****

Memorandum

**TO:** Roger Baker (ComEd), David Nichols (ComEd)

**CC:** Jennifer Fagan (Itron), Jeff Erickson (Navigant), Jennifer Hinman (Illinois Commerce Commission)

**FROM:** Adam Burke, Amanda Dwelley, Bill Norton, Rick Winch (Opinion Dynamics)

**DATE:** May 31, 2012

**RE:** Fridge & Freezer Recycle Rewards Program PY4 Metering Study:   
DRAFT Savings Results

The PY4 Fridge & Freezer Recycle Rewards (FFRR) program evaluation involved an *in situ* metering study conducted between July 2011 and March 2012. The objectives of this study were to:

* Specify an Illinois-specific regression equation that can be used to estimate gross unit energy consumption (UEC) for the units collected by ComEd’s program
* Specify an equation with the same variables as the current lab-based metering regression equation (but using *in situ* metering data) and compare results with the current equation.[[1]](#footnote-1)

This document serves as an interim memo summarizing results of gross savings estimation. A full methodology and results summary will be included in the PY4 evaluation report.

***1. Metering Study Overview***

**Data Collection**

The evaluation team metered a sample of refrigerators and freezers in participant homes for an average of three weeks prior to their being removed by the program and recycled at JACO’s facility. Participants were recruited and screened by telephone. The evaluation team used a monetary incentive and multiple contact attempts to increase the response rate and minimize non-response and selectivity bias.

The metering study collected 5-minute interval demand and average kWh (from power meters), 5-minute interval internal temperature data, and light usage (on/off). We metered the appliance on a staggered basis between July 2011 and March 2012. The evaluation team also recorded appliance characteristics that have been associated with energy consumption in previous metering studies, including characteristics that are already recorded by the ComEd FFRR program. Each unit was metered for an average of three weeks before being removed for recycling through the FFRR program.

In total, we metered 121 refrigerators and 34 freezers, resulting in 130 valid sample points for analysis. summarizes the units metered and the final metered sample after accounting for unusable data associated with logger malfunctions.

Table 1. Metering Sample Frame and Final Sample

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Refrigerator** | **Freezer** | **Total** |
| **Total Metered Units** | **121** | **34** | **155** |
| Complete logger failurea | 13 | 6 | 19 |
| Partial logger failureb | 6 | 0 | 6 |
| **Units with valid power data** | **102** | **28** | **130** |

a Meter did not record any power data

b Meter either (a) recorded less than 1 day of data, or (b) recorded dates & times that could not be aligned with installation times)

**Existing Savings Approach**

To date, gross savings estimates for FFRR have relied on a regression equation for estimating refrigerator and freezer Unit Energy Consumption (UEC) that is based on a large database of over 2,200 units metered in California using Department of Energy (DOE) laboratory-based metering protocols. The DOE lab test methodology uses a prescribed procedure for metering unit energy consumption, which includes metering each unit at a constant ambient temperature of 90 degrees Fahrenheit. The regression equations derived from the lab-metered data estimate usage as a function of unit characteristics (age, size, configuration, and defrost mode). The characteristics of units collected by JACO for ComEd are then input into these models to estimate full-year UECs (representing kWh savings) that are specific to ComEd’s program.

**Metering Study Savings Analysis Approach**

The energy savings equation was estimated following a two-stage modeling process:

1. During the first stage we estimated the relationship between observed average hourly demand and outdoor temperature for *each unit*. We conducted sensitivity analyses to identify the Stage 1 estimation method that provided the best fit of hourly data. We then predicted what average hourly demand would be during typical weather and time periods for each unit in the sample (assuming 30-year typical weather conditions). Hourly estimates are annualized to a full-year UEC by multiplying average hourly demand by 8,766 hours per year.
2. During the second stage we estimate the relationship between annualized consumption (as predicted in first-stage models) and unit characteristics. We tested the lab-based metering specification and alternative specifications to find the best-fitting model (in terms of explanatory power, relative precision and usefulness for estimating program savings). The coefficients from the second-stage model can be used to re-estimate savings for the PY1-PY3 participant populations using mean values of appliance characteristics.

The next section provides estimated savings results from the preferred equation (developed from Stage 2 models). The proceeding sections provide more detail on the results of each analysis stage.

***2. Preliminary Savings Results***

**Preliminary Savings Algorithm**

Based on sensitivity analysis of multiple alternative models conducted to date (including re-estimation of the previous program model) and preliminary stakeholder feedback, we recommend the model below for estimating gross UEC for refrigerators and freezers recycled through the ComEd FFRR program.

Table . ComEd *in situ* metering model (Model C)  
(Dependent variable: Annual UEC in kWh)

(n=130, R2 = 0.38)

|  |  |  |
| --- | --- | --- |
| **Variable Description** | **Coefficient** | **Robust t-statistic[[2]](#footnote-2)** |
| Intercept | -103.39 | -0.45 |
| Freezer dummy (=1 if freezer) | 433.40 | 2.73 |
| Side-by-side dummy (= 1 if side-by-side) | 614.91 | 3.96 |
| Chest dummy (= 1 if chest freezer) | -490.78 | -2.55 |
| Single door dummy (= 1 if single door) | -797.90 | -1.80 |
| Age | 23.93 | 3.11 |
| Pre-1993 dummy (=1 if manufactured pre-1993) | 289.82 | 2.00 |
| Cubic Feet | 13.52 | 1.28 |
| Manual defrost dummy (= 1 if manual defrost) | -381.23 | -3.03 |

This model results in lower gross savings estimates than the program has used in previous years. This model is based on primary data from 130 PY4 ComEd program units, and applies to typical weather conditions in ComEd territory.

**Preliminary Savings Results**

Here we use the coefficients of the preferred *in situ* regression model to re-estimate gross per unit savings for PY1-PY3 units using each year’s summary statistics. Gross per unit savings for refrigerators and freezers in each year are reported in .

Table 3. Preliminary Re-Estimation of PY1-PY3 Gross Savings by Appliance Type   
Using Preferred *in situ* Metering Model

|  |  |  |  |
| --- | --- | --- | --- |
| **Metric** | **PY1** | **PY2** | **PY3** |
| **Gross Annual kWh per Refrigerator** | **818** | **869** | **937** |
| Gross kWh RP | 10.4% | 9.0% | 8.4% |
| **Gross Annual kWh per Freezer** | **1,238** | **1,083** | **1,220** |
| Gross kWh RP | 12.6% | 11.9% | 11.8% |

Gross and adjusted gross per unit savings (incorporating each year’s part-use factor) for the preferred *in situ* model are reported below. Gross savings estimated with this model are about half of gross savings reported in previous evaluation years.

Table 4. Preliminary Re-estimation of PY1-PY3 Gross and Adjusted Gross Savings  
Using Preferred *in situ* Metering Model

|  |  |  |  |
| --- | --- | --- | --- |
| **Metric** | **PY1** | **PY2** | **PY3** |
| *Refrigerators and freezers (n)* | *11,513* | *25,011* | *39,983* |
|  |  |  |  |
| **Gross Annual kWh per unit** | **930** | **911** | **980** |
| Gross kWh RP | 7.9% | 7.4% | 7.4% |
|  |  |  |  |
| **Part Use Factor** | **0.705** | **0.872** | **0.880** |
| Part Use RP | 7.7% | 3.8% | 3.4% |
|  |  |  |  |
| **Adjusted Annual kWh per unit** | **656** | **794** | **862** |
| Adjusted kWh RP | 11.0% | 8.4% | 8.2% |

**Discussion**

**In future program years, the evaluation team believes that the preferred algorithm from this *in situ* metering study will provide more accurate estimates of savings in ComEd territory compared with estimates from the previous algorithm. Gross savings estimates from the ComEd *in situ* models are in line with** observed consumption from the metering study sample. Additionally, gross savings estimates are in line with gross savings reported from *in situ* evaluations in Michigan, Ontario and California. Specifically:

* 1. For their respective program populations, recent *in situ* evaluations in Michigan, Ontario and California reported gross refrigerator UEC of 1,074-1,255 kWh, and gross freezer UEC of 1,173-1,270 per unit
  2. Using the ComEd PY3 population characteristics as inputs, regression-based equations from *in situ* metering in Michigan and Ontario predict gross refrigerator UEC of just under 1,000 kWh for refrigerators, and gross freezer UEC of 1,025-1,173 per unit ()

**Estimated gross per unit savings from *in situ* metering are lower than what the program estimated in PY1-PY3. Potential reasons for the difference between preliminary *in situ* estimates and the previous lab-based metering estimates include:**

1. Annualized, observed unit energy consumption of the metered sample was, on average, about half of average UEC of previous estimates. Therefore regression modeling is unlikely to yield a UEC estimate close to the previous estimates, even after accounting for slight differences between the metered sample and program populations (rather, we’d expect estimates to be closer to observed UEC).
   * + Before adjusting for weather conditions or unit characteristics, the evaluation team observed an average annualized UEC of 957 kWh per year for the 130 units in the metering sample (see the blue box in ). This is about half of the weighted average annual kWh estimates from the previous California lab-based metering model (see ).
2. The previous algorithm was based primarily on units metered in California under DOE protocols, with a constant 90F ambient temperature.
   * + About 87% of the units used to develop the previous lab-based metering regression were units whose UEC was estimated using DOE protocols
     + Metering studies using DOE protocols often show higher consumption when compared with *in situ* metering results
3. The sample used to develop the previous model was comprised predominantly of older units (recycled in 1993/1994), with a minority of units recycled after 2000. Partial effects of some appliance characteristics (e.g., age) are likely different within these populations.[[3]](#footnote-3)
   * + 72% of the units in the previous algorithm sample were from a 1993-1994 lab-based metering study, 9% from 1998 lab-based metering study, 6% from 2003 lab-based metering study, and 13% from a 2004-2005 dual monitoring study.

**The ability of these (or any) models to accurately predict savings from future program populations depends on accurately collecting appliance characteristics that are inputs to the regression equation. Since PY1, the program has improved (reduced) the proportion of units whose configuration or defrost mode is unknown, and should continue these efforts. Supplemental analysis of the sensitivity of these models to alternative age estimation (see Appendix B) revealed some sensitivity in gross savings predictions based on the source of age information (from the metering study or program tracking data). Therefore we recommend continued focus on data collection quality assurance.**

***3. Detailed Results***

**First-Stage Models**

Because each unit’s weather sensitivity (due to location in home) and time-of-day & day-of-week sensitivity (due to usage patterns) may vary, we tested for different relationships in these factors by including variables other than temperature. We tested seven specifications of bivariate and multivariate models for each unit in the sample, to determine whether inclusion of time-of-day or day-of week terms provided a better fit than temperature alone. The basic form of a model with additional terms is:

*AvekWt = Tempt + PeakHourt + WeekendHolidayt + εt*

With parameters defined as:

*AveKWt*: Average kW at hour t, based on average of 5-minute interval kW reads across the hour.[[4]](#footnote-4)

*Tempt*: Average hourly temperature time t, at the weather station closest to the participant’s home.[[5]](#footnote-5)

*PeakHourt*: A dummy variable taking a value of 1 when the hour is in peak hours (1:00-5:00PM CST during standard time and 1:00-5:00PM CDT during daylight savings time)[[6]](#footnote-6)

*WeekendHolidayt*: A dummy variable taking a value of 1 when the hour falls on a weekend or holiday (a value of 0 would help define PJM performance hours)

*ε*t: Idiosyncraticerror

We tested each set of models using both hourly data and smoothed hourly data (a moving average of hourly kW and temperature, to smooth spikes in usage related to motor and defrost cycling). Among each set of models (non-smoothed and smoothed), we selected the best-fitting model for each unit primarily based on Akaike information criterion (AIC). summarizes the number of appliances whose average hourly demand was best predicted by each model specification. For many units, hourly temperature alone was the best predictor of hourly demand.

Table 5. Hourly Demand Models Used for Estimating Average Hourly Consumption

|  |  |  |
| --- | --- | --- |
| **Model Specification  (Independent Variables)** | **Number of Units with Hourly Demand Best Predicted by Each Model Specification** | |
| **Non-Smoothed Data** | **Smoothed Data** |
| *Temp* | 44 | 15 |
| *Temp Temp2* | 13 | 18 |
| *Temp PeakHour* | 19 | 10 |
| *Temp WeekendHoliday* | 11 | 13 |
| *Temp PeakHour WeekendHoliday* | 10 | 21 |
| *Temp Temp2 PeakHour* | 16 | 27 |
| *Temp Temp2 WeekendHoliday* | 17 | 26 |

In addition to the models described above, we examined model fit and the distribution of Stage 1 UEC estimates using:

* Temperature only (linear temperature for all units)
* Lagged temperature instead of hourly temperature

These models were used to predict annual UEC at the average Typical Meteorological Year temperature for ComEd territory (50.12 degrees Fahrenheit), and average time-of-day (16.7% peak) and weekend-holiday (31.3%), where appropriate.[[7]](#footnote-7)

We compared different Stage 1 model approaches based on three criteria:

* Explanatory power of Stage 1 models: Smoothed data provided a much better fit of weather-based trends in consumption than hourly data (compare values in second data column of ). (By definition, best-fit models provide a better fit than linear temperature extrapolation.)
* The ability of the models to extrapolate beyond the observation season: We looked at average percentage change in UEC (from observed to predicted) for units metered in cooler periods vs. warmer periods (See rows 9, 11, 13, 15 of ). Since many units were located in unconditioned space, we’d expect that, on average, data collected from units metered in cooler months would show slightly lower average usage for the period we metered than what we might estimate as the unit’s annual average if we metered for 365 days; therefore we’d expect a slightly higher UEC after weather adjustment (on average). Similarly, we’d expect that, on average, data collected from units metered in warmer months would show a slightly higher average usage over the period we metered than what might observe as the unit’s annual average if we metered for 365 days; therefore we’d expect a slightly lower UEC after weather adjustment (on average). Regardless of extrapolation method, the average predicted UEC of units metered in colder periods is still lower than average predicted UEC of units metered in warmer periods.[[8]](#footnote-8) However, the linear temperature models provided a slightly larger percentage change in observed hourly demand among units metered in warmer periods.
* Explanatory power of Stage 2 models: Finally, we also looked at R-squared and precision of savings estimates for the PY3 population using each set of Stage 1 dependent variables (see Stage 2 Model columns of ).[[9]](#footnote-9) Though Stage 1 explanatory power is slightly better for when the best-fit Stage 1 model is used for each unit, there are no major differences in Stage 2 explanatory power.

Considering all of these factors, we recommend using smoothed hourly data for each unit, but including only a linear temperature term (Rows 14 & 15 of ).

below shows how predicted UEC from Stage 1 models varies by Stage 1 estimation method (rows 8-17). The blue box shows unadjusted UEC, based on extrapolating average hourly kW for each unit to a full year. It also shows a breakdown of observed and predicted annual UEC by the approximate season of metering (columns). Predicted annual UEC values include:

* Row 8: Predictions using the best-fit Stage 1 modeling approach described above
* Row 10: Predictions using smoothed hourly kW, and taking the best-fit model for each unit
* Row 12: Predictions using hourly temperature alone (linear)
* Row 14: Predictions using smoothed hourly kW, and using temperature only for each unit (linear)

Finally, compares average annual gross UEC estimates for the PY3 population using unadjusted UEC as well as predictions from each option for Stage 1 modeling. The bold-outlined box shows average annual UEC estimated from Stage 1 modeling options, compared to unadjusted UEC (top row). In Stage 2 models, using predictions from any Stage 1 model as a dependent variable achieves slightly higher explanatory power and better precision than using unadjusted UEC as the dependent variable (top row). As expected, annual kWh predictions from Stage 1 models are all slightly higher than when using unadjusted UEC, because estimates from Stage 1 models assume a higher temperature than the average temperature observed across metering. Based on these results we recommend using smoothed data and a linear temperature extrapolation for each unit (row 14 in ). Linear temperature extrapolation is also supported by other *in situ* studies (see Consumers Energy Annual Evaluation 2010 Report).

Table 6. Comparison of Observed and Predicted Annual kWh by Season of Metering

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Row** | **Metering Season 🡪** | **Winter Metering**  *Under 40 WTHI* | | **Shoulder Metering[[10]](#footnote-10)**  *40-60 WTHI* | **Summer Metering**  *60-80 WTHI* | **All Units** |
| 1 | n | 55 | | 41 | 34 | 130 |
| *Season Characteristics* | | | | | |  |
| 2 | Mean WTHI | 37.1 | 52.1 | | 71.7 | 50.9 |
| 3 | Mean Temperature (range) | 33.0  (26 - 36.2) | 50.8 (39.7 - 59.9) | | 74.4  (62.2 - 81.2) | 49.4  (26 - 81.2) |
| 4 | Install Dates | Nov 28, 2011 –  Feb 14, 2012 | Sep 14, 2011 –  Feb 14, 2012 | | Jul 14, 2011 – Sep 7, 2011 | Jul 14, 2011 – Feb 14, 2011 |
| *Unit Characteristics* | | | | | |  |
| 5 | Pct freezers | 11% | | 24% | 35% | 22% |
| 6 | Average Age | 21.7 | | 23.1 | 28.7 | 24.0 |
| *Observed and Predicted kWh* | | | | | |  |
| 7 | **Avg kWh, Observed** (Annualized from hourly data) | **780** | | **923** | **1,284** | **957** |
| 8 | **Avg kWh, Predicted** (from ***best-fit*** Stage 1 models) | 870 | | 922 | 1,226 | 980 |
| 9 | Average % Change from Observed | *+11.6%* | | *-0.1%* | *-4.5%* | *+2.4%* |
| 10 | **Avg kWh, Predicted**  (from ***smoothed best-fit*** Stage 1 models) | 868 | | 922 | 1,230 | 980 |
| 11 | Average % Change from Observed | *+11.3%* | | *-0.1%* | *-4.2%* | *+2.4%* |
| 12 | **Avg kWh, Predicted** (from ***linear hourly temperature*** models) | 867 | | 918 | 1,206 | 972 |
| 13 | Average % Change from Observed | *+11.1%* | | *-0.5%* | *-6.0%* | *+1.6%* |
| 14 | **Avg kWh, Predicted** (from ***smoothed*** ***linear hourly temperature*** models) | 867 | | 918 | 1,201 | 971 |
| 15 | Average % Change from Observed | *+11.2%* | | *-0.6%* | *-6.4%* | *+1.4%* |
| 16 | **Peak kW**  (Predicted for PJM demand models) | 0.139 | | 0.135 | 0.156 | 0.142 |

Table 7. Predicted Average UEC and Regression Fit among Stage 2 Models, based on Stage 1 Models[[11]](#footnote-11)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Dependent Variable** | **Stage 1 Modeling Method** | **Predicted Average UEC (from Stage 1)** | | **California Lab-Based Metering Equation (Stage 2)** | | **Model A (Stage 2)** | | **Model B (Stage 2)** | |
| UEC Estimate and (CV) | *Average Adjusted R2* | *R2* | *PY3 Estimate (RP)* | *R2* | *PY3 Estimate (RP)* | *R2* | *PY3 Estimate (RP)* |
| *Observed* | *Unadjusted UEC  (Annualized from hourly kW)* | *957 (0.67)* | *n/a* | *0.41* | *916 (16.3%)* | *0.40* | *1,063 (8.0%)* | *0.39* | *1,090 (10.5%)* |
| Stage 1 Prediction Options | Hourly data &  Best-fit Stage 1 models | 980  (0.66) | 0.078 | 0.41 | 980 (15.3%) | 0.42 | 1,106 (7.4%) | 0.40 | 1,143 (9.9%) |
| Smoothed data &  Best-fit Stage 1 models | 980  (0.66) | 0.210 | 0.42 | 958 (15.0%) | 0.42 | 1,088 (7.2%) | 0.41 | 1,127 (9.6%) |
| Hourly data &  Linear temperature only | 972  (0.64) | 0.064 | 0.41 | 1,002 (15.1%) | 0.41 | 1,114 (7.4%) | 0.40 | 1,162 (9.7%) |
| Smoothed data &  Linear temperature only ***(preferred)*** | 971  (0.64) | 0.178 | 0.42 | 956 (14.9%) | 0.42 | 1,088 (7.3%) | 0.41 | 1,127 (9.6%) |

*Note: Description of Stage 2 Models is below. Summary information is provided here for Stage 1 comparison purposes only*.

**Second-Stage Models**

After predicting annual UEC at the average Typical Meteorological Year temperature for ComEd territory (50.12 degrees Fahrenheit) for each unit using smoothed hourly data and linear temperature models for each unit, we specified a Stage 2 model identical to the lab-based metering regression equation, to examine similarity of coefficients and model fit. compares coefficients in both models.

Table 8. Comparison of Coefficients in California Lab-Based Metering Equation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable Description** | **California Lab-Based Metering Equation**  (R2 = 0.43) | | **ComEd *in situ* Metering Equation**  (R2 = 0.42) | |
| **Coefficient** | **t-stat.** | **Coefficient** | **Robust**  **t-stat[[12]](#footnote-12)** |
| Intercept | -422.41 | -0.77 | -55.79 | -0.04 |
| Freezer dummy (=1 if freezer) | 169.05 | 1.84 | 76.54 | 0.47 |
| Bottom freezer dummy (=1 if unit is bottom freezer) | 595.38 | 2.91 | 34.92 | 0.21 |
| Side-by-side dummy (= 1 if unit is side-by-side) | -129.36 | -0.34 | 117.59 | 0.23 |
| Single door dummy (= 1 if unit is single door) | -417.10 | -4.73 | -575.86 | -2.40 |
| Frost free dummy (= 1 if unit is frost free) | -445.03 | -1.00 | -1561.40 | -1.17 |
| Natural log of unit age | 405.21 | 2.15 | 113.69 | 0.24 |
| Cubic Feet of unit (per tracking system data) | 43.65 | 4.59 | 17.44 | 1.03 |
| Label Amps | 104.10 | 4.83 | 11.28 | 0.78 |
| Freezer dummy x frost free dummy | 319.11 | 1.94 | 329.34 | 1.11 |
| Bottom freezer dummy x frost free dummy | -302.05 | -1.28 | (omitted due to collinearity) | |
| Side-by-side dummy x frost free dummy | 1451.32 | 3.80 | 633.63 | 1.42 |
| Side-by-side dummy x amps | -126.43 | -2.88 | -9.60 | -0.19 |
| Frost free dummy x ln(age) | 299.82 | 2.09 | 519.59 | 1.28 |
| Dummy if mfg. year is 1990 or earlier[[13]](#footnote-13) | 1197.83 | 2.61 | -289.36 | -0.17 |
| Ln(age) x age 15 up dummy | -524.98 | -3.08 | 158.39 | 0.30 |

All but three coefficients in the *in situ* model share a similar direction as the lab-based model, though the magnitudes vary. The last column of shows that when all of the coefficients and interaction effects are included in a single model, few partial effects are significant at a 90% confidence level (two-tailed), including terms involving side-by-side units, age, manufacturing year, and size. Relatively low statistical significance is likely due to collinearity between terms (that may be more pronounced in the smaller ComEd metering sample than the California lab-based metering sample).

If this *in situ* model is used to re-estimate savings for PY1-PY3, the relative precision around the per unit gross savings estimates (at 90% confidence in a one-tailed test) exceeds 10%. shows potential results. Because precision falls below evaluation standards, we searched for more appropriate model specifications.

We considered all relevant appliance characteristics available in program tracking data for inclusion in alternative models, such as:

1. Dummy variables for all configurations (top freezer, bottom freezer, side-by-side, single-door, chest and upright freezers).
2. Dummy variables for appliance features (e.g., manual defrost and through-door ice)
3. Alternate specification of continuous variables – age, cubic feet, label amps (e.g., squared term or natural log of age)[[14]](#footnote-14)
4. Appliance vintage - Dummy variable for manufacturing year before 1990 (when first National Appliance Energy Conservation Act standards became effective) or before 1993 (first update of NAECA standards)
5. Location in home - The program tracks location in home, but does not currently track summer or winter space conditioning. Therefore location in home served as a proxy for potential weather sensitivity – for example, units located in a garage, porch or patio may show more sensitivity to climactic conditions.
6. Number of occupants in the home - The program does not track the number of occupants, though this variable was available through primary data collection.
7. Interaction terms

We examined model fit, precision, and statistical significance of individual terms under different specifications.[[15]](#footnote-15) We also tested separate refrigerator and freezer models.

To select the most appropriate model for future FFRR program savings estimation, we weighed criteria such as:

* Model fit (explanatory power)
* Relative precision (using the PY1-PY3 participant population characteristics)
* Savings estimates for different appliance configurations (relative to observed UEC (annualized from hourly), Stage 1 estimates, evaluation of savings for each configuration in other recent *in situ* models, and evaluation of savings for each configuration in original California lab-based metering model.

In addition to re-estimation of the California lab-based metering model, we identified four models that met at least one of these criteria. The main difference between the models is how age and vintage are specified. All models include a continuous age term, which accounts for degradation over time. It is believed that the marginal impact of degradation decreases over time, and this appears to be confirmed by the negative sign on Age-squared variable in Model A.[[16]](#footnote-16) There may also be a “vintage” effect based on manufacture before 1990 or 1993 NAECA efficiency standards, which may cause a difference in efficiency independent of other characteristics (that are included in the model). Models B-C allow for age as well as a separate “vintage” partial effect related to efficiency standards. Model B.1 allows for a difference in the slope of age (degradation year-over-year) based on vintage cohort.[[17]](#footnote-17)

The regression coefficients and t-statistics of versions of Model A are presented in . This table also shows coefficients of analogous models run only with refrigerators and freezers. Because results are consistent between the pooled and separate models (Average UEC by appliance type and configuration) but precision is better for the pooled model, we recommend using a pooled model. Results from other models are shown with pooled models only.[[18]](#footnote-18)

The regression coefficients of Model B, C and B.1 are shown in . Here we discuss the trade-offs of each model:

**Re-Estimation of the California lab-based metering model:** This model controls for multiple interactions between configurations and features. Similar to Models A-C, point estimates for different configurations are in line with observed UEC. However, the lower precision around estimates (related to collinearity) does not make this model ideal for evaluation purposes.

**Model A:** Model A controls for multiple configurations and represents age non-linearly (with an age and age-squared term). It has slightly higher explanatory power that Models B and C, and better relative precision than B.1.

**Models B:** Model B controls for multiple configurations and represents age as well as manufacturing year prior to 1990. While explanatory power is not quite as high as Model A, the inclusion of a vintage dummy representing manufacture pre- or post-NAECA standards is consistent with other *in situ* and lab-based metering studies.

**Model C:** Model C is similar to Model B, but includes a dummy for manufacturing year prior to the 1993 update to NAECA standards rather than 1990. Research on average annual energy consumption of new appliances suggests a more pronounced change in slope before vs. after 1993 compared with before vs. after 1990 (see Appendix ). Coefficients and results of models B and C are similar. Both models have relatively strong precision.

**Model B.1**: This variation on Model B allows for a different slope on age in the periods before and after the original NAECA standards, and significant coefficient on the analogous ln(age) x pre-1990 interaction in the California lab-based metering model). Though a lower marginal effect of age among pre-1990 units is supported by the model, precision is not as strong as simpler models.

Table 9. Coefficients and T-Statistics of Model A

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Pooled Model A**  (n=130, R2 = 0.42) | | **Refrigerators Only** (n=102, R2 = 0.42) | | **Freezers Only**  (n=28, R2=0.51) | |
| **Variable Description** | **Coefficient** | **Robust t-statistic** | **Coefficient** | **Robust t-statistic** | **Coefficient** | **Robust t-statistic** |
| Intercept | -695.70 | -2.42 | -1034.59 | -2.37 | -60.50 | -0.09 |
| Freezer dummy (=1 if freezer) | 410.79 | 2.66 |  |  | -551.57 | -2.53 |
| Side-by-side dummy (= 1 if side-by-side) | 655.92 | 4.35 | 631.99 | 4.31 |  |  |
| Chest dummy (= 1 if chest freezer)[[19]](#footnote-19) | -399.27 | -2.21 |  |  |  |  |
| Single door dummy (= 1 if single door) | -567.58 | -3.11 |  |  |  |  |
| Age | 87.55 | 6.02 | 96.01 | 5.41 | 79.28 | 1.75 |
| Age-squared | -0.94 | -4.20 | -1.09 | -4.09 | -0.74 | -0.86 |
| Cubic Feet | 7.40 | 0.72 | 18.13 | 1.22 | 12.23 | 0.41 |
| Manual defrost dummy (= 1 if manual defrost)[[20]](#footnote-20) | -350.58 | -2.90 | -202.90 | -1.46 | -706.23 | -2.74 |
| Overall PY3 Estimate (RP) | 1,088 (7.3%) | |  | |  | |
| Refrigerator Estimate (RP) | 1,037 (7.9%) | | 1,037 (8.4%) | |  | |
| Freezer Estimate (RP) | 1,344 (10.5%) | |  | | 1,385 (13.1%) | |

Table 10. Coefficients and T-Statistics of Models B and C

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Model B**  (n=130, R2 = 0.38) | | **Model C** (n=130, R2 = 0.38) | | **Model B.1**  (n=130, R2=0.41) | |
| **Variable Description** | **Coefficient** | **Robust t-statistic** | **Coefficient** | **Robust t-statistic** | **Coefficient** | **Robust t-statistic** |
| Intercept | -3.91 | -0.02 | -103.39 | -0.45 | -412.46 | -1.57 |
| Freezer dummy (=1 if freezer) | 406.94 | 2.63 | 433.40 | 2.73 | 429.88 | 2.67 |
| Side-by-side dummy (= 1 if side-by-side) | 596.29 | 3.85 | 614.91 | 3.96 | 628.11 | 4.18 |
| Chest dummy (= 1 if chest freezer)[[21]](#footnote-21) | -471.28 | -2.52 | -490.78 | -2.55 | -429.42 | -2.18 |
| Single door dummy (= 1 if single door) | -805.01 | -2.17 | -797.90 | -1.80 | -732.71 | -3.56 |
| Age | 20.19 | 2.42 | 23.93 | 3.11 | 49.12 | 4.24 |
| Pre-1990 dummy (=1 if manufactured pre-1990) | 344.49 | 2.02 |  |  | 1,030.80 | 2.86 |
| Pre-1993 dummy (=1 if manufactured pre-1993) |  |  | 289.82 | 2.00 |  |  |
| Cubic Feet | 14.20 | 1.31 | 13.52 | 1.28 | 10.84 | 1.00 |
| Manual defrost dummy (= 1 if manual defrost) | -362.05 | -2.86 | -381.23 | -3.03 | -363.39 | -2.94 |
| Age X Pre-1990 |  |  |  |  | -36.27 | -2.47 |
| Overall PY3 Estimate (RP) | 997 (7.5%) | | 980 (7.4%) | | 1,127 (9.6%) | |
| Refrigerator Estimate (RP) | 956 (8.4%) | | 937 (8.4%) | | 1,081 (10.2%) | |
| Freezer Estimate (RP) | 1,232 (11.5%) | | 1,220 (11.8%) | | 1,340 (12.1%) | |

Gross savings results of the models tested are fairly consistent across program years for each model, though there is some variation across models. All estimates from *in situ* models are lower than estimates reported in PY1-PY3 (first row).

Table 11. Average Annual UEC Using California Lab-Based Metering Coefficients vs.   
ComEd *in situ* Metering Coefficients (for same specification)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **PY1** | **PY2** | **PY3** |
| **Original California Lab-Based Model *(Reported)*** |  |  |  |
| Weighted Average Annual kWh[[22]](#footnote-22) | 1,929 | 2,003 | 1,864 |
| **Re-Estimation of California Lab-Based Model** |  |  |  |
| Weighted Average Annual kWh | 945 | 902 | 956 |
| Relative Precision | 14.9% | 15.0% | 14.9% |
| **Model A** |  |  |  |
| Weighted Average Annual kWh | 1,038 | 1,033 | 1,088 |
| Relative Precision | 8.0% | 7.3% | 7.3% |
| **Model B (1990 dummy)** |  |  |  |
| Weighted Average Annual kWh | 953 | 933 | 997 |
| Relative Precision | 8.1% | 7.5% | 7.5% |
| **Model C (1993 dummy)** |  |  |  |
| Weighted Average Annual kWh | 930 | 911 | 980 |
| Relative Precision | 7.9% | 7.4% | 7.4% |
| **Model B.1** |  |  |  |
| Weighted Average Annual kWh | 1,063 | 1,061 | 1,127 |
| Relative Precision | 10.0% | 9.0% | 9.6% |

Next, we compared estimates of savings for different appliance configurations using PY3 summary statistics for each configuration.[[23]](#footnote-23) We compared model estimates of PY3 savings for each configuration to observed and predicted UEC (from Stage 1 models) from the metering sample. We also entered the same ComEd PY3 summary statistics for each configuration into two models recently developed from *in situ* metering as part of other program evaluations, so that we could make a fair comparison between what the coefficients of *in situ* models in other jurisdictions would have predicted for ComEd’s PY3 population ().

Table 12. Comparison of Average UEC across Metering Studies using ComEd PY3 Participant Characteristics

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study & Model** | **Appliance Type** | | **Configuration** | | | | | |
| **All Fridge** | **All Freezer** | **Top Freezer** | **Bottom Freezer** | **Side-by-Side** | **Single Door** | **Chest** | **Upright** |
| **Metering Study Sample Observations** |  |  |  |  |  |  |  |  |
| Observed kWh (annualized estimate) | 908 | 1,134 | 787 | 822 | 1,291 | 323 | 1,097 | 1,162 |
| *Sq Ft observed* | *19.6* | *16.0* | *18.7* | *18.4* | *22.8* | *9.0* | *15.6* | *16.4* |
| *Energy Intensity (from Observed)* | *46* | *71* | *42* | *45* | *57* | *36* | *70* | *71* |
| **Metering Study Sample UEC** |  |  |  |  |  |  |  |  |
| Predicted UEC (from Stage 1 models) | 937 | 1,091 | 802 | 937 | 1,337 | 361 | 1,005 | 1,156 |
| *Energy Intensity (from Predicted)* | *48* | *68* | *43* | *51* | *59* | *40* | *64* | *71* |
|  |  |  |  |  |  |  |  |  |
| **ComEd *in situ* Metering Study Models** |  |  |  |  |  |  |  |  |
| CA Lab-Based Metering Re-Estimation | 898 | 1,220 | 902 | 638 | 1,591 | 428 | 1,279 | 1,241 |
| Model A Estimates | 1,037 | 1,344 | 1,042 | 754 | 1,684 | 655 | 1,153 | 1,483 |
| Model B Estimates | 956 | 1,232 | 962 | 742 | 1,584 | 266 | 963 | 1,377 |
| Model C Estimates | 937 | 1,220 | 945 | 720 | 1,584 | 272 | 948 | 1,374 |
| Model B.1 Estimates | 1,081 | 1,340 | 1,082 | 810 | 1,723 | 446 | 1,088 | 1,475 |
|  |  |  |  |  |  |  |  |  |
| **Other *in situ* Metering Studies**[[24]](#footnote-24) |  |  |  |  |  |  |  |  |
| Consumers Energy (2010) | 995 | 1,025 | 870 | 871 | 1,749 | 343 | 1,087 | 1,040 |
| Ontario Power Authority (2010) | 998 | 1,173 | 885 | 1,525 | 1,177 | 684 | 1,156 | 1,262 |
|  |  |  |  |  |  |  |  |  |
| **Lab-Based Metering Studies** |  |  |  |  |  |  |  |  |
| Ameren PY2 (2010)[[25]](#footnote-25) | 1,139 | 1,180 | 1,143 | 1,131 | 1,475 | 1,389 | 1,267 | 1,139 |
| California 2004-2005 | 1,983 | 1,966 | 2,015 | 2,313 | 1,573 | 1,430 | 1,984 | 1,939 |
|  |  |  |  |  |  |  |  |  |

Based on a comparison of potential models, Models B and C are preferable to other models for the following reasons:

* Relative precision around PY1-PY3 estimates is relatively strong (especially compared with relative precision using a re-estimation of the California lab-based metering model)
* Point estimates are in line with UEC observed within the metering sample
* The inclusion of dummy variables for manufacturing year before NAECA standards provides for a cohort effect that is supported by theory and the metering sample

UEC estimates from Models B and C are similar across years and configurations. Because LBNL research on the relationship between year of manufacture and UEC suggests that a more pronounced change in the relationship between year of manufacture and UEC occurred after the first NAECA update (1993) compared with 1990, Model C is preferable to B. Additionally, as the program matures, more units may be manufactured around the time of this change in standards (if not later), making the 1993 change in standard a potentially more relevant indicator of a cohort effect than the earlier standard.

**References**

ADM Associates, Inc., Athens Research, Hiner & Partners, Innovologie LLC. 2008. *Evaluation Study of the 2004-05 Statewide Residential Appliance Recycling Program; 2004-2005 Programs #1114, #1157, #1232, and #1348*. Prepared for the California Public Utilities Commission. April.

Bushman, Kate; Katie Ryder; Doug Bruchs; Jane Colby; Carol Mulholland; M. Sami Khawaj. 2010. *Appliance Recycling Program Evaluation – PY2*. Prepared for Ameren Illinois. Portland, Oregon: The Cadmus Group, Inc./Energy Services. September.

The Cadmus Group, Itron, Inc., Jai J. Mitchell Analytics, KEMA, PA Consulting Group, and Summit Blue Consulting, LLC. 2010. *Residential Retrofit High Impact Measure Evaluation Report.* Prepared for the California Public Utilities Commission. February.

Consumers Energy Annual Evaluation 2010 Report. 2011. *Direct Testimony of Chris Neme on Behalf of NRDC, ELPC & MEC*. U-16670 – October 12, 2011. The Cadmus Group, Energy Services. March 31.

Khawaja, M. Sami; Doug Bruchs; Josh Keeling; Josh Rushton. 2011. *2010 Great Refrigerator Roundup Program – Impact Evaluation.* Prepared for Ontario Power Authority. Portland, Oregon: The Cadmus Group, Inc.August 31.

Long, J. Scott and Laurie H. Ervin. 2000. “Using Heteroscedasticity Consistent Standard Errors in the Linear Regression Model.” *The American Statistician*. 54 (3) (August): 217-224.

McMahon, James E.; Peter Chan; Stuart Chaitkin. 2000. “Impacts of U.S. Appliance Standards to Date.” As published in proceedings of the 2nd International Conference on Energy Efficiency in Household Appliances and Lighting*,* Naples, Italy. September 27-29. Berkeley, California: Energy Efficiency Standards Group, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory – 45825.

National Climatic Data Center. Global Surface Summary of the Day Observations from Chicago O’Hare International Airport, Chicago, IL, 1982-2011. Data provided by the Midwestern Regional Climate Center, April 2012.

National Climatic Data Center. Global Surface Summary of the Day Observations from Greater Rockford Airport, Rockford, IL, 1982-2011. Data provided by the Midwestern Regional Climate Center, April 2012.

National Climatic Data Center. Local Climatological Data Hourly Observations from Chicago O’Hare International Airport, Chicago, IL, July 1, 2011 – March 20, 2012. Data provided by the Midwestern Regional Climate Center, March 2012.

National Climatic Data Center. Local Climatological Data Hourly Observations from Greater Rockford Airport, Rockford, IL, July 1, 2011 – March 20, 2012. Data provided by the Midwestern Regional Climate Center, March 2012.

United States Department of Energy. 1979. *10 CFR Appendix A1 to Subpart B of Part 430* - *Uniform Test Method for Measuring the Energy Consumption of Electric Refrigerators and Electric Refrigerator-Freezers.* [Mouse over help for Citation Text says The citation text which is listed in square brackets at the end of CFR sections. For example, "[T.D. 6500, 25 FR 11737, Nov. 26, 1960, as amended by T.D. 6525, 26 FR 189, Jan. 11, 1961]". Search field operator example is cfrcitationtext:"25 FR 11737".](http://www.gpo.gov/fdsys/)47 FR 34526, Aug. 10, 1982; 48 FR 13013, Mar. 29, 1983, as amended at 54 FR 36240, Aug. 31, 1989; 54 FR 38788, Sept. 20, 1989; 62 FR 47539, 47540, Sept. 9, 1997; 68 FR 10960, Mar. 7, 2003.

**Appendix A. Supplemental Information**

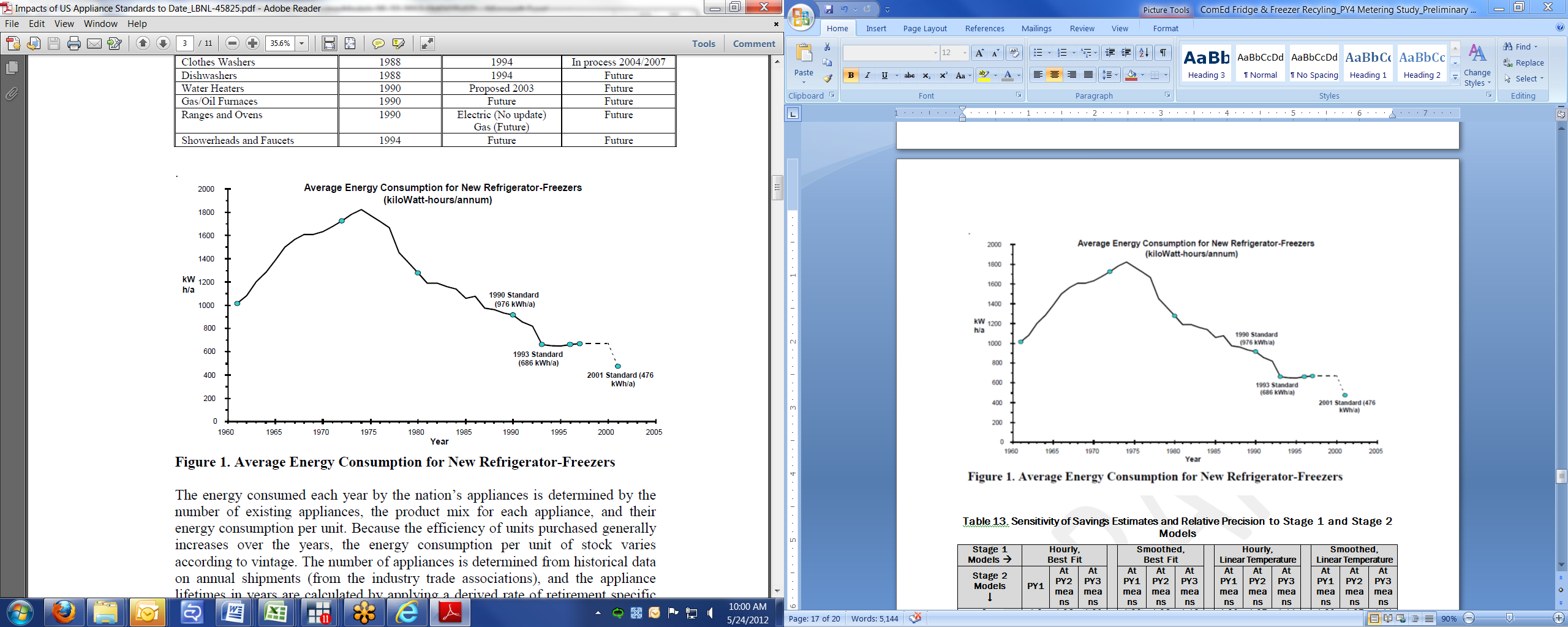
Table 12. Data Collected During Appliance Recycling Metering Study

|  |  |  |
| --- | --- | --- |
| **Data Point** | **Application** | **Data collection method** |
| Power (5 minute interval) | Energy usage and demand | Meters |
| Internal temperature (5 minute interval) | QA/QC power data (e.g., start and end dates/time of unit usage) | Meters |
| Light usage (on/off) | QA/QC power data (e.g., determine that unit was used during metering period) | Meters |
| Metering start and end dates & times | Clean power data and append weather | Technician report |
| Participant address and ZIP | Look up local weather data | Participant self-report and technician verification |
| Unit configuration | Potential association with energy consumption | Participant self-report and technician verification |
| Frost-free/manual defrost | Potential association with energy consumption | Participant self-report and technician verification |
| Through-door features | Potential association with energy consumption | Participant self-report and technician verification |
| Estimated Age | Potential association with energy consumption | Participant self-report and technician verification |
| Estimated Internal Capacity (size) | Potential association with energy consumption | Participant self-report and technician verification |
| Nameplate information | Look up additional information, if needed | Technician report |
| Primary/secondary unit | Study qualification; Potential association with energy consumption | Participant self-report |
| Location in home | Potential association with energy consumption | Participant self-report and technician verification |
| Air conditioned space (in summer) | Potential association with energy consumption | Participant self-report and technician verification |
| Heated space (in winter) | Potential association with energy consumption | Participant self-report and technician verification |
| Household occupants (#) | Potential association with energy consumption | Participant self-report |
| Occupants by age group | Potential association with energy consumption | Participant self-report |
| Part-Use Factors | Energy use and demand calculations | Participant Surveys |
| Hourly temperature and relative humidity data to calculate WTHI using PJM guidelines | Potential association with energy consumption | Rockford and O’Hare airports weather stations |

Table 13. Refrigerator and Freezer Unit Characteristics

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **PY1** | **PY2** | **PY3** | **PY1-PY2 Pooled** | **PY1-PY3 Pooled** | **Metering Sample** |
| Ex Post Count | 11,513 | 25,011 | 39,983 | 36,524 | 76,507 | 130 |
| % Refrigerator | 73.3% | 80.2% | 84.9% | 78.0% | 81.6% | 78.5% |
| % Freezer | 26.7% | 19.8% | 15.1% | 22.0% | 18.4% | 21.5% |
| *Refrigerator Configuration* |  |  |  |  |  |  |
| % Top Freezer | 10.3% | 46.0% | 49.1% | 34.7% | 42.2% | 52.3% |
| % Bottom Freezer | 0.7% | 2.6% | 9.6% | 2.0% | 6.0% | 4.6% |
| % Side-by-Side | 3.1% | 13.3% | 14.7% | 10.1% | 12.5% | 20.0% |
| % Single Door | 1.7% | 6.8% | 6.7% | 5.2% | 6.0% | 1.5% |
| % Unknown | 57.5% | 11.6% | 4.8% | 26.1% | 15.0% | 0.0% |
| *Freezer Configuration* |  |  |  |  |  |  |
| % Chest | 1.6% | 5.8% | 3.9% | 4.5% | 4.2% | 9.2% |
| % Upright | 2.4% | 12.7% | 8.8% | 9.4% | 9.1% | 12.3% |
| % Unknown | 22.7% | 1.3% | 2.4% | 8.0% | 5.1% | 0.0% |
| *Defrost Type* |  |  |  |  |  |  |
| % Manual | 51.3% | 38.6% | 14.4% | 42.6% | 27.8% | 28.4% |
| % Frost Free / Auto | 44.5% | 48.1% | 83.4% | 47.0% | 66.0% | 71.7% |
| % Part Frost Free | 0.1% | 2.1% | 0.7% | 1.5% | 1.1% | 0.0% |
| % Unknown | 4.1% | 11.2% | 1.5% | 9.0% | 5.1% | 0.0% |
| *Through Door Features* |  |  |  |  |  |  |
| % with Water/Ice | 17.6% | 23.0% | 25.6% | 21.3% | 23.5% | 19.7% |
| *Age* |  |  |  |  |  |  |
| Average age | 27.0 | 25.7 | 24.9 | 26.1 | 25.5 | 23.9 |
| % Age 15 years or higher | 89.6% | 86.0% | 70.5% | 87.1% | 78.4% | 84.6% |
| Mfg. year before 1990 | 73.4% | 66.5% | 63.1% | 68.7% | 65.8% | 49.2% |
| Mfg. year before 1993 | 83.4% | 76.8% | 74.0% | 78.9% | 76.3% | 65.4% |
| *Size & Amps* |  |  |  |  |  |  |
| Average size (cubic feet) | 16.8 | 17.6 | 18.0 | 17.4 | 17.7 | 18.8 |
| Average label amps | 4.8 | 5.5 | 5.9 | 5.3 | 5.6 | 7.0 |
| *Location* |  |  |  |  |  |  |
| % Garage | 45.9% | 47.85% | 45.3% | 47.2% | 46.2% | 56.2% |
| % Basement | 37.1% | 23.8% | 21.0% | 28.0% | 24.3% | 28.5% |
| % Kitchen / Non-basement inside | 10.9% | 14.1% | 12.5% | 13.1% | 12.8% | 13.1% |
| % Porch / Patio | 0.6% | 2.0% | 3.5% | 1.6% | 2.6% | 1.5% |
| % Other or Unknown | 5.6% | 12.2% | 17.8% | 10.1% | 14.1% | 0.8% |

Figure 1. Average Annual Energy Consumption for New Refrigerators and Freezers by Year



*Source: McMahon, Chan, and Chaitkin (2000).*

**Appendix B. Age and Vintage Sensitivity Analysis**

We also tested the sensitivity of our models to how age and vintage were recorded in the metering study compared with program data collection. For the metering study, meter installation technicians either recorded manufacturing year from the label (if available) or estimated age if the year was NOT available. Technicians were able to find manufacturing year for about one-third of units, and estimated age for all but four of the remaining units. Age for these four units was taken from the program database.

On average, age as reported in the program tracking database is about 3.9 years older than ages used in the metering study (average age in the metering study of 24.0 years, vs. 27.9 years for the same units in the tracking database). Similarly, among units for which year was recorded by the metering study, year as reported in the program tracking database reflects an age about 4.8 years older than used in the metering study.

Using the database ages to re-estimate coefficients in Model A, we found the explanatory power of the model to be much lower (an R2 of 0.18, compared with 0.42 using the metering study age), and the coefficients on age are not individually or jointly significant. Using Model C, the explanatory power of the model is lower, and coefficients on age and vintage are not individually significant (though they are jointly significant at a 90% confidence level). PY3 program savings estimates are actually slightly lower using these models (Tables 14 & 15).

Next, we compared what estimated savings would be using the metering study coefficients and (a) only metering sample characteristics, or (b) metering sample characteristics, substituting age as recorded by the metering study with age from the program tracking database. For Model A, the metering sample has a predicted average UEC of 1,080 kWh using metering data collection, and 1,230 kWh when year from the program tracking data is used for age (a 14% difference). For Model C, the metering sample has a predicted average UEC of 971 kWh using metering data collection, and 1,115 kWh when year from the program tracking data is used for age and vintage (a 15% difference).

Based on the difference in age and sensitivity of savings estimates to how year or age are collected, we recommend that the program continue to improve data collection QA/QC to ensure that characteristics of future units are reflected accurately in the program tracking database. For example, future evaluation plans could include a process to independently (and routinely) verify appliance characteristics tracked by the program.

Table 14. Comparison of Model A Using Age from the Metering Study vs. Program Tracking Database

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Metering Study Age** | | **Program Age** | |
| **Variable Description** | **Coefficient** | **Robust t-statistic** | **Coefficient** | **Robust t-statistic** |
| Intercept | -695.70 | -2.42 | 34.30 | 0.08 |
| Freezer dummy (=1 if freezer) | 410.79 | 2.66 | 468.91 | 2.71 |
| Side-by-side dummy (= 1 if side-by-side) | 655.92 | 4.35 | 450.99 | 2.62 |
| Chest dummy (= 1 if chest freezer) | -399.27 | -2.21 | -238.42 | -1.09 |
| Single door dummy (= 1 if single door) | -567.58 | -3.11 | -340.86 | -2.19 |
| Age | 87.55 | 6.02 | 23.55 | 0.82 |
| Age-squared | -0.94 | -4.20 | -0.18 | -0.41 |
| Cubic Feet | 7.40 | 0.72 | 17.02 | 1.34 |
| Manual defrost dummy (= 1 if manual defrost) | -350.58 | -2.90 | -165.85 | -1.29 |
| **R2** | **0.42** | | **0.18** | |
| PY3 Estimate (RP) | 1,088 (7.3%) | | 937 (9.9%)[[26]](#footnote-26) | |

Table 15. Comparison of Model C Using Age from the Metering Study vs. Program Tracking Database

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Metering Study Age** | | **Program Age** | |
| **Variable Description** | **Coefficient** | **Robust t-statistic** | **Coefficient** | **Robust t-statistic** |
| Intercept | -103.39 | -0.45 | 129.43 | 0.45 |
| Freezer dummy (=1 if freezer) | 433.40 | 2.73 | 477.87 | 2.72 |
| Side-by-side dummy (= 1 if side-by-side) | 614.91 | 3.96 | 457.81 | 2.66 |
| Chest dummy (= 1 if chest freezer) | -490.78 | -2.55 | -242.84 | -1.12 |
| Single door dummy (= 1 if single door) | -797.90 | -1.80 | -329.78 | -2.32 |
| Age | 23.93 | 3.11 | 7.86 | 1.08 |
| Pre-1993 dummy (=1 if manufactured pre-1993) | 289.82 | 2.00 | 214.58 | 1.24 |
| Cubic Feet | 13.52 | 1.28 | 17.25 | 1.42 |
| Manual defrost dummy (= 1 if manual defrost) | -381.23 | -3.03 | -175.52 | -1.39 |
| **R2** | **0.38** | | **0.19** | |
| PY3 Estimate (RP) | 980 (7.4%) | | 920 (7.6%)[[27]](#footnote-27) | |

1. For PY1-PY3, the ComEd program used a regression formula from a meta-analysis of predominantly lab-based metering results that included nearly 1,600 units recycled between 1993 and 2005. See: ADM Associates, Inc., Athens Research, Hiner & Partners, Innovologie LLC (2008). Evaluation Study of the 2004-05 Statewide Residential Appliance Recycling Program. [↑](#footnote-ref-1)
2. Robust t-statistic use a heteroskedasticity-consistent covariance matrix (HCCM) to adjust standard errors for observed heteroskedasticity (related to magnitude of observed & Stage 1 UEC estimates). We used a version of HCCM called HC3 that has better small-sample properties (n<about 250) than the HC0 robust estimator of variance (a.k.a. Huber or White estimator). The HC3 estimator was first proposed by MacKinnon and White (1985) and is available in Stata 11. Source: Long and Erwin (2000). [↑](#footnote-ref-2)
3. Although a dummy variable for each sample was included, the coefficients are still interpreted as the partial effect of each characteristic (or unit change in the characteristic) holding other factors such as sample constant. [↑](#footnote-ref-3)
4. In smoothed data, moving average window for hourly kW and temperature includes two hours before and after, to account for some of the longer cycling periods observed. [↑](#footnote-ref-4)
5. Weather data for Chicago O’Hare Airport and Rockford Airport comes from the National Climatic Data Center NWS Cooperative Network, provided in hourly and daily format by the Midwestern Regional Climate Center. In some models we allowed for a non-linear relationship between temperature and hourly kW to account for the possibility that temperature within the home (even in unconditioned spaces) may vary within a narrower range than outdoor ambient temperature. [↑](#footnote-ref-5)
6. We also tested using a later peak period (e.g., 3-6pm CDT) and hourly dummies for each peak hour. For most units, a single variable representing the PJM peak period provided better model fit and statistical precision. [↑](#footnote-ref-6)
7. Typical Meteorological Year temperature calculated using 30 year (1982-2011) average daily temperature from O’Hare and Rockford stations, weighted by the PY3 proportion of participants closest to each station (89% O’Hare). [↑](#footnote-ref-7)
8. We wouldn’t expect complete equality given differences in characteristics within each period. [↑](#footnote-ref-8)
9. Precision estimates incorporate heteroskedasticity-consistent standard errors (i.e., robust standard errors) that are described in more detail below. [↑](#footnote-ref-9)
10. The shoulder season units were metered under similar temperature conditions as TMY temperature in ComEd territory. [↑](#footnote-ref-10)
11. R-squared (R2)can beused to compare explanatory power within a group of similar models (e.g., column) but should be interpreted with caution across models (across columns) because it generally increases as more independent variables are added to the model. In this case, the California Lab-Based Metering equation has the most independent variables [↑](#footnote-ref-11)
12. Robust t-statistic use a heteroskedasticity-consistent covariance matrix (HCCM) to adjust standard errors for observed heteroskedasticity (related to magnitude of observed & Stage 1 UEC estimates). We used a version of HCCM called HC3 that has better small-sample properties (n<about 250) than the HC0 robust estimator of variance (a.k.a. Huber or White estimator). The HC3 estimator was first proposed by MacKinnon and White (1985) and is available in Stata 11. Source: Long and Erwin (2000). [↑](#footnote-ref-12)
13. This dummy variable was intended to represent units manufactured before 1990, though it is sometimes stated as a dummy variable for age. Therefore for comparison purposes we used a dummy variable equal to 1 if the unit was manufactured prior to 1990. [↑](#footnote-ref-13)
14. We also examined sensitivity to modeling age based on manufacturing year recorded in the program tracking database rather than age collected in the metering study. Results are shown in Appendix B. [↑](#footnote-ref-14)
15. We began by assessing the variables and interaction terms that were significant in peak demand model, used to estimate peak demand for PJM purposes. [↑](#footnote-ref-15)
16. Language developed through collaboration with the Ameren evaluation team (The Cadmus Group) [↑](#footnote-ref-16)
17. Though Lawrence-Berkeley National Laboratory research on average annual energy consumption for new refrigerators and freezers over time () suggests a more pronounced change in slope in 1993, our sample supported a more detectable change in slope in 1990 rather than 1993 (based on significance of age & vintage interaction in model B.1 and an analogous model with a dummy for 1993 and its interaction), likely because a greater majority of units in the sample (and PY3 population) were manufactured before 1993 (providing fewer sample points to determine a different marginal effect). [↑](#footnote-ref-17)
18. Only results from separate appliance models are shown for Model A, because separate models for Models B and C yielded lower explanatory power and less precision than separate models for Model A. [↑](#footnote-ref-18)
19. We also tested analogous models without the chest dummy, because before controlling for features like age and defrost, the chest freezers in our sample showed a smaller difference in UEC from upright freezers than model coefficients predict. However, the chest coefficient remained strong across models, and other sources suggest that chest freezers may be more energy efficient than upright, because less cold air flows out when you open chest freezers (whereas upright freezers may lose more cold air as it flows down and out. (Source: Energy Star - http://www.energystar.gov/index.cfm?fuseaction=find\_a\_product.showProductGroup&pgw\_code=FRZ and Natural Resources Canada -http://oee.nrcan.gc.ca/equipment/appliance/3906) [↑](#footnote-ref-19)
20. We also tested the interaction between manual defrost and freezers in pooled models, and although this interaction is significant and adds explanatory power to the models, it results in less realistic estimates for different configurations (e.g., larger overstatements and understatements of average UEC per configuration relative to what was observed and what other *in situ* studies have found). [↑](#footnote-ref-20)
21. We also tested analogous models without the chest dummy, because before controlling for features like age and defrost, the chest freezers in our sample showed a smaller difference in UEC from upright freezers than model coefficients predict. However, the chest coefficient remained strong across models, and other sources suggest that chest freezers may be more energy efficient than upright, because less cold air flows out when you open chest freezers (whereas upright freezers may lose more cold air as it flows down and out. (Source: Energy Star - http://www.energystar.gov/index.cfm?fuseaction=find\_a\_product.showProductGroup&pgw\_code=FRZ and Natural Resources Canada -http://oee.nrcan.gc.ca/equipment/appliance/3906) [↑](#footnote-ref-21)
22. UEC values reported in PY1-PY3, weighted by the proportion of refrigerators and freezers in each year. [↑](#footnote-ref-22)
23. For simplicity of this memo, we compare only estimates based on PY3 characteristics. PY3 characteristics were selected because they are expected to be more similar to future program years and are more similar to the metering sample than PY1-PY2 characteristics. [↑](#footnote-ref-23)
24. References for *in situ* and lab-based metering studies provided in Appendix [↑](#footnote-ref-24)
25. The Ameren PY2 evaluation models are based on a database maintained by the California Energy Commission (CEC) that contains lab-based metering results of unit energy consumption at the time of manufacture, for 61,000 makes and models manufactured between 1978 and 2008. These models require the application of a degradation factor of 1.5% to account for the fact that the model estimates energy consumption of units at the time of manufacture, not at time of retirement. This degradation factor was applied to the estimates obtained by entering ComEd PY3 characteristics into the equations. [↑](#footnote-ref-25)
26. Estimated using coefficients from the model using age from the program tracking database, and average age of PY3 units from the program tracking database. [↑](#footnote-ref-26)
27. Estimated using coefficients from the model using age and year from the program tracking database, and average age and vintage of PY3 units from the program tracking database. [↑](#footnote-ref-27)