RESEARCH ARTICLE

Rational Choices and Welfare Changes in Philippine Family Energy Demand: Evidence from Family Income and Expenditure Surveys

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This study found Philippine family demands for (1) electricity, (2) gas and liquid fuels, (3) solid fuels, (4) food, and (5) others—based on *Family Income and Expenditure Surveys* (FIES) in 2009, 2012, and 2015—are *rational* (i.e., expenditure-minimizing). Specifically, all own-price elasticities are negative (downward sloping demand curves). Cross-price elasticities between (1), (2), and (3) are positive (substitutes) while cross-price elasticities of (1), (2), and (3) with (4) or (5) are mostly negative (generally complements). Income elasticities are positive (normal goods), except for (3), comprising "fuelwood, charcoal, and biomass residues" that are consumed less at higher incomes (inferior goods). These elasticities yield a Hicks-Slutsky substitution matrix that is *symmetric* and *negative semi-definite*—the necessary and sufficient conditions for expenditure minimization—a finding unprecedented in a Philippine demand study. These results validate computing *compensating variation* (CV) and *equivalent variation* (EV) that are changes in compensated incomes for restoring welfare after prices change. During 2009-2015, the overall Consumer Price Index increased 3.08 percent annually to which energy price increases contributed 0.23 percentage points, about equal to mid-point CV and EV estimates of welfare losses ranging 0.18 to 0.30 percent of 2009 total expenditures. However, improved household energy end-use efficiency by "waste" reduction compensated the above welfare losses even without increasing total expenditures or investing in efficiency improvements.

Keywords: Expenditure minimization, energy demand, end-use efficiency, welfare change

JEL classification: C43, D11, D13

This study examines Philippine family expenditures on five commodity groups, namely, *electricity*, *gas and liquid fuels*, *solid fuels*, *food*, and *other* in a complete demand framework to determine if these expenditures reflect rational choices in the sense of consistency with utility maximization or, by duality, with expenditure minimization.[1] Moreover, this study determines the money equivalent of welfare changes—measured by CV and EV—due to changes in prices of the above commodities assuming no changes in expenditures or income while prices change.

The focus is on demand for "energy" goods, e.g., electricity, gas and liquid fuels, and solid fuels. Since these goods are consumed to serve an end-use, e.g., cooking, it appears sensible to include "food." But to complete the demand framework while keeping it simple, "other" is included to cover all other goods. Altogether, they exhaust total expenditures in each of three rounds of FIES in 2009, 20012, and 2015.[2]

This study is organized as follows. Section 2 presents, as background, FIES expenditures on the above five commodity groups by different income levels and poverty incidence. Section 3 presents the specification of the *generalized logit model of expenditure shares* (GLMES) (Dumagan & Mount, 1993, 1996; Rothman, Ho, & Mount, 1994) and the results of the estimation of GLMES "household" and "per capita" demand systems for the above commodities. Section 4 presents the **RE**versible **S**econd-**OR**der **T**aylor (RESORT) welfare change algorithm (Dumagan & Mount, 1997) and the computed CV and EV from price changes—focusing on energy prices—during 2009-2012, 2012-2015, and 2009-2015 based on the estimated GLMES demand system. Section 5 examines welfare implications of the countervailing effects of energy efficiency improvements against increases in energy prices and then explores evidence of such improvements from FIES and *Household Energy Consumption Survey*. Section 6 concludes this study.

Background of this study

Expenditure patterns are manifestations of purchasing power and, thus, are related to trends in income levels and poverty incidence (Table 1).[3]

During 2009-2015, household and per capita incomes increased—household income by 4.4 percent and per capita income by 4.8 percent per year—while poverty incidence decreased from 26 percent to under 22 percent for the whole population.[4] In 2009, almost 77 percent of income came from non-agriculture sources and this share increased to 81 percent in 2015. This indicates a widening diversity of income sources and, thus, a lessening of risks to income losses.

The increase in income, decrease in poverty incidence, and widening diversity in income sources indicate a rise in purchasing power. This is reflected by the rise of household and per capita expenditures (Table 2), 3.4 percent and 3.8 percent per year respectively, during 2009-2015.[5]

Around 50 percent of expenditures were on food; about 43 percent were spent on others (not elsewhere classified or N.E.C.); and under 7 percent were spent on the energy goods, comprising electricity, gas and liquid fuels, and solid fuels. Gas and liquid fuels include *liquid petroleum gas*, *kerosene*, *gasoline*, and *diesel*. Solid fuels include *fuelwood*, *charcoal*, and *biomass residues*.[6]

Similar patterns of expenditures on the above commodity groups by income class are shown by FIES in 2009, 2012, and 2015. Thus, FIES 2015 pattern of expenditures should suffice to represent the similarities (Table 3).

Table 1. *Income, source of income, and poverty incidence*

Year	Total income (PhP)		Income share (%)		Poverty incidence (%)	
	Household	Per capita	Agriculture	Non-agriculture	Household	Population
2009	206,179.3	51,168.7	23.2	76.8	20.9	26.2
2012	234,614.9	58,583.3	21.1	78.9	19.9	25.0
2015	266,962.3	67,622.1	19.0	81.0	16.6	21.5

Source: Philippine Statistics Authority, Family Income and Expenditure Survey

Table 2. *Expenditure and Expenditure Shares*

Year	Total expenditures (PhP)		Expenditure share (%)				
	Household	Per capita	Electricity	Gas and liquid fuels	Solid fuels	Food	Others, N.E.C.
2009	175,551.0	43,237.5	3.2	1.2	1.9	50.8	42.9
2012	192,540.0	47,751.6	3.8	1.3	2.1	51.2	41.6
2015	214,816.2	54,190.9	3.6	1.0	2.0	49.3	44.2

Source: Philippine Statistics Authority, Family Income and Expenditure Survey

Table 3. *Expenditures, expenditures shares, and poverty incidence by per capital income decile in 2015*

Per capita income decile	Total expenditures (PhP)		Expenditure share (%)					Poverty incidence (%)	
	Household	Per capita	Electricity	Gas and Liquid fuels	Solid fuels	Food	Others, N.E.C.	Household	Population
All households	**214,816.2**	**54,190.9**	**3.6**	**1.0**	**2.0**	**49.3**	**44.2**	**16.6**	**21.5**
First	89,156.9	14,736.5	1.7	0.6	4.2	63.7	29.8	100.0	100.0
Second	110,219.2	20,372.4	2.2	0.6	3.5	60.1	33.6	66.2	67.4
Third	121,979.0	24,461.5	2.7	0.7	3.1	57.7	35.8	0.0	0.0
Fourth	139,928.5	29,491.9	3.0	0.8	2.6	55.0	38.5	0.0	0.0
Fifth	160,788.9	35,397.6	3.5	1.0	2.1	52.2	41.2	0.0	0.0
Sixth	188,514.3	42,619.5	3.9	1.1	1.6	49.2	44.1	0.0	0.0
Seventh	216,957.2	51,626.3	4.2	1.3	1.2	46.5	46.8	0.0	0.0
Eight	260,049.6	64,778.3	4.6	1.4	0.8	42.1	51.1	0.0	0.0
Ninth	326,248.1	87,654.9	4.8	1.3	0.4	37.6	55.8	0.0	0.0
Tenth	534,416.8	170,802.6	4.9	1.0	0.2	28.9	65.0	0.0	0.0

Source: Philippine Statistics Authority, Family Income and Expenditure Survey.
Note: Poverty incidence is based on national per capita income threshold.

Table 4. *Consumer price indexes (2012=100)*

	2009	2012	2015	2009-2015 annual % change
All Items	89.2	100.0	107.0	3.08
Electricity (ND)	75.5	100.0	96.9	4.26
Gas and liquid fuels	72.1	100.0	77.0	1.11
Solid fuels (ND)	84.8	100.0	111.0	4.59
Food	88.8	100.0	110.9	3.78
Others	91.1	100.0	106.1	2.56

Source: Philippine Statistics Authority, Family Income and Expenditure Survey.

The poorest households or individuals (i.e., those in the first income decile) spend the largest share of 63.7 percent on food. They also have the largest share of 4.2 percent spent on solid fuels but the lowest 1.7 percent spent on electricity. It is interesting that the expenditure share of solid fuels uniformly decreases while the expenditure share of electricity uniformly increases as incomes rise (i.e., from the first to the tenth decile). Moreover, the expenditure share of gas and liquid fuels also appears to rise with income. Thus, there is a discernible shift in energy use of households and individuals from solid fuels to electricity and/or gas and liquid fuels as incomes rise.

To complement the above changes in expenditures, FIES data show changes in prices (Table 4). All prices increased from 2009 to 2012 and also from 2012 to 2015 except for the *fall* in prices of electricity and those of gas and liquid fuels. However, all prices rose on average for the entire period 2009-2015.

The overall consumer price indexes show that prices of "all items" rose 3.1 percent per year—representing the national average annual inflation rate—from 2009 to 2015 (see footnote 3 for the formula). However, prices of three commodity groups rose faster than the national average. Among these three, prices of solid fuels had the highest annual increase (4.6 percent) followed by electricity prices (4.3 percent) and food prices (3.8 percent). The remaining two commodity groups had prices rising slower than the national average, shown by prices of gas and liquid fuels rising the slowest (1.1 percent) and prices of others rising less slow (2.6 percent).

From the above background, this study proceeds to implement the GLMES demand system.

The generalized logit model of expenditure shares (GLMES)

The GLMES demand system (Dumagan & Mount, 1993, 1996; Rothman, Ho, & Mount, 1994) embodies the restrictions of utility maximization or expenditure minimization although it is *not* derived from an indirect utility or expenditure function.

Specification of GLMES

Let the prices and corresponding quantities at time t be p_i^t and x_i^t representing $i = 1,2, ..., n$ commodities. Also, let income or expenditure be I^t. Therefore, the expenditure share is

$$w_i^t = \frac{p_i^t x_i^t}{I^t} \quad ; \quad 1 \geq w_i^t \geq 0 \quad ; \qquad (1)$$
$$\sum_{i=1}^{n} w_i^t = 1 \quad ; \quad I^t = \sum_{i=1}^{n} p_i^t x_i^t \ .$$

Non-negativity and additivity of expenditure shares

To satisfy non-negativity of each expenditure share and their additivity in (1), define a logit specification,

$$w_i^t = \frac{e^{f_i^t}}{e^{f_1^t} + e^{f_2^t} + \cdots + e^{f_n^t}} = \frac{e^{f_i^t}}{\sum_{j=1}^{n} e^{f_j^t}} \ . \qquad (2)$$

The right-hand side of (2) is the "logit" specification—thus, explains the name *generalized logit model of expenditure shares*—that forces expenditure share to satisfy (1) regardless of the functional form of f_i^t. However, f_i^t is defined below as a function of p_i^t and I^t that satisfies the other theoretical restrictions.

Zero-degree homogeneity in prices and income

By equating (1) to (2), the demand function for a good may be solved from

$$\ln x_i^t = -\ln\left(\frac{p_i^t}{I^t}\right) + f_i^t - \ln \sum_{j=1}^{n} e^{f_j^t} \ ; \qquad (3)$$

$$f_i^t = \alpha_{i0} + \sum_{j=1}^{n} \alpha_{ij}\, \theta_{ij}^{t-1} \ln\left(\frac{p_j^t}{p_i^t}\right) + \beta_i \ln\left(\frac{I^t}{p_i^t}\right) . \qquad (4)$$

From (3) and (4), proportional changes in prices and income will not change $\ln x_i^t$ and x_i^t. This is equivalent to zero-degree homogeneity in prices and income of x_i^t so that the sum of price and income elasticities equals zero.

It may first be noted that symmetry of Hicksian cross-price effects in GLMES holds for any set of budget shares. Thus, for infinitesimal changes in shares, the time lag in the original data, t - 1, may be replaced by an infinitesimal lag, t - δ, where δ approaches zero. This means that the elasticities may be computed conditionally by using the shares evaluated at time t, i.e., using the current value in place of the lagged value of θ in (4). In this case, omitting the time superscript to simplify notation, symmetry requires

$$\alpha_{ik} = \alpha_{ki} \quad ; \quad w_i \theta_{ik} = w_k \theta_{ki} \quad ;$$
$$\theta_{ik} = \frac{w_k^{\gamma}}{w_i^{1-\gamma}} \quad ; \quad \theta_{ki} = \frac{w_i^{\gamma}}{w_k^{1-\gamma}} \ . \qquad (5)$$

Given (5), the GLMES ordinary price and income elasticities in (3) and (4) become

$$E_{ii} = \frac{\partial x_i}{\partial p_i}\frac{p_i}{x_i} = -1 - \sum_{k=1}^{n} \alpha_{ik}\theta_{ik} - (1 - w_i)\beta_i$$
$$= -1 - \sum_{k=1}^{n} \alpha_{ik}\theta_{ik} - \beta_i + w_i\beta_i\ ; \tag{6}$$

$$E_{ik} = \frac{\partial x_i}{\partial p_k}\frac{p_k}{x_i} = \alpha_{ik}\theta_{ik} + w_k\beta_k\ ; \tag{7}$$

$$E_{iI} = \frac{\partial x_i}{\partial I}\frac{I}{x_i} = 1 + (1 - w_i)\beta_i - \sum_{k=1}^{n} w_k\beta_k\ . \tag{8}$$

It can be verified that any good is homogeneous of degree zero in prices and income by

$$\sum_{j=1}^{n} E_{ij} + E_{iI} = 0\ . \tag{9}$$

Symmetry of compensated cross-price effects

Hicksian compensated demand, x_i^h, is related to Marshallian ordinary demand, $x_{i,}$ by the Slutsky equation

$$\frac{\partial x_i^h}{\partial p_k} = \frac{\partial x_i}{\partial p_k} + x_k\frac{\partial x_i}{\partial I}\ . \tag{10}$$

The expression in (10) is the compensated price effect, which is an element of the HSSM. It can be expressed in terms of ordinary price and income elasticities by

$$\frac{\partial x_i^h}{\partial p_k} = \frac{I}{p_i p_k}(E_{ik}w_i + w_i w_k)E_{iI} \quad ;$$
$$\frac{\partial x_k^h}{\partial p_i} = \frac{I}{p_k p_i}(E_{ki}w_k + w_k w_i)E_{kI}\ . \tag{11}$$

Therefore, from (5) to (11), the GLMES compensated price effects are

$$\frac{\partial x_i^h}{\partial p_i} = -\frac{I}{p_i^2}\left[w_i - w_i^2 + \sum_{k=1}^{n}\alpha_{ik}(w_i w_k)^{\gamma} + \left(w_i - 2w_i^2\right)\beta_i + w_i^2\sum_{j=1}^{n} w_j\beta_j\right]\ ; \tag{12}$$

$$\frac{\partial x_i^h}{\partial p_k} = \frac{I}{p_i p_k}\left[w_i w_k + \alpha_{ik}(w_i w_k)^{\gamma} + w_i w_k(\beta_i + \beta_k) - w_i w_k\sum_{j=1}^{n} w_j\beta_j\right]\ ; \tag{13}$$

$$\frac{\partial x_k^h}{\partial p_i} = \frac{I}{p_k p_i}\left[w_k w_i + \alpha_{ki}(w_k w_i)^{\gamma} + w_k w_i(\beta_k + \beta_i) - w_k w_i\sum_{j=1}^{n} w_j\beta_j\right]\ . \tag{14}$$

From (13) and (14), GLMES has a symmetric HSSM that is not necessarily NSD. However, as shown later (Table 7), the estimated HSSM in this study is NSD that was also true in earlier GLMES applications.[7]

Application of GLMES to Philippine FIES 2009, 2012, and 2015

By defining a ratio of expenditure shares, w_i^t/w_n^t where w_n^t is the share of a common reference good, (2) yields

$$\ln\left(\frac{w_i^t}{w_n^t}\right) = f_i^t - f_n^t \quad ; \quad i = 1,2,\cdots,n-1\ . \tag{15}$$

For symmetry in (5), lagged shares are replaced by current shares in (4) so that GLMES from (15) is a non-linear system of expenditure shares that is linear in parameters given by

$$\ln\left(\frac{w_i^t}{w_n^t}\right) = f_i^t - f_n^t = \alpha_{in}^* + \sum_{j=1}^{n}\alpha_{ij}\,\theta_{ij}^t\ln\left(\frac{p_j^t}{p_i^t}\right) - \sum_{j=1}^{n}\alpha_{nj}\,\theta_{nj}^t\ln\left(\frac{p_j^t}{p_n^t}\right) + \beta_i\ln\left(\frac{I^t}{p_i^t}\right) - \beta_n\ln\left(\frac{I^t}{p_n^t}\right) \quad ;$$
$$\alpha_{in}^* = \alpha_{i0} - \alpha_{n0}\ . \tag{16}$$

There are n = 5 commodity groups covering (1) electricity, (2) gas and liquid fuels, (3) solid fuels, (4) food, and (5) others. Letting the expenditure share of group #5 as the common denominator, (16) yields four equations defined by Equations 1, 2, 3, and 4 that are written out in Appendix A of this paper.

The data cover expenditures of around forty thousand households spread over seventeen regions in FIES in 2009, 2012, and 2015. Two versions were estimated depending on the consumer decision making unit (DMU). In one, the DMU is the household in which case the income variable, I^t, is *household* total expenditures. In the other, the DMU is an individual so that I^t is *per capita* total expenditures. However, prices are the same since market prices are not differentiated between households and individuals. Also, expenditure shares by commodity are the same because total expenditures for all households must equal total expenditures for all individuals. That is, if E_i^t is total expenditures on commodity i and E^t is the overall total, then if N is the number of households or the number of individuals,

$$E^t = \sum_{i=1}^{n} E_i^t \quad ; \quad \frac{E^t}{N} = \frac{1}{N}\sum_{i=1}^{n} E_i^t \quad ; \qquad (17)$$
$$1 = \sum_{i=1}^{n}\left(\frac{E_i^t}{E^t}\right) = \sum_{i=1}^{n} w_i^t \ .$$

Four GLMES versions of the household model and of the per capita model were estimated (Appendix B). Model 1 had neither year nor region fixed effects; Model 2 had only year fixed effects; Model 3 had only region fixed effects; and Model 4 had both year and region fixed effects. Model 4 is preferrable because it is able to account for shocks common across regions within each year, e.g., effect of the 2008-2009 Global Financial Crisis, and also for time-invariant unobserved characteristics among regions, e.g., base prices used to normalize regional consumer price indices.

Model selection is based on log-likelihood and Bayesian information criterion (BIC) goodness-of-fit tests. From the estimation results, Model 4 among household models and Model 4 among per capita models had the *highest* log-likehood and *lowest* BIC values and, therefore, are the *preferred* models. The parameters estimated by the latter models are presented in Table 5.

The parameters β_1, β_2, β_3, and β_4 are each unique in their corresponding Equations 1 to 4 but β_5 is common in all four. Given these features and the cross-equation symmetry constraint that $a_{ij} = a_{ji}$, there are fifteen unique slope parameters.

Consistency between household and per capita models

Although the prices and expenditure shares are the same, the household and per capita models yield different parameter estimates because the *level* of total expenditures differs between a typical household and a typical individual. However, if households and individuals are consistently "rational," the parameters for the same commodity may differ in size but not in sign. This turned out to be the case (Table 5) where the signs of all parameters of the household and per capita models are consistently the same, although their absolute values are different.

Table 5. *GLMES parameter estimates*

	Household model	Per capita model
$\alpha_{12} = \alpha_{21}$	0.0058	0.0122
	(0.0056)	(0.0259)
$\alpha_{13} = \alpha_{31}$	0.0189 **	0.0959 ***
	(0.0087)	(0.0338)
$\alpha_{14} = \alpha_{41}$	-0.0266	-0.0561
	(0.0196)	(0.0475)
$\alpha_{15} = \alpha_{51}$	-0.0435 *	-0.1082 **
	(0.0252)	(0.0547)
$\alpha_{23} = \alpha_{32}$	0.0238 ***	0.1167 ***
	(0.0079)	(0.0365)
$\alpha_{24} = \alpha_{42}$	0.0059	0.0040
	(0.0118)	(0.0319)
$\alpha_{25} = \alpha_{52}$	-0.0274 **	-0.0745 **
	(0.0121)	(0.0319)
$\alpha_{34} = \alpha_{43}$	-0.0050	-0.0384
	(0.0185)	(0.0579)
$\alpha_{35} = \alpha_{53}$	0.0530 *	0.0633
	(0.0277)	(0.0738)
$\alpha_{45} = \alpha_{54}$	-0.4073 ***	-0.4629 ***
	(0.1241)	(0.1736)
β_1	0.4755 *	0.5325 **
	(0.2457)	(0.2631)
β_2	0.4860 **	0.6352 ***
	(0.2015)	(0.2443)
β_3	-1.3727 ***	-0.9270 ***
	(0.3402)	(0.3237)
β_4	0.1633	0.2847
	(0.2542)	(0.2686)
β_5	0.6748 **	0.7333 ***
	(0.2639)	(0.2793)
γ	0.27	0.44

*Source: Author's estimates in Appendix B. Note that *,**,*** denote statistical significance at the 10, 50 and 1% alpha-levels, respectively. Figures in parenthesis are standard errors. The subscripts refer to commodity groups 1 - electricity, 2 - gas and liquid fuels, 3 - solid fuels, 4 - food, and 5 - others not elsewhere classified. Moreover, the last parameter γ--which appears in the symmetry restriction in equation (5)--was estimated by grid search for the value that maximizes the log-likelihood.*

Consistency of elasticity estimates with theoretical expectations[8]

The consistency in signs of parameters between the household and per capita models translate over to consistency in signs of their price and income elasticities (Table 6).

In both models, the own-price elasticities—shown in the main diagonal of the tables—are *all* negative. Therefore, the individual demand curves are all downward-sloped as expected in theory. The income elasticities are positive for electricity, gas and liquid fuels, food, and other goods but negative for solid fuels. That is, the first four are normal goods that are consumed more as incomes rise. In contrast, solid fuels—which comprise fuelwood, charcoal, and biomass residues—are inferior goods that are consumed less as incomes rise. These signs are consistent with the pattern of expenditure shares and income levels (Table 3) where expenditure shares of electricity, gas and liquid fuels, food, and other goods tend to be higher but the expenditure share on solid fuels tend to be lower in higher income deciles where poverty incidence is lower. Moreover, the food income elasticity is positive and below one, around 0.76 on average, which shows that food is a necessity. In contrast, the income elasticities for electricity, gas and liquid fuels hover around 1.1, thus, indicating that they are not strongly luxuries.

The cross-price elasticities between the energy goods, namely, electricity, gas and liquid fuels, and solid fuels, are all *positive*. This means they are *substitutes* which stands to reason because they serve the same purpose, for example, in cooking and lighting. These energy goods have mostly *negative* cross-price elasticities (i.e., complements) with food and other goods, except the cross-price elasticity of gas and liquid

Table 6. GLMES price and income elasticities

Household model

	Price elasticity					Income elasticity
	Electricity	Gas and Liquid	Solid fuels	Food	Others	
Electricity	-0.9071 ***	0.0250	0.0470	-0.1648	-0.0648	1.0647 ***
	(0.0656)	(0.0182)	(0.0294)	(0.1583)	(0.2276)	(0.1968)
Gas and Liquid fuels	0.0800	-1.2723 ***	0.1763 ***	0.1961	-0.2553	1.0753 ***
	(0.0593)	(0.1717)	(0.0656)	(0.2639)	(0.2754)	(0.1870)
Solid fuels	0.1919 **	0.1653 ***	-0.8748 ***	-0.0186	1.3196 ***	-0.7834 ***
	(0.0793)	(0.0537)	(0.2146)	(0.3331)	(0.5076)	(0.2820)
Food	-0.0023	0.0088	-0.0222 **	-0.4592 ***	-0.2777 *	0.7526 ***
	(0.0148)	(0.0072)	(0.0107)	(0.1354)	(0.1592)	(0.0894)
Others	-0.0122	-0.0081	0.0086	-0.4725 ***	-0.7798 ***	1.2640 ***
	(0.0133)	(0.0055)	(0.0130)	(0.1198)	(0.1463)	(0.0819)

Note: *, **, *** denote statistical significance at the 10-, 5- and 1-% alpha-levels, respectively. Figures in parentheses are standard errors.

Per capita model

	Price elasticity					Income elasticity
	Electricity	Gas and Liquid	Solid fuels	Food	Others	
Electricity	-0.8699 ***	0.0186	0.0784 **	-0.1199	-0.1274	1.0202 ***
	(0.0709)	(0.0227)	(0.0313)	(0.1764)	(0.2376)	(0.1533)
Gas and Liquid fuels	0.0546	-1.2446 ***	0.1982 ***	0.1523	-0.2834	1.1229 ***
	(0.0724)	(0.1869)	(0.0664)	(0.2712)	(0.2837)	(0.1581)
Solid fuels	0.2695 ***	0.1910 ***	-0.7492 ***	-0.1681	0.8961	-0.4393 **
	(0.0874)	(0.0576)	(0.2259)	(0.4282)	(0.5899)	(0.2173)
Food	-0.0014	0.0086	-0.0223	-0.5742 ***	-0.1830	0.7724 ***
	(0.0179)	(0.0081)	(0.0142)	(0.1521)	(0.1735)	(0.0703)
Others	-0.0170	-0.0078	0.0011	-0.3393 ***	-0.8580 ***	1.2211 ***
	(0.0150)	(0.0059)	(0.0152)	(0.1255)	(0.1482)	(0.0605)

Note: *, **, *** denote statistical significance at the 10-, 5- and 1-% alpha-levels, respectively. Figures in parentheses are standard errors.

Table 7. *GLMES Hicks-Slutsky substitution matrix*

Household model

	Electricity	Gas and Liquid fuels	Solid fuels	Food	Others
Electricity	-0.6126	0.0296	0.0415	0.2032	0.3104
Gas and Liquid fuels	0.0296	-0.3496	0.0448	0.1562	0.0651
Solid fuels	0.0415	0.0448	-0.2142	-0.0877	0.2251
Food	0.2032	0.1562	-0.0877	-0.9538	0.7213
Others	0.3104	0.0651	0.2251	0.7213	-1.2991
Note:					
Eigenvalues	-1.9120	-0.8719	0.0000	-0.4112	-0.2342

Per capita model

	Electricity	Gas and Liquid fuels	Solid fuels	Food	Others
Electricity	-0.1485	0.0062	0.0157	0.0524	0.0673
Gas and Liquid fuels	0.0062	-0.0883	0.0129	0.0377	0.0178
Solid fuels	0.0157	0.0129	-0.0444	-0.0207	0.0394
Food	0.0524	0.0377	-0.0207	-0.4402	0.3815
Others	0.0673	0.0178	0.0394	0.3815	-0.5015
Note:					
Eigenvalues	-0.8563	-0.2107	0.0000	-0.1026	-0.0533

fuels with food and that of solid fuels with other goods. That is, energy is generally consumed *together* with food and other goods.

Demand differences between income classes

This study estimated two sets of price and income elasticities from the household and per capita models (Table 6). However, expenditure shares vary between income classes (Table 3). For example, electricity expenditure shares consistently rise from the first (poorest) decile to the tenth (richest) decile based either on household or per capita incomes. This indicates that demand for electricity differs between income classes across households or across individuals. This is shown below by differences in own-price elasticities between income classes that may be "inferred" based on the own-price elasticity, expenditure shares, and parameter estimates.

Recall the own-price elasticity formula in (6), $E_{ii} =- 1 - \sum_{k=1}^{n} \alpha_{ik}\theta_{ik} - \beta_i + w_i\beta_i$. In this study, i = 1 is *electricity* for which the estimates show $\beta_1 > 0$ (Table 5) and $E_{11} < 0$ (Table 6). Moreover, as noted above, expenditure shares of electricity rise with incomes (Table 3). Therefore, for electricity, $w1\beta_1$ is more positive as income increases which implies from (6) that $E_{11} < 0$ increases (i.e., less negative or the demand curve is steeper) as income increases. By implication, price elasticity for electricity is more negative (i.e., flatter demand curve) as income decreases.

The above results imply that for the *same* electricity price increase, the quantity demanded by lower income classes will reduce by *more* than the quantity demanded by higher income classes. That is, electricity is less affordable for the poor. This result is intuitively correct or theoretically expected, which happily is implied by this study's empirical results.

In principle, the above analysis may be applied to differentiate demand between income classes for any of the five goods in this study.

Overall consistency of the estimated GLMES with consumer theory

All own-price and income elasticities have the theoretically expected signs and very high statistical significance. In contrast, the cross-price elasticities generally have the expected signs but are mostly not statistically significant. However, all the above elasticities in the household and per capita models yield HSSMs that are symmetric and NSD (Table 7).

The diagonal elements of HSSM are compensated own-price effects that in theory are negative, which are satisfied by both models. The off-diagonal diagonal elements are compensated cross-price effects that could be positive or negative. However, at least one of these cross-price effects must be positive. Therefore, each good must have at least one substitute which is satisfied by both models. In fact, the goods have similar relations in the two models because the two HSSMs have the same sign for the same element.

In Table 7, each HSSM is NSD by the fact that their corresponding eigenvalues are all non-positive with one zero (Strang, 1980). NSD implies that the estimated GLMES is consistent with utility maximization or expenditure minimization. Therefore, the ordinary demand functions in (3)—together with their price and income elasticities (Table 6) and compensated cross-price effects (Table 7)—provide theoretically valid basis for welfare change analysis.

Appraising the validity of HSSM from the estimated GLMES

By mathematical specification, GLMES satisfies the *additivity* property by (1) and (2) and the *zero-degree homogeneity* property by (3) and (4) without parameter restrictions. The only GLMES property requiring parameter restrictions is global *symmetry* in (5).

Therefore, by virtue of (1), (2), (3), (4), and (5), GLMES is guaranteed to yield in *any* application a *symmetric* and *singular* HSSM, which are necessary but not sufficient for a "rational" (i.e., utility-maximizing or expenditure-minimizing) demand system. Therefore, the symmetric HSSM of GLMES necessarily has one zero eigenvalue for singularity but the other eigenvalues may not be non-positive. However, the sufficient condition is NSD (i.e., one zero eigenvalue while all others are non-positive) that the HSSM of the estimated GLMES has satisfied in Table 7. That is, NSD is an empirical issue for GLMES but this is also true for other demand systems in practice.

Since the properties of additivity, zero-degree homogeneity, and symmetry are mathematically embodied in GLMES, testing for these properties is not clear-cut compared to similar testing in other demand systems that require parameter restrictions for the above properties, for example, in the AIDS (Deaton & Muellbauer, 1980) or the translog (Christensen, Jorgenson, & Lau, 1975). However, since the elasticities in Table 6 embody the above properties, their theoretically correct signs and their levels of statistical significance serve as indirect or implicit tests of the above properties. In this regard, it is comforting to note that *all* own-price elasticities and income (expenditure) elasticities are very highly statistically significant at 1%-alpha levels. In contrast, while the cross-price elasticities have in most cases the theoretically correct signs, they are mostly not statistically significant. However, since the latter result appears "neutral" vis-à-vis the null hypothesis of "zero", it does not necessarily detract from the very high statistical significance of all own-price and income elasticities. Therefore, it is arguable that the symmetry and NSD of the HSSM are statistically significant by implication.

The above results imply that GLMES is capable of capturing rational demand behavior yet it does not impose stringent data requirements as shown by a typical equation given by (16). This equation shows that *current expenditures* and *price indexes* of commodity groups will suffice, which were all the data used to generate Table 7. While these data are still considered legitimate, their desirability has been eroded by econometric or statistical issues—e.g., imprecision in price elasticity estimates or cross-section differences in price indexes—depending on the level of aggregation of price indexes used in demand system studies in the US (Castellón, Boonsaeng, & Carpio, 2015; Slesnick, 2005) and in the UK (Hoderlein & Mihaleva, 2008).

The criticisms in the above US and UK studies pertaining to the use of *current expenditures* and *price indexes* apply to the estimated GLMES in this study. However, as in the above studies, the issue is not legitimacy but the level of aggregation especially of the price indexes because it is a limiting factor. This study utilized *three* rounds of FIES in 2009, 2012, and 2015 each covering around *forty thousand* households across *seventeen* regions. Since detailed commodity prices are not available in standard FIES data release, "regional" prices are expedient. However, using regional prices as proxy for prices paid by households may introduce bias in the estimation since commodity prices may vary significantly and systematically within regions. To mitigate this problem, regionally representative average households were generated to match FIES household data with available regional prices. Hence, regional "current expenditures" and "price indexes" took the place of income and price variables in the estimation.[9]

In the above light, it appears more remarkable that—while using less desirable regional current expenditures and price indexes—GLMES still yielded statistically significant price and income elasticities with theoretically correct signs and values comparable to earlier studies noted in the next section. Moreover, GLMES succeeded in showing consistency with rational demand behavior by the symmetry and NSD of the HSSM.

Comparing this study to earlier studies of Philippine energy demand

The demand system framework distinguishes this study from past studies on Philippine energy demand that involved "single" equation estimation (Danao, 2001; Manalo-Macua, 2007). Unfortunately, single equation specification implies that conformity with the theory of utility maximization or expenditure maximization is limited to the signs of the elasticities. These are negative own-price elasticity; positive (negative) cross-price elasticity for substitutes (complements); and positive (negative) income elasticity for normal (inferior) goods.

However, although based on different methodologies, some of the elasticities estimated in this study appear in line with the elasticities obtained by the above earlier studies. In Table 6, the own-price elasticity of electricity is 0.91 in the household model and 0.87 in the per capita model. These are not too far off from the electricity own-price elasticity of 0.85 for the class of electricity consumers with air conditioners and 0.74 for all classes obtained by Danao (2001) and 0.86 obtained by Manalo-Macua (2007). Also in Table 6, the income elasticity of electricity is 1.06 in the household model and 1.02 in the per capita model. These are also not that far off from the electricity income elasticity of 0.81 for the class of electricity consumers with air conditioners and 0.75 for all classes obtained by Danao (2001) and 0.91 obtained by Manalo-Macua (2007). Unfortunately, all the other elasticities in Table 6 have no comparable counterparts in the above earlier studies that were limited to electricity demand.

This study utilizes the price and income elasticities (Table 6) and compensated price effects (Table 7) to compute CV and EV from price changes discussed in the next section.

RESORT algorithm for determining welfare effects of price changes

Algorithms to compute compensated income from ordinary demand functions date back, as noted by Balk (1995), to Malmquist (1953) and Vartia (1983). However, Dumagan and Mount (1997) proposed the **RE**versible **S**econd-**OR**der **T**aylor (RESORT) algorithm based on a second-order Taylor series expansion of the expenditure function and showed that setting to zero RESORT's second-order terms yields the Malmquist-Vartia (M-V) algorithm as a *special* case.[10]

RESORT applies to many goods but to visualize how it works, consider the simplest case of two goods in Figure 1. The budget $I^o = C(P^o, U^o)$ defines the "original" minimum expenditure to attain utility U^o at the price vector P^o. Suppose the price of good 1 rises but the price of good 2 falls so much more that the budget line becomes steeper and tangent to a higher indifference curve U^T where minimum expenditure is $I^T = C(P^t, U^T)$ at the "terminal" price vector P^T.

CV is the *change* in compensated income on U^o as P^o changes to P^T so that $CV = C(P^T, U^O) - C(P^O, U^O)$ while EV is the change on U^T so that $EV = C(P^T, U^T) - C(P^O, U^T)$. Given the *same* budget level, $I^O = I^T$ or $C(P^O, U^O) = C(P^T, U^T)$. Therefore,

$$CV = C(P^T, U^O) - C(P^O, U^O) \leq 0 \;\; if \;\; P^T \leq P^0 \; ; \quad (18)$$
$$CV \geq 0 \;\; if \;\; P^T \geq P^0 \; ;$$
$$= C(P^T, U^O) - C(P^T, U^T) \leq 0 \;\; if \;\; U^T \geq U^0 \; ; \quad (19)$$
$$CV \geq 0 \;\; if \;\; U^T \leq U^0 \; ;$$

$$EV = C(P^T, U^T) - C(P^O, U^T) \leq 0 \;\; if \;\; P^T \leq P^0 \; ; \quad (20)$$
$$EV \geq 0 \;\; if \;\; P^T \geq P^0 \; ;$$
$$= C(P^O, U^O) - C(P^O, U^T) \leq 0 \;\; if \;\; U^T \geq U^0 \; ; \quad (21)$$
$$EV \geq 0 \;\; if \;\; U^T \leq U^0 \, .$$

In (18) to (21), CV and EV have the same signs in the same direction as the change in prices and in opposite direction to the change in welfare.

If prices fall, welfare rises so that CV and EV are negative. In this case, CV and EV measure the *maximum* amount that may be *taken* (i.e., negative) from the consumer to *restore* welfare at U^O by shifting the budget line tangent to U^T *back* to tangency to U^O in Figure 1. Conversely, if prices rise, welfare falls so that CV and EV are positive and they measure the *minimum* amount that may be *given* (i.e., positive) to the consumer to restore welfare at U^O. However, CV and EV differ in size because CV is determined by P^T in (19) while EV is determined by P^O in (21).

In Figure 1, the *unknown* compensated income to compute CV is $C(P^T, U^O)$ that RESORT computes starting from $C(P^O, U^O)$ while staying on U^O as prices change from P^O to P^Y (see arrow). But the unknown compensated income to compute EV is $C(P^O, U^T)$ that RESORT computes starting from $C(P^O, U^O) = C(P^T, U^T)$ while staying on U^T as prices change *back* from P^T to P^O (see arrow). Since computing $C(P^O, U^T)$ starting from $C(P^T, U^T)$ is like computing $C(P^T, U^O)$ starting from $C(P^O, U^O)$, the latter computation suffices to illustrate RESORT.

Let there be $i = 1,2,...,n$ goods with prices $P^O = \{p_i^O\}$ and $P^T = \{p_i^T\}$. Following Vartia (1983), break up the total change in each price, $\{p_i^O\}$ to $\{p_i^T\}$, into price steps from 0 to Z. That is,

$$s = 0, \cdots, Z \quad ; \quad 1 \le Z < \infty \; ; \tag{22}$$

$$\Delta p_i = p_i(s+1) - p_i(s) = \frac{1}{Z}\left(p_i^T - p_i^O\right) \quad ; \qquad p_i(0) = p_i^O \quad ; \quad p_i(Z) = p_i^T \, . \tag{23}$$

Let q be an auxiliary variable, $s \le q \le s+1$, and let $C(p(q), U^O)$ be the expenditure function. The expenditure function $C(s+1)$ may be expressed as a line integral or as a Taylor series expansion around $C(s)$. An rth-order Taylor series with a remainder R gives

$$C(s+1) = C(s) + \sum_{i=1}^{n} \int_{s}^{s+1} \frac{\partial C(p(q), U^O)}{\partial p_i(q)} dp_i(q) \; ; \tag{24}$$

$$= C(s) + \sum_{m=1}^{r} \frac{1}{m!} d^m C(p(q), U^O) + R \, . \tag{25}$$

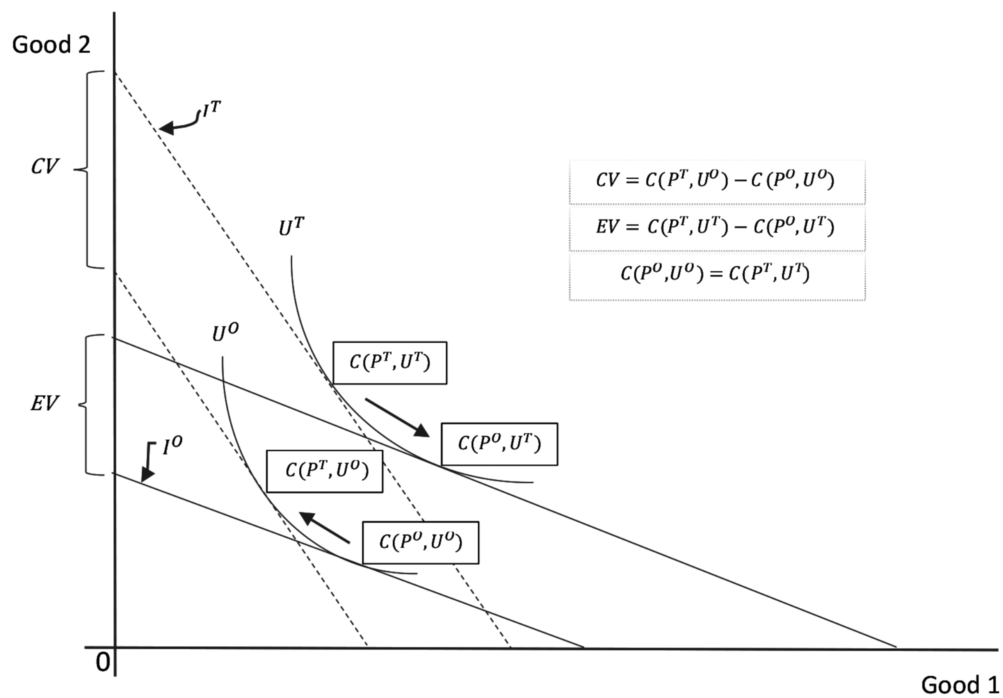

Fig. 1 Illustrating CV and EV

In (25), $d^m C(p(q), U^O)$ is the total differential of order *m* of the expenditure function. Starting from $C(0) = C(P^O, U^O)$, the terminal value is *C(0)* plus the sum of changes in compensated income at each step. Therefore, the solution $C(P^T, U^O)$ is the value of *C(s)* at the last step *Z*

$$C(P^T, U^O) = C(P^O, U^O) + \sum_{s=0}^{Z} \left(C(s+1) - C(s)\right) \quad ;$$

$$C(0) = C(P^O, U^O) \,. \tag{26}$$

By Shepard's lemma and duality,

$$\left.\frac{\partial C(p(q), U^O)}{\partial p_i}\right]_{q=s} = x_i^h(p(s), U^O) = x_i(p(s), C(s)) \,. \tag{27}$$

The result in (27) makes RESORT *practical* because the *ordinary* demand function, $x_i(\cdot)$, behaves like the *compensated* demand function, $x_i^h(\cdot)$, when compensated income, *C(s)*, replaces ordinary income. This permits RESORT to "stay on" U^O or U^T by using $x_i(\cdot)$. Moreover, the Slutsky equation obtains from $x_i(\cdot)$ compensated price effects,

$$\frac{\partial^2 C(p(q), U^O)}{\partial p_i \partial p_j} = \frac{\partial x_i^h}{\partial p_j} = \frac{\partial x_i}{\partial p_j} + x_j \frac{\partial x_i}{\partial C} = S_{ij} \text{ , all } i, j \tag{28}$$

Combining (25) to (28) and ignoring the remainder *R* yield a second-order Taylor series approximation $C_r(s + 1)$ to "true" compensated income $C(s + 1)$,

$$C_r(s+1) = C_r(s) + \sum_{i=1}^{n} x_i\left(p(s), C_r(s)\right) \Delta p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} S_{ij}\left(p(s), C_r(s)\right) \Delta p_i \, \Delta p_j \,. \tag{29}$$

The computation starts from $C_r(0) = C(P^O, U^O)$ at $P^O = \{p_i^O\}$. At any step $s + 1$, (12) requires evaluating ordinary demand functions and their derivatives given the prices and compensated incomes from the preceding step *s*. In this view, (29) is a "forward" second-order approximation.

However, the forward approximation in (29) may be *reversed* by solving $C_r(s)$ starting from $C_r(s+1)$ as prices change from $p(s+1)$ back to $p(s)$. Hence, using (23), the reverse of (29) or the "backward" approximation is

$$C_r(s) = C_r(s+1) - \sum_{i=1}^{n} x_i\left(p(s+1), C_r(s+1)\right) \Delta p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} S_{ij}\left(p(s+1), C_r(s+1)\right) \Delta p_i \, \Delta p_j \,. \tag{30}$$

The "solution" $C_r(s)$ in (30) will not necessarily equal its "known" value in (29). Similarly, the "solution" $C_r(s+1)$ in (29) will not necessarily equal its "known" value in (30). To ensure the above equalities, combine (29) and (30) and solve $C_r(s+1)$ from

$$\begin{aligned} C_r(s+1) = {} & C_r(s) + \frac{1}{2}\sum_{i=1}^{n} x_i\left(p(s), C_r(s)\right) \Delta p_i \\ & + \frac{1}{2}\sum_{i=1}^{n} x_i\left(p(s+1), C_r(s+1)\right) \Delta p_i \\ & + \frac{1}{4}\sum_{i=1}^{n}\sum_{j=1}^{n} S_{ij}\left(p(s), C_r(s)\right) \Delta p_i \, \Delta p_j \\ & - \frac{1}{4}\sum_{i=1}^{n}\sum_{j=1}^{n} S_{ij}\left(p(s+1), C_r(s+1)\right) \Delta p_i \, \Delta p_j \,. \end{aligned} \tag{31}$$

The values of $C_r(s)$ and $C_r(s+1)$ in (31) satisfy the "forward" solution in (29) and the "backward" solution in (30). Thus, (31) is a **RE**versible **S**econd-**OR**der **T**aylor (RESORT) algorithm that yields a unique approximate solution of "true" compensated income at each price step. Since $C_r(s+1)$ is in both sides of (31), the RESORT solution requires iteration.

In sum, RESORT starts with $C(P^O, U^O) = C(P^T, U^T)$ and constructs price steps linking P^O to P^T based on (23). Then, RESORT computes compensated incomes from the estimated ordinary demand functions, x_i from (3) utilizing the estimated parameters (Table 1), price and income elasticities (Table 6), and HSSM (Table 7). The computed compensated incomes are valid because they are expenditure-minimizing from the fact that HSSM is symmetric and NSD.

In turn, RESORT computes *changes* in compensated incomes (i.e., CV and EV) to measure welfare changes corresponding to price change scenarios defined later in Tables 8, 9, and 10 where, in accordance with (18) to (21), CV and EV are computed as *percent* values,

Table 8. *Compensating variation (CV) and equivalent variation (EV) from price changes, 2009-2012*

	Aggregate price indexes (CPI)			Price change scenarios					Total expendtures in 2009: Household = 175,551.0; Per capita = 43,237.5. Total expendtures in 2012: Household = 192,540.0; Per capita = 47,751.6. Annual % CV and % EV to stay as well off in 2009			
									Household		Per capita	
	2009	2012	Annual % CPI change	Electricity	Gas and liquid Fuels	Solid fuels	Food	Others	% CV	% EV	% CV	% EV
1	89.21	100.00	3.88	X	X	X	X	X	4.10	4.07	4.43	4.39
2	94.26	100.00	1.99	X	X	X	X		1.82	1.82	2.73	2.74
3	98.24	100.00	0.59	X	X	X			0.46	0.45	0.75	0.73
4	98.43	100.00	0.53	X	X				0.41	0.40	0.66	0.64
5	98.82	100.00	0.40	X					0.29	0.28	0.47	0.45
6	99.60	100.00	0.13		X				0.11	0.11	0.19	0.18
7	99.82	100.00	0.06			X			0.05	0.05	0.08	0.08
8	96.02	100.00	1.36				X		1.36	1.37	1.98	1.98
9	94.94	100.00	1.74					X	2.32	2.27	1.71	1.67

Source: Authors' calculations as explained in Appendix Table C for the computation of the CPI in a "price change scenario" and in Appendix Table D for the computation of the corresponding CV and EV. Note that in each price change scenario, a good with an "x" has prices changing alone or together with prices of other goods while a good with no "x" has constant prices.

Table 9. *Compensating variation (CV) and equivalent variation (EV) from price changes, 2012-2015*

	Aggregate price indexes (CPI)			Price change scenarios					Total expendtures in 2012: Household = 192,540.0; Per capita = 47,751.6. Total expendtures in 2015: Household = 214,816.2; Per capita = 54,190.9. Annual % CV and % EV to stay as well off in 2012			
									Household		Per capita	
	2012	2015	Annual % CPI change	Electricity	Gas and liquid Fuels	Solid fuels	Food	Others	% CV	% EV	% CV	% EV
1	100.00	107.00	2.28	X	X	X	X	X	2.52	2.51	2.63	2.62
2	100.00	103.52	1.16	X	X	X	X		1.10	1.11	1.58	1.58
3	100.00	99.66	-0.11	X	X	X			-0.09	-0.10	-0.15	-0.15
4	100.00	99.52	-0.16	X	X				-0.12	-0.13	-0.20	-0.21
5	100.00	99.85	-0.05	X					-0.03	-0.03	-0.05	-0.05
6	100.00	99.67	-0.11		X				-0.09	-0.09	-0.15	-0.16
7	100.00	100.13	0.04			X			0.03	0.03	0.06	0.06
8	100.00	103.86	1.27				X		1.20	1.20	1.73	1.74
9	100.00	103.48	1.15					X	1.44	1.42	1.06	1.05

Source: Authors' calculations as explained in Appendix Table C for the computation of the CPI in a "price change scenario" and in Appendix Table D for the computation of the corresponding CV and EV. Note that in each price change scenario, a good with an "x" has prices changing alone or together with prices of other goods while a good with no "x" has constant prices.

Table 10. *Compensating variation (CV) and equivalent variation (EV) from price changes, 2009-2015*

	Aggregate price indexes (CPI)			Price change scenarios					Total expendtures in 2009: Household = 175,551.0; Per capita = 43,237.5. Total expendtures in 2015: Household = 214,816.2; Per capita = 54,190.9. Annual % CV and % EV to stay as well off in 2009			
									Household		Per capita	
	2009	2015	Annual % CPI change	Electricity	Gas and liquid Fuels	Solid fuels	Food	Others	% CV	% EV	% CV	% EV
1	89.21	107.00	3.08	x	x	x	x	x	3.32	3.29	3.54	3.50
2	94.26	103.52	1.57	x	x	x	x		1.49	1.51	2.17	2.19
3	98.24	99.66	0.24	x	x	x			0.18	0.18	0.30	0.29
4	98.43	99.52	0.19	x	x				0.14	0.14	0.23	0.22
5	98.82	99.85	0.17	x					0.13	0.13	0.21	0.20
6	99.60	99.67	0.01		x				0.01	0.01	0.02	0.02
7	99.82	100.13	0.05			x			0.04	0.04	0.07	0.07
8	96.02	103.86	1.32				x		1.32	1.33	1.88	1.89
9	94.94	103.48	1.44					x	1.91	1.85	1.41	1.36

Source: Authors' calculations as explained in Appendix Table C for the computation of the CPI in a "price change scenario" and in Appendix Table D for the computation of the corresponding CV and EV. Note that in each price change scenario, a good with an "x" has prices changing alone or together with prices of other goods while a good with no "x" has constant prices.

$$\frac{CV}{C(P^O,U^O)} \times 100\% = \left[\frac{C(P^T,U^O)}{C(P^O,U^O)} - 1\right] \times 100\% = \left[\frac{C(P^T,U^O)}{C(P^T,U^T)} - 1\right] \times 100\% = \text{percent CV}\,; \tag{32}$$

$$\frac{EV}{C(P^O,U^T)} \times 100\% = \left[\frac{C(P^T,U^T)}{C(P^O,U^T)} - 1\right] \times 100\% = \left[\frac{C(P^O,U^O)}{C(P^O,U^T)} - 1\right] \times 100\% = \text{percent EV}\,. \tag{33}$$

Recall that CV and EV are *positive* when prices *rise* $(P^T > P^O)$ and welfare *falls* $(U^T < U^O)$. In this case, CV or EV is the amount that may be *given to* (positive) a household or an individual to restore original welfare. Conversely, when prices *fall* and welfare *rises*, CV or EV is the amount that may be *taken from* (negative) a household or an individual to restore original welfare.

Highlighting welfare changes

To avoid repetition, all percent changes should be understood as *annual* in the following analysis where alternative price change scenarios are devised to highlight the relation between *percent CPI change* and *percent CV or EV*. In each price change scenario—labelled 1 to 9 (Table 8, Table 9, and Table 10)—there is an *aggregate* price index (CPI) representing the weighted average of the sub-aggregate price indexes for electricity, gas and liquid fuels, solid fuels, food, and other. This CPI is calculated assuming that a sub-aggregate price index is changing *alone* or *together* with others as indicated by "x" in the price change scenario or constant without "x."

In the same scenario, percent CPI change and percent CV or EV use the *same* set of changing or constant sub-aggregate price indexes. The difference is that *percent CPI change* is the usual CPI computation that has nothing to do with a demand system, in general, or with RESORT, in particular, while *percent CV or EV* is calculated by RESORT from the estimated GLMES ordinary demand functions. However, percent CPI change and percent CV (or EV) are analytically related considering that in theory the CPI, which is the official COLI, *approximates* the true COLI, the ratio $C(P^T,U^O)/C(P^O,U^O)$, given the standard of living U^O. This may be seen from[11]

$$CPI \approx \frac{C(P^T,U^O)}{C(P^O,U^O)} = COLI \quad ; \quad CV = C(P^T,U^O) - C(P^O,U^O)\,. \tag{34}$$

It follows from (32) and (34) that

$$\text{percent CPI change} = [CPI - 1]100\% \approx \left[\frac{C(P^T, U^O)}{C(P^O, U^O)} - 1\right]100\% = \frac{CV}{C(P^O, U^O)}100\% = \text{percent CV}. \quad (35)$$

The values of percent CPI change in the first line of (35) are reported in the left-hand sides of Tables 8, 9, and 10 and they *approximate* the values of percent CV in the right-hand sides of the same tables. To firm up the connection, it may be noted that the CPI is for *all* individuals while *household* represents a family of more than one individual and *per capita* represents a single individual. Hence, it is not unwarranted to interpret percent CPI change as approximating the *average* of the household percent CV and of the per capita percent CV. [12]

In light of the above differences in approaches, it is notable in Tables 8, 9, and 10 that percent CPI change and percent CV or EV have the *same sign* in each price change scenario. Moreover, their corresponding absolute percent values are in many cases *quite close*.

Turning now to the results, CV and EV are computed assuming *no* change in household or per capita *expenditures* in each period. Thus, there is a *net* welfare gain (loss) if the percent increase in total expenditures is greater (less) than the percent CV or EV.

In Table 8, total household expenditures increased from 175,551.0 in 2009 to 192,540.0 in 2012 while total per capita expenditures also increased from 43,237.5 in 2009 to 47,751.6 in 2012. These translate to increases of 3.13 percent for households and 3.37 percent per capita that were *not* enough to cover the CV and EV of around 4.10 percent for households and around 4.40 percent per capita of welfare losses from overall price increases. That is, there was a net welfare loss during 2009-2012.

It is interesting to note in Table 9 that there were welfare gains when prices of energy goods fell *together* (scenarios 3 and 4). Moreover, there were also welfare gains from the *individual* fall in electricity price (scenario 5) and in gas and liquid fuels prices (scenario 6). However, there was a net welfare loss from the individual rise in solid fuel prices (scenario 7).

But overall, the increase in expenditures was 3.72 percent for households and 4.31 percent per capita, which were more than enough to cover CV and EV of a little over 2.50 percent for households and 2.60 percent per capita. Therefore, there was a net welfare gain during 2012-2015.

Finally, during 2009-2015, Table 10 shows that welfare loss from simultaneous increases in energy prices (scenario 3) was quite small in the range of 0.18 to 0.30 percent. The largest welfare losses from price increases were those from food (scenario 8), ranging from 1.32 to 1.89 percent.

However, expenditures increased from 175,551.0 to 214,816.2 for households or 3.42 percent and increased from 43,237.5 to 54,190.9 per capita or 3.84 percent that were *more* than enough to cover the CV and EV of around 3.30 percent for households and 3.50 percent per capita in scenario 1 when all prices changed. Thus, there was a net welfare gain.

Overall, it appears that welfare losses of Philippine families from generally rising prices during 2009-2015 were more than compensated by increases in total expenditures. That is, Philippine families were better off in welfare terms in 2015 than they were in 2009.

Implications of the welfare change analytic framework for practice

Tables 8, 9, and 10 showed that—although they are computed differently—percent CPI change and percent CV or EV have the *same sign* and their corresponding absolute percent values are in many cases *quite close* in each price change scenario. For example, Table 10 showed that the combined effect of simultaneous changes in the three energy prices (row 3) increases the CPI by 0.24 percent per year, which equals the *average* of household 0.18 percent CV and per capita 0.30 percent CV per year. Moreover, if the three energy prices change *one at a time* (row 5, 6, and 7), the sum of the individual percent changes in CPI equals 0.23 percent. The corresponding sums of household percent CV and per capita percent CV are, respectively, 0.18 percent and 0.30 percent for an average of 0.24 percent, about equal to the 0.23 percent CPI change.

The above results indicate that percent CPI change is a practical equivalent of percent CV for measuring welfare change if demand system estimation is infeasible. In practice, percent CPI change is the "headline inflation rate" computed by statistical agencies. Since percent CV is, in (35), the percent change of $C(P^T, U^O)$ from *old* expenditure $C(P^O, U^O)$ to restore the standard of living U^O at the *new* prices, the headline inflation rate may be interpreted equivalently as the minimum increase in total expenditures (or income) to maintain the standard of living. Therefore, the welfare effects of price changes may be determined by the contribution of the same price changes to the CPI inflation rate. This result has practical relevance to determining the welfare effects of policies that affect energy prices as discussed below.

Welfare effects of energy efficiency improvements

The energy goods in this study may be looked at analytically as inputs into a household's or an individual's production of goods and services for "end-use" consumption, for example, food-at-home, space cooling, water heating, or travel. For simplicity, let this end-use good or service be x_i and let the energy input be x_i^*. For example, x_i could be "miles travelled" and x_i^* could be "gallons of gasoline." In this case, there is an end-use price per mile, p_i, that is related to the price per gallon of gasoline, p_i^*. Under a fixed-coefficient production technology, where e_i is the output-input ratio—for example, *miles-per-gallon* (mpg) efficiency—the above example yields

$$x_i = e_i x_i^* \quad ; \quad p_i = p_i^*/e_i \quad ; \quad p_i x_i = p_i^* x_i^* \,. \tag{36}$$

No "data" for (x_i, p_i) exist but they exist for (x_i^*, p_i^*). Given a fixed coefficient technology, (36) implies that data on household expenditures on energy inputs, $p_i^* x_i^*$, may be used to proxy for the household's end-use demand using x_i^* as an input. In this case, taking e_i as parameters, the end-use price and income elasticities are the same as the input price and income elasticities. That is, using the notation in (6), (7), and (8), the GLMES ordinary price and income elasticities become

$$E_{ii} = \frac{\partial x_i}{\partial p_i}\frac{p_i}{x_i} = \frac{\partial x_i^*}{\partial p_i^*}\frac{p_i^*}{x_i^*} \;;\; E_{ik} = \frac{\partial x_i}{\partial p_k}\frac{p_k}{x_i} = \frac{\partial x_i^*}{\partial p_k^*}\frac{p_k^*}{x_i^*} \;; \qquad E_{iI} = \frac{\partial x_i}{\partial I}\frac{I}{x_i} = \frac{\partial x_i^*}{\partial I}\frac{I}{x_i^*} \,. \tag{37}$$

Moreover, the compensated own-price and cross-price effects from (10) also become

$$S_{ii} = \frac{\partial x_i}{\partial p_i} + x_i\frac{\partial x_i}{\partial I} = \frac{\partial x_i^*}{\partial p_i^*} + x_i^*\frac{\partial x_i^*}{\partial I} \;; \qquad S_{ik} = \frac{\partial x_i}{\partial p_k} + x_k\frac{\partial x_i}{\partial I} = \frac{\partial x_i^*}{\partial p_k^*} + x_k^*\frac{\partial x_i^*}{\partial I} \,. \tag{38}$$

Suppose now that the price of the energy inputs change from p_i^* to p_i^{*c} by $(\pi_i \times 100)\%$ and the efficiency coefficients also change from e_i to e_i^c by $(\rho_i \times 100)\%$. That is,

$$p_i^{*c} = (1+\pi_i)p_i^* \quad ; \quad e_i^c = (1+\rho_i)e_i \,. \tag{39}$$

Table 11. *Household fuel used in the Philippines, 2011*

	Proportion of 20,969,000 households	Proportion of households that use this fuel for		
		Lighting	Cooking	Water heating
Electricity	87.2	74.0	17.5	3.8
Gas and liquid fuels				
LPG	41.2	*	40.5	2.0
Kerosine	34.3	30.3	2.1	0.1
Gasoline	23.6	0.4	*	*
Diesel	4.9	0.3	*	*
Solid fuels				
Fuelwood	54.2	*	54.0	20.1
Charcoal	36.4	*	35.3	11.2
Biomass residues	22.3	*	20.1	6.2

Source: National Statistics Office (now part of PSA) and Department of Energy, *2011 Household Energy Consumption Survey*.
Note: A household may report more than one type of fuel used. Households reporting the use of gasoline or diesel include those who used them for their vehicles.

It follows from (36) and (39) that

$$\frac{\Delta p_i}{p_i} = \frac{p_i^c - p_i}{p_i} = \frac{p_i^{*c}}{p_i^*}\frac{e_i}{e_i^c} - 1 = \frac{\pi_i - \rho_i}{1 + \rho_i} \,. \qquad (40)$$

The result in (40) means that the change in end-use prices depends on the difference between the rate of change, π_i, of "market" prices of household energy inputs and on the rate of change, ρ_i, in the household's energy efficiency. While households or individuals may not be able to affect π_i, they can affect ρ_i to *change* end-use prices and consequently change their welfare.[13]

Going back to earlier analyses, energy prices *rose* during the entire period 2009-2015 (Table 10). In price change scenario 3—when all prices of the *three* energy commodity groups changed at the same time—the *combined* effect is an increase of 0.24 percent per year of the aggregate price index (CPI) from 2009 to 2015. This increase may look very small but it is due to the small weight of energy goods in the CPI which is only 7.4 percent (Appendix C). Note that the CPI increased 3.08 percent (price change scenario 1) per year during the above period. Hence, the contribution of energy goods is 3.08 percent 0.074≈0.24 percent, which may be decomposed into *individual* energy price change contribution in scenarios 5, 6, and 7.

In the above light, (40) may be related to Table 10 where π_i is the *individual* per year increase in energy price which was 0.17 percent for *electricity*; 0.01 percent for *gas and liquid fuels*; and 0.05 percent for *solid fuels* that add up to around 0.24 percent per year. Therefore, to fully compensate for welfare losses from energy price increases—by making (40) zero—it only takes annual energy efficiency improvements (i.e., ρ_i>0) of 0.17 percent for *electricity*; 0.01 percent for *gas and liquid fuels*; and 0.05 percent for *solid fuels*. In this regard, to have some idea about the scope of energy efficiency improvements, a profile of Philippine household fuel use from the last *Household Energy Consumption Survey* (HECS) in 2011 would be useful.

Table 11 shows that 87.2 percent of Philippine households had electricity of which 74.0 percent used electricity for lighting and less than 18 percent used it for cooking or water heating. After electricity, the next most common source of lighting is kerosene which was used by 34 percent of households also for a little bit of cooking or water heating. For cooking, most households used fuelwood (54.0 percent), followed by LPG (40.5 percent), charcoal (35.3 percent), and biomass residues (20.1 percent). For water heating, most households used fuelwood (20.1 percent), followed by charcoal (11.2 percent), and biomass residues (6.2 percent). Moreover, almost 24 percent of households had vehicles for which they used gasoline or diesel. Some households (less than 0.5 percent) used gasoline and diesel as fuel for electricity generators.

The 2011 HECS reported that 88.5 percent of the total 18.5 million households that used *any* fuel undertook measures to reduce energy use for lighting, cooking, refrigeration, ironing of clothes, space cooling, and/or washing of clothes.

To reduce electricity for lighting, 90.9 percent of households switched off lights when not needed; 85.4 percent opted for natural lighting when necessary; 75.3 percent switched to more energy efficient lighting; and 66.6 percent cited keeping lamps and lighting fixtures clean to reduce energy consumption.

Moreover, to reduce energy use in cooking, 20.6 percent of households kept pots and pans covered; 19.9 percent reduced heat when the water/food had boiled; 19.5 percent prepared the food to be cooked before turning on the stove; 18.7 percent re-heated cooked food only when necessary; and 17.0 percent thawed frozen food thoroughly before cooking.

To promote energy efficiency and conservation, the national government, through the Department of Energy, has implemented the National Energy Efficiency and Conservation Program (NEECP). A major component of NEECP is the Energy Labeling and Efficiency Standards that intended to improve the efficiency and performance of household appliances and other energy-consuming devices to generate energy savings. Awareness of this labeling program increased from 10.3 percent of households in 2004 to 26.2 percent in 2011, indicating a growing appreciation of the importance and use of energy labels. As a result, the Energy Labeling and Efficiency Standards program is credited to have generated increased energy savings from 805.8 KTOE in 2007 to 2,210.8 KTOE in 2011, which translated to almost 29 percent increase per year.[14]

Finally, it appears from the energy end-uses in Table 11 that household energy efficiencies are not all technological in nature but rather changeable by energy-use habits, simply by reducing waste. Thus, during 2009-2015, waste reduction would have sufficed to wipe out the relatively small welfare losses from combined energy price increases of 0.24 percent (row 3, Table 10)—comprising 0.17 percent from *electricity*, 0.01 percent from *gas and liquid fuels*; and 0.05 percent from *solid fuels*—even without investing in efficiency improvements. Moreover, on top of energy savings from waste reduction, there were substantial energy savings from investments in more efficient appliances induced by the Energy Labeling and Efficiency Standards program.

Conclusion

This study found Philippine family demands for (1) electricity, (2) gas and liquid fuels, (3) solid fuels, (4) food, and (5) "others" are rational. Specifically, all own-price elasticities are negative. Cross-price elasticities between (1), (2), and (3) are positive (substitutes) while cross-price elasticities of (1), (2), and (3) with (4) or (5) are mostly negative (generally complements). Income elasticities are positive, except for solid fuels in (3) that are consumed less at higher incomes.

To confirm rationality, the above price and income elasticities from GLMES yield an HSSM that is symmetric and NSD—thus, satisfying the necessary and sufficient conditions for expenditure minimization—a finding unprecedented in a Philippine demand study. Therefore, the above results are valid for use by RESORT to calculate CV and EV. However, if data limitations make demand system estimation infeasible—so that GLMES and RESORT are infeasible as well—*percent CPI change* would be a practical approximation to the unknown *percent CV* as a measure of welfare change.

During 2009-2015, the CPI increased 3.1 percent annually to which energy price increases, with a weight of 7.4 percent, contributed 0.23 percentage points, about equal to mid-point CV and EV estimates from 0.18 to 0.30 percent of 2009 total expenditures. This CV or EV measures welfare losses from energy price increases assuming *no* change in total expenditures. However, total expenditures increased annually by over 3.4 percent which was more than enough compensation for all welfare losses.

Overall, improvements in household energy efficiency from *waste* reduction more than fully compensated for the above relatively small welfare losses even without increases in total expenditures or without investments in efficiency improvements. However, rationality implies that investing in costly higher technical efficiency should be considered after all waste is exhausted by costless reduction in habitual inefficiency.

Notes

[1] It may be noted that "household" is more commonly used than "family" in demand studies of a group of individuals sharing the same dwelling. However, family demand is used in this study for consistency with the fact that the data come from the *Family Income and Expenditure Surveys* where household and family are used interchangeably.

[2] FIES 2018 data were not available at the same level of detail as the data from FIES 2009, 2012, and 2015.

[3] The estimates in Table 1 for "income" and in Table 2 for "expenditure" are for representative Philippine households using regional averages, instead of actual household observations, because of this study's data limitations based on available FIES data. Hence, "total" should be interpreted as total income or expenditure of an average household and is used in the tables to rationalize computation of "shares" of the totals.

[4] To calculate the annual growth rate, let the end-year value be V_t and the beginning-year value be V_{t-s} spanning $t-(t-s)=s$ years. Therefore, $V_t=V_{t-s}\,(1+r)^s$ from which $[(V_t/V_{t-s})^{1/s}-1] \times 100\% = r \times 100\%$="annual growth rate".

[5] In Table 2, expenditures are nominal values but their percent rises reflect increases in purchasing power because during the same period the "all items" CPI rose at a slower rate of 3.08 percent as shown later in Table 4.

[6] Table 11 of this study shows the proportion of households using these fuels for specific end-uses based on the last *Household Energy Consumption Survey* in 2011 by the National Statistics Office (now part of the Philippine Statistics Authority) and Department of Energy.

[7] Symmetry and NSD are the "integrability" conditions (Jehle & Reny, 2011) that imply there exists in principle a well-behaved indirect utility or expenditure function underlying GLMES although it may not be recoverable in closed form. Dumagan and Mount (1996) point out that GLMES has more desirable theoretical properties than the standard models like the "almost ideal demand system" (AIDS) (Deaton & Muellbauer, 1980) or the translog (Christensen, Jorgenson, & Lau, 1975). Moreover, Rothman, Hong, and Mount (1994) show that these standard models violate NSD more often than GLMES.

[8] At this juncture, it may again be noted that because of this study's data limitations by using FIES price data—that are essentially price averages for all households by region—the parameter estimates are subject to aggregation bias by glossing over heterogeneity between households. However, the above prices are the only ones available to this study—thus, permitting the annual regional aggregation—but not the prices that households from different income

groups (within regions) paid or faced. There are alternative techniques to infer prices at the household level but these involve several issues that will introduce complications beyond the scope of the present study. Nevertheless, given the data limitations, the theoretical framework of this study is an improvement over earlier energy demand studies in the Philippines because by design this study is capable of determining rationality in terms of the properties of the Hicks-Slutsky substitution matrix—discussed in detail later—that other Philippine energy demand studies are not even able to measure.

[9] Expenditures are for "consumption" goods and exclude those for durable goods because expenditures are "flows" so that inclusion of durables requires flows of "services" that are not available in FIES.

[10] Dumagan and Abrigo (2021) show that M-V's and RESORT's approximations are equal up to two decimal places to the "true" compensated comes in the AIDS (Deaton & Muellbauer, 1980). Thus, RESORT's superiority over M-V is not necessarily on *numerical* accuracy but on the *ability* of RESORT to check, using its second-order terms, symmetry and NSD of the HSSM that M-V cannot do.

[11] The old CPI was based on the Laspeyres price index so that CPI = $P^T \cdot X^O / P^O \cdot X^O$ where the numerator and denominator are inner products of the new price vector P^T, old price vector P^O, and old quantity vector X^O. If the utility level $U(X^O) = U^O$, expenditure minimization implies $P^O \cdot X^O = C(P^O, U^O)$ and $P^T \cdot X^O \geq C(P^T, U^O)$. In this case, the old CPI is theoretically an upper bound to the COLI, i.e., CPI$\geq C(P^T, UO) / C(P^O, U^O)$. However, this upper bound may not anymore apply to the Philippine official CPI (2012 = 100) because it is now based on a "modified" Laspeyres price index. In the modification, price relatives at the 5-digit level are classified into groups and the geometric mean is computed from a group's price relatives. These geometric means are aggregated at higher levels by Laspeyres aggregation, weighted by 2012 expenditure shares at each level to obtain the overall CPI (PSA, 2018). In view of this modification, the approximation in (34) could still be true but the inequality could go either way.

[12] The approximation applies as well to percent CPI change and percent EV because CV and EV are very close as may be seen in Tables 8, 9, and 10.

[13] If (40) applies to an individual or household, π_i is the electricity price inflation rate multiplied by electricity's share in the individual's or household's budget. Hence, welfare losses can be minimized by buying less electricity.

[14] KTOE stands for kilotonne of oil equivalent. One TOE is the amount of energy released by burning one tonne of crude oil equal to 39,683,207.2 British thermal units (BTU) or 11.63 megawatt-hours (MWh).

Acknowledgements

The authors would like to acknowledge the School of Government, Ateneo de Manila University for financial support through Access to Sustainable Energy Programme-Clean Energy Living Laboratories Project funded by the European Union. Moreover, at Ateneo, they would like to thank Josef Yap for suggesting this study and overseeing it proficiently; Geoffrey Ducanes for his expert comments; Majah-Leah Ravago for moderating a webinar; Mark Manantan, Ariza Francisco, and Adrian Glova for coordinating this study in ways that made it proceed smoothly. At De La Salle, they would like to thank Cesar Rufino also for his expert comments; Alellie Sobrevinas for moderating a webinar co-hosted by Rica Sauler, Mayen Dabbay, and Leslie Paulie. All comments at the webinars were intellectually engaging and improved the revision. However, the authors' views expressed herein do not necessarily reflect the views of the study benefactors, Ateneo de Manila University, or those of the authors' home institutions, De La Salle University and Philippine Institute for Development Studies.

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Appendix A. GLMES equations estimated in this study

Equation 1

$$\ln\left(\frac{w_1^t}{w_5^t}\right) = \alpha_{10} - \alpha_{50} + \alpha_{12}\theta_{12}^t \ln\left(\frac{p_2^t}{p_1^t}\right) + \alpha_{13}\theta_{13}^t \ln\left(\frac{p_3^t}{p_1^t}\right) + \alpha_{14}\theta_{14}^t \ln\left(\frac{p_4^t}{p_1^t}\right)$$
$$+ \alpha_{15}\theta_{15}^t \ln\left(\frac{p_5^t}{p_1^t}\right) - \alpha_{51}\theta_{51}^t \ln\left(\frac{p_1^t}{p_5^t}\right) - \alpha_{52}\theta_{52}^t \ln\left(\frac{p_2^t}{p_5^t}\right) - \alpha_{53}\theta_{53}^t \ln\left(\frac{p_3^t}{p_5^t}\right)$$
$$- \alpha_{54}\theta_{54}^t \ln\left(\frac{p_4^t}{p_5^t}\right) + \beta_1 \ln\left(\frac{I^t}{p_1^t}\right) - \beta_5 \ln\left(\frac{I^t}{p_5^t}\right). \tag{A-1}$$

Equation 2

$$\ln\left(\frac{w_2^t}{w_5^t}\right) = \alpha_{20} - \alpha_{50} + \alpha_{21}\theta_{21}^t \ln\left(\frac{p_1^t}{p_2^t}\right) + \alpha_{23}\theta_{23}^t \ln\left(\frac{p_3^t}{p_2^t}\right) + \alpha_{24}\theta_{24}^t \ln\left(\frac{p_4^t}{p_2^t}\right)$$
$$+ \alpha_{25}\theta_{25}^t \ln\left(\frac{p_5^t}{p_2^t}\right) - \alpha_{51}\theta_{51}^t \ln\left(\frac{p_1^t}{p_5^t}\right) - \alpha_{52}\theta_{52}^t \ln\left(\frac{p_2^t}{p_5^t}\right) - \alpha_{53}\theta_{53}^t \ln\left(\frac{p_3^t}{p_5^t}\right)$$
$$- \alpha_{54}\theta_{54}^t \ln\left(\frac{p_4^t}{p_5^t}\right) + \beta_2 \ln\left(\frac{I^t}{p_2^t}\right) - \beta_5 \ln\left(\frac{I^t}{p_5^t}\right). \tag{A-2}$$

Equation 3

$$\ln\left(\frac{w_3^t}{w_5^t}\right) = \alpha_{30} - \alpha_{50} + \alpha_{31}\theta_{31}^t \ln\left(\frac{p_1^t}{p_3^t}\right) + \alpha_{32}\theta_{32}^t \ln\left(\frac{p_2^t}{p_3^t}\right) + \alpha_{34}\theta_{34}^t \ln\left(\frac{p_4^t}{p_3^t}\right)$$
$$+ \alpha_{35}\theta_{35}^t \ln\left(\frac{p_5^t}{p_3^t}\right) - \alpha_{51}\theta_{51}^t \ln\left(\frac{p_1^t}{p_5^t}\right) - \alpha_{52}\theta_{52}^t \ln\left(\frac{p_2^t}{p_5^t}\right) - \alpha_{53}\theta_{53}^t \ln\left(\frac{p_3^t}{p_5^t}\right)$$
$$- \alpha_{54}\theta_{54}^t \ln\left(\frac{p_4^t}{p_5^t}\right) + \beta_3 \ln\left(\frac{I^t}{p_3^t}\right) - \beta_5 \ln\left(\frac{I^t}{p_5^t}\right). \tag{A-3}$$

Equation 4

$$\ln\left(\frac{w_4^t}{w_5^t}\right) = \alpha_{40} - \alpha_{50} + \alpha_{41}\theta_{41}^t \ln\left(\frac{p_1^t}{p_4^t}\right) + \alpha_{42}\theta_{42}^t \ln\left(\frac{p_2^t}{p_4^t}\right) + \alpha_{43}\theta_{43}^t \ln\left(\frac{p_3^t}{p_4^t}\right)$$
$$+ \alpha_{45}\theta_{45}^t \ln\left(\frac{p_5^t}{p_4^t}\right) - \alpha_{51}\theta_{51}^t \ln\left(\frac{p_1^t}{p_5^t}\right) - \alpha_{52}\theta_{52}^t \ln\left(\frac{p_2^t}{p_5^t}\right) - \alpha_{53}\theta_{53}^t \ln\left(\frac{p_3^t}{p_5^t}\right)$$

$$- \alpha_{54}\theta_{54}^{t} \ln\left(\frac{p_4^t}{p_5^t}\right) + \beta_4 \ln\left(\frac{I^t}{p_4^t}\right) - \beta_5 \ln\left(\frac{I^t}{p_5^t}\right) . \qquad \text{(A-4)}$$

GLMES estimates Equations 1 to 4 simultaneously using *seemingly unrelated regression* (SUR) (see: https://www.stata.com/manuals/rsureg.pdf) to correct for error correlations due to cross-equation constraints. Gamma, which appears as the exponent of the parameter theta, was estimated by running a series of SUR with theta pre-computed with a given gamma, between 0 and 1, where in each run gamma was raised in increments of 0.01. The parameter estimates shown in Appendix B are for the gamma that maximizes log-likelihood. Moreover, based on criteria that preferred models are those with highest log-likelihood and lowest BIC, Model 4 among household models and also Model 4 among per capita models were chosen and reported in the text.

SUR permits direct computing of the GLMES price and income elasticities and obtaining estimates of their standard errors based on the delta method since the full variance-covariance matrix of all parameters are available. Since the above elasticities (and the elements of the HSSM) are non-linear in parameters, Stata's nlcom (see: https://www.stata.com/manuals/rnlcom.pdf) was used in the computations.

Appendix B. GLMES parameter estimates

	Household models				Per capita models			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
$\alpha_{12} = \alpha_{21}$	0.0044 *	0.0038	0.0019 ***	0.0058	0.0031	-0.0016	0.0021 ***	0.0122
	(0.0024)	(0.0064)	(0.0007)	(0.0056)	(0.0024)	(0.0091)	(0.0008)	(0.0259)
$\alpha_{13} = \alpha_{31}$	0.0032	-0.0031	0.0042 ***	0.0189 **	0.0032	-0.0060	0.0041 ***	0.0959 ***
	(0.0031)	(0.0079)	(0.0012)	(0.0087)	(0.0037)	(0.0124)	(0.0012)	(0.0338)
$\alpha_{14} = \alpha_{41}$	-0.0142	-0.0285	0.0155 **	-0.0266	-0.0179	-0.0280	0.0162 ***	-0.0561
	(0.0169)	(0.0322)	(0.0063)	(0.0196)	(0.0159)	(0.0368)	(0.0062)	(0.0475)
$\alpha_{15} = \alpha_{51}$	-0.0793 ***	-0.1021 ***	-0.0269 ***	-0.0435 *	-0.0784 ***	-0.1391 ***	-0.0297 ***	-0.1082 **
	(0.0151)	(0.0324)	(0.0070)	(0.0252)	(0.0144)	(0.0367)	(0.0068)	(0.0547)
$\alpha_{23} = \alpha_{32}$	0.0021	0.0199 **	-0.0007	0.0238 ***	0.0031	0.0367 ***	-0.0010	0.1167 ***
	(0.0025)	(0.0082)	(0.0009)	(0.0079)	(0.0029)	(0.0131)	(0.0009)	(0.0365)
$\alpha_{24} = \alpha_{42}$	-0.0171 *	-0.0236	-0.0083 ***	0.0059	-0.0135	-0.0205	-0.0069 **	0.0040
	(0.0090)	(0.0220)	(0.0025)	(0.0118)	(0.0091)	(0.0272)	(0.0027)	(0.0319)
$\alpha_{25} = \alpha_{52}$	-0.0180 **	-0.0537 **	0.0047 *	-0.0274 **	-0.0237 ***	-0.0859 ***	0.0024	-0.0745 **
	(0.0085)	(0.0220)	(0.0026)	(0.0121)	(0.0084)	(0.0267)	(0.0028)	(0.0319)
$\alpha_{34} = \alpha_{43}$	-0.0013	-0.0021	-0.0008	-0.0050	-0.0005	-0.0056	-0.0009	-0.0384
	(0.0073)	(0.0179)	(0.0027)	(0.0185)	(0.0086)	(0.0272)	(0.0026)	(0.0579)
$\alpha_{35} = \alpha_{53}$	-0.0017	-0.0046	0.0163 ***	0.0530 *	-0.0107	-0.0227	0.0109 **	0.0633
	(0.0096)	(0.0270)	(0.0048)	(0.0277)	(0.0111)	(0.0386)	(0.0044)	(0.0738)
$\alpha_{45} = \alpha_{54}$	-0.5328 ***	-0.9875 ***	0.0339	-0.4073 ***	-0.5381 ***	-0.9436 ***	0.0122	-0.4629 ***
	(0.1381)	(0.2463)	(0.0682)	(0.1241)	(0.1247)	(0.2523)	(0.0631)	(0.1736)
β_1	2.6592 ***	2.7461 ***	-0.3005	0.4755 *	2.6660 ***	2.9460 ***	-0.2595	0.5325 **
	(0.4085)	(0.6002)	(0.2762)	(0.2457)	(0.3999)	(0.6093)	(0.2420)	(0.2631)
β_2	2.3733 ***	2.4477 ***	-0.2893 *	0.4860 **	2.3723 ***	2.6810 ***	-0.2510	0.6352 ***
	(0.3923)	(0.6142)	(0.1584)	(0.2015)	(0.3911)	(0.6182)	(0.1694)	(0.2443)
β_3	0.2110	0.3289	-1.6809 ***	-1.3727 ***	0.5969	0.9028	-1.4803 ***	-0.9270 ***
	(0.4277)	(0.6277)	(0.3139)	(0.3402)	(0.4266)	(0.6369)	(0.2851)	(0.3237)
β_4	1.7422 ***	1.7930 ***	-0.5467 **	0.1633	1.7914 ***	2.0523 ***	-0.4675 **	0.2847
	(0.4220)	(0.6277)	(0.2587)	(0.2542)	(0.4102)	(0.6305)	(0.2327)	(0.2686)
β_5	2.3617 ***	2.4242 ***	0.4746 *	0.6748 **	2.4075 ***	2.6670 ***	0.2919	0.7333 ***
	(0.4244)	(0.6279)	(0.2856)	(0.2639)	(0.4127)	(0.6315)	(0.2502)	(0.2793)
γ	0.00	0.11	0.00	0.27	0.00	0.15	0.00	0.44
Year fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Region fixed effects	No	No	Yes	Yes	No	No	Yes	Yes
γ	0.00	0.11	0.00	0.27	0.00	0.15	0.00	0.44
log-likelihood	90	102	322	372	90	101	318	360
BIC	-102	-94	-315	-382	-102	-93	-306	-359
N	51	51	51	51	51	51	51	51
NSD HSSM	Yes	No	Yes	Yes	Yes	No	Yes	Yes

Note: *, **, *** denote statistical significance at the 10-, 5- and 1-% alpha-levels, respectively. Figures in parentheses are standard errors. The subscripts refer to consumption items: 1 - electricity, 2 - gas and liquid fuels, 3 - solid fuels, 4 - food, and 5 - others not elsewhere classified. Moreover, the last parameter γ--which appears in the symmetry restriction in equation (5)--was estimated by grid search for the value that maximizes the log-likelihood.

Appendix C. Consumer price indexes (CPI) in alternative price change scenarios

CPI (2012 = 100)

	CPI			Fixed
	2009	2012	2015	weights
Electricity (ND)	75.5	100.0	96.9	4.8
Gas and Liquid fuels	72.1	100.0	77.0	1.4
Solid fuels (ND)	84.8	100.0	111.0	1.2
Food	88.8	100.0	110.9	35.5
Others	91.1	100.0	106.1	57.1
All Items	89.2	100.0	107.0	100.0

Source: Philippine Statistics Authority.

The aggregate price indexes below are weighted averages calculated by assigning a value of 100 to the index or indexes that are assumed constant in each price change scenario 1 to 9. The reason is that a constant index has a relative change of 1 and, therefore, equals the base year 2012 index value of 100. Thus, indexes that are constant in each scenario have values equal to 100 in 2009 and in 2015.

2009 aggregate CPI in price change scenarios, last row (shown in column 2, Table 8 and Table 10 in Section 4 of this paper)

	1	2	3	4	5	6	7	8	9
					Weights				
Electricity (ND)	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Gas and Liquid fuels	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Solid fuels (ND)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Food	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
Others	57.1	57.1	57.1	57.1	57.1	57.1	57.1	57.1	57.1
All Items	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
					Price indexes				
Electricity (ND)	75.5	75.5	75.5	75.5	75.5	100.0	100.0	100.0	100.0
Gas and Liquid fuels	72.1	72.1	72.1	72.1	100.0	72.1	100.0	100.0	100.0
Solid fuels (ND)	84.8	84.8	84.8	100.0	100.0	100.0	84.8	100.0	100.0
Food	88.8	88.8	100.0	100.0	100.0	100.0	100.0	88.8	100.0
Others	91.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.1
2009 aggregate CPI (weighted sum)	**89.21**	**94.26**	**98.24**	**98.43**	**98.82**	**99.60**	**99.82**	**96.02**	**94.94**

2015 aggregate CPI in price change scenarios, last row (shown in column 3, Table 9 and Table 10 in Section 4 of this paper)

	1	2	3	4	5	6	7	8	9
					Weights				
Electricity (ND)	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Gas and Liquid fuels	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Solid fuels (ND)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Food	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
Others	57.1	57.1	57.1	57.1	57.1	57.1	57.1	57.1	57.1
All Items	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
					Price indexes				
Electricity (ND)	96.9	96.9	96.9	96.9	96.9	100.0	100.0	100.0	100.0
Gas and Liquid fuels	77.0	77.0	77.0	77.0	100.0	77.0	100.0	100.0	100.0
Solid fuels (ND)	111.0	111.0	111.0	100.0	100.0	100.0	111.0	100.0	100.0
Food	110.9	110.9	100.0	100.0	100.0	100.0	100.0	110.9	100.0
Others	106.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	106.1
2015 aggregate CPI (weighted sum)	**107.00**	**103.52**	**99.66**	**99.52**	**99.85**	**99.67**	**100.13**	**103.86**	**103.48**

The aggregate CPI in the above tables are weighted averages calculated by assigning a value of 100 to the index or indexes that are assumed constant. The reason is that a constant index is "constant" relative to the base and, therefore, equals the base year index value of 100. Thus, indexes that are assumed constant have values equal to 100 in 2009, base year 2012, and 2015. Hence, the change in the aggregate CPI, for example from 2009 to 2012, is due *only* to the sub-aggregate indexes that are changing from 2009 to 2012 in each price change scenario.

Appendix D. Compensated incomes from price changes

Compensated incomes (2009 - 2012)

s

Household	Per capita
C(P0,U0) = C(P1, U1) = 175,551.0	C(P0,U0) = C(P1, U1) = 43,237.5

	Aggregate price indexes (CPI)			Price change scenarios					Compensated incomes in 2012 to stay on U0 = 2009			
									Household		Per capita	
	2009	2012	Annual % CPI change	Electricity	Gas and liquid Fuels	Solid fuels	Food	Others	C(P1,U0)	C(P0,U1)	C(P1,U0)	C(P0,U1)
1	89.21	100.00	3.88	X	X	X	X	X	198,024	155,771	49,248	38,009
2	94.26	100.00	1.99	X	X	X	X		185,294	166,283	46,881	39,874
3	98.24	100.00	0.59	X	X	X			177,986	173,201	44,217	42,302
4	98.43	100.00	0.53		X				177,700	173,484	44,096	42,422
5	98.82	100.00	0.40	X					177,088	174,065	43,845	42,655
6	99.60	100.00	0.13		X				176,146	174,980	43,481	43,005
7	99.82	100.00	0.06			X			175,802	175,305	43,343	43,133
8	96.02	100.00	1.36				X		182,809	168,542	45,855	40,763
9	94.94	100.00	1.74					X	188,039	164,121	45,488	41,140

Source: Authors' calculations from the GLMES demand system and RESORT welfare change algorithm applied to FIES 2009, 20012, and 2015.

Compensated incomes (2012 - 2015)

Total expendtures in 2012

Household	Per capita
C(P0,U0) = C(P1, U1) = 192,540.0	C(P0,U0) = C(P1, U1) = 47,751.6

	Aggregate price indexes (CPI)			Price change scenarios					Compensated incomes in 2015 to stay on U0 = 2012			
									Household		Per capita	
	2012	2015	Annual % CPI change	Electricity	Gas and liquid Fuels	Solid fuels	Food	Others	C(P1,U0)	C(P0,U1)	C(P1,U0)	C(P0,U1)
1	100.00	107.00	2.28	X	X	X	X	X	207,460	178,737	51,616	44,192
2	100.00	103.52	1.16	X	X	X	X		198,981	186,291	50,045	45,562
3	100.00	99.66	-0.11	X	X	X			192,009	193,092	47,540	47,973
4	100.00	99.52	-0.16	X	X				191,831	193,267	47,463	48,049
5	100.00	99.85	-0.05	X					192,352	192,728	47,677	47,826
6	100.00	99.67	-0.11		X				192,017	193,079	47,536	47,975
7	100.00	100.13	0.04			X			192,729	192,353	47,833	47,671
8	100.00	103.86	1.27				X		199,549	185,745	50,278	45,346
9	100.00	103.48	1.15					X	200,970	184,567	49,286	46,284

Source: Authors' calculations from the GLMES demand system and RESORT welfare change algorithm applied to FIES 2009, 20012, and 2015.

Compensated incomes (2009 - 2015)

Total expendtures in 2009

Household	Per capita
C(P0,U0) = C(P1, U1) = 175,551.0	C(P0,U0) = C(P1, U1) = 43,237.5

	Aggregate price indexes (CPI)			Price change scenarios					Compensated incomes in 2015 to stay on U0 = 2009			
									Household		Per capita	
	2009	2015	Annual % CPI change	Electricity	Gas and liquid Fuels	Solid fuels	Food	Others	C(P1,U0)	C(P0,U1)	C(P1,U0)	C(P0,U1)
1	89.21	107.00	3.08	X	X	X	X	X	213,494	144,569	53,264	35,165
2	94.26	103.52	1.57	X	X	X	X		191,808	160,469	49,187	37,958
3	98.24	99.66	0.24	X	X	X			177,458	173,697	44,015	42,485
4	98.43	99.52	0.19	X	X				177,030	174,113	43,826	42,670
5	98.82	99.85	0.17	X					176,908	174,234	43,775	42,720
6	99.60	99.67	0.01		X				175,671	175,433	43,287	43,188
7	99.82	100.13	0.05			X			175,949	175,168	43,413	43,066
8	96.02	103.86	1.32				X		189,874	162,171	48,362	38,633
9	94.94	103.48	1.44					X	196,698	157,268	47,020	39,868

Source: Authors' calculations from the GLMES demand system and RESORT welfare change algorithm applied to FIES 2009, 20012, and 2015.

The following examples may help to understand the above computations. For illustration, the compensated incomes C(P1, U0) = 213,494 and C(P0, U1) = 144,569 of the "household" model in "price change scenario 1" are computed as explained below.

For CV = C(P1,U0) - C(P0,U0) the *starting* total expenditure is C(P0, U0) = 175,551 in 2009 when the price vector is P0 = {75.5,72.1,84.8,88.8,91.1} where the elements are the 2009 FIES price indexes of the five commodity groups (see the top table of Appendix C). Starting from P0 in 2009 and following the step-by-step price changes defined by equation (23) in the text, the *terminal* price vector is P1 consisting of the 2015 FIES price indexes given by P1 = {96.9,77.0,111.0,110.9,106.1}. C(P0, U0), P0 and P1 are used by the RESORT algorithm in (31)—together with the estimated demand functions in (3), price and income elasticities (Table 6) and cross-price effects (Table 7)—to compute compensated income C(P1, U0) = 213,494. Therefore,

$$\text{CV} = \text{C(P1, U0)} - \text{C(P0, U0)} = 213{,}494 - 175{,}551 = 37{,}943\,;$$

$$\frac{\text{CV}}{\text{C(P0, U0)}} \times 100\% = \left[\left(\frac{213{,}494}{175{,}551}\right)^{(1/6)} - 1\right] \times 100\% = 3.32\%\,.$$

Note that CV covers the period 2009-2015 spanning six years, which is taken into account in computing the *annual percent CV* of 3.32% above and in Table 10.

For EV = C(P0, U1) - C(P0, U1) the *starting* total expenditure is C(P1, U1) = 175,551 in 2009 since C(P0, U9) = C(P1, U1) *before* compensation. C(O9M U1) is computed starting from C(P1, U1) so P1 = {96.9,77.0,111.0,110.9,106.1} is the starting price vector and P0 = {75.5,72.1,84.8,88.8,91.1} is the terminal price vector following the step-by-step price changes defined by equation (23). Similarly,C(P1, U1), P0, and P1 are used by the RESORT algorithm in (31)—together with the estimated demand functions in (3), price and income elasticities (Table 6), and cross-price effects (Table 7)—to compute compensated income C(P0, U1) = 144,569. These yield the *annual percent EV* reported in Table 10 given below by

$$\text{EV} = \text{C(P1, U1)} - \text{C(P0, U1)} = 175{,}551 - 144{,}569 = 30{,}982\,;$$

$$\frac{\text{EV}}{\text{C(P0, U1)}} \times 100\% = \left[\left(\frac{175{,}551}{144{,}569}\right)^{(1/6)} - 1\right] \times 100\% = 3.29\%\,.$$