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Working Papers in AGRICULTURAL ECONOMICS

June 1992 92-8

Welfare Effects of Improving End-Use Efficiency: Theory and Application to Residential Electricity Demand

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Welfare Effects of Improving End-Use Efficiency:

Theory and Application to Residential Electricity Demand

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Abstract -- *This paper applies the money metric approximation to the Hicksian equivalent variation and the generalized logit model of consumer demand to the analysis of the welfare effects of end-use efficiency improvements in various electricity conservation options. The results are compared with the standard cost-effectiveness criterion based on the net present value of energy conservation investments. If the assumptions implicit in the use of this criterion hold, namely, zero end-use price and income elasticities, the net present value of an investment will be the same as the money equivalent of the net welfare change calculated by the money metric. Thus, the standard net present value is consistent with the theory of the rational consumer, to the extent that the money metric and consumer demand models in this paper embody utility-maximizing behavior. However, the welfare-theoretic evaluation framework of this paper is more general since it encompasses cases where the above assumptions of the net present value criterion do not hold.*

Keywords: Demand systems; Welfare effects; End-use efficiency; Energy conservation

1. Purpose

In the theory of consumer behavior, the traditional mindset for welfare change measurement is predicated on the tenet that "more is better." In contrast, the philosophy behind energy conservation is that "less is better." However, these two are not in fundamental conflict because it is possible to increase final goods consumption, hence

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The usual disclaimer applies that this paper does not reflect the policies of the institutions with which the authors are affiliated. However, while taking full responsibility for the views and analysis in this paper, the authors would like to acknowledge the research assistance of Jong Ho Hong and Martha Czerwinski, the helpful comments of Duane Chapman on an earlier draft, and financial support from the Department of Agricultural Economics of Cornell and the New York State Department of Public Service. They would also like to thank Noel Uri for his encouraging review of this manuscript.

improve consumer welfare, at the same time reduce energy input use per unit of output by improving efficiency. But total energy use could rise as a result because improving input efficiencies, *ceteris paribus*, reduces the (implicit) prices of final goods and, depending on demand elasticities, could then increase final output demand such that the (derived) demand for energy inputs will also increase. In this view, improved energy efficiency increases welfare in the sense that "less waste is better" even if total energy use also increases. However, it is possible to increase consumer welfare and promote energy conservation as twin objectives of improved energy efficiency.

In other words, improving energy efficiency increases welfare by reducing energy waste without at the same time necessarily saving energy. It is for this reason that the evaluation of energy conservation investments by the standard net present value criterion could overestimate benefits due to the presumption that potential energy savings are realized. In contrast, no such presumption is maintained in the welfare-theoretic evaluation framework proposed in this paper. This framework combines the money metric welfare change measure to approximate the Hicksian equivalent variation (McKenzie, 1983; Dumagan, 1989, 1991) and an energy demand system specified as a generalized logit model of expenditure shares (Dumagan and Mount, 1991). This was applied in a recent publication (Dumagan and Mount, 1992) to the analysis of the welfare effects of carbon emissions penalties on residential energy consumers in New York state.

The specific purpose of this paper is to apply the above analytical framework to the analysis of the welfare effects of investments in energy conservation for the improvement of electricity end-use efficiency in the residential sector of New York state. The evaluation of these conservation investments by the money metric provides a first opportunity to compare this welfare change measure with the standard cost-effectiveness criterion based on the net present value of energy conservation investments. The analytical results from the welfare measure in combination with the demand model are shown to rationalize the standard net present value criterion. In particular, it is shown that if the assumptions implicit in the use of this criterion hold, which are zero end-use price and income elasticities, the net present value of an investment in energy conservation will be the same as the money equivalent of the welfare change calculated by the money metric measure. This implies that the standard net present value criterion is consistent with the theory of the rational consumer, to the extent that the money metric welfare measure and demand model in this paper embody the theoretical implications of utility-maximizing behavior. However, the welfare-theoretic evaluation framework of this paper is more general since it encompasses cases where the above assumptions of the net present value criterion do not hold.

This paper is organized as follows. Section 2 lays out the utility-maximizing properties of the generalized logit model of demand in this study. Section 3 relates improved input efficiency to its effect on the prices of final goods in the framework of the money metric measure of welfare change, in order to determine the effects on the welfare of consumers of improvements in energy efficiency. Section 4 presents the results from fitting a dynamic and stochastic version of the model in section 2 to energy consumption data in the residential sector of New York state from 1960 to 1987. Section 5 estimates the welfare effects on residential energy consumers in New York state of specific investments in more energy efficient electric end-uses (e. g., lighting, refrigeration, water heating and clothes drying) and of a comprehensive package of cost-effective state-wide conservation options to save electricity. Also, the net present values of the electricity savings from each conservation option are calculated based on standard cost-effectiveness criteria. Section 6 analytically demonstrates the generality of the money metric by showing that the standard net present value is a special case of the money metric welfare measure. Section 7 concludes this paper with a summary of findings.

2. A Generalized Logit Model of Expenditure Shares

The consumer demand model in this study is specified analytically such that it satisfies non-negativity and additivity of expenditure shares; zero-degree homogeneity in prices and income; and symmetry of the Hicksian cross-price effects. Moreover, the estimated model has a symmetric and negative semi-definite Hicks-Slutsky substitution matrix. Thus, the model is consistent with utility maximization or with its dual, expenditure minimization.[1]

Non-Negativity and Additivity of Expenditure Shares

Let the prices and corresponding quantities at any time period t be given by p_{it} and x_{it}, $i = 1, 2, ..., n$. Given that expenditures or income in the same period is I_t, then by definition of the budget constraint,

$$w_{it} = \frac{p_{it}\, x_{it}}{I_t} \quad ; \quad 1 \geq w_{it} \geq 0 \quad ; \quad \sum_{i=1}^{n} w_{it} = 1 \, . \tag{1}$$

In (1), w_{it} is the expenditure share of each commodity. In order to satisfy (1), define a logit specification of shares,

[1]Unlike the translog model (Christensen, Jorgenson and Lau, 1975; Christensen and Caves, 1980) and the "almost ideal demand system" or AIDS (Deaton and Muellbauer, 1980a and 1980b), the generalized logit model in this paper is not derived from an explicit indirect utility function (translog) or from an expenditure function (AIDS).

$$w_{it} = \frac{e^{f_{it}}}{e^{f_{1t}} + \ldots + e^{f_{nt}}} = \frac{e^{f_{it}}}{\sum_{j=1}^{n} e^{f_{jt}}} \tag{2}$$

where f_{it} is a function of p_{it}, $i = 1, 2, \ldots, n$ and I_t. The logit specification guarantees that the non-negativity and additivity of expenditure shares are satisfied because (2) strictly satisfies (1) for every set of predicted shares.[2]

By defining the share w_{nt} of an arbitrarily chosen nth good in accordance with (2),

$$\ln\left(\frac{w_{it}}{w_{nt}}\right) = f_{it} - f_{nt} \quad ; \quad i = 1, 2, \ldots, n-1 \, . \tag{3}$$

Thus, the non-linear expenditure system implied by (2) can be estimated as a linear system in (3) by specifying f_{it} as a linear function in (5) below.

Zero-Degree Homogeneity in Prices and Income

By equating w_{it} in (1) to that in (2),

$$\ln x_{it} = -\ln\left(\frac{p_{it}}{I_t}\right) + f_{it} - \ln \sum_{j=1}^{n} e^{f_{jt}} \, . \tag{4}$$

The demand functions x_{it} in (4) are homogeneous of degree zero in prices and income given the following specification,[3]

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[2]In contrast, other models can predict nonsensical negative shares. For example, Lutton and LeBlanc (1984) showed that the translog can generate negative share predictions.

[3]For this result, it is sufficient to define Marshallian demand for any good as a function of the ratios of its own price to income and to the prices of the other goods. This insures that proportional changes in all prices and income will leave demand unchanged, which is required by the above homogeneity property.

$$f_{it} = \alpha_{io} + \sum_{j=1}^{n} \alpha_{ij} \, \theta_{ij(t-1)} \ln\left(\frac{p_{jt}}{p_{it}}\right) + \beta_i \ln\left(\frac{I_t}{p_{it}}\right) \tag{5}$$

where α_{io} and α_{ij} are parameters; and $\theta_{ij(t-1)}$ is a lagged variable weight which will be shown later to determine global Hicksian symmetry.

It follows from (4) and (5) that the own-price, cross-price and income elasticities are

$$E_{iit} = -1 - (1 - w_{it})\left(\sum_{k=1}^{n} \alpha_{ik} \, \theta_{ik(t-1)} + \beta_i\right) - \sum_{k=1}^{n} w_{kt} \, \alpha_{ki} \, \theta_{ki(t-1)} \; ; \tag{6}$$

$$E_{ikt} = \alpha_{ik} \, \theta_{ik(t-1)} - \sum_{i=1}^{n} w_{it} \, \alpha_{ik} \, \theta_{ik(t-1)} + w_{kt}\left(\sum_{i=1}^{n} \alpha_{ki} \, \theta_{ki(t-1)} + \beta_k\right) ; \tag{7}$$

$$E_{iIt} = 1 + (1 - w_i) \, \beta_i - \sum_{k=1}^{n} w_{kt} \, \beta_k \quad ; \quad i \neq k \, . \tag{8}$$

It can be verified that for any good i,

$$\sum_{j=1}^{n} E_{ijt} + E_{iIt} = 0 \, . \tag{9}$$

The result in (9) means that this model is zero-degree homogeneous in prices and income.

Symmetry of the Hicksian Cross-Price Effects

Hicksian symmetry can be obtained in the logit model above by defining θ as the following function of lagged shares and by imposing symmetry on the α coefficients,

$$\theta_{ik(t-1)} = \frac{w_{k(t-1)}^{\gamma}}{w_{i(t-1)}^{(1-\gamma)}} \quad ; \quad w_{i(t-1)} = \frac{p_{i(t-1)}\, x_{i(t-1)}}{I_{(t-1)}} \quad ; \quad \alpha_{ik} = \alpha_{ki} \tag{10}$$

where γ is a parameter.[4] To show that (10) is sufficient for global Hicksian symmetry, consider the Slutsky equation

$$\frac{\partial x_{it}}{\partial p_{kt}} = \frac{\partial x_{it}^{h}}{\partial p_{kt}} - x_{kt}\frac{\partial x_{it}}{\partial I_{t}} \tag{11}$$

where the superscript h distinguishes the Hicksian from the Marshallian demand functions. Now, the Hicksian cross-price effect in (11) can be expressed in terms of Marshallian price and income elasticities and budget shares as

$$\frac{\partial x_{it}^{h}}{\partial p_{kt}} = \frac{I_t}{p_{it}\, p_{kt}} \left(E_{ikt}\, w_{it} + w_{it}\, w_{kt}\, E_{iIt}\right) \quad ; \tag{12}$$

$$\frac{\partial x_{kt}^{h}}{\partial p_{it}} = \frac{I_t}{p_{kt}\, p_{it}} \left(E_{kit}\, w_{kt} + w_{kt}\, w_{it}\, E_{kIt}\right) . \tag{13}$$

Symmetry of the Hicksian cross-price effects holds in the generalized logit model for any set of predicted budget shares. For infinitesimal changes of shares, the time lag defined by 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 (10). In this case, omitting the time subscript t for simplicity,

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[4]Considine's (1990) model is a special case of the generalized logit model in the sense that his global symmetry restriction may be obtained from (10) by setting $\gamma = 1$, thus eliminating the denominator of θ, and then replacing the actual lagged value of the share by its predicted value. His symmetry restrictions on the price parameters are equivalent to the above restrictions on the α coefficients.

$$w_i \theta_{ik} = w_k \theta_{ki} \ . \tag{14}$$

In view of (14), the price and income elasticities in (6) to (8) simplify to

$$E_{ii} = -1 - \sum_{k=1}^{n} \alpha_{ik} \theta_{ik} - (1 - w_i) \beta_i \quad ; \tag{15}$$

$$E_{ik} = \alpha_{ik} \theta_{ik} + w_k \beta_k \ . \tag{16}$$

$$E_{iI} = 1 + (1 - w_i) \beta_i - \sum_{k=1}^{n} w_k \beta_k \ . \tag{17}$$

Substituting these elasticities into (12) and (13) gives the Hicksian price effects,

$$\frac{\partial x_i^h}{\partial p_i} = -\frac{I}{p_i^2} \left[w_i - w_i^2 + \sum_{k=1}^{n} \alpha_{ik} (w_i w_k)^\gamma + (w_i - 2w_i^2) \beta_i + w_i^2 \sum_{j=1}^{n} w_j \beta_j \right] \ ; \tag{18}$$

$$\frac{\partial x_i^h}{\partial p_k} = \frac{I}{p_i p_k} \left[w_i w_k + \alpha_{ik} (w_i w_k)^\gamma + w_i w_k (\beta_i + \beta_k) - w_i w_k \sum_{j=1}^{n} w_j \beta_j \right] \ ; \tag{19}$$

$$\frac{\partial x_k^h}{\partial p_i} = \frac{I}{p_k p_i} \left[w_k w_i + \alpha_{ki} (w_k w_i)^\gamma + w_k w_i (\beta_k + \beta_i) - w_k w_i \sum_{j=1}^{n} w_j \beta_j \right] . \tag{20}$$

The Hicksian cross-price effects in (19) and (20) are symmetric given that $\alpha_{ik} = \alpha_{ki}$ in (10). Global symmetry holds for every set of shares and for any value of γ.[5]

[5] If the expenditure function is twice continuously differentiable with respect to prices, Hicksian symmetry follows by Young's theorem. If the indirect utility function is obtainable, Roy's identity yields the Marshallian demand system and Hicksian symmetry can be verified by means of the Slutsky equation. Thus, symmetry holds for demand systems derived from expenditure functions or indirect utility functions with the usual properties but not necessarily for demand systems that are directly specified. Hence, there is a need to check for symmetry in the latter case (Lau, 1976).

Moreover, while this is not assured analytically, the Hicks-Slutsky substitution matrix from the estimated model is negative semi-definite. With symmetry, this implies that there exists in principle an underlying expenditure function or indirect utility function that rationalizes the above logit model (Samuelson, 1950; Katzner, 1970; Hurwicz & Uzawa, 1971; Johnson, Hassan & Green, 1984, Varian, 1984; LaFrance & Haneman, 1986).

3. Price Effects of Efficiency Improvements and the Money Metric Welfare Measure

The residential logit model in section 2 was fitted to price and quantity data for electricity, natural gas, fuel oil and for a composite non-energy good defined to complete the demand system. Clearly, electricity and fuels are "intermediate" goods used by households as inputs for such processes as lighting, cooking, air conditioning and space or water heating. That is, there is a household production function that converts the above energy inputs into the final goods consumed by households.

Efficiency improvements in the household production function may improve welfare since these improvements could reduce the implicit prices of final goods, given the price of the inputs. For example, improving thermal efficiency of a residence by insulation may reduce the price of "comfort". Everything else remaining the same, this price reduction improves welfare because it implies a movement downwards along a demand curve, which is a movement upwards to higher indifference curves. Unfortunately, there are no data on the prices and quantities of final goods produced and consumed by households such as "comfort". Thus, a way must be found to determine the effects of improved energy efficiency on the implicit prices of these household goods. These price effects can then be used in the money metric measure of welfare change to calculate a money equivalent of the increase in welfare from energy efficiency investments.

Suppose that in the model described above no data are available on the prices and quantities of final consumer goods, in which case data on intermediate inputs to produce these goods are used instead. In place of x_{it} and p_{it}, which are not known, substitute x_{it}^* and p_{it}^* where

$$x_{it} = x_{it}^* e_{it} \quad ; \quad p_{it} = \frac{p_{it}^*}{e_{it}} \quad ; \quad w_{it}^* = \frac{p_{it}^* x_{it}^*}{\sum_{i=1}^{n} p_{it}^* x_{it}^*} . \tag{21}$$

In (21), it is assumed that the household transforms inputs into outputs according to a fixed coefficient technology. In this case, efficiency is defined by the coefficient e_{it}, which is the output-input ratio. For example, if x_{it} measures miles traveled and x_{it}^* measures gasoline consumed, then e_{it} equals the miles-per-gallon efficiency. Thus, p_{it} is the price per mile and p_{it}^* is the price per gallon.

In the preceding example, travel (measured in miles) is the final good and the welfare effects of a change in the price per mile, due to a change in the efficiency of the car, need to be measured. Notice that, given the price of gasoline, an increase in miles-per-gallon efficiency reduces the price per mile and thus improves welfare, i.e., increases the level of satisfaction from travel. In this case, the problem is to calculate this welfare improvement from estimates of the gasoline demand function using data on x_{it}^* and p_{it}^*. It is supposed that the travel demand function cannot be estimated because there is no corresponding data on e_{it}. The gasoline demand function, in the above example, could be part of a complete demand system and, thus, the welfare effects of other sources of price changes in the system need to be determined. At the same time, the welfare effects of the cost of the efficiency improvements need to be considered.

In the framework of a multi-good demand model that exemplifies utility-maximizing behavior, Dumagan (1989, 1991) reformulated McKenzie's (1983) third-order Taylor series expansion of an indirect utility function to derive a money metric approximation to the Hicksian equivalent variation. The reformulation is given by

$$\frac{MM_3}{I} = \frac{\Delta I}{I} - \sum_{i=1}^{n} w_i \frac{\Delta p_i}{p_i} - \sum_{i=1}^{n} w_i E_{iI} \frac{\Delta p_i}{p_i} \frac{\Delta I}{I}$$

$$+ \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} (w_i w_j E_{jI} - w_i E_{ij}) \frac{\Delta p_i}{p_i} \frac{\Delta p_j}{p_j}$$

$$+ \frac{1}{6} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \left(w_i p_j p_k \frac{\partial^2 x_j}{\partial I \, \partial p_k} + w_i w_j E_{ik} E_{jI} \right) \frac{\Delta p_i}{p_i} \frac{\Delta p_j}{p_j} \frac{\Delta p_k}{p_k}$$

$$- \frac{1}{6} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \left(\frac{p_i p_j p_k}{I} \frac{\partial^2 x_i}{\partial I \, \partial p_k} + I w_i w_j p_k \frac{\partial^2 x_k}{\partial I^2} \right) \frac{\Delta p_i}{p_i} \frac{\Delta p_j}{p_j} \frac{\Delta p_k}{p_k}$$

$$- \frac{1}{6} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} (w_i w_j w_k E_{jI} E_{kI} - w_i w_k E_{ij} E_{kI}) \frac{\Delta p_i}{p_i} \frac{\Delta p_j}{p_j} \frac{\Delta p_k}{p_k}$$

$$+ \frac{1}{2} \sum_{i=1}^{n} \sum_{k=1}^{n} \left(I w_i p_k \frac{\partial^2 x_k}{\partial I^2} - p_i p_k \frac{\partial^2 x_i}{\partial p_k \, \partial I} \right) \frac{\Delta p_i}{p_i} \frac{\Delta p_k}{p_k} \frac{\Delta I}{I}$$

$$+ \frac{1}{2} \sum_{i=1}^{n} \sum_{k=1}^{n} (w_i w_k E_{iI} E_{kI}) \frac{\Delta p_i}{p_i} \frac{\Delta p_k}{p_k} \frac{\Delta I}{I} - \frac{1}{2} \sum_{i=1}^{n} I p_i \frac{\partial^2 x_i}{\partial I^2} \frac{\Delta p_i}{p_i} \left(\frac{\Delta I}{I} \right)^2 \qquad (22)$$

where, by definition,

$$I = \sum_{i=1}^{n} p_i x_i \quad ; \quad w_i = \frac{p_i x_i}{I} \quad ; \quad E_{ij} = \frac{\partial x_i}{\partial p_j} \frac{p_j}{x_i} \quad ; \quad E_{iI} = \frac{\partial x_i}{\partial I} \frac{I}{x_i} \, . \qquad (23)$$

In (22) and (23), x_i, $i = 1, ..., n$, are final consumer goods with prices p_i. Thus, the money metric measures welfare change using the parameters of the estimated demand functions for final consumer goods, in addition to the price and quantity data to determine the expenditure shares and elasticities.

The money metric imposes no restrictions on observable demand functions other than those implied by utility maximization. In particular, it does not require the equality of income elasticities among the goods with the changing prices (unitary income elasticities when all prices change, i.e., homothetic preferences) that is required for the uniqueness of the Marshallian consumer's surplus (Just, Hueth and Schmitz, 1982). Dumagan (1989, 1991) showed that (22) is zero-degree homogeneous in prices and income, non-increasing in prices and non-decreasing in income, which are properties of a welfare indicator. That is, welfare is unchanged or (22) equals zero when prices and income change in the same proportion. Also, (22) cannot be positive (negative) when all prices are rising (falling) with income unchanged and cannot be negative (positive) when income is rising (falling) with prices unchanged.

Suppose that (22) needs to be calculated but no data are available on x_{it} and p_{it} where t stands for time. However, there are data on x_{it}^* and p_{it}^* for all $i = 1, ..., n$ and for income or expenditure, I_t. That is, it is possible to estimate the demand system

$$\begin{aligned} x_{1t}^* &= F_1(p_{1t}^*, \ldots, p_{nt}^*;\, I_t)\ ; \\ &\vdots \\ x_{nt}^* &= F_n(p_{1t}^*, \ldots, p_{nt}^*;\, I_t)\ . \end{aligned} \tag{24}$$

Suppose that x_{it} and x_{it}^* are related by a fixed coefficient technology according to (21). Let the efficiency or output-input coefficients e_{it} be fixed at a point in time. Suppressing the time subscript t for simplicity of notation, it follows from (21) that

$$\frac{\partial x_i^*}{\partial p_i^*}\frac{p_i^*}{x_i^*} = \frac{\partial x_i}{\partial p_i}\frac{p_i}{x_i} = E_{ii} \quad ; \quad \frac{\partial x_i^*}{\partial p_j^*}\frac{p_j^*}{x_i^*} = \frac{\partial x_i}{\partial p_j}\frac{p_j}{x_i} = E_{ij} \quad ; \tag{25}$$

$$\frac{\partial x_i^*}{\partial I}\frac{I}{x_i^*} = \frac{\partial x_i}{\partial I}\frac{I}{x_i} = E_{iI} \quad ; \quad p_i^* x_i^* = p_i x_i \quad ; \quad w_i^* = w_i \; . \tag{26}$$

Thus, the elasticities are the same for the final goods and intermediate goods, given a fixed coefficient technology.[6] Moreover, their corresponding levels of expenditure and shares are equal. These results imply that the welfare effects of the changes in the prices of final goods and in income can be calculated by the money metric welfare measure in (22) using the parameters of the intermediate good demand functions.

4. Residential Energy Demand in New York State (1960-1987)

An example of an intermediate good demand system is the model of residential energy demand for the state of New York estimated by Dumagan (1991). This is a dynamic and stochastic version of the generalized logit model in section 2 which was fitted to data from 1960 to 1987 on New York residential consumption of electricity, natural gas, fuel oil and a composite "other" commodity defined to complete the demand system. Since the consumption of the above energy inputs is by and large governed by a fixed coefficient technology, e.g., by household appliances with given efficiencies and by residencies with given thermal insulation properties, the estimated model can be used to determine the welfare effects of improvements in household energy efficiency.

[6] While the efficiency coefficient is fixed at a point in time, it is viewed in this paper as a parametric constant that can be changed by policy. That is, a policy to improve energy efficiency changes the value of the efficiency coefficient to a higher constant value.

The empirical model estimated the system of equations in (3) where (5) was respecified as the following dynamic and stochastic version,

$$f_{it} = \alpha_{io} + \sum_{i=1}^{n} \alpha_{ij}\, \theta_{ij(t-1)} \ln\left(\frac{p_{jt}}{p_{it}}\right) + \beta_i \ln\left(\frac{I_t}{p_{it}}\right) + \lambda_i \ln x_{i(t-1)} + e_{it} \tag{27}$$

where $x_{i(t-1)}$ is lagged quantity of good i and e_{it} is a stochastic error term. This respecification does not change the short-run elasticities in (15), (16) and (17) but introduces a different set of long-run elasticities.

Table 1 presents the parameter estimates. The price parameters are symmetric, i.e.,

TABLE 1 -- ESTIMATES OF PRICE, INCOME AND LAG PARAMETERS

Parameter	Estimate	Standard Error	t-ratio
$\alpha_{12} = \alpha_{21}$	0.02466	0.00688	3.58
$\alpha_{13} = \alpha_{31}$	0.01134	0.00399	2.84
$\alpha_{14} = \alpha_{41}$	- 0.00351	0.00078	- 4.47
$\alpha_{23} = \alpha_{32}$	0.06215	0.00854	7.28
$\alpha_{24} = \alpha_{42}$	0.00229	0.00146	1.57
β_1	- 0.94216	0.00552	- 170.55
β_2	- 0.89085	0.00978	- 91.02
β_3	- 0.80782	0.01421	- 56.84
β_4	- 0.65919	0.04107	- 16.05
λ_1	0.81398	0.02024	40.21
λ_2	0.76135	0.02104	36.18
λ_3	0.50438	0.02815	17.92
λ_4	0.67261	0.04244	15.85

Source: Dumagan (1991).

$\alpha_{ij} = \alpha_{ji}$, $i,j = 1, ..., 4, i \neq j$. Note that α_{ij} is not estimated for $i = j$ since in this case the logarithm of the price ratio equals zero. The income parameters are β_1 , β_2 , β_3 and β_4. The lag coefficients are λ_1 , λ_2 , λ_3 and λ_4. The t-ratios of the estimated parameters are absolutely greater than 2 with only one exception, α_{24}. Moreover, the estimated model fits the data very well with R-square values close to one for each equation.[7]

Consistency of the Estimates With Consumer Theory

In Table 2, the matrix denoted by SRPIE gives the short-run price and income elasticities of demand computed at the point of means. The rows define the quantities (Qty), namely, EL for electricity, NG for natural gas, OL for oil and OT for the other composite good. The second to the fifth columns are for the prices and the sixth is for income. Thus, the diagonal elements of the first four rows and the four columns are the own-price elasticities and the off-diagonal elements are the cross-price elasticities.

TABLE 2 -- SHORT-RUN PRICE AND INCOME ELASTICITIES (SRPIE)

SRPIE	EL Price	NG Price	OL Price	OT Price	Income
EL Qty	- 0.0666	0.0153	0.0036	- 0.6755	0.7232
NG Qty	0.0165	- 0.2266	0.0529	- 0.6175	0.7745
OL Qty	0.0030	0.0566	- 0.6559	- 0.2612	0.8576
OT Qty	- 0.0098	- 0.0079	- 0.0035	- 0.9850	1.0062

Source: Dumagan (1991).

[7]Dumagan (1991) gives all the pertinent goodness-of-fit statistics.

All the own-price elasticities are negative and all the income elasticities are positive, implying that the goods are all normal. The positive cross-price elasticities imply that electricity, natural gas and oil are substitutes. However, the cross-price elasticities with the other composite good are negative, implying complementarity. The sum of the elasticities in a given row is zero because of zero-degree homogeneity in prices and income.

The matrix denoted by HSSM in Table 3 is the Hicks-Slutsky substitution matrix also computed at the point of means. The diagonal elements are non-positive and the off-diagonal elements are symmetric as required by theory. It can be shown that the sum of the elements in the same row weighted by the prices is zero because of zero-degree homogeneity in prices of the underlying Hicksian demand function.

TABLE 3 -- HICKS-SLUTSKY SUBSTITUTION MATRIX (HSSM)

HSSM	EL Price	NG Price	OL Price	OT Price
EL Qty	- 0.0189	0.0270	0.0097	0.1645
NG Qty	0.0270	- 0.9449	0.2090	2.8037
OL Qty	0.0097	0.2090	- 1.7217	8.9139
OT Qty	0.1645	2.8037	8.9139	- 68.7688

Source: Dumagan (1991).

Finally, EVA in Table 4 gives the eigenvalues of the HSSM in Table 3. All are non-positive and one of them is zero because the HSSM is singular. Thus, the HSSM is negative semi-definite and implies that the estimated model is consistent with the theory of utility-maximization at the mean values of the expenditure shares.

TABLE 4 -- EIGENVALUES OF THE HSSM

EVA	Column 1
Row 1	- 3.7*E-15
Row 2	- 0.1277
Row 3	- 1.2829
Row 4	- 70.0437

Source: Dumagan (1991).

In this model, symmetry of the HSSM holds globally according to the specification in (19) and (20). Also, negative semi-definiteness of the HSSM, while not assured analytically, holds at every data point of the sample of observations in the estimated model. This finding is significant in that it implies that the estimated model embodies utility-maximizing behavior. Therefore, this model is valid as a basis for measuring the welfare effects of price and income changes in combination with the money metric welfare measure. In principle, this measurement of welfare effects can start from any data point in the sample. This is warranted by the finding that the HSSM is symmetric and negative semi-definite at every sample observation.

In view of the above findings, the estimated model can be used to determine the welfare effects of improvements in household energy end-use efficiency. For this purpose, the price and income elasticities computed from the estimated model in Table 2 are applicable to the money metric measure in (22). The second-order partial derivatives required in (22) can be approximated by the second-order derivatives of the elasticity formulas in (15), (16) and (17), by using the computed elasticity values above as parametric constants on the right-hand side of these formulas. Thus, the estimated parameters together with the energy prices, quantities and expenditure levels comprise a sufficient set of data for the calculation of the money metric measure of welfare change from energy efficiency improvements.

The money metric in (22) is derived by a Taylor series expansion where all the terms are evaluated at the initial or original levels of prices, quantities and income, which are also used as the basis for computing the discrete changes in prices and income. To compute these changes, let the original price and income vector for the final goods be $[p_1, ..., p_n, I]$. The corresponding original price and income vector for the intermediate goods is $[p_1^*, ..., p_n^*, I]$. These are related by the vector of the original efficiency coefficients $[e_1, ..., e_n]$.

Let the original price and income vector of final goods change to $[p_1^c, ..., p_n^c, I^c]$ because of changes in intermediate good prices to p_i^{*c} by $(100\ \alpha_i)\%$ and in the efficiency coefficients to e_i^c by $(100\ \beta_i)\%$, $i = 1, ..., n$. This means that

$$p_i^{*c} = (1 + \alpha_i)p_i^* \quad ; \quad e_i^c = (1 + \beta_i)e_i \ . \tag{28}$$

Therefore, from (21) and (28),

$$\frac{\Delta p_i}{p_i} = \frac{p_i^c - p_i}{p_i} = \frac{p_i^{*c}}{p_i^*}\frac{e_i}{e_i^c} - 1 = \frac{\alpha_i - \beta_i}{1 + \beta_i} \ . \tag{29}$$

Thus, the percent changes in the prices of final goods can be expressed precisely in terms of the percent changes in intermediate good (input) prices and in terms of the percent changes in the efficiencies of using these inputs. Given the level of income, the money metric measure shows that welfare improves unequivocally when the prices of final goods fall. It follows from (29) that this happens only if input efficiencies rise faster than the rise in input prices, i.e., β_i exceeds α_i.

The treatment of the change in income in the welfare change calculation depends on the formulation of the demand system. For example, the residential logit model of energy demand for the state of New York was modeled as a complete demand system. One possibility is that, if the state economy is considered as a closed system, then changes in income should be treated endogenously. This implies, in particular, that in the calculation of the welfare effects of efficiency improvements, the costs of these improvements may be treated as short-run negative changes in income. The reason is that income in this model is equivalent to total expenditures available for final goods consumption in the welfare change calculation. In the short-run, this total is fixed so that any expenditures for efficiency improvements implies a diversion of expenditures from final consumption, i.e., $\Delta I < 0$ in the money metric formula in (22) and its absolute value equals the efficiency improvement costs.

It may be noted that the benefits from efficiency improvements accrue over their lifetimes. However, costs may be incurred only at the time these improvements are put in place, i.e., the investment costs, although maintenance costs may also be incurred as benefits accrue. In view of this, the money metric in (22) should be adapted to measure the annual net benefits throughout the life of the efficiency improvements. The present value sum of these annual net benefits should then be calculated to obtain the present value money equivalent of the welfare gains from improved efficiency.

Improvements in the efficiency of input utilization result in welfare gains if input prices are unchanged since the (implicit) prices of final goods produced with these inputs fall. These welfare gains accrue as a result of the fall in the latter prices, no matter what happens to the level of input utilization as a consequence of improved efficiency. To show this, suppose that input prices are given in (21). It follows that

$$\frac{\partial \ln x_i}{\partial \ln e_i} = \frac{\partial \ln x_i^*}{\partial \ln e_i} + 1 \quad ; \quad \frac{\partial \ln p_i}{\partial \ln e_i} = -1 \,. \tag{30}$$

Combining (30) into the familiar elasticity expressions,

$$\frac{\partial x_i^*}{\partial e_i}\frac{e_i}{x_i^*} = -\left(1 + \frac{\partial x_i}{\partial p_i}\frac{p_i}{x_i}\right) \tag{31}$$

which implies that the elasticity of input use with respect to a change in efficiency is positive (negative) if the own-price elasticity of the final good is less (greater) than - 1. In other words, an improvement in efficiency will increase (decrease) input use if the demand for the final good is own-price elastic (inelastic). In either case, however, the fall in the price of the final good implies a movement downwards along its demand curve, which is equivalent to a movement upwards to higher indifference curves, i.e., an improvement in the level of welfare from the consumption of the final good. This improvement in welfare as a consequence of the improvement in input efficiency is clearly independent of the direction of change of input utilization. This is consistent with the fact that, everything else remaining the same, a fall in price improves consumer welfare regardless of what happens to consumer expenditure.[8]

The preceding analysis implies that, everything else remaining the same, improvements in energy efficiency will improve consumer welfare even if energy consumption rises. That is, a fall in energy consumption, i.e., energy conservation, is not necessary for welfare improvement to result from improved energy efficiency. Therefore, it cannot be concluded that there is no welfare improvement from improved energy efficiency simply because no energy savings are realized.

However, it is possible to increase consumer welfare and promote energy conservation as twin objectives of improved energy efficiency. For example, it is clear from (31) that the elasticity of input utilization with respect to efficiency is negative if the

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[8]The direction of change in the consumer's total expenditure depends on the elasticity of the demand curve on the segment along which price falls. Total expenditure decreases (increases) if the own-price elasticity is greater (less) than -1. Whatever happens to total expenditure, however, consumer welfare improves as a result of a fall in price.

demand for the final good is inelastic with respect to its own price. This implies that energy savings can be realized, at the same time that consumer welfare increases, by improving energy efficiency in the production of own-price inelastic final goods.

In general, the conclusion is that a money equivalent of the welfare change from improved energy efficiency does not imply that energy savings are in the end realized. For this reason, the net present value from standard cost-effectiveness criteria could overestimate the benefits from energy conservation by presuming that potential energy savings are realized. On purely welfare-theoretic grounds, the latter standard net present value could result in an incorrect ranking of investments in improved energy efficiency. The reason is that there is no fixed relation between the money equivalent of a welfare change and the net present value of energy savings from energy efficiency investments.

5. Electricity Conservation in the Residential Sector of New York State

In order to apply jointly the money metric measure of welfare change and the generalized logit model of demand proposed in this study, consider the case of recommended electricity conservation options summarized in Tables 5A and 5B. As noted in the bottom of the table, this list of 32 options covers a variety of electric end-uses in the residential sector of New York state. This is from a study conducted for the New York State Energy Research and Development Authority (NYSERDA) based on an analysis of actual energy use patterns in different dwellings, saturation rates of the affected appliances and technically feasible electricity conservation options statewide. Thus, the evaluation of these conservation options by the money metric provides a first opportunity to test this welfare change measure in comparison with the standard cost-effectiveness criterion for conservation where the benefits are directly tied to energy savings.

TABLE 5A -- ELECTRICITY CONSERVATION ASSESSMENT OF THE NEW YORK STATE RESIDENTIAL SECTOR (Discount Rate = 6%)

Area Code	Conservation Option	Life of Option (Years)	Marginal CSE ($/Kwh)	Potential Savings (Gwh/yr)
1. FRE	Current sales ave. (1986)	20	0.004	373
2. REF	Current sales ave. (1986)	20	0.010	1,876
3. REF	Best current (1988)	20	0.011	1,865
4. REF	Near-term advanced	20	0.013	781
5. EWH	Traps & blanket (EF=0.9)	13	0.013	265
6. FRE	Best current (1988)	20	0.014	259
7. FRE	Near-term advanced	20	0.015	129
8. ESH1	Infiltration reduction	15	0.017	593
9. RAN	Improved oven	18	0.022	212
10. ESH2	Storm windows	20	0.022	112
11. ESH2	Low-emissivity film	10	0.024	35
12. RAN	Improved cooktop	18	0.025	74
13. LTG	Tungsten halogen lamps - 300 hr/yr	9	0.027	697
14. LTG	Energy saving lamps - 620 hr/yr	1.2	0.030	82
15. LTG	Energy saving lamps - 1,240 hr/yr	0.6	0.030	98
16. EWH	Front loading clothes washing	13	0.034	447
17. LTG	Compact flourescents 1,240 hr/yr	6	0.036	1,102

Note: See Table 5B for the source and for explanations of the area codes (e.g., REF or LTG) of the electricity conservation option.

TABLE 5B -- ELECTRICITY CONSERVATION ASSESSMENT OF THE NEW YORK STATE RESIDENTIAL SECTOR (Discount Rate = 6%)

Area Code	Conservation Option	Life of Option (Years)	Marginal CSE ($/Kwh)	Potential Savings (Gwh/yr)
18. ESH1	Heat pump #1, HSPF = 7	15	0.042	236
19. LTG	IRF lamps, 300 hr/yr	9	0.044	813
20. LTG	Compact flourescents 620 hr/yr	12	0.045	918
21. ESH1	Heat pump #2, HSPF = 8	15	0.055	23
22. ECD	Heat pump clothes dryer	18	0.065	858
23. ESH1	Low-emissivity film	20	0.079	163
24. RAC	RAC: 8.5 EER	12	0.093	144
25. CAC	Window film	10	0.137	76
26. RAC	RAC: 10.0 EER	12	0.152	87
27. CAC	CAC: 10.0 SEER	12	0.161	79
28. RAC	RAC: 12.0 EER	12	0.195	91
29. CAC	Variable speed drive	12	0.221	55
30. CAC	CAC: 12.0 SEER	12	0.316	47
31. ESH1	Add 3" fiberglass in roof/ceiling	20	0.455	25
32. CAC	CAC: 14.0 SEER	12	0.463	37

Notes: (1) 1986 residential energy consumption was 34, 577 Gwh. (2) REF: refrigerator; FRE: freezer; EWH: electric water heater; LTG: lighting; RAC: room air conditioner; CAC: central air conditioner; RAN: cooking range; ECD: electric clothes dryer; ESH1: electric space heating in single-family and small (2-4 units) multi-family homes; ESH2: electric space heating in large (5+ units) multi-family homes.

Source: THE POTENTIAL FOR ELECTRICITY CONSERVATION IN NEW YORK STATE, A Report Prepared for the New York State Energy Research and Development Authority (Washington, DC: American Council for an Energy-Efficient Economy, September 1989).

In Tables 5A and 5B, Marginal *CSE* (cost of saved energy) is defined as

$$CSE = \left(\frac{CIC}{PS}\right) CRF \tag{32}$$

where *CIC* is the conservation investment cost; *PS* is the potential savings in electricity; and *CRF* is the capital recovery factor. *PS* for each conservation option is given in the table. *CRF* is by definition the reciprocal of the present value factor, *PVF*, which is

$$PVF = \sum_{i=1}^{L} \frac{1}{(1 + d)^i} = \frac{1}{d}\left[1 - \frac{1}{(1 + d)^L}\right]. \tag{33}$$

In (33), d is the discount factor and L is the life of the option. Since

$$CRF = \frac{1}{PVF} \tag{34}$$

then *CIC* can be solved for each option. This is possible since the NYSERDA conservation study also gives the life of each option.

6. The Money Metric Measure and the Standard Cost-Effectiveness Criterion

It will be assumed that the implementation of each conservation option in Tables 5A and 5B involves a reallocation of a portion of current expenditures to pay for implementation, which is a one time investment. However, while the investment costs are incurred only at the time of implementation, the benefits from the price-reducing effects of the improvement in end-use efficiency will accrue throughout the life of the investment. In this framework, the money metric measure of the welfare effects of each electricity conservation option can be computed and then compared to the net benefits from the same options computed based on standard cost-effectiveness criteria.

The money metric measure can be used for simpler cases where not all prices change or when prices and income do not change at the same time. Thus, it can be applied to the electricity conservation options in Tables 5A and 5B, which involve a change only in the end-use price of electricity. Assuming that only one price changes at the same time with a change income, then the generalized money metric in (22) simplifies to[9]

$$\frac{MM_3}{I} = \frac{\Delta I}{I} - w_1 \frac{\Delta p_1}{p_1} - w_1 E_{1I} \frac{\Delta p_1}{p_1} \frac{\Delta I}{I} + \frac{1}{2}(w_1^2 E_{1I} - w_1 E_{11}) \left(\frac{\Delta p_1}{p_1} \right)^2$$

$$+ \frac{1}{6} \left(w_1 p_1^2 \frac{\partial^2 x_1}{\partial I \, \partial p_1} + 2 w_1^2 E_{11} E_{1I} - \frac{p_1^3}{I} \frac{\partial^2 x_1}{\partial p_1^2} - I w_1^2 p_1 \frac{\partial^2 x_1}{\partial I^2} - w_1^3 E_{1I}^2 \right) \left(\frac{\Delta p_1}{p_1} \right)^3$$

$$+ \frac{1}{2} \left(I w_1 p_1 \frac{\partial^2 x_1}{\partial I^2} - p_1^2 \frac{\partial^2 x_1}{\partial p_1 \partial I} + w_1^2 E_{1I}^2 \right) \left(\frac{\Delta p_1}{p_1} \right)^2 \frac{\Delta I}{I}$$

$$- \frac{1}{2} I p_1 \frac{\partial^2 x_1}{\partial I^2} \frac{\Delta p_1}{p_1} \left(\frac{\Delta I}{I} \right)^2 \qquad (35)$$

where the subscript 1 denotes electricity. In terms of the money metric, *CIC* in (32) enters into equation (35) as a negative change in income or total expenditures, i. e.,

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[9]Equation (35) above should be the same as equation [5.15] on page 119 of Dumagan (1991) when the latter equation is corrected for a typographical error in line 4, where the exponent "2" of the last term should be "3".

$$CIC = -\ \Delta I \tag{36}$$

since it is treated as a reallocation of a portion of current consumption expenditures to pay for the conservation investment. However, this investment has the effect of reducing the end-use price of electricity according to (29). Since input prices (e. g., electricity price) are assumed constant, i. e., $\alpha_i = 0$, then (28) and (29) imply that the percent reduction in electric end-use price from implementing conservation option $q = i$ is

$$\frac{\Delta p_1}{p_1} = -\ \frac{\beta_q}{1 + \beta_q} \le 0 \quad ; \quad \beta_q = \frac{e_q^c}{e_q} - 1 \ge 0 \quad ; \quad e_q^c \ge e_q \ . \tag{37}$$

This means that, everything else remaining the same, end-use price falls if efficiency improves. To compute β_q in this application to electricity (denoted by the subscript 1), recall (21) where efficiency is the ratio of end-use or final output to input. Thus,

$$e_q^c = \frac{x_1^c}{x_1^{*c}} \quad ; \quad e_q = \frac{x_1}{x_1^*} \tag{38}$$

where the asterisk (*) distinguishes the electricity input from the electricity end-use output. As before, the superscript c designates the changed levels after the implementation of the conservation option q. From (37) and (38), it follows that

$$\beta_q = \frac{x_1^*}{x_1^{*c}} \frac{x_1^c}{x_1} - 1 = \frac{x_1^* - x_1^{*c}}{x_1^* - (x_1^* - x_1^{*c})} = \frac{PS_q}{x_1^* - PS_q} \quad \mathit{if} \quad x_1^c = x_1 \ . \tag{39}$$

In general, (39) implies that an efficiency improvement ($\beta_q > 0$) which leads to a fall in end-use price ($\Delta p_1/p_1 < 0$) according to (37) could lead to an increase in electric end-use output ($x_1^c > x_1$) such that electricity input use also increases ($x_1^{*c} > x_1^*$) at the same time. This implies that consumer welfare could increase from energy efficiency improvements without at the same time saving energy. Thus, the measurement of the welfare effects of energy efficiency need not necessarily be tied to energy savings because none may be realized while welfare is improved.

However, (39) also shows that welfare effects can be based on energy savings when the end-use level remains the same, i.e., $x_l^c = x_l$. In this case, $PS_q = x_l^* - x_l^{*c}$ is the potential savings of electricity input from option q in Tables 5A and 5B and x_l^* is the base total electricity consumption at the time of the implementation. In 1986, x_l^* = 34,577 Gwh in the NYSERDA study. This situation is equivalent to the case where the end-use price and income elasticities are zero, which is not supported by the elasticities for electricity in Table 2. But because the own-price elasticity (-0.0666), in particular, is small in absolute value and greater than -1, then some electricity savings are realized according to (25) and (31), although lower than the potential savings from each conservation option reported in Tables 5A and 5B. This suggests a more conservative or smaller value of β_q. Thus, for the purpose of computing the money metric welfare measure in (35), β_q was given the value of

$$\beta_q = \frac{PS_q}{x_1^*} \tag{40}$$

which is smaller than that in (39).

It is assumed that the implementation cost of each conservation option q is a one-time investment cost while the associated end-use price reduction persists throughout the life of the option. However, the end-use price reduction results only after the conservation option has been in place, i. e., ΔI and $\Delta p_l/p_l$ are not observed at the same time. This implies that in (35), the terms involving the product of ΔI and $\Delta p_l/p_l$ are zero. Moreover, the persistence of the end-use price reduction means that all the terms involving $\Delta p_1/p_1$ have to be multiplied by the present value factor in (33) for each option q, denoted by PVF_q, to measure the benefits from the implementation of the option. Hence, the net present value money metric welfare effect of conservation option q is,[10]

$$MM_{3q} = - CIC_q + I\left[w_1\left(\frac{\beta_q}{1+\beta_q}\right) + \frac{1}{2}(w_1^2 E_{1I} - w_1 E_{11})\left(\frac{\beta_q}{1+\beta_q}\right)^2\right.$$

$$- \frac{1}{6}\left(w_1 p_1^2 \frac{\partial^2 x_1}{\partial I \partial p_1} + 2 w_1^2 E_{11} E_{1I} - \frac{p_1^3}{I}\frac{\partial^2 x_1}{\partial p_1^2}\right)\left(\frac{\beta_q}{1+\beta_q}\right)^3$$

$$\left. + \frac{1}{6}\left(I w_1^2 p_1 \frac{\partial^2 x_1}{\partial I^2} + w_1^3 E_{1I}^2\right)\left(\frac{\beta_q}{1+\beta_q}\right)^3\right] PVF_q \; . \tag{41}$$

The Net Present Value From Standard Cost-Effectiveness Criteria

The marginal cost of saved energy, denoted by CSE in Tables 5A and 5B, is conceptually the cost incurred to avoid consumption of a unit of energy, e. g., a Kwh of electricity. The benefit from this avoidance is not having to pay the marginal price of energy, which is the price p_1^* per Kwh. Thus, option q is cost-effective if its associated cost of saved energy, CSE_q, is no more than p_1^*. That is, cost-effectiveness requires that

[10]Equation [5.18] on page 121 of Dumagan (1991) had typographical errors that when corrected lead to equation (41) above. That is, the latter equation should replace the former. Fortunately, the typograhical errors in the text transcription of equation [5.18] did not carry over to the computer algorithm, which computed equation (41) as intended. Thus, the results reported in Tables 5.4A, 5.4B and 5.4C on pages 123 to 125 of Dumagan (1991) are correct and are consolidated in Tables 6A and 6B of this paper.

$$p_1^* - CSE_q \geq 0 \quad for\ all\ q \tag{42}$$

$$NPV_q = (p_1^* - CSE_q)\, PS_q PVF_q = p_1^* PS_q PVF_q - CIC_q \tag{43}$$

by using (32) to (34). From (43), NPV_q is the difference between the present value of the energy savings generated over the life of option q and its implementation (investment) cost. Since an investment is, in principle, undertaken to maximize its net present value, then conservation options should be ranked from largest to smallest NPV_q rather than from smallest to largest CSE_q . It is clear from (43) that the option with the smallest CSE_q does not necessarily have has the largest NPV_q , i. e., the cheapest option is not necessarily the most profitable.[11]

Tables 6A and 6B show the net present values of the money metric net welfare effects, MM_{3q} from (41), and the net present values using standard cost-effectiveness criteria, NPV_q from (43). Current 1987 data on prices, quantities and income or expenditure were used together with the data in Tables 5A and 5B. These were combined with the estimated parameters of the generalized logit model of residential energy demand in section 4 to obtain MM_{3q}. An estimated statewide marginal price for electricity of p_1^* = \$ 0.08502/Kwh in current 1987 dollars and a discount rate of 6 % were used for both MM_{3q} and NPV_q. It is estimated in this study that all the options from # 1 to # 23, which have positive money metric net welfare effects as well as positive standard net present values, cost a total of \$ 2,793.05 million nominal dollars in 1987. This total amount represents a per capita investment cost of \$ 156.69 or merely 0.87 %

[11]Energy conservation options are usually ranked from smallest to largest *CSE* in order to define a "conservation supply curve". This supply curve implies that the higher the price of energy, the more energy will be supplied by conservation because options with the higher *CSE*'s will become cost-effective.

TABLE 6A -- CONSERVATION IMPLEMENTATION COST (CIC), MONEY METRIC (MM_3) AND STANDARD NET PRESENT VALUE (NPV) OF GAINS FROM ELECTRICITY CONSERVATION OPTIONS (1987 CURRENT DOLLARS PER CAPITA AND % OF 1987 PER CAPITA INCOME)

	CIC (Total, Million $ in 1987)	MM_3 (Per Capita $ in 1987)	NPV (Per Capita $ in 1987)
1. FRE	$ 17.11	$ 19.85 0.111 %	$ 19.45 0.108 %
2. REF	$ 215.18	$ 88.17 0.491 %	$ 90.56 0.504 %
3. REF	$ 235.31	$ 86.44 0.481 %	$ 88.83 0.494 %
4. REF	$ 116.45	$ 36.40 0.203 %	$ 36.19 0.201 %
5. EWH	$ 30.50	$ 9.69 0.054 %	$ 9.48 0.053 %
6. FRE	$ 41.59	$ 12.10 0.067 %	$ 11.84 0.066 %
7. FRE	$ 22.19	$ 5.97 0.033 %	$ 5.81 0.032 %
8. ESH1	$ 97.91	$ 22.20 0.124 %	$ 21.98 0.122 %
9. RAN	$ 50.50	$ 8.30 0.046 %	$ 8.12 0.045 %
10. ESH2	$ 28.26	$ 4.66 0.026 %	$ 4.54 0.025 %
11. ESH2	$ 6.18	$ 0.91 0.005 %	$ 0.88 0.005 %
12. RAN	$ 20.03	$ 2.77 0.015 %	$ 2.70 0.015 %
13. LTG	$ 128.00	$ 15.45 0.086 %	$ 15.43 0.086 %
14. LTG	$ 2.77	$ 0.29 0.002 %	$ 0.28 0.002 %
15. LTG	$ 1.68	$ 0.178 0.001 %	$ 0.173 0.001 %
16. EWH	$ 134.54	$ 11.42 0.064 %	$ 11.33 0.063 %

TABLE 6B -- CONSERVATION IMPLEMENTATION COST (CIC), MONEY METRIC (MM_3) AND STANDARD NET PRESENT VALUE (NPV) OF GAINS FROM ELECTRICITY CONSERVATION OPTIONS (1987 CURRENT DOLLARS PER CAPITA AND % OF 1987 PER CAPITA INCOME

	CIC (Total, Million $ in 1987)	MM_3 (Per Capita $ in 1987)	NPV (Per Capita $ in 1987)
17. LTG	$ 195.08	$ 14.54 0.081 %	$ 14.90 0.083 %
18. ESH1	$ 96.27	$ 5.61 0.031 %	$ 5.53 0.031 %
19. LTG	$ 243.31	$ 12.48 0.069 %	$ 12.73 0.071 %
20. LTG	$ 346.34	$ 16.81 0.094 %	$ 17.28 0.096 %
21. ESH1	$ 12.29	$ 0.385 0.002 %	$ 0.376 0.002 %
22. ECD	$ 603.86	$ 9.56 0.053 %	$ 10.43 0.058 %
23. ESH1	$ 147.70	$ 0.58 0.003 %	$ 0.63 0.004 %
24. RAC	$ 112.28	- $ 0.61 - 0.003 %	- $ 0.54 - 0.003 %
25. CAC	$ 76.63	- $ 1.71 - 0.010 %	- $ 1.63 - 0.009 %
26. RAC	$ 110.87	- $ 2.86 - 0.016 %	- $ 2.74 - 0.015 %
27. CAC	$ 106.63	- $ 2.95 - 0.016 %	- $ 2.82 - 0.016 %
28. RAC	$ 148.77	- $ 4.90 - 0.027 %	- $ 4.71 - 0.026 %
29. CAC	$ 101.91	- $ 3.66 - 0.020 %	- $ 3.52 - 0.020 %
30. CAC	$ 124.52	- $ 5.30 - 0.030 %	- $ 5.11 - 0.028 %
31. ESH1	$ 130.47	- $ 6.18 - 0.034 %	- $ 5.95 - 0.033 %
32. CAC	$ 143.62	- $ 6.83 - 0.038 %	- $ 6.58 - 0.037 %
Total*	$ 2,793.05	$ 384.76	$ 389.47

*These totals include only the options q = 1, 2, ..., 23 with positive values of MM_{3q} and NPV_q.

of nominal per capita income in 1987. For this per capita investment cost, the total money metric net welfare change per capita is $ 384.76 using a discount rate of 6 %. The corresponding standard net present value of gains per capita is $ 389.47 using the same discount rate. This represents an overall net rate of return of 245.55 % using the money metric welfare gain or 248.56 % using the standard net present value.

The money metric and the standard net present value differ conceptually with respect to the realization of energy savings. Given an improvement in energy efficiency, which results in a fall of end-use prices, the money metric takes into account the effects of end-use demand elasticities on energy consumption. The effect of these elasticities is to tend to counteract the effect of the efficiency improvement on the level of energy consumption. In this framework, the money metric does not presume that the potential energy savings will in the end be realized. At the same time, however, welfare improves from the fall in end-use prices. In contrast, the standard net present value calculation ignores the effects of end-use demand elasticities, thereby presuming that the savings potential is in the end realized.

In view of the above contrasting presumptions about energy savings, the near equality between the money metric net welfare effects and the standard net present values implies that end-use demand elasticities have negligible counter effects on potential savings. That is, it can be presumed that the actual savings of electricity from each option will be close to the potential savings. The recommendable options # 1 to # 23 in Tables 6A and 6B yield a total electricity savings potential of 12,011 Gwh/year from Tables 5A and 5B. This represents an annual savings of 34.74 % relative to the total residential electricity consumption of 34,577 Gwh/year in 1986.

A remarkable result in the preceding tables is the fact that the money metric and the standard net present value yield almost identical results not only in terms of the signs but also in terms of the absolute values of the gains from each of the conservation options. A simple regression of MM_{3q} against NPV_q for all options $q = 1, 2, \ldots, 32$ yields

$$\underset{}{MM_{3q}} = \underset{(0.0763)}{0.05264} + \underset{(0.0031)}{0.97813}\, NPV_q \tag{44}$$

with an R^2 practically equal to 1. The numbers in parentheses are the standard errors of the coefficients. Hence, the intercept is not significantly different from zero. However, the slope coefficient is significantly different from zero as well as significantly different from one. These imply a statistical proportional relationship between MM_{3q} and NPV_q with a proportionality constant of 0.97813. That is, for all the 32 conservation options in Tables 6A and 6B, MM_{3q} is statistically about 98 % of NPV_q. This finding may be explained below.

The standard net present value calculation of the gains from energy conservation assumes that the estimated energy savings are realized. This is equivalent to assuming that energy end-use demand elasticities are zero, implying from (31) that the percent reduction in the level of energy consumption is exactly equal to the negative of the percent improvement in end-use efficiency. Thus, suppose that all end-use elasticities are zero. Then, substituting from (26), MM_{3q} in (41) becomes

$$MM_{3q} = -\, CIC_q + p_1^* x_1^* \left(\frac{\beta_q}{1 + \beta_q} \right) PVF_q \, . \tag{45}$$

Since (45) assumes that (39) holds, it follows that

$$MM_{3q} = - CIC_q + p_1^* PS_q PVF_q = NPV_q \tag{46}$$

recalling NPV_q in (43). The result in (46) means that the money metric net welfare change and the net present value of the energy savings from efficiency improvements are equal if end-use elasticities are equal to zero. The implication is that NPV_q is conceptually a first-order money metric since it can be verified that the assumption of zero elasticities reduces any higher order money metric to a first-order, thus yielding the equality between the two measures in (46).

However, in general, the numerical values of a third-order money metric could be very close to the standard net present values even if elasticities are not zero, provided that the expenditure shares as well as the elasticities of the goods with changing prices are very small in absolute values. If so, the sum of the second-order and third-order terms in (41) may be close to zero. Consider that only the end-use price of electricity is being reduced in the above analysis. In this regard, the mean value of the expenditure share of electricity over the sample period is only 1.007 % and at the point of means, the short-run own-price and income elasticities are, respectively, - 0.0666 and 0.7232. In principle, this explains the almost equiproportional relationship between MM_{3q} and NPV_q summarized by (44).

In general, however, it follows that the net present value could differ from the third-order money metric if the good with the changing price has a large expenditure share and/or large absolute values of the elasticities. Therefore, the near identity between the money metric and net present value calculations summarized by (44) does not necessarily constitute a debunking of the more complicated money metric or an endorsement of the simpler net present value in every instance, considering that (44) happens only when the price and income elasticities or the expenditure shares are very small.

7. Conclusion

This paper demonstrated the joint application of the money metric and of the generalized logit model of consumer demand to the evaluation of the welfare effects of improvements in energy end-use efficiency. It also clarified the conceptual differences between the money metric and the net present value from the standard cost-effectiveness criterion for the evaluation of investments in energy conservation. Moreover, this paper also analyzed the conditions under which the two measures will yield approximately equal numerical results.

In the evaluation of specific electricity conservation options in the residential sector of New York state, it was found that the options with positive money metric net welfare effects represent an overall per capita investment cost of \$ 156.69 which was a mere 0.87 % of nominal per capita income in 1987. Using a 6 % discount rate, these options together yield a money metric net welfare change of \$ 384.76 per capita, representing an overall net rate of return of 245.55 %. For the same package of options, using the same discount rate, the overall net present value of electricity savings based on the standard cost-effectiveness criterion is \$ 389.47 per capita or an overall net rate of return of 248.56 %. This near equality between the money metric net welfare effect and the standard net present value implies that realized savings of electricity would be close to the potential savings of 12,011 Gwh/year, which is 34.74 % of total residential electricity consumption in 1986.

However, the above similar empirical findings between the money metric and the standard net present value do not hold, in general. It may be expected only in cases where the good with the changed price has a very small expenditure share and/or very small absolute values of the demand elasticities. It was shown that the net present value ignores the effects of end-use demand elasticities on the level of energy consumption after the improvement in efficiency. For this reason, it is in principle equivalent only to a first-order money metric. Therefore, a third-order money metric is preferable for being a more precise as well as a more general measure of welfare change in comparison to the net present value from the standard cost-effectiveness criterion for the evaluation of energy efficiency investments.

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