Pulses	0.79	
			Fish	**1.08**	
			Eggs	0.65	
			Meat	**1.33**	
			Vegetables	0.63	
			Fruits	**1.59**	
			Other food	**1.32**	
Nirmali and Edirisinghe (2015)	LA-AIDS	Sri Lanka	Cereals	0.99	None of the food items are elastic.
			Pulses	0.99	
			Meat	0.99	
			Edible oils	0.99	
			Milk powder	0.99	
			Sugar	0.99	

Author(s) and the year of publication	Model used	Country focus	Elasticities by commodity		Overall comments and limitations of the study
			Food items	Expenditure elasticities	
Akram (2020)	QUAIDS	Pakistan	Beef & Mutton	**1.72**	50 percent of food items are elastic, and where the elasticity of Hoteling and home delivery of food has a large elasticity.
			Chicken	**1.35**	
			Seafood	**1.79**	
			Milk & Yogurt	0.21	
			Eggs	**1.01**	
			Fruits & Dry Fruits	**3.09**	
			Vegetables	0.49	
			Sugar & Sweet products	0.99	
			Spices	0.24	
			Edible oils & Ghee	0.38	
			Hoteling & Home delivery of food	**7.00**	
			Tea & Coffee	0.49	
			Soft drinks & Bottled water	**2.36**	
			Wheat	0.20	
			Rice	0.46	
			Pulses	0.79	
			Bakery products	**1.85**	
			Miscellaneous food items	**2.18**	
Aziz et al. (2011)	LA-AIDS	Pakistan	Cereals	0.54	Only fruits, meats, milk, and milk products are elastic.
			Pulses	0.87	
			Fruits	**1.33**	
			Edible oils & fats	0.82	
			Sugar & Gur	0.66	
			Meat	**1.22**	
			Vegetables	0.76	
			Tea, Coffee & Soft drinks	0.83	
			Milk & Milk product	**1.21**	
Kumar et al. (2011)	QUAIDS	India	Cereals	0.19	Almost all the food items are price inelastic except milk.
			Pulses	0.72	
			Vegetables & Fruits	0.82	
			Milk	**1.64**	
			Edible oils	0.77	
			Sugar	0.94	
			Other food commodities	0.89	
			Beef	**3.69**	
			Chicken	**1.09**	
			Mutton	0.18	
			Fish	0.82	

Notes: GEASI: Generalized Exact Affine Stone Index;
EASI: Exact Affine Stone Index;
LA-AIDS: Linear approximation of the strict Almost Ideal Demand System;
QUAIDS: Quadratic Almost Ideal Demand System.
See text for further details on these food demand models.

3. METHODOLOGY

For this study, an AIDS model has been chosen for estimation. This section explains the rationale for (i) choosing a particular form of AIDS model by (ii) applying the Stone Price Index and (iii) the generalized composite commodity theorem. It starts by laying out the theoretical framework underpinning a household demand system.

3.1 The compensated and uncompensated demand functions

A consumer can be an individual or a household composed of one or more individuals, and can be represented by utility functions and indifference curves. A 'rational' consumer seeks to maximize the utility from spending his/her given disposable income on a commodity or a commodity bundle, given his/her tastes and preferences. A utility function thus measures the level of satisfaction (formally, utility; usually denoted by U) that the consumer expects to experience from consuming the commodity bundle reflecting his/her preferences at a particular point in time, and is usually denoted as:

$$U = u(q) \qquad (1);$$

where, $q = (q_1, q_2, \dots, q_n)'$ is an $n \times 1$ vector and $q_1, q_2, \dots, q_n$ are the individual commodities in the bundle.

As such, a consumer's choice for the mix of commodities becomes a constrained optimization problem; namely, utility-maximizing or cost-minimizing (refers to 'duality' in consumption). The solution can be sought from the perspective of the uncompensated and compensated demand configurations (Varian 1992). The uncompensated (*aka* Marshallian) demand function is defined with commodity prices and consumer expenditure as arguments, whereas the compensated (*aka* Hicksian) demand function is defined in terms of commodity prices and utility.

The Marshallian demand system is derived from utility maximization subject to the consumer's budget constraint. That is:

$$\max\ U = u(q) \qquad (2),$$

such that

$$x \geq \sum_{i=1}^{n} p_i q_i \qquad (3);$$

where, $q_i \geq 0\ for\ i = 1, 2, \dots, n$; $p_i > 0$ are the corresponding fixed prices; and x is the total expenditure or disposable income. The inequality constraints were proposed by Deaton and Muellbauer (1980). A justifiable linear equation form of the non-linear Equation (3) will be if only the consumer consistently attains the interior solution on the upper boundary of his/her opportunity or feasible set. The resulting equation will then become simply as follows:

$$\mathrm{x} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{p_i q_i} \qquad (4).$$

That is, Equation (4) gets rid of all the imposed inequality conditions on quantities and prices in Equation (3).

By maximizing the utility function (Eq. 1) subject to the budget constraint (Eq. 4), the associated Marshallian (or uncompensated) demand functions can be derived, whose parameters should satisfy several restrictions; namely, the adding-up, homogeneity, and Slutsky's symmetry.

(i) The adding-up restriction implies that the total expenditure must exhaust the budget; that is:

$$\sum_{i=1}^{n} p_i q_i = x \quad (5);$$

or, equivalently, the sum of the budget share (w_i) for all commodities in the chosen bundle must add to unity:

$$\sum_{i=1}^{n} w_i = 1 \quad (6).$$

Expressed in terms of elasticities, Equation (5) provides (a) the Engel aggregation condition:

$$\sum_{i=1}^{n} w_i \varepsilon_i = 1 \quad (7);$$

and (b) the Cournot aggregation conditions as follows:

$$\sum_{i=1}^{n} w_i \varepsilon_{ij} = -w_j; \quad \forall\, j = 1, 2, \dots, n \quad (8).$$

where ε_i and ε_{ij} are, respectively, income and price elasticities; and w_i's are the budget shares.

(ii) The homogeneity (of degree zero) conditions imply 'no money illusion' such that

$$q_i(ap, ax) = q_i(p, x) \quad (9);$$

where, a is an arbitrary constant.
As before, the homogeneity restrictions can also be rewritten in terms of elasticities as follows:

$$\sum_{j=1}^{n} \varepsilon_{ij} + \varepsilon_i = 0; \quad \forall\, j = 1, 2, \dots, n \quad (10).$$

(iii) The Slutsky symmetry conditions imply as follows:

$$\varepsilon_{ij} = \varepsilon_{ji} \frac{w_j}{w_i} + w_j(\varepsilon_j - \varepsilon_i); \quad \forall\, i, j = 1, 2, \dots, n \quad (11).$$

Equivalently, by solving the 'dual' problem of cost minimization, the Hicksian (or compensated) demand functions can be derived, whose parameters should satisfy similar restrictions.

3.2 The rationale for choosing the Stone Price corrected AIDS framework

The Almost Ideal Demand System (AIDS) propounded by Deaton and Muellbauer (1980) is one of the most popular demand systems in empirical demand analysis. AIDS is used in applied demand analysis because of its various desirable properties: It (i) is an arbitrary first-order approximation to any demand system; (ii) satisfies the axiom of choice; (iii) aggregates exactly over consumers without invoking parallel linear Engel curves; (iv) has a functional form which is inconstant with unknown household-budget data; (v) allows the homogeneity and symmetry property to be tested and imposed through linear restrictions on fixed parameters.

Based on microeconomic household demand theory, the first step in the AIDS model specification is to derive the expenditure function, $C(p, U)$, as follows:

$$\ln C(p, U) = a(p) + Ub(p) \quad (12);$$

where,

$a(p) = \alpha_0 + \sum_i \alpha_i \ln p_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij}^{*} \ln p_i \ln p_j$;

$b(p) = \beta_0 \prod_i p_i^{\beta_i}$; U is the utility level; p_i is the price of the i^{th} good and p_j is the price of the j^{th} good; and α , β and γ^* are the parameters.

Following the 'duality' theory in consumption, the Marshallian (or, uncompensated) demand functions can be derived from the expenditure function (Eq. 12) by applying Shephard's Lemma and replacing the unobservable utility level with the indirect utility that corresponds to the expenditure function (Varian 1992):

$$q_i(p, X) = \frac{X}{p_i}\left(\alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_i \ln(\frac{X}{P})\right) \quad (13);$$

where q_i is the chosen quantity of consumption of the i^{th} good; $\gamma_{ij} = \frac{1}{2}(\gamma_{ij}^{*} + \gamma_{ji}^{*})$; and P is a translog price index:

$$\ln P = \alpha_0 + \sum_i \alpha_i \ln p_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j \quad (14).$$

For empirical estimation, the AIDS food demand model is usually specified in the budget-share form as follows:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_i \ln\left(\frac{X}{P}\right) + \mu_i \quad (15);$$

where w_i is the observed budget share of the i^{th} good (i.e., $w_i = \frac{P_i Q_i}{X}$); X is the total expenditure on all goods in the system; P is the price index; μ_i is the residuals with mean zero and constant variance. Hence, the observed budget share, w_i, equals some systematic Marshallian demand function, $g_i\ (r, z)$, plus an error term.

Since Equations (15) are linear except for the translog price index P, to avoid non-linear estimation, Deaton and Muellbauer (1980) proposed to approximate the translog price index by the Stone index, P^S. This simplification of the original AIDS model is commonly called Linear Approximation of the AIDS (LA-AIDS):

$$w_i = \alpha_i^S + \sum_j \gamma_{ij}^S \ln p_j + \beta_i^S \ln\left(\frac{X}{P^S}\right) + \mu_i^S \quad (16);$$

where,

$$\ln P^S = \sum_i w_i \ln p_i. \quad (17);$$

and α^S, β^S and γ^S are the parameters of the LA-AIDS.

Since the Stone index includes current budget shares (w_i), they appear both on the right-hand side and on the left-hand side of the LA-AIDS Equation (16). So, the resulting correlation between the regressor $\ln\left(\frac{X}{P^S}\right)$ and the error term μ_i^S lead to a simultaneous bias of the estimation (Eales and Unnevehr 1988). Therefore, several empirical studies including one by Eales and Unnevehr (1988) used lagged shares in the Stone price index.

An alternative proposed by Hahn (1994) was to overcome this problem by using a log-linear analog of the Laspeyres price index that does not depend on current shares. Another solution is an econometric estimation by the Three-Stage Least Squares (3SLS) method (Alston et al. 1994; Buse and Chan 2000). However, as the Stone price index makes the estimated parameters inconsistent (Moschini 1995; Buse 1994), the use of this index seemed to be inappropriate. Furthermore, as the Stone price index is not invariant to changes in the units of measurement which is undesirable, Moschini (1995) proposed several other price indices. The Moschini-corrected Stone price index in the LA-AIDS is given by:

$$\ln P = \sum_i w_i \ln \frac{p_i}{p_i^0} \quad (18).$$

It is to be noted that the AIDS model automatically fulfills the adding-up condition which implies:

$$\sum_i \alpha_i = 1;\ \sum_i \beta_i = 0;\ \sum_i \gamma_{ij} = 0\ \forall\ j \quad (19).$$

Homogeneity can be imposed by parameter restrictions and it guarantees that there is no 'money illusion'; that is, if all the prices and income change by the same rate, the chosen mix of demanded commodities do not change. More succinctly, homogeneity conditions imply:

$$\sum_i \gamma_{ij} = 0 \quad \forall\ j \quad (20).$$

Symmetry restrictions that require that compensated demand be symmetric (Varian 1992) imply:

$$\gamma_{ij} = \gamma_{ji} \quad \forall\ i,j \quad (21)$$

3.3 Elasticities of the LA-AIDS

The expenditure (or income) elasticities (η_i) and Marshallian (uncompensated) price elasticities (Θ_{ij}) of the AIDS can be derived from the uncompensated demand functions (Buse 1994; and Green and Alston 1990):

$$\eta_i = \frac{\partial q_i}{\partial X}\frac{X}{q_i} = 1 + \frac{\beta_i^s}{w_i}, \quad \forall\ i \quad (22),$$

and $$\Theta_{ij} = \frac{\partial q_i}{\partial p_j}\frac{p_j}{q_i} = -\delta_{ij} + \frac{\gamma_{ij}^s}{w_i} - \frac{\beta_i^s w_j}{w_i} = -\delta_{ij} + \frac{\left(\gamma_{ij}^s - \beta_i^s w_j\right)}{w_i}, \quad \forall\ i,j \quad (23);$$

where, δ_{ij} is the Kronecker delta holding a value of unity (=1) for $i = j$ (own-price elasticities) and zero (=0) for $i \neq j$ (cross-price elasticities). Hicksian (compensated) price elasticities (Θ_{ij}^H) can be derived from either Hicksian (compensated) demand functions or by inserting the expenditure elasticity and Marshallian price elasticity in the Slutsky equation in the elasticity form (Deaton and Muellbauer 1980; and Moschini 1995):

$$\Theta_{ij}^H = \Theta_{ij} + \eta_i . w_j,\ \forall\ i,j \quad (24).$$

3.4 The weak separability tests

Separability is the mathematical property of a function which is a pivotal economic concept that is used to deal with aggregation problems. 'Weak' separability and 'strong' separability are commonly distinguished in economic literature for aggregation purposes. Weak separability for any partition R of r mutually exclusive and exhaustive subsets $N_1, N_2, \ldots, N_r$ is necessary and sufficient for a (production, cost or utility) function to be of the form $F(X_1, X_2, \ldots, X_r)$, where the aggregate X_s is a function of only the elements of N_s and N_s is a subset of the set (of input factors, prices or commodities) $N = \{1, 2, \ldots, n\}$. By contrast, strong separability implies that the function is of the form $F(X_1 + X_2 + \cdots + X_r)$.

According to Reed et al. (2005), weak separability can be tested using the Wald test under the null hypothesis:

H_0: Our aggregation scheme is based on weakly separable.

For details on the Wald test, see Appendix.

3.5 Calculating composite commodity index

There are different indexing methods such as the Fisher index, Laspeyres index, and Paasche index. As can be seen from their functional forms, all these indexing approaches require two types of variables: the base-year and current-year variables, regardless whether they are price or quantity variables. However, this study is not dealing with the time-series data, and also not projecting the future here. To deal with historical data, weighted sum of shares could be used. Ideally, substitution in the demand system be allowed, but because of the type of data used it was avoided. The calculation of the composite commodities is described below:

Let the expenditure of j^{th} food item in i^{th} composite commodity is e_{ij} so that the total expenditure is given by: $\sum_j e_{ij}$. Thus, the share of the j^{th} food item in the i^{th} composite commodity is:

$w_{ij}^* = \frac{e_{ij}}{\sum_j e_{ij}}$.

That is, w_{ij}^* is the within-group budget share for j^{th} food item in i^{th} composite commodity.

So, the price of the higher-level composite commodity is:

$P_i = \sum_j w_{ij}^* p_{ij}$; where, p_{ij} is the price of j^{th} food item in i^{th} composite commodity.

And, similarly, the quantity of the higher-level composite commodity is given by:

$Q_i = \sum_j w_{ij}^* q_{ij}$; where, q_{ij} is the quantity of j^{th} food item in i^{th} composite commodity.

As an example, if w_{11}^* and p_{11} were the within-group budget share and price for the lower-level food item Rice-Fine in the higher-level Cereal composite item, respectively, then $w_{11}^* = \frac{e_{11}}{\sum_j e_{1j}}$ with e_{11} being the expenditure of Rice-Fine in Cereal Composite item, and $\sum_j e_{1j}$ the total expenditure of the Cereal composite item. And $P_1 = \sum_j w_{1j}^* p_{1j}$ would give the price of the Cereal composite item.

4. DATA SOURCES AND COMMODITY AGGREGATION

The food demand system is estimated using the BBS Household Income and Expenditure Survey (HIES) data for the years 2000, 2005, 2010, and 2016 (BBS 2019). In this study, the data used are the monthly income and expenditure for the rural and urban households for above mentioned years. The BBS datasets contain many missing and undefined values, which needed to be cleaned before using them. The incomplete data was to be avoided for estimation. As a result, after removing the incomplete data points (with missing and undefined values) a total of 13,810 complete data points for households were used to estimate the LA-AIDS food demand model for Bangladesh.

4.1 The 10 composite food commodities

In this study, the following ten composite food commodities are defined: Cereals, Edible oils, Fish, Fruits, Meat, Milk, Other, Pulses, Spices, and Vegetables. Table A.1 in Appendix lists the corresponding lower-level food items as included in the BBS HIES.

4.2 The Wald test result

The statistical test for weak separability reduces to a test that relative prices are uncorrelated with the model error of the composite demand system as the model errors are presumed to be stationary (Reed et al. 2005). For the weak separability test, the Wald test was used. Appendix Table A.2 suggests that the aggregation scheme in this study cannot be based on weakly separable preferences, so the demand elasticities for 10 broadly defined food categories appear to be reasonable.

5. RESULTS AND DISCUSSIONS

5.1 Estimated parameters of the LA-AIDS food demand model

Table 2 shows the estimated parameters of the LA-AIDS food demand system in Bangladesh that was represented by Equations (16). A specialist, open-source package ***micEconAids*** from the ***R*** software suit, developed by Henningsen (2017), was used in this study to estimate the model parameters and the related elasticities (Eqs. 16, 22, 23 and 24). As mentioned earlier, the parameters were estimated by imposing all the theoretical restrictions on the model. The estimated parameters in Equations (16) represent average responses of a representative household in terms of changes in his/her expenditure shares in responses to changes in prices and (the Stone price adjusted) disposable income. The estimated parameters of the (Stone price index adjusted) disposable income ($\beta_i^S,\ \forall\, i$) suggest that Fish, Fruits, Meat, Spices and Other are luxury composite food items while the remaining food groups are necessities. Of the total of 120 parameters, 105 were found highly significant statistically.

5.2 Expenditure (or income) elasticities

An expenditure (or income) elasticity measures the percentage change in quantity demanded when expenditure (or disposable income) changes by 1 percent, with prices and other demand shifters remain unchanged. Table 3 shows the expenditure elasticities and own-price elasticities for the 10 composite commodities. For example, the estimated expenditure elasticity value of 0.83 for Cereals suggests that a 10 percent increase in household expenditure (disposable income) would, on average, increase the demand for Cereals by 8.3 percent. Food items with an estimated positive income elasticity were regarded as ‘everyday’ (*aka* ‘normal’) goods. As such, Fruits, Fish, Meat and Spices composite food commodities were expenditure (or income) elastic and, hence, could be considered luxury foods; the remaining were income inelastic, meaning that those were necessities.

5.3 Own-price elasticities

Table 3 also provides the estimated *uncompensated* and *compensated* own-price elasticities of demand for the 10 composite food commodities in Bangladesh. As expected, all the own-price elasticities were estimated to have negative signs, indicating that the demand curves were downward slopping. Also, the estimated *uncompensated* and *compensated* own-price elasticities suggest that all the composite food items were price inelastic except for Spices whose *uncompensated* own-price elasticity was estimated at -1.01.

Table 2: Estimated parameters of the LA-AIDS food demand system in Bangladesh

Regressors	Composite food items									
	Cereals	Edible Oils	Fish	Fruits	Meat	Milk	Other	Pulses	Spices	Vegetables
Constant	0.69 (39.63***)	0.10 (24.54***)	-0.12 (-8.67***)	0.03 (3.83***)	-0.01 (-0.81)	0.15 (24.20***)	-0.16 (-12.60***)	0.07 (24.00***)	0.06 (8.26***)	0.19 (31.88***)
Cereals	0.06 (37.46***)	0.00 (6.10***)	-0.02 (-17.64***)	-0.02 (-36.27***)	-0.02 (-32.27***)	-0.01 (-21.85***)	-0.00 (-4.42***)	-0.01 (-21.77***)	0.0077 (-13.54***)	0.01 (8.37***)
Edible Oils	0.00 (6.10***)	0.00 (10.68***)	-0.00 (-16.88***)	0.00 (-0.31)	-0.00 (-9.37***)	-0.00 (-6.16***)	-0.00 (-19.33***)	-0.00 (-0.73)	0.00 (8.91***)	0.00 (0.75)
Fish	-0.02 (-17.64***)	-0.00 (-16.88***)	0.05 (56.98***)	0.00 (7.65***)	-0.02 (-32.86***)	0.00 (2.06**)	-0.00 (-3.22***)	-0.00 (-10.30***)	-0.00 (-8.26***)	-0.01 (-21.76***)
Fruits	-0.02 (-36.27***)	0.00 (-0.31)	0.00 (7.65***)	0.02 (61.49***)	-0.00 (-3.48***)	0.00 (7.20***)	0.00 (0.03)	0.00 (3.95***)	-0.00 (-0.43)	-0.00 (-16.22***)
Meat	-0.02 (-32.27***)	-0.00 (-9.37***)	-0.02 (-32.86***)	-0.00 (-3.48***)	0.06 (96.93***)	-0.00 (-5.43***)	-0.00 (-6.24***)	-0.00 (-18.45***)	-0.00 (-3.79***)	-0.01 (-28.87***)
Milk	-0.01 (-21.85***)	-0.00 (-6.16***)	0.00 (2.06**)	0.00 (7.20***)	-0.00 (-5.43***)	0.02 (80.39***)	-0.00 (-17.82***)	-0.00 (-6.00***)	-0.00 (-9.35***)	-0.00 (-13.12***)
Other	-0.00 (-4.42***)	-0.00 (-19.33***)	-0.00 (-3.22***)	0.00 (0.03)	-0.00 (-6.24***)	-0.03 (-17.82***)	0.02 (47.86***)	-0.00 (-12.80***)	-0.00 (-24.41***)	-0.00 (-10.79***)
Pulses	-0.01 (-21.77***)	-0.00 (-0.73)	-0.0020 (-10.30***)	0.00 (3.95***)	-0.00 (-18.45***)	-0.00 (-6.00***)	-0.00 (-12.80***)	0.01 (77.98***)	-0.00 (-3.84***)	0.00 (0.09)
Spices	0.01 (13.54***)	0.00 (8.91***)	-0.00 (-8.26***)	-0.00 (-0.43)	-0.00 (-3.79***)	-0.00 (-9.35***)	-0.00 (-24.41***)	-0.00 (-3.84***)	-0.00 (-1.54***)	0.00 (8.99***)
Vegetables	0.01 (8. 37***)	0.00 (0.75)	-0.01 (-21.76***)	-0.00 (-16.22***)	-0.01 (-28.87***)	-0.00 (-13.12***)	-0.00 (-10.79***)	0.00 (0.09)	0.00 (8.99***)	0.02 (35.22***)
Stone price adjusted income	-0.04 (-25.80***)	-0.01 (-14.96***)	0.03 (21.13***)	0.00 (5.02***)	0.01 (10.99***)	-0.01 (-16.41***)	0.03 (23.41***)	-0.00 (-14.81***)	0.00 (2.86***)	-0.01 (-15.28***)

Notes: Authors' estimates. Values in parentheses indicate t-value. *** highly significant at 1% level; ** significant at 5% level; and * critically significant at 10% level.

The *uncompensated* own-price elasticity consists of two-component effects: Price or substitute effect; and income effect. On the other hand, *compensated* own-price elasticities purely depend on price or substitute effect (Varian 1992). So, the absolute values of *uncompensated* own-price elasticities are greater than the absolute values of *compensated* own-price elasticities, which suggest the presence of income effects (Table 3).

Table 3: Own-price and expenditure elasticities of all 10 composite commodities

Food items	Own-price elasticity		Expenditure elasticity
	Uncompensated	*Compensated*	
Cereals	-0.68	-0.46	0.83
Edible Oils	-0.89	-0.85	0.87
Fish	-0.69	-0.50	**1.16**
Fruits	-0.65	-0.60	**1.07**
Meat	-0.47	-0.35	**1.10**
Milk	-0.61	-0.58	0.78
Other	-0.85	-0.68	**1.21**
Pulses	-0.54	-0.52	0.85
Spices	**-1.01**	-0.93	**1.02**
Vegetables	-0.78	-0.71	0.90

Notes: Authors' estimates. Values in parentheses indicate t-value.
*** highly significant at 1% level;
** significant at 5% level; and
* critically significant at 10% level.

Table 4: Marshallian (uncompensated) own- and cross-price elasticities for composite commodities

Food items	Cereals	Edible Oils	Fish	Fruits	Meat	Milk	Other	Pulses	Spices	Vegetables
Cereals	**-0.68**	0.03	-0.07	-0.06	-0.08	-0.01	-0.03	-0.01	0.04	0.04
Edible Oils	0.15	**-0.89**	-0.11	0.00	-0.05	0.00	-0.06	0.01	0.05	0.03
Fish	-0.20	-0.04	**-0.69**	0.01	-0.10	-0.02	0.02	-0.02	-0.03	-0.08
Fruits	-0.39	-0.01	0.06	**-0.65**	-0.02	0.01	0.01	0.00	-0.01	-0.08
Meat	-0.27	-0.03	-0.14	-0.01	**-0.47**	-0.03	0.00	-0.03	-0.02	-0.10
Milk	-0.04	0.01	-0.01	0.03	-0.03	**-0.61**	-0.09	0.00	-0.03	-0.01
Other	-0.15	-0.03	0.01	-0.01	-0.01	-0.05	**-0.85**	-0.02	-0.04	-0.05
Pulses	-0.11	0.01	-0.09	0.02	-0.10	0.00	-0.06	**-0.54**	-0.01	0.03
Spices	0.08	0.02	-0.04	0.00	-0.02	-0.03	-0.05	-0.01	**-1.01**	0.03
Vegetables	0.12	0.01	-0.11	-0.04	-0.10	-0.01	-0.04	0.01	0.04	**-0.78**

Notes: Authors' estimates.

5.3 Cross-price elasticities

The cross-price elasticity of demand measures the responsiveness of demand for one commodity following a change in the price of another related commodity, *ceteris paribus* (Varian 1992). Depending on the sign, cross-price elasticity indicates the relationship between two products: A negative sign indicates a *complementary* relationship between the two products, whereas a positive sign indicates a *substitution* relation. Table 4 shows the Marshallian (or uncompensated) own- and cross-price elasticities, including the substitute (or price) effects and income effects. Table 5 provides Hicksian (or compensated) own- and cross-price elasticities, representing the pure price (or substitute) effects. As would be obvious, the diagonal elements in Tables 4 and 5 represent the own-price elasticities as reported in Table 3, whereas off-diagonal elements are cross-price elasticities. It's worth noting that there are some changes in sign between the values of *uncompensated* and *compensated* cross-price elasticities.

Table 5: Hicksian (Compensated) own and cross-price elasticity of all composite commodity groups

Food item	Cereals	Edible Oils	Fish	Fruits	Meat	Milk	Other	Pulses	Spices	Vegetables
Cereals	**-0.46**	0.06	0.06	-0.02	0.01	0.03	0.09	0.01	0.10	0.11
Edible Oils	0.37	**-0.85**	0.02	0.05	0.05	0.04	0.06	0.03	0.12	0.10
Fish	0.10	0.01	**-0.50**	0.07	0.02	0.03	0.18	0.01	0.06	0.02
Fruits	-0.11	0.04	0.23	**-0.60**	0.10	0.06	0.16	0.03	0.08	0.01
Meat	0.01	0.02	0.03	0.04	**-0.35**	0.02	0.16	0.00	0.07	-0.01
Milk	0.17	0.04	0.12	0.07	0.06	**-0.58**	0.02	0.03	0.03	0.05
Other	0.16	0.02	0.21	0.05	0.12	0.00	**-0.68**	0.01	0.05	0.06
Pulses	0.11	0.05	0.05	0.06	-0.01	0.04	0.06	**-0.52**	0.05	0.10
Spices	0.35	0.07	0.12	0.05	0.09	0.02	0.09	0.02	**-0.93**	0.12
Vegetables	0.36	0.05	0.04	0.01	-0.01	0.03	0.09	0.03	0.11	**-0.71**

Notes: Authors' estimates.

5.4 Comparison of estimates with those from other studies

Several studies estimated the food demand elasticities for composite food items in Bangladesh in the past. However, those estimates were based on old data which need to be updated or a single-year dataset. However, in what follows, an attempt is made to compare the current estimates with those presented by some recent studies on Bangladesh as well as other South Asian countries with similar food habits as Bangladesh, namely, India, Pakistan and Sri Lanka. The comparison made was shown in Table 6, where the maximum and the minimum values were taken as the ranges of the relevant elasticities drawn from across the reviewed papers. In general, the estimated elasticities in this study were found to fall within the identified ranges.

Table 6: Comparison of the estimated elasticities with those from selected past estimates

Composite food items	Range of own-price elasticities: Other studies		Range of expenditure elasticities: Other studies	Own-price elasticities: This study		Expenditure elasticities: This study	Comments
	Uncompensated	Compensated		Uncompensated	Compensated		
Cereals	(-0.03, -2.74)	(-0.03, -0.53)	(0.02, 1.10)	-0.68	-0.46	0.83	All the elasticities are in the range.
Edible Oils	(-0.25, -1.39)	(-0.22, -1.31)	(0.30, 1.77)	-0.89	-0.85	0.87	All the elasticities are in the range.
Fish	(-0.43, -2.67)	(-0.27, -0.81)	(0.67, 1.79)	-0.69	-0.50	**1.16**	All the elasticities are in the range.
Fruits	(-0.60, -1.00)	(-0.56, -0.96)	(0.36, 3.09)	-0.65	-0.60	**1.07**	All the elasticities are in the range.
Meat	(-0.67, -2.03)	(-0.48, -0.96)	(0.67, 2.46)	-0.47	-0.35	**1.10**	Though the expenditure elasticity is in the range, own-price elasticities are out of the range.
Milk	(-0.35, -1.04)	(-0.27, -0.97)	(0.21, 1.87)	-0.61	-0.58	0.78	All the elasticities are in the range.
Other	(-0.01, -1.00)		(0.75, 0.89)	-0.85	-0.68	**1.21**	
Pulses	(-0.24, -1.00)	(-0.15, -0.97)	(0.22, 1.00)	-0.54	-0.52	0.85	All the elasticities are in the range.
Spices	(-0.76, -1.45)	(-0.76, -1.33)	(0.24, 1.60)	-1.01	-0.93	**1.02**	All the elasticities are in the range.
Vegetables	(-0.31, -0.92)	(-0.26, -0.65)	(0.26, 0.96)	-0.78	-0.71	0.90	All the elasticities are in the range.

6. CONCLUSIONS

Credible agriculture and food policy analyses and policy reforms must be underpinned by robust and current empirics about the sector. This study quantified the food-demand responsiveness in Bangladesh by using BBS' most recent household income and expenditure data to estimate an LA-AIDS food demand system as well as comparing these with previously estimated elasticities provided in studies on Bangladesh and a few South Asian countries. The estimates presented in this paper showed that all food items in Bangladesh modelled had a positive expenditure (or income) elasticity, indicating that all goods are 'normal' (and not 'inferior' goods). As the composite food items, namely, Fish, Meat, Fruits, and Spices were expenditure elastic, they could be considered luxury food commodities. The remaining composite food items are all income inelastic, identifying these as necessities. Accordingly, any increase in households' total disposable income would be accompanied by a more than proportionate increase in the food budget expenditure on Fish, Meat, Fruits and Spices. This also implies that as the economy of Bangladesh keeps on growing, leading to an ever higher *per capita* household income, the economy will likely witness some structural shift in food demand—households will increasingly spend a higher share of its total food budget on the protein-rich, more balanced food basket involving fish, meat, fruits and spices.

The Marshallian (or uncompensated) and Hicksian (or compensated) own-price elasticities indicated that all food items (except for Spices, when any price hike remains uncompensated) were price inelastic. However, the cross-price elasticities were estimated to be very low, indicating no considerable complementarity and substitutability across the 10 higher-level composite food items considered in the study; yielding support to consumption separability across the food groups. However, the relationships between various food groups are somewhat 'ambiguous' as the study found changing of signs across *uncompensated* and *compensated* cross-price elasticity estimates.

While comparing with other studies, the estimated expenditure elasticities for different composite food items in this study seem to fall in the identified ranges of estimates. In addition, almost all own-price elasticities were in the range except for Meat, which needed further investigation.

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APPENDIX

A.1 Aggregation over low-level commodities: An application of the GCCT method

In this paper, different types of low-level food items were aggregated over some higher-level composite food items (Table A.1). But, is it justifiable to use composite food items instead of individual food items? There are several theories, among which the most popular one is the Generalized Composite Commodities Theorem (GCCT), proposed by Lewbel (1996). Wang (1997) also compared the popular theories in this regard across separability in consumption, Hicks-Leontief composite commodity theory, and GCCT.

Table A.1: The mapping scheme of the lower-level food items into the ten higher-level composite food commodities used in this study

No.	*Composite/Higher-level food items*	*Lower-level food items*
1	Cereals	Rice-Fine, Rice-Medium, Rice-Coarse, Beaten Rice, Pop Rice, Puffed Rice, Wheat (Atta), Flour, Vermivelli/Suji, Bread/Bonroti, Biscuits, Cake, and others.
2	Edible Oils	Mustard Oil, Soybean Oil, Palm Oil, Dalda, Ghee, and others.
3	Fish	Hilsa, Rhui/Katla, Pangash, Boal/Air, Magur/Shing, Koi, Silver Carp, Shoal/Gajar, Puti/Telapia, Mala-kachi, Other small fishes, Shrimp, Dried Fish, Elfish, Sea fish, Baila, and others.
4	Fruits	Ripe Banana, Mango, Melon/ Bangi, Jack fruit, Leeches, Ripe Papaya, Guava, Pineapple, Safeda, Palm, Bedana, Apple, Orange, Grape, BlackBerry, Amra/Kamranga, and others.
5	Meat	Beef, Buffalo, Mutton, Sheep, Hen, Duck, and others.
6	Milk	Liquid Milk, Powder Milk, Curd, Casein/ Butter, Milk drinks, and others.
7	Other	**Eggs:** Hen eggs, Duck eggs, **Sweetmeat:** Rasogolla/Chamcham, Jilapi/Bundia/Amriti, Halua/Batasha/Kadma, **Drinks:** Soft Drinks, Ovaltine/Horlicks, Tea/Coffee leaf, Liquid of sugarcane/Date/Palm, **Sugar & Molasses:** Sugar/Misri, Molasses, Khaja/Logneze/Toffee, Chocolate, **Miscellaneous Food:** Pickles, Jelly/Jam, Amshatta, Sauce/Sirka, **Dining Out:** Meals (Rice/Biriani), Fried Chicken, Fish, Meat, Patties/Cake, Sandwich, Burger, Hotdog, Pizza, Tea, Coffee, Samucha/Singara/Puri/Cake, Soft Drinks/Bottle water, **Tobacco & Tobacco Products:** Cigarette, Tobacco Leaf, Bidies, Gul and Other, **Betel Leaf & Chewgoods:** Betel Leaf & Chewgoods, Betel Nut, Zorda/tobacco leaf, Lime, Khoer, Rolled betel leaf, and others
8	Pulses	Lentil (Musur), Chickling-Vetch (Mug), Green gram (Boot), Pea gram (Kheshari), Mashkalai, and others.
9	Spices	Dried Chili, Green Chili, Onion, Garlic, Turmeric, Salt, Ginger, Cummins, Coriander-seed, Aromatic-seed, Clove/Black, pepper, and others.
10	Vegetables	Potatoes, Brinjal, White Gourd/pumpkin, Water gourd, Balsam apple, Perbol (Patal), Snake gourd, Green banana/ Papaya, Arum, Cauliflower/ Cabbage, Bean/Lobey, Tomato, Radish, Ladies finger, Leafy veg, and others.

Separability is a crucial economic concept introduced independently by Hicks (1939) and Leontief (1936, and 1947) to deal with utility (and production) aggregation problems. This concept was employed by Strotz (1957) to analyze two-stage optimization in utility theory: Given separability, the first stage involves partitioning commodities into subsets and optimizing intensities within each subset. While holding the within-subset intensities fixed, the between-subset intensities are optimized in the second stage. Unfortunately, the separability assumptions required for the group demand functions tend to be very stringent, which is difficult to test because of multicollinearity of disaggregated prices; and also requires group price indices that depend on the parameters of the individual utility function. Though there are many attempts to relax the restrictions, even the 'weak' form of separability imposes extreme restrictions on elasticity equality among every good in every group (Lewbel 1996).

Hicks-Leontief's theorem states that if the prices of a group of goods change in the same proportion, then the group of goods behaves just as if they were a single commodity. However, it can be shown by empirical evidence that even though the prices of related goods tend to move in the same direction, they do not move exactly proportionally.

Hicks-Leontief composite commodity theory was the only alternative to separability for aggregation over commodities before Lewbel (1996) proposed the Generalized Composite Commodities Theorem (GCCT). GCCT justifies aggregation under milder conditions. It relaxes the restriction of constant relative prices within groups by strengthening the requirement that independence holds across all groups (Reed et al. 2005). It can be tested without specifying a parametric model and in contrast to other aggregation procedures, the early empirical evidence is very encouraging and supports the generalized composite commodity theorem (Davis et al. 2000; Lewbel 1996).

GCCT can be summarized as follows:
Let
$z = log\ x$ be the log of consumer's total expenditure, x;
$r_i = log\ p_i$ be the log of the price of commodity $i,\ i = 1,\dots,n;\ r = (r_1, r_2, \dots, r_n)'$;
$R_I = log\ P_I$ be the log of the price of group $I,\ I = 1,\dots,s.\ R = (R_1, R_2, \dots, R_s)'$;
$\rho_i = log\ \frac{p_i}{P_I} = r_i - R_I$ be the difference between the log of individual price and the log of group price, for $i \in I;$ and ρ is the vector of ρ_i. Let G_I (R, z) be the group I equivalent of g_i (r, z) which is similar to Equation (15). And let $G_I^*(\mathrm{r}, z) = \sum_{i \in I} g_i$ (r, z) $= G_I^*(R^* + \rho, z)$ be the budget share demand function for group I.

Let H be the corresponding matrix with H_{IJ} at the (I, J) position such that:

$$H_{IJ}(R, z) = \int \frac{\partial G_I^*(R^* + \rho, z)}{\partial z} \times G_J^*(R^* + \rho, z) dF(\rho) - \frac{\partial G_I(R, z)}{\partial z} G_J(R, z); \quad \text{and}$$

$\underline{H}$ be the corresponding matrix with $\underline{H}_{IJ}$ at the (I, J) position such that:

$$\underline{H}_{IJ}(R, z) = cov[R, z] = \int G_I^*(R^* + \rho, z) \times G_J^*(R^* + \rho, z) dF(\rho) - G_I(R, z) G_J(R, z).$$

Now, let us assume that $g_i(r,z)$'s are some rational demand functions that satisfy the adding-up, homogeneity, symmetry, and negative semi-definiteness properties (Varian 1992). Also assume that the distribution of the random vector ρ is independent of R and $z,$ such that the group demand functions $G_I(R,z)$ satisfies the homogeneity and adding-up conditions. Given that H *is* symmetric, $G_I(R,z)$ is symmetric. Besides, $\underline{H} - H$ if is negative semi-definite, then $G_I(R,z)$ also satisfies the negative semi-definite property.

For further details on GCCT, see Lewbel (1996).

Given the required assumption, many commonly used model specifications satisfy the GCCT. In this paper, the GCCT approach to commodity aggregation was used for estimating an LA-AIDS model for the food demand in Bangladesh.

A.1.1 Weak separability: Performing the Wald tests

The Wald test is a method to determine if a model's explanatory variables are statistically significant so that they offer additional explanation to the model. If variables do not add 'value' in the aforementioned sense can be deleted without affecting the model in question in any meaningful way. The Wald test can be used for many different models, including discrete, binary or continuous variables. The null hypothesis for the Wald test is that some parameters are equal to some predetermined values. If the null hypothesis is rejected, it suggests that the variables in question can be removed without much loss to the model fit.

As such, whether the aggregation of commodities performed in this study is appropriate or not was validated using the Wald test. Here, the null hypothesis is:

H_0: Our aggregation scheme is based on 'weak' separable in consumption.

The Wald test is usually discussed in terms of the Chi-squared distribution (and statistic) because the sampling distribution (as the sample size, *n*, approaches infinity) is usually known. This test variant is sometimes called the Wald Chi-squared Test to differentiate it from the Wald log-linear Chi-squared test, a non-parametric variant based on the log odds ratios (Agresti, (1990).

The Wald test statistics are:

$$W = \frac{(\hat{\theta}-\theta_0)^2}{\frac{1}{I_n(\hat{\theta})}} = I_n(\hat{\theta}).(\hat{\theta}-\theta_0)^2;$$

where, $\hat{\theta}$ = Maximum Likelihood Estimator (MLE); and
$I_n(\hat{\theta})$ = Expected Fisher Information (evaluated at the MLE).

Table A.2 shows the estimated values for Wald Chi-squared statistics. The results seem to suggest that the aggregation scheme used in this study could not be based on weakly separable preferences. So, the demand elasticities for all 10 broadly defined food categories appear to be reasonable.

Table A.2: Weak Separability tests

Groups	W	$P(W>\chi^2)$
Cereals	1570.89	< 0.0001
Edible Oils	601.98	< 0.0001
Fish	75.21	< 0.0001
Fruits	14.66	< 0.0001
Meat	0.66	< 0.0001
Milk	585.48	< 0.0001
Other	158.70	< 0.0001
Pulses	576.08	< 0.0001
Spices	68.20	< 0.0001
Vegetables	1015	< 0.0001

***Notes**: W*'s are the Wald statistics with the null hypothesis that relative prices are not related to the composite model error. The third column reports the probabilities of observing the reported level of *W* under the null of weak separability.

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