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Addressing Pre-Commitment Bias with a Generalized EASI Model: An Application to Food Demand in Russia

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The Exact Affine Stone Index (EASI) demand model offers distinct advantages over its predecessors. However, it does not account for pre-committed demand. This can bias elasticity estimates when such pre-commitments are present. We derive a generalized EASI model that allows for pre-committed demand. We illustrate the advantage of this model in an empirical analysis of food demand in Russia using provincial-level panel data. The results provide strong empirical evidence for the presence of pre-committed demand for key food commodities. The findings extend the literature on food demand in Russia by estimating elasticities that account for pre-commitments and unobserved regional heterogeneity.

Key words: demand system, generalized EASI model, pre-committed demand

Introduction

Public policy on trade and food security and the analysis of policy impact on nutrition and health rely heavily on economic models of consumer behavior and demand structure estimation. However, many of the advanced models used in the literature are unable to account for a widely observed phenomenon: pre-committed demand, the portion of consumer demand that is insensitive to variations in economic factors (Gorman, 1976; Piggott, 2003; Tonsor and Marsh, 2007). Over the pre-committed portion of demand, commodities are deemed to be nondiscretionary, with prices playing little role in explaining consumer behavior. Once these pre-commitment levels are achieved, however, consumers become considerably sensitive to price movements over the discretionary portion of the demand curve (Rowland, Mjelde, and Dharmasena, 2017). This phenomenon is more frequently observed in the context of developing nations characterized by subsistence consumption, low incomes, widespread inequality, and food insecurity (Samuelson, 1947; Stone, 1954; Pollak and Wales, 1981). However, recent studies in the agricultural economics literature have revealed presence of food demand pre-commitments not only in the context of developing nations (Hovhannisyan and Gould, 2011) but also in the context of developed nations such as the United States and Japan (Tonsor and Marsh, 2007). Pre-commitments have also been observed in nonfood contexts such as energy consumption (Rowland, Mjelde, and Dharmasena, 2017). Most importantly, in settings where pre-commitments exist but are not explicitly accounted for in demand estimations, their effects on consumption are wrongly attributed to other demand determinants included in the model (Tonsor and Marsh, 2007; Rowland, Mjelde, and Dharmasena, 2017; Hovhannisyan and Bozic, 2017). This can result in biased and inconsistent economic effects and erroneous policy implications, with the resulting policies being incapable of producing the intended effect (Hovhannisyan and Gould, 2012).

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Recent advances in consumer demand theory coupled with increased availability of disaggregate consumption data provide better opportunities for more accurate delineation of consumer behavior. Lewbel and Pendakur's (2009) Exact Affine Stone Index (EASI) model has recently gained prominence in the economic literature due to several advantages it has over more traditional demand models such as Deaton and Muellbauer's (1980) Almost Ideal Demand System (AIDS) and its variants (e.g., Hovhannisyan and Khachatryan, 2017). Specifically, the EASI specification relieves Gorman's 1981 rank restriction on Engel curves and allows for arbitrary curvilinear effects, with the shape of the Engel curve determined by the data. Further, the EASI model accounts for unobserved consumer heterogeneity, which is necessary because consumers vary not only in terms of their economic circumstances but also with respect to their tastes and preferences (Browning and Carro, 2007). The importance of modeling flexible Engel curves and allowing for unobserved consumer heterogeneity cannot be overstated given the empirical evidence of highly nonlinear Engel curves and findings indicating that typical observables (e.g., income, prices, and demographics) can only explain half of the variation in budget shares (Banks, Blundell, and Lewbel, 1997; Hovhannisyan and Devadoss, 2018). However, despite its major advantages over previous demand systems, such as the AIDS family of models, the EASI model in its current specification does not account for potential pre-committed consumption quantities and may produce demand estimates that do not accurately reflect the actual demand structure.[1]

This paper extends the applicability of the EASI demand model to situations in which the presence of pre-committed demand is a valid assumption. Its contribution to the literature is twofold: First, it introduces the generalized EASI (GEASI) model that incorporates potential pre-committed quantities into the consumer demand structure. The main advantage of the GEASI is that the Marshallian, Hicksian, and expenditure elasticities derived from this specification provide an accurate reflection of consumer price and income responsiveness in the presence of a pre-committed demand component. An additional enhancement provided is that the estimated economic effects are not dependent on the unit of measurement when the shifters are incorporated through demographic translation (Alston, Chalfant, and Piggott, 2001).

Second, the paper presents new empirical evidence from the application of the GEASI specification to the estimation of food demand structure in Russia. The choice of Russia as an empirical setting is motivated by two major factors: First, empirical evidence on food demand in Russia is relatively limited, despite the important role that Russia has historically played in global food markets. The existing empirical literature in this area is limited in its ability to inform current public policy in that the previous studies either do not reflect present reality (e.g., Sheng, 1997; Elsner, 1999) or have a limited scope of analysis focusing on a small number of narrowly defined food commodities (e.g., Shiptsova, Goodwin, and Holcomb, 2004). A more recent study by Staudigel and Schröck (2015) is the first to examine consumer food preferences in Russia based on Russian Longitudinal Monitoring Survey (RLMS) data covering 1995–2010. Despite offering the first comprehensive analysis of considerably disaggregate food categories, a major limitation of this study stems from the data quality, as the survey is based on 7-day recall information. More specifically, the empirical findings rely on that assumption that 7-day recall information accurately reflects consumption patterns throughout the year. This can be a strong assumption under a wide range of circumstances and, if not true, may lead to biased demand estimates (Altonji and Siow, 1987). Additionally, the previous literature does not account for unobserved regional heterogeneity, which may reflect the effects of cultural, religious, and other idiosyncrasies on local food customs. Finally, previous studies employ demand specifications such as linear approximate AIDS or similar systems, which are characterized by restrictive Engel curves and produce elasticities that depend on the data scale (Alston, Chalfant, and Piggott, 2001). The second reason underlying our choice of Russia as an empirical setting is driven by the recent economic wars involving Russia. The economic

[1] The generalized AIDS (Bollino, 1987) and the generalized quadratic AIDS (Banks, Blundell, and Lewbel, 1997) models account for pre-commitments, but they are still subject to the same restrictive assumptions of representative consumer and constrained Engel curves.

sanctions imposed on Russia by Western countries and a subsequent Russian import ban in 2014 on a number of food and agricultural products from the United States, European Union, Canada, and Australia have elevated Russia to the center of global policy debates. While the importance of Russia's role in global agri-food trade is generally recognized by policy makers and researchers, many questions remain regarding the structure of food demand in Russia and related short-term and long-term trade implications.

Our empirical analysis is based on the most recent nationally representative, provincial-level panel data on household food consumption in Russia over 2007–2014. The unique contribution of this empirical application is that the resulting food demand elasticities account for potential pre-commitments as well as for unobserved regional heterogeneity. The results provide strong empirical evidence for the presence of pre-committed demand for key food commodity groups such as cereals, eggs, and fats/oils. Further comparative analysis illustrates the presence of significant bias in elasticity estimates when demand estimations do not account for existing pre-commitments. The refined demand estimation approach presented in this paper offers a methodological solution for eliminating such bias and producing most reliable elasticity estimates for informing public policy. The empirical findings on the structure of food demand in Russia provide valuable and timely insights for policy decisions in light of ongoing economic sanctions and Russia's increasingly prominent global role.

The Generalized EASI Demand Model

Consider the following cost function underlying the EASI demand system (Lewbel and Pendakur, 2009):

$$(1) \qquad \ln C(p,u,\varepsilon) = u + \sum_{j=1}^{J} m_j(u) \ln p_j + \sum_{j=1}^{J}\sum_{k=1}^{J} \alpha_{jk} \ln p_j \ln p_k + \sum_{j=1}^{J} \varepsilon_j \ln p_j,$$

where C represents cost, u is utility, $m_j(u)$ is a general function of u, p_j expresses the jth product's price, ε_j reflects unobserved preference heterogeneity, and α_{jk} are parameters.

Using the Shephard's Lemma (i.e., $\frac{\partial \ln C}{\partial \ln p_i} = w_i$) and the cost function in equation (1), Lewbel and Pendakur (2009) derive a linear approximate EASI demand specification that satisfies the restrictions stemming from consumer theory:

$$(2) \qquad w_i(p,u,\varepsilon) = m_i(u) + \sum_{k=1}^{J} \alpha_{ik} \ln p_k + \varepsilon_i.$$

To incorporate pre-committed demand into the EASI system, we follow Bollino (1987) to generalize the EASI cost function in equation (1) by including overhead costs:[2]

$$(3) \qquad \ln\left(C - t'p\right) = u + \sum_{j=1}^{J} m_j(u) \ln p_j + \sum_{j=1}^{J}\sum_{k=1}^{J} \alpha_{jk} \ln p_j \ln p_k + \sum_{j=1}^{J} \varepsilon_j \ln p_j,$$

where t_j is a parameter representing pre-committed quantity of the jth product.

The GEASI model is derived through the application of the Sheppard's Lemma to this more general cost function in equation (3). More specifically, differentiating both sides of the cost function with respect to $\ln p_i$ generates the following functional relationship:

$$(4) \qquad \frac{\partial \ln(C - t'p)}{\partial \ln p_i} = m_i(u) + \sum_{k=1}^{J} \alpha_{ik} \ln p_k + \varepsilon_i.$$

[2] The approach used by Bollino (1987) to derive the generalized AIDS model from the indirect utility function cannot be applied here, since $m_j(u)$ is, in general, an unknown function of utility.

Further simplification of the left side of equation (4) yields:

$$(5)\quad \frac{\partial \ln(C - t'p)}{\partial \ln p_i} = \frac{\partial \ln(C - t'p)}{\partial p_i}\frac{\partial p_i}{\partial \ln p_i} = \left(\frac{1}{(C - t'p)}\frac{\partial (C - t'p)}{\partial p_i}\right)p_i = \left(\frac{(\partial C/\partial p_i) - t_i}{C - t'p}\right)p_i.$$

Substituting equation (5) into equation (4) results in

$$(6)\qquad \left(\frac{(\partial C/\partial p_i) - t_i}{C - t'p}\right)p_i = m_i(u) + \sum_{k=1}^{J}\alpha_{ik}\ln p_k + \varepsilon_i.$$

Rearranging equation (6) yields the following expression for $\frac{\partial C}{\partial p_i}$:

$$(7)\qquad \frac{\partial C}{\partial p_i} = t_i + \frac{1}{p_i}(C - t'p)\left(m_i(u) + \sum_{k=1}^{J}\alpha_{ik}\ln p_k\right).$$

Next, both sides of equation (7) are multiplied by $(\frac{p_i}{C})$ to generate Hicksian budget share equations, since $w_i = \left(\frac{\partial C}{\partial p_i}\right)\left(\frac{p_i}{C}\right) = \left(\frac{q_i p_i}{C}\right)$:

$$(8)\qquad w_i = \frac{t_i p_i}{C} + \left(1 - \frac{t'p}{C}\right)\left(m_i(u) + \sum_{k=1}^{J}\alpha_{ik}\ln p_k\right).$$

Finally, the implicit GEASI Marshallian demand system is obtained by i) substituting consumer total expenditure X for C given a utility-maximizing consumer and ii) replacing $m_i(u)$ with a particular function offered by Lewbel and Pendakur (2009):

$$(9)\qquad w_i = \frac{t_i p_i}{X} + \left(1 - \frac{t'p}{X}\right)\left(\sum_{r=0}^{L}\beta_{ir}\left(\ln\left(X - t'p\right) - w'\ln p\right)^r + \sum_{k=1}^{J}\alpha_{ik}\ln p_k\right) + \varepsilon_i,$$

where $m_i(u)$ is replaced by $\sum_{r=1}^{L}\beta_{ir}y^r$ with $y = \ln(X - t'p) - w'\ln p$ and r denotes the order of the polynomial function of real income that provides a flexible representation of Engel curves. Note that the system in equation (9) is subject to the theoretical restrictions of adding up $(\sum_{i=1}^{J}\beta_{i0} = 1;\ \sum_{i=1}^{J}\beta_{ir} = 0,\ \forall\, r = 1,\ldots,L;\ \sum_{i=1}^{J}\alpha_{ik} = 0,\ \forall\, k = 1,\ldots,J)$ and symmetry $(\alpha_{ik} = \alpha_{ki},\ \forall\, i,k = 1,\ldots,J)$. Clearly, the EASI model is nested in the GEASI specification and can be obtained via the joint restriction of $t_i = 0,\ \forall\, i = 1,\ldots,J$ on the GEASI model.

As defined previously, t_j is the pre-committed demand for the jth product that is insensitive to income and price changes and $\sum_i t_i p_i$ represents pre-committed expenditures. The supernumerary expenditures can then be obtained as $X - \sum_i t_i p_i$ (see Zheng and Henneberry, 2009, for an excellent description of these demand and expenditure components).

Elasticity Formulas for the GEASI Model

We derive the expenditure, Hicksian, and Marshallian elasticity formulas for the GEASI model using the expenditure share equations in equation (9). Specifically, the GEASI expenditure elasticity formula is[3]

$$(10)\qquad E = (diag(W))^{-1}\left[\left[I_J + \left(\left(\frac{X - t'p}{X}\right) * B\right)(\ln p)'\right]^{-1}\left[\frac{t \circ p}{X} + \frac{t'p}{X}A + B\right]\right] + 1_J,$$

[3] Appendix A provides details concerning the elasticity derivations.

where $\boldsymbol{E}$ is the $(J \times 1)$ expenditure elasticity vector with e_i denoting its ith element, $\boldsymbol{W}$ represents the $(J \times 1)$ vector of observed commodity budget shares, $\ln p$ is the $(J \times 1)$ vector of log prices, $\boldsymbol{B}$ is a $(J \times 1)$ vector with its ith element represented by $\sum_{l=1}^{L} \beta_{il} l y^{l-1}, A = \left(\sum_{r=0}^{L} \beta_{ir} (\ln (X - t'p) - w' \ln p)^r + \sum_{k=1}^{J} \alpha_{ik} \ln p_k \right)$, 1_J is a $(J \times J)$ vector of ones, and $t \circ p = [t_1 p_1, \ldots, t_N p_N]$ is the Hadamard–Schur product. Equation (10) accounts for the fact that expenditure shares (w_i) also appear on the right side of the GEASI system through real expenditure (y_{rt}) and its polynomials. Further, the EASI expenditure elasticity formula is nested in equation (10) and can be obtained from this more general formula via the imposition of the joint restrictions of $t_i = 0, \ \forall\, i = 1, \ldots, J$:

(11)
$$E = (diag\,(W))^{-1} \left[\left(I_J + B (\ln p)' \right)^{-1} B \right] + 1_J,$$

Hicksian elasticities for the GEASI model are

(12)
$$e_{ij}^{H} = \frac{1}{w_i} \left[\frac{t_i p_i}{X} - \frac{t_i p_i}{X} A + \left[1 - \frac{t'p}{X} \right] \alpha_{ij} \right] + w_j - \delta_{ij}, \ \forall\, i, j = 1, \ldots, J,$$

where δ_{ij} is the Kronecker delta equaling 1 if $i = j$, and 0 otherwise. The respective EASI formula can then be generated based on $t_i = 0, \ \forall\, i = 1, \ldots, J$:

(13)
$$e_{ij}^{H} = \frac{\alpha_{ij}}{w_i} + w_j - \delta_{ij}, \ \forall\, i, j = 1, \ldots, J.$$

Using the Hicksian (e_{ij}^{H}) and expenditure elasticity estimates (e_i), the Marshallian price elasticities (e_{ij}^{M}) can be obtained from the Slutsky equation, $e_{ij}^{M} = e_{ij}^{H} \frac{\alpha_{ij}}{w_i} - w_j e_i$:

(14)
$$e_{ij}^{M} = \left[\left[\frac{t_i p_i}{X} - \frac{t_i p_i}{X} A + \left[1 - \frac{t'p}{X} \right] \alpha_{ij} \right] + (w_j - \delta_{ij}) w_i \right] \frac{\alpha_{ij}}{w_i^2} - w_j e_i.$$

Finally, the EASI Marshallian elasticity formula is nested in equation (14) and simplifies to

(15)
$$e_{ij}^{M} = \left[\frac{\alpha_{ij}}{w_i} + w_j - \delta_{ij} \right] \frac{\alpha_{ij}}{w_i} - w_j e_i.$$

The effects of pre-committed demand on the various elasticities cannot be easily understood from these formulas. Intuitively, however, ignoring pre-commitment consumption would generate elasticity estimates that are too inelastic because elasticities represent a weighted average of consumer price sensitivity over pre-committed (near 0) and discretionary portions (highly elastic) of demand; unless accounted for, the effects of consumer insensitivity over pre-committed demand are wrongly attributed to all consumption, thus dampening the elasticity value (Rowland, Mjelde, and Dharmasena, 2017).

Data and Construction of Variables

The empirical advantage of the GEASI model is illustrated through an empirical study of food demand structure in Russia. The analysis is based on the most recent household food expenditures panel data provided by the Russian Federation's Federal State Statistics Service (FSSS).[4] The data provide detailed information on consumption patterns for representative households from across Russia's 76 provincial-level administrative divisions (including oblasts, autonomous republics, etc.) over an 8-year period from 2007 to 2014. The data are collected by the FSSS through quarterly

[4] Available online at http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/en/main [Accessed 30 Dec. 2016].

Table 1. Descriptive Statistics for Food Expenditures, Prices, and Budget Shares

Variable	Mean	Std. Dev.	Min.	Max.
Per capita expenditure (rubles per capita)				
Meats	1,023.8	357.6	381.4	2,963.8
Vegetables	364.7	137.2	111.0	1,334.4
Cereals	508.1	152.4	208.9	1,132.0
Eggs	66.6	25.5	23.2	274.8
Fats/oil	58.8	14.7	24.0	104.3
Sugar	226.1	76.9	74.6	623.4
Dairy	505.2	191.0	171.1	1,745.4
Other	9,175.9	4,852.2	464.0	39,796.7
Agricultural commodity price (rubles/kg)				
Meats	15.2	5.1	4.8	58.1
Vegetables	4.2	5.2	0.8	66.3
Cereals	4.4	1.8	1.6	17.8
Eggs	0.3	0.2	0.1	1.8
Fats/oil	4.8	1.3	1.5	9.2
Sugar	6.0	2.3	1.6	14.5
Dairy	2.3	1.6	0.5	17.7
Other (consumer price index for consumer goods)	109.5	3.1	103.8	119.3
Budget share (%)				
Meats	9.4	3.2	3.9	29.5
Vegetables	3.3	1.1	1.2	10.3
Cereals	4.7	1.7	1.4	14.2
Eggs	0.6	0.3	0.2	2.9
Fats/oil	0.6	0.2	0.2	2.6
Sugar	2.1	0.8	0.4	7.9
Dairy	4.6	1.4	1.8	13.2
Other	74.7	8.1	24.0	90.4
Per capita income (1,000 rubles)	21.5	4.6	10.9	33.2

Notes: In 2007, the exchange rate US$1 for 25 Russian rubles; by 2014, the U.S. dollar had appreciated to 37 rubles per $1. *Source:* Household Food Expenditure Survey, Federal State Statistics Service of Russian Federation, 2007–2014 (http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/en/main [Accessed 30 Dec. 2016]).

surveys of representative households as part of the Household Income and Food Expenditure Survey. The survey is conducted using a two-stage stratified systematic random sampling method, in which one-third of households are dropped each period and replaced with a fresh sample of equal size based on a rotating-sample design. The collected data are subsequently aggregated by the FSSS to both the annual and the administrative-division level.

The current study is focused on the seven most widely consumed food commodity groups, categorized as meats (i.e., beef, poultry, pork, and other meats), vegetables, cereals, eggs, fats/oils, sugar, and dairy. We supplement this incomplete system with a composite numéraire good (i.e., "other") reflecting all remaining food and nonfood products that a typical household purchases but that are not individually modeled in our demand system (see an example of this approach in Zhen et al. (2014). This relaxes the restrictive implications of the separability or two-stage budgeting assumptions for the parameters and elasticities of the resulting conditional demand systems (Moschini, Moro, and Green, 1994). Categorizing commodities this way results in 4,864 observations for the GEASI demand system. The descriptive statistics presented in Table 1 illustrate the relative importance of each commodity group sampled. As it appears, meats account for the largest average budget share (9.4%) of the included individual commodities, followed by cereals (4.7%), dairy (4.6%), vegetables (3.3%), and sugar (2.1%). Eggs (0.6%) and fats/oils (0.6%), in contrast, account for relatively lower shares of total expenditures on food commodities included in the analysis. Other food and nonfood consumer goods and services account for the remaining 74.7% of consumer budget. Meats are the most expensive food group (15.2 rubles/kg), followed by sugar (6.0 rubles/kg) and fats/oils (4.8 rubles/kg).

Empirical Application

The choice of Russia as an empirical setting serves a dual purpose of i) illustrating the empirical value of the GEASI model and ii) contributing timely and relevant empirical insights on food demand in Russia for informing policy decisions. The combination of the advanced modeling approach and the detailed panel data used in this paper allows us to address the shortcomings discussed above in a single application while also accounting for potential pre-commitments in the demand structure.

Estimation Methods

We base our analysis of food demand in Russia on the following empirical specification of the GEASI model:

$$(16) \qquad w_{it} = \sum_{k=1}^{K} \phi_{ik} d_r + \sum_{l=0}^{L} \beta_{il} \left(\ln(X) - w' \ln p\right)^l + \sum_{j=1}^{J} \alpha_{ij} \ln p_{jt} + \xi_{it},$$

where t_i is modified to incorporate regional fixed effects (i.e., $\tilde{t}_i = t_{i0} + \sum_{k=1}^{K} t_{ik} d_k$), with t_{i0}, t_{ik} representing parameters to be estimated (e.g., Tonsor and Marsh, 2007; Zheng and Henneberry, 2009) and d_k denotes the dummy variable representing economic region k (Russia comprises 12 economic regions).

It deserves noting that the EASI model is nested in the GEASI and can be obtained from the latter via the joint restriction of $\tilde{t}_i = 0$, $\forall\, i = 1, \ldots, J$, as follows:

$$(17) \qquad w_{it} = \frac{\tilde{t}_i p_{it}}{X} + \left(1 - \frac{\tilde{t}' p}{X}\right) \left(\sum_{l=0}^{L} \beta_{il} \left(\ln\left(X - \tilde{t}' p\right) - w' \ln p\right)^l + \sum_{j=1}^{J} \alpha_{ij} \ln p_{jt} \right) + \varepsilon_{it},$$

where ϕ_{ik} are parameters representing demographic effects.

We estimate a series of GEASI and EASI specifications allowing for a range of Engle curves extending from linear to sextic using the GAUSSX programming module. The demand equations are estimated using the nonlinear least squares estimation procedure with allowance being made for contemporaneous correlation across the stochastic terms of the system. To identify the GEASI specification that offers the best fit of the data, the degree of polynomial function (L) is increased one at a time starting at $L = 1$, and the likelihood ratio (LR) test procedure is adopted to evaluate the incremental gain in the explanatory power of the more general models. It is worth noting that L should be less than the number of demand equations (R) for the demand system to converge. The results indicate that the GEASI system provides the best fit of the data at $L = 3$, incorporating higher degrees of income nonlinearity does not enhance the model's explanatory power considerably (the respective p-value associated with the test statistic is 0.00). Based on the results of model diagnostics, the cubic GEASI model is deemed to be the most preferred specification for the use in the analysis. Based on the LR test outcome, the GEASI model is further found empirically superior to the EASI model across all the specifications considered (Table 2). The results are robust to the inclusion of regional fixed effects, which account for unobserved time-invariant characteristics of the Russian administrative divisions/provinces. As discussed previously, this unobserved regional

Table 2. Summary of the Model Diagnostic Tests

Hypothesis	Likelihood Ratio Value	p-Value
Linear vs. quadratic GEASI model ($\beta_{i2} = 0,\ \forall\ i = 1,\ldots,J$)	41.3	0.00
Quadratic vs. cubic GEASI model ($\beta_{i3} = 0,\ \forall\ i = 1,\ldots,J$)	17.9	0.02
Cubic vs. quartic GEASI model ($\beta_{i4} = 0,\ \forall\ i = 1,\ldots,J$)	12.8	0.12
Commodities are not consumed in pre-committed quantities ($t_j = 0,\ \forall\ j = 1,\ldots,n$)		
(i.e., GEASI and EASI models are equivalent)		
Linear Engel curve ($r = 1$)	263.0	0.00
Quadratic Engel curve ($r = 2$)	186.8	0.00
Cubic Engel curve ($r = 3$)	192.1	0.00

Notes: Tests use 8 degrees of freedom. EASI and GEASI specifications are estimated on household food expenditure panel data obtained from the Russian Federation FSSS (http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/en/main [Accessed 30 Dec. 2016]). The data cover 76 provinces and administrative districts over 2007–2014 and include seven widely consumed food commodity groups (meats, vegetables, cereals, eggs, fats/oils, sugar, and dairy). The demand system equation uses 4,434 observations. The degree of polynomial functions estimated cannot exceed 6 (i.e., $R < J$), otherwise the resulting Engel curves will be arbitrarily complex (Lewbel and Pendakur, 2009).

Table 3. Pre-Committed and Discretionary Demand as a Percentage of Annual Average Consumption

Commodity	Annual Average[a] (kg)	Pre-Commitment (kg)	Pre-Commitment Percentage[b] (%)	Discretionary Percentage[c] (%)
Cereals	118.6	69.9	58.9	41.1
Eggs	250.0	180.3	72.1	27.9
Fats/oil	12.6	12.3	97.6	2.4
Sugar	38.4	25.6	66.7	33.3

Notes: [a]Average quantity demanded for the respective commodities over 2007–2014. [b]Pre-commitment level as a percentage of annual average quantity demanded. [c]Portion of annual average quantity demanded that responds to changes in economic factors.

heterogeneity can influence food consumption patterns through its effects on deeply rooted local food customs and traditions. Finally, it should be borne in mind that the differences between the EASI and GEASI models are specific to these particular demand specifications and the empirical setting of the underlying study.

Empirical Results

Table 4 presents the parameter estimates from the GEASI system with a cubic Engel curve structure. Pre-committed demand coefficients for cereals (t_3), eggs (t_4), fats/oils (t_5), and sugar (t_6) are estimated to be positive and statistically significant, which provides evidence for pre-committed consumption levels for cereals (69.9 kg), eggs (180.3 units), fats/oils (12.3 kg), and sugar (25.6 kg). To evaluate the relative importance of these pre-commitments in Russian consumers' food demand structure, we also compute the shares of pre-commitment and discretionary amounts in total consumption. Pre-commitments account for 58.9%, 72.1%, 97.6%, and 66.7% of cereal, eggs, fats/oils, and sugar consumption, respectively (Table 3).

Tables 5 and 6 report the GEASI Marshallian (e_{ij}^{M}), expenditure (e_i), and Hicksian elasticity (e_{ij}^{H}) estimates based on the formulas derived in Appendix A and evaluated at sample mean values. The own-price elasticity estimates are consistent with consumer theory and statistically significant. Further, own-price elasticities are unitary elastic only for fats/oils (-1.051) and cereals (-1.017) and fall in the range of -1.051 (for fats/oils) to -0.841 (for vegetables), which conforms to prior expectations given the degree of commodity aggregation. Income elasticities are estimated to be positive, significant, and inelastic for all food commodities (ranging from 0.683 for vegetables to 0.904 for fats/oils), while that for nonfood items is found to be 1.062. Zhen et al. (2014) and other studies report similar findings, which are consistent with the Engel's law.

Table 4. Parameter Estimates from the GEASI Expenditure Share Equations

Parameter	Meats	Veg.	Cereals	Eggs	Fats/Oil	Sugar	Dairy	Other
Pre-committed demand	21.904	0.029	69.896**	180.300***	12.262***	25.617**	30.314	0.003
	(16.653)	(32.293)	(28.865)	(58.400)	(2.041)	(10.293)	(98.453)	(29.896)
Intercept	0.098***	0.033***	0.049***	0.006***	0.006***	0.021***	0.046***	0.740***
	(0.001	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)
Real income (linear)	−0.109***	−0.106***	−0.069***	−0.013***	−0.005***	−0.030***	−0.132***	0.464***
	(0.030)	(0.008)	(0.014)	(0.002)	(0.002)	(0.007)	(0.011)	(0.057)
Real income (quadratic)	−0.025***	−0.002	−0.012***	0.000	−0.001***	−0.004***	−0.007***	0.051***
	(0.005)	(0.002)	(0.003)	(0.000)	(0.000)	(0.001)	(0.002)	(0.011)
Real income (cubic)	0.003	0.002**	0.002*	0.000**	0.000**	0.000	0.002**	−0.010
	(0.003)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.006)
Price meats	0.056***	0.002	0.018***	0.001	0.002***	0.016***	0.015***	−0.110***
	(0.013)	(0.003)	(0.004)	(0.001)	(0.001)	(0.002)	(0.003)	(0.021)
Veg. price		0.049***	0.016***	0.003***	0.001	0.002	0.012***	−0.084***
		(0.005)	(0.003)	(0.001)	(0.000)	(0.001)	(0.002)	(0.006)
Cereal price			−0.011	0.005***	0.004***	0.000	0.024***	−0.055***
			(0.009)	(0.001)	(0.001)	(0.002)	(0.003)	(0.011)
Egg price				0.000	−0.001*	0.000	0.002***	−0.010***
				(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
Fats/oils price					−0.003***	−0.002***	0.003***	−0.005***
					(0.001)	(0.000)	(0.001)	(0.001)
Sugar price						0.003	0.010***	−0.029***
						(0.005)	(0.002)	(0.005)
Dairy price							0.040***	−0.105***
							(0.007)	(0.008)
Other price								0.398***
								(0.024)

Notes: Standard errors are in parentheses. Single, double, and triple asterisks (*, **, ***) indicate parameter estimates that are statistically different from 0 at the 10%, 5%, and 1% significance levels, respectively.

Table 5. Marshallian Price and Income Elasticity Estimates from the GEASI System

Item	Meats	Veg.	Cereals	Eggs	Fats/Oil	Sugar	Dairy	Other	Income
Meats	−0.929***	0.006***	0.025***	0.002	0.003***	0.020***	0.021***	−0.031***	0.884***
	(0.016)	(0.003)	(0.004)	(0.001)	(0.001)	(0.002)	(0.004)	(0.012)	(0.032)
Veg.	0.036***	−0.841***	0.062***	0.011***	0.003	0.011***	0.050***	−0.014	0.683***
	(0.009)	(0.017)	(0.008)	(0.002)	(0.002)	(0.004)	(0.008)	(0.011)	(0.023)
Cereals	0.052***	0.038***	−1.017***	0.011***	0.009***	0.004	0.056***	−0.006	0.854***
	(0.008)	(0.006)	(0.019)	(0.001)	(0.001)	(0.004)	(0.006)	(0.012)	(0.030)
Eggs	0.034***	0.054***	0.085***	−0.997***	−0.007	−0.003	0.046***	0.002	0.786***
	(0.009)	(0.008)	(0.011)	(0.019)	(0.004)	(0.008)	(0.010)	(0.009)	(0.025)
Fats/oil	0.047***	0.012	0.073***	−0.008	−1.051***	−0.025***	0.061***	−0.011	0.904***
	(0.010)	(0.009)	(0.012)	(0.005)	(0.014)	(0.008)	(0.012)	(0.013)	(0.030)
Sugar	0.090***	0.012	0.008	−0.001	−0.007***	−0.981***	0.053***	−0.030***	0.856***
	(0.009)	(0.007)	(0.010)	(0.002)	(0.002)	(0.024)	(0.008)	(0.012)	(0.034)
Dairy	0.059***	0.035***	0.065***	0.007***	0.009***	0.027***	−0.899***	−0.015	0.712***
	(0.007)	(0.005)	(0.007)	(0.001)	(0.001)	(0.004)	(0.017)	(0.010)	(0.024)
Other	−0.021***	−0.013***	−0.010***	−0.002***	−0.001	−0.005***	−0.017***	−0.993***	1.062***
	(0.003)	(0.001)	(0.002)	(0.000)	(0.000)	(0.001	(0.001	(0.086)	(0.008)

Notes: Standard errors are in parentheses. Single, double, and triple asterisks (*, **, ***) indicate parameter estimates that are statistically different from 0 at the 10%, 5%, and 1% significance levels, respectively. The first column represents commodities with price change.

Table 6. Hicksian Elasticity Estimates from the GEASI System

Item	Meats	Veg.	Cereals	Eggs	Fats/Oil	Sugar	Dairy	Other
Meats	−0.846***	0.036***	0.067***	0.007***	0.008***	0.038***	0.062***	0.629***
	(0.014)	(0.003)	(0.004)	(0.001)	(0.001)	(0.002)	(0.004)	(0.023)
Veg.	0.100***	−0.818***	0.094***	0.015***	0.007***	0.026***	0.081***	0.496***
	(0.009)	(0.016)	(0.008)	(0.002)	(0.002)	(0.004)	(0.007)	(0.017)
Cereals	0.132***	0.066***	−0.977***	0.016***	0.014***	0.022***	0.095***	0.632***
	(0.008)	(0.006)	(0.018)	(0.001)	(0.001)	(0.004)	(0.006)	(0.022)
Eggs	0.108***	0.080***	0.122***	−0.992***	−0.003	0.013	0.082***	0.590***
	(0.009)	(0.008)	(0.011)	(0.019)	(0.004)	(0.008)	(0.010)	(0.019)
Fats/oil	0.132***	0.042***	0.115***	−0.003	−1.046***	−0.007	0.102***	0.664***
	(0.011)	(0.009)	(0.012)	(0.005)	(0.014)	(0.008)	(0.012)	(0.022)
Sugar	0.170***	0.041***	0.049***	0.004	−0.002	−0.963***	0.092***	0.609***
	(0.009)	(0.007)	(0.010)	(0.002)	(0.002)	(0.024)	(0.008)	(0.024)
Dairy	0.126***	0.059***	0.099***	0.011***	0.013***	0.042***	−0.867***	0.517***
	(0.007)	(0.005)	(0.007)	(0.001)	(0.001)	(0.004)	(0.016)	(0.017)
Other	0.079***	0.022***	0.040***	0.005***	0.005***	0.017***	0.032***	−0.200***
	(0.003)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(3.386)

Notes: Standard errors are in parentheses. Single, double, and triple asterisks (*, **, ***) indicate parameter estimates that are statistically different from 0 at the 10%, 5%, and 1% significance levels, respectively. The first column represents commodities with price change.

Table 7. Difference between Marshallian and Income Elasticities from the EASI and GEASI Models

	Uncompensated Own- and Cross-Price Elasticities								
Commodity	**Meats**	**Veg.**	**Cereal**	**Eggs**	**Fats/Oil**	**Sugar**	**Dairy**	**Other**	**Income Elasticity**
Meats	0.016***	0.000	−0.002***	0.000	0.000	−0.001*	−0.001*	0.002**	−0.014***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.004)
Veg.	−0.002*	−0.003***	0.000	0.003***	−0.002***	−0.001	−0.003***	0.001	0.008
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.008)
Cereal	−0.003***	0.001	**0.031*****	−0.001	−0.001*	−0.002***	0.002***	0.001	−**0**.030**
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.015)
Eggs	0.009***	0.022***	0.002*	**0.126*****	−0.022***	−0.005***	0.018***	−0.007***	−**0**.144***
	(0.001)	(0.001)	(0.001)	(0.001	(0.000)	(0.000)	(0.001)	(0.001)	(0.016)
Fats/oil	0.008***	−0.008***	−0.003***	−0.024***	**0.125*****	−0.001	−0.002	0.024***	−**0.120*****
	(0.001)	(0.001)	(0.001)	(0.000))	(0.001)	(0.000)	(0.001)	(0.001)	(0.013)
Sugar	−0.002*	−0.001*	−0.004***	−0.002***	−0.001	**0.033*****	0.000	0.002*	−**0.027*****
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.010)
Dairy	−0.003***	−0.002***	0.000	0.002***	−0.001	−0.001	−0.002*	0.000	0.006**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.003)
Other	−0.002***	0.000	−0.002***	−0.001	−0.001*	−0.001*	0.000	0.000	0.006
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.068)	(0.022)

Notes: Standard errors are in parentheses. Single, double, and triple asterisks (*, **, ***) indicate parameter estimates that are statistically different from 0 at the 10%, 5%, and 1% significance levels, respectively. The first column represents commodities with price change.

Comparative Analysis and Pre-Commitment Bias in Elasticity Estimates

To examine the effects of omitting pre-committed demand on estimated elasticities, we present a comparative analysis of the EASI and GEASI models. Specifically, we conduct a paired t-test by computing the difference between the respective elasticity estimates and obtaining the corresponding standard errors based on $\sqrt{\sigma_{easi}^2/N + \sigma_{geasi}^2/N}$, where σ_{easi} and σ_{geasi} represent the parameter standard errors from the EASI and GEASI models, respectively, and N is sample size. Ignoring pre-commitments can lead to biases in the estimated Marshallian and income elasticities (Table 7).[5] Specifically, the bias is statistically significant for the great majority of own-price, cross-price, and income elasticities; however, it is more pronounced for the commodities for which consumer behavior is found to be nondiscretionary over a certain portion of the demand curve (i.e., cereals, eggs, fats/oils, and sugar). The EASI estimates appear less elastic vis-à-vis the respective GEASI measures for the commodities with statistically significant pre-committed quantities (t_i) because the unaccounted low elasticity over the nondiscretionary portion of actual demand tends to be wrongly attributed by the EASI model to the entire estimated demand curve, thus generating inaccurate estimates of economic effects (Rowland, Mjelde, and Dharmasena, 2017).

Summary and Conclusions

This study contributes to the literature both methodologically and empirically. From the methodological perspective, it presents a solution to the problems associated with pre-commitment bias in demand estimations. Specifically, it introduces the GEASI demand model, which allows us to estimate Marshallian, Hicksian, and expenditure elasticities that promise to provide more accurate reflections of consumer price and income responsiveness in the presence of pre-committed demand (while maintaining all of the advantages of the EASI specification over its predecessors). From the empirical perspective, the significance of pre-commitment bias is illustrated in the context of consumer food preferences and consumption patterns in Russia using novel household food expenditure panel data obtained from the Russian Federation's FSSS. Specifically, we use the Marshallian own-price elasticity estimates from the EASI and GEASI specifications and projected food prices changes for Russia (Organisation for Economic Cooperation and Development and Food and Agriculture Organization of the United Nations, 2015) to illustrate the practical implications of the pre-commitment bias in price-induced consumption response. Domestic food prices have been on the rise following the 2014 embargo imposed by Russia on imports of meat, dairy, fruit, and vegetables from the European Union, United States, Canada, Australia, and Norway (Organisation for Economic Cooperation and Development and Food and Agriculture Organization of the United Nations, 2015).[6] Given that the Russian government extended the import ban until the end of 2017, food prices rose an average of 10% annually over 2013–2017 (FSSS) and are expected to stay on a rising trajectory in the near future (Michalopoulos, 2016). Using these price forecasts and the estimated own-price elasticities, we find that ignoring pre-commitments considerably understates the predicted reductions in the consumption of these commodities in 2020. The estimated monetary equivalent of the bias ranges from $76 million for meats to $130 million for eggs.

The estimated elasticities uniquely extend the empirical literature on food demand in Russia in that both potential pre-commitments and unobserved provincial heterogeneity have been considered. The empirical findings offer valuable and timely insights into the food demand structure in Russia and can be useful in informing public policy decisions in light of Russia's increasing global role.

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[5] The Hicksian elasticity estimates and the bias stemming from the omission of pre-commitments are not presented to preserve space but are available upon request.

[6] These products collectively account for about two-thirds of total food expenditures in Russia (Organisation for Economic Cooperation and Development and Food and Agriculture Organization of the United Nations, 2015).

The distinct advantages of the GEASI model create a potential for a wide range of empirical applications, such as examining consumer response to changing food structures stemming from various economic and social reforms. This makes the approach useful for researchers and policy makers in a range of disciplines, including agricultural economics, international development, health and nutrition, and trade.

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Appendix A: Derivation of the Expenditure, Hicksian, and Marshallian Elasticity Formulas for the GEASI Model

Expenditure Elasticities

To develop the expenditure elasticities for the GEASI model, we first derive the general formula for the expenditure elasticity using the definition of expenditure shares $w_i = \frac{p_i q_i}{X}$, which is rearranged to $q_i = \frac{w_i X}{p_i}$:

(A1)
$$\frac{\partial q_i}{\partial \ln X} = \frac{1}{p_i}\left[\frac{\partial X}{\partial \ln X} w_i + X\frac{\partial w_i}{\partial \ln X}\right] = \frac{1}{p_i}\left[X w_i + X\frac{\partial w_i}{\partial \ln X}\right];$$

(A2)
$$\frac{\partial q_i}{\partial \ln X} = \frac{\partial e^{\ln q_i}}{\partial \ln X} = q_i \frac{\partial \ln q_i}{\partial \ln X};$$

(A3)
$$\begin{aligned}\frac{\partial \ln q_i}{\partial \ln X} &= \frac{1}{q_i}\frac{\partial q_i}{\partial \ln X} = \frac{1}{q_i}\left[\frac{1}{p_i}\left[X w_i + X\frac{\partial w_i}{\partial \ln X}\right]\right]\\ &= \frac{1}{p_i q_i}\left[X w_i + X\frac{\partial w_i}{\partial \ln X}\right] = \frac{w_i}{p_i q_i}X + \frac{X}{p_i q_i}\frac{\partial w_i}{\partial \ln X}\\ &= \frac{1}{X}X + \frac{1}{w_i}\frac{\partial w_i}{\partial \ln X} = \frac{1}{w_i}\frac{\partial w_i}{\partial \ln X} + 1;\end{aligned}$$

where we use the fact that $\frac{w_i}{p_i q_i} = \frac{p_i q_i}{X}\frac{1}{p_i q_i} = \frac{1}{X}$ and $\frac{X}{p_i q_i} = \frac{1}{w_i}$.

We then obtain the GEASI expenditure elasticities by substituting $\frac{\partial w_i}{\partial \ln X}$ (derived from the GEASI model) into equation (A3). To this end, we utilize the respective GEASI expenditure share equations (see equation 9):

(A4)
$$w_i = \frac{t_i p_i}{X} + \left[1 - \frac{t'p}{X}\right]\left(\sum_{r=0}^{L}\beta_{ir}\left(\ln\left(X - t'p\right) - w'\ln p\right)^r + \sum_{k=1}^{J}\alpha_{ik}\ln p_k\right) + \varepsilon_i.$$

Let $A_1 = \frac{t_i p_i}{X}$, $A_2 = \left[1 - \frac{t'p}{X}\right]$, and $A_3 = \left(\sum_{r=0}^{L}\beta_{ir}(\ln(X - t'p) - w'\ln p)^r + \sum_{k=1}^{J}\alpha_{ik}\ln p_k\right)$. The derivative of the expenditure shares with respect to log expenditure (i.e., $\frac{\partial w_i}{\partial \ln X}$) is

(A5)
$$\frac{\partial w_i}{\partial \ln X} = \frac{\partial A_1}{\partial \ln X} + \frac{\partial A_2}{\partial \ln X}A_3 + \frac{\partial A_3}{\partial \ln X}A_2;$$

(A6)
$$\frac{\partial (A_1)}{\partial \ln X} = \frac{\partial (t_i p_i / X)}{\partial \ln X} = t_i p_i \frac{\partial (1/X)}{\partial \ln X} = t_i p_i\left(-X^{-2}X\right) = -\frac{t_i p_i}{X};$$

(A7)
$$\frac{\partial (A_2)}{\partial \ln X} = \frac{\partial\left(1 - \frac{t'p}{X}\right)}{\partial \ln X} = \frac{t'p}{X};$$

(A8)
$$\frac{\partial (A_3)}{\partial \ln X} = \left[\sum_{r=0}^{L} r\beta_{ir}\left(\ln\left(X - t'p\right) - w'\ln p\right)^{r-1} + \sum_{k=1}^{J}\alpha_{ik}\ln p_k\right]\left[\frac{X}{X - t'p} - \left(\frac{\partial w}{\partial \ln X}\right)'\ln p\right];$$

where $\left(\frac{\partial w}{\partial \ln X}\right)' = \left(\frac{\partial w_1}{\partial \ln X}, \ldots, \frac{\partial w_i}{\partial \ln X}, \ldots, \frac{\partial w_N}{\partial \ln X}\right)'$. Substituting equations (A6)–(A8) into equation (A5) results in

$$\frac{\partial w_i}{\partial \ln X} = -\frac{t_i p_i}{X} + \frac{t'p}{X}A_3$$

$$\text{(A9)} \qquad + \left[\sum_{r=0}^{L} r\beta_{ir}\left(\ln\left(X - t'p\right) - w'\ln p\right)^{r-1} + \sum_{k=1}^{J} \alpha_{ik}\ln p_k\right]\left[\frac{X}{X - t'p} - \left(\frac{\partial w}{\partial \ln X}\right)'\ln p\right]A_2$$

$$= -\frac{t_i p_i}{X} + \frac{t'p}{X}A_3 + A_4\left[\frac{X}{X - t'p} - \left(\frac{\partial w}{\partial \ln X}\right)'\ln p\right]A_2,$$

where $A_4 = \left[\sum_{r=0}^{L} r\beta_{ir}(\ln(X - t'p) - w'\ln p)^{r-1} + \sum_{k=1}^{J}\alpha_{ik}\ln p_k\right]$.

Equation (A9) represents a $(J \times J)$ system of implicit equations, with $\frac{\partial w_i}{\partial \ln X}$, $\forall\ i = 1,\ldots,J$ appearing on both sides of each equation. Using matrix algebra, we solve the system in equation (A9) for $\frac{\partial w_i}{\partial \ln X}$ as follows:

$$\text{(A10)} \qquad \frac{\partial w}{\partial \ln X} = \left[I_J + \left(\left(\frac{X - t'p}{X}\right) \times \boldsymbol{B}\right)(\ln p)'\right]^{-1}\left[\frac{t \circ p}{X} + \frac{t'p}{X}A_3 + \boldsymbol{B}\right],$$

where $\boldsymbol{B}$ is a $(J \times 1)$ vector with its jth element equaling $(\sum_{r=1}^{L} r\beta_{il}y^{r-1})$ and A_3 is as previously defined (i.e., $A_3 = \left(\sum_{r=0}^{L}\beta_{ir}(\ln(X - t'p) - w'\ln p)^r + \sum_{k=1}^{J}\alpha_{ik}\ln p_k\right)$).

Finally, we obtain the GEASI expenditure elasticity formula by substituting equation (A10) into equation (A3):

$$\text{(A11)} \qquad \boldsymbol{E} = (diag(\boldsymbol{W}))^{-1}\left[\left[I_J + \left(\left(\frac{X - t'p}{X}\right) \times \boldsymbol{B}\right)(\ln p)'\right]^{-1}\left[\frac{t \circ p}{X} + \frac{t'p}{X}A_3 + \boldsymbol{B}\right]\right] + 1_J,$$

where $\boldsymbol{E}$ is the $(J \times 1)$ expenditure elasticity vector with e_i denoting its jth element, $\boldsymbol{W}$ is the $(J \times 1)$ vector of observed commodity budget shares, $\ln p$ is the $(J \times 1)$ vector of log prices, and $\mathbf{1}_J$ is a $(J \times 1)$ vector of ones.

Hicksian and Marshallian Elasticities

We derive the GEASI Hicksian elasticities by deriving $\frac{\partial w_i}{\partial \ln p_j}$ for our more general model and substituting back into the Hicksian elasticity formula provided in general terms:

$$\text{(A12)} \qquad e_{ij}^{H} = \frac{1}{w_i}\left[\frac{\partial w_i}{\partial \ln p_j}\right] + w_j - \delta_{ij},\ \forall\ i,j = 1,\ldots,J.$$

Using the GEASI expenditure share equations in equation (9), we obtain

$$\text{(A13)} \qquad \frac{\partial w_i}{\partial \ln p_j} = -\frac{t_j p_j}{X}A_3 + \left[1 - \frac{t'p}{X}\right]\alpha_{ij},\ \forall\ i \neq j;$$

$$\text{(A14)} \qquad \frac{\partial w_i}{\partial \ln p_i} = \frac{t_i p_i}{X} - \frac{t_i p_i}{X}A_3 + \left[1 - \frac{t'p}{X}\right]\alpha_{ij}.$$

Equations (A13) and (A14) are substituted into equation (A12) to yield the GEASI Hicksian elasticity formulas:

$$\text{(A15)} \qquad e_{ij}^{H} = \frac{1}{w_i}\left[\frac{t_i p_i}{X} - \frac{t_i p_i}{X}A_3 + \left[1 - \frac{t' p}{X}\right]\alpha_{ij}\right] + w_j - \delta_{ij},\ \forall\, i, j = 1, \ldots, J.$$

Marshallian price elasticities (e_{ij}^{M}) are obtained from the Slutsky equation, $e_{ij}^{M} = e_{ij}^{H}\frac{\alpha_{ij}}{w_i} - w_j e_i.$:

$$\text{(A16)} \qquad e_{ij}^{M} = \left[\left[\frac{t_i p_i}{X} - \frac{t_i p_i}{X}A + \left[1 - \frac{t' p}{X}\right]\alpha_{ij}\right] + (w_j - \delta_{ij})w_i\right]\frac{\alpha_{ij}}{w_i^2} - w_j e_i.$$