Major Appliance Replacement in Canada

Denise Young

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Executive Summary

Some 8% of residential energy use in Canada has been attributed to the use of major household appliances. Although the energy efficiency of these appliances has improved significantly in recent years, the extent to which these improvements in energy efficiency will have an impact on overall energy demand, and subsequently on the environment, depends on how quickly the newer and more efficient models replace older models in household use. Thus, the rates at which households replace various appliances have important implications for the realization of household energy demand savings in response to technological improvements.

In this report, data from the 2003 of Household Energy Use (SHEU03) are used to examine appliance replacement patterns in Canada for refrigerators, freezers, dishwashers, clothes washers and clothes dryers. The data indicate that the average age at which appliances are replaced is lowest for dishwashers, with almost one-third being replaced before they are 11 years old. The average replacement age is highest for refrigerators, with almost one-third of them in use for more than 20 years before being ‘replaced’. Further, energy savings from improved refrigerator technology may not be realized in the short-run since as many as 25% of households continue to use older energy-inefficient models alongside newer models when the older refrigerators are ‘replaced’.

Survival curves based on the SHEU03 data indicate that the linear survival curves that are typically used in models of residential energy demand tend overestimate the replacement rates of appliances in the older age ranges in Canada. This would lead to underestimates of the number of older appliances in use and overestimates of the energy savings that can be expected in any given period from appliance replacement. The replacement patterns found in the Canadian data are, however, sensitive to household characteristics, such as income. This implies that there may be scope for targeted policies that focus on lower-income households to reduce residential energy use.

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1. Introduction

The energy efficiency of major household appliances has improved significantly in recent years. These advances in energy efficiency are due in part to regulatory efforts that have led to the imposition of standards for household appliances and in part to improvements in technology that would have arisen in the absence of such standards (Kooney *et al* 1998, Kim *et al* 2006, Lu 2006, OEE 2005). The extent to which these improvements in energy efficiency will have an impact on overall energy demand, and subsequently on the environment, depends on how quickly the newer and more efficient models replace older models in household use. In other words, the rates at which households replace various appliances have important implications for the realization of household energy demand savings in response to technological improvements.

In previous studies, simple linear retirement and survival curves have been posited for the purpose of forecasting appliance replacement rates (Hwang *et al* 1994, Koomey *et al* 1998, Lu 2006). These linear survival curves are used because of (i) the ease with which they can be applied in the context of the larger forecasting models in which they are embedded; and (ii) a lack of appropriate data that allow for a detailed examination of actual appliance retirement and replacement patterns in specific regions.

The Survey of Household Energy Use (SHEU) -2003, conducted by Statistics Canada on behalf of Natural Resources Canada's Office of Energy Efficiency, provides the type of data that are needed to empirically examine the rate at which newer appliances enter into household use. The survey offers an overview of Canadian residential energy use and contains several questions pertaining to the current and replacement ages of five major household appliances: refrigerators, freezers, dishwashers, washing machines and dryers. This information allows us to examine the replacement patterns for a variety of major household appliances in Canada. Combining this information with other demographic data obtained from the survey allows us, furthermore, to determine whether or not there are any obvious policy strategies which could be followed in order to induce households to modify the rates at which they replace their older appliances with newer models embodying more energy efficient technologies.

In the next section we examine the recent literature on the impacts of these energy efficiency improvements in major appliances on household energy demand, with a focus on the use of 'survival' or 'retirement' curves in these models. Section 3 provides an overview of the pertinent components of the SHEU-03 data set, including summary statistics on appliance retirement and survival rates, and empirical (Kaplan-Meier) survival curves. In Section 4 we undertake a parametric statistical analysis in order to examine the size of the impacts of socio-economic factors on appliance replacement rates. In this section we also examine the determinants of the decision by many households to continue to use (instead of discard) older refrigerators after the purchase of a newer model. Section 5 discusses the policy implications of our results and presents conclusions.

2. Background Information and Literature Review

The percentage of residential energy demand attributed to the use of major household appliances varies across regions. In Canada, it is estimated that appliance use accounts for about 8% of total residential energy use (OEE 2006a). This is much lower than the estimated percentages of residential energy use, ranging from 17% to 30%, that have been attributed solely to refrigerators in Japan, Thailand and China (Lu 2006).

In a bid to curb residential energy consumption, many countries have imposed energy efficiency standards for newly manufactured household appliances (Koomey *et al* 1998, OEE 2005, Lu 2006). As a result, major gains have been realized in terms of the energy usage characteristics of appliances that are currently being sold on the market. Over an approximately two decade period from 1980 to 2002, the average efficiency of a 20-22 ft^3 top/bottom refrigerator increased by 150% in the US (Kim *et al* 2006). Measurements from Canada indicate that most major household appliances, with the exception of electric ranges, have seen dramatic improvements in energy efficiency over the 1990-2003 period (OEE 2005).

In spite of the improvements in the energy efficiency of household appliances, there have been increases in overall residential energy consumption. In Canada, for example, residential sector energy use increased by 13% over the 1990-2003 period. It is estimated that the stock of appliances grew by 33% over this same period. The increase in appliance use is due partially to increases in population over this period and partially to an increase in the average number of appliances being used by a typical household (OEE 2006a).

One reason for the increase in residential energy consumption is that the improved average energy efficiency of household appliances, obtained through a combination of research and development activities undertaken by manufacturers and the removal of the most energy inefficient models from the market, has not yet made its full impact on residential energy demand. The reductions in energy demand are being realized gradually as new models replace older less energy efficient models in individual households. Not only are the older models less energy efficient to begin with, but their energy use tends to increase as these appliances age (Bos 1993). As a result, the 'retirement' rate of older models has important impacts on aggregate residential energy use.

Although the newer models tend to use less energy[1], there are tradeoffs involved that affect the decision to switch from an older less efficient model. For a typical household, any gains in performance and energy efficiency must be weighed against the time and monetary costs involved in 'retiring' the old appliance and purchasing and installing a new model in their home. In many jurisdictions, the time costs of searching for a more energy-efficient appliance has been reduced through government initiatives. Initiatives such as Canada's "EnerGuide" labeling system and "Energy Star" designations make it easy for consumers to quickly identify which models perform best in terms of energy consumption (OEE 2006b).

This leaves consumers with the monetary cost of appliance replacement. While the 'use' stage of an appliance's life cycle will account for the majority of the energy consumed, the bulk of the related household expenses occur with the purchase price of the appliance. While it has been estimated that an optimal life cycle for a refrigerator, from an energy-use or global-warming perspective, might lead to a household buying and retiring 6 or 7 models over the course of 35

[1] To the extent that households opt to replace smaller-capacity appliances with larger-capacity models with added energy-using features, the savings from the retirement of older models may be limited.

years, the optimal life cycle based on cost objectives would have the same household buying and retiring only 2 models over that time period (Kim *et al* 2006).

On a more aggregate level, there are tradeoffs in terms of the environmental and resource costs of continuing to use older less energy efficient models versus the various material, energy and environmental costs associated with the production and delivery of new models. Increasing product life through re-use (i.e., second-hand use) decreases production demand and waste management costs while promoting resource conservation. A recent study suggests that, for the case of Austria, once all of the energy costs associated with production of raw materials, fabrication, usage, collection and recycling are taken into account, an increase in the lifespan of current appliances through repair and re-use could lead to as much as a 12% reduction in associated energy use. Given that household appliances account for under 2% of total energy demand in Austria, this would translate to only about a 0.22% reduction in national energy demand (Truttmann and Rechberger 2006).

In studies that examine the aggregate impact of improved energy efficiency for household appliances on residential energy demand, one of the required model components is the specification of an equation that captures the 'retirement' rates (or 'survival' curves) for individual appliances. In these models, it is generally assumed that old appliance models are discarded when a new model is purchased.[2] A further simplifying assumption is that retirement (or survival) curves are linear (Hwang *et al* 1994, Koomey *et al* 1998, Lu 2006).

For example, Koomey et al (1998) posit that all appliances are retired somewhere between 2/3 and 4/3 of the average life span. In other words, it is assumed that no appliance is replaced before 2/3 of the average lifespan for that category of appliance and all appliances are retired by 4/3 of the average lifespan, with a linear function capturing the retirement rates in between these two extremes. This can also be expressed in terms of 'survival' rates, whereby all appliances survive until they reach 2/3 of the average lifespan and no appliances survive beyond 4/3 of the

[2] To the extent that this assumption is incorrect, these models will overstate the gains that are available from the changing composition of the appliance stock. From the SHEU-03 data, it can be seen (see Section 3) that, while households tend to discard most appliances after the purchase of a new model, a sizable proportion of households continue to use their previous 'main' refrigerator in addition to the newly purchased model.

average lifespan with a linear function capturing the retirement rates in between these two extremes. Figure 1 illustrates this type of survival curve for an appliance whose average lifespan is 21 years.

Linear retirement or survival curves can be specified in terms of an average appliance life in conjunction with a set of parameters that determine the minimum and maximum life span, or the minimum and maximum life spans can be specified directly. While Koomey *et al* (1998) and Lu (2006) select the former approach, Hwang et al (1994) opt for the latter. Although no explicit retirement or survival equation is used in their models *per se*, Kim *et al* (2006) allow for a maximum life span of 20 years for a refrigerator, while Truttmann and Rechberger (2006) choose a specification whereby all appliances are used over a fixed lifespan and retired at the end of either 10 or 15 years, depending on the scenario under consideration.

Whether or not these linear specifications adequately capture actual household behaviour is an empirical question. The suitability of the underlying assumptions regarding appliance life spans can be examined by looking at actual data on household appliance replacement ages. In the next section, we consider data drawn from the SHEU-2003 survey of Canadian households.

3. Appliance Replacement in Canada: Summary Statistics and Empirical Survival Curves

3.1 Summary Statistics

The 2003 Survey of Household Energy Use (SHEU-2003) was conducted by Statistics Canada in 2004 on behalf of Natural Resource Canada's Office of Energy Efficiency (OEE 2006a). Households from across the country (excluding the northern territories) were surveyed and asked about several facets of their energy and appliance use over the 2003 calendar year. Of particular interest for this study are the questions related to appliance replacement activities and respondent demographics.

Information on retirement ages for appliances was gathered for refrigerators, freezers, dishwashers, clothes washers and clothes dryers. Respondents were asked for the approximate ages at which various appliances were replaced and whether or not an appliance was still working when it was replaced. For households who had replaced an appliance, the possible categories that a respondent could choose from were: (1) 3 years or less; (2) 4 to 5 years; (3) 6 to 10 years; (4) 11 to 15 years; (5) 16 to 20 years; (6) 21 to 25 years; (7) 26 years or more; (8) don't know / refuse.

Tables 1 through 6 provide breakdowns of replacement age by appliance. Replacement ages for refrigerators are provided in aggregate and for the sub-group of refrigerators which were replaced due to failure.[3] From these Tables we see that, for each of the five appliances, there have been retirements in all 7 of the age groups. For all appliances, the most common age at replacement is either 11 to 15 years (dishwashers, dryers) or 16 to 20 years (refrigerators, freezers, clothes washers). The distributions of retirement ages, however, vary across appliances.

Dishwashers constitute the appliance that is most likely to be replaced within 5 years of purchase. Dishwashers are also the least likely appliances to survive beyond 20 years in household use. Clothes washers and dryers exhibit similar patterns to each other in terms of retirement age, with the bulk of these appliances being replaced after 11 to 20 years of use. The appliances most likely to survive beyond 20 years of use are refrigerators and freezers. Over 30% of refrigerators that were replaced due to failure were used for over 20 years before a newer model was purchased. For freezers, over 40% survived for more than 20 years, with over 20% surviving more than 25 years.

These results match up reasonably well with some, but not all, of the assumptions in Hwang *et al* (1994) regarding minimum and maximum replacement ages, on which they base their (linear) appliance retirement functions for the US. They assign the lowest minimum (0 years) and maximum (25 years) ages to dishwashers and the highest minimum (11 years) and maximum (31 years) ages to freezers. Their assumptions regarding the relative minimum retirement ages for clothes washers and dryers (2 years and 9 years, respectively) and maximum retirement ages for

[3] While many households report that they replaced refrigerators for reasons other than appliance failure, all reported replacements for other household appliances were due to a breakdown of the previous appliance.

these two appliances (25 years for washers, 30 for dryers) are somewhat at odds with the Canadian data which show quite similar retirement age distributions for washers and dryers. While these assumptions may or may not be valid for US households, their use in a Canadian model would lead to earlier predicted energy gains from the introduction of more energy efficient clothes washers in the marketplace than would be supported by the data.

3.2 Life tables and empirical survival curves

The summary statistics presented in Tables 1 through 6 provide information on appliances that were replaced. They do not incorporate any of the available information from SHEU-2003 on the ages of appliances that are still in use in Canadian households. The information on the age of appliances at replacement can be combined with survey information on the current ages (at the time of the survey) of appliances for households that had not yet replaced their older models. The combined data can be used to compute "Life Tables" and Empirical Survival Curves (Greene 2002).

While the SHEU-2003 data for appliance replacement ages are recorded according to age-range categories (described above), the current age of an original appliance is either recorded in years or according to the same categories as used for the replacement ages, depending on how the respondent chose to answer the question. For the purposes of producing our Life Tables and Empirical Survival Curves, any ages recorded in years are converted to the appropriate category. In our graphs of the Empirical Survivals, the mid-point of each category is used. Based on the distribution of reported ages for appliances currently in use, the 'mid-point' assigned to the final category is 30 for all appliances except refrigerators, where a value of 35 is used.

The *Life Tables* (Tables 7 through 12) and *Empirical Survival Curves* (Figures 2 through 7) are calculated using the software package LIMDEP according to the methodology of Cutler and Ederer (1958). For each of the 7 possible discrete appliance age groups, t_j , (t_1 = 1 to 3 years, t_2 = 4 to 5 years, ... , t_7 = 26 years or more) the *Life Table* information presented consists of:

N_j = the number of observations that 'enter' age group t_j (i.e., the number of appliances that survive to at least t_j before replacement);

C_j = the number of censored observations in age group t_j (i.e., the number of observations that correspond to appliances whose age corresponds to t_j and were not replaced);

R_j = the number of appliances in the 'risk set' for age group t_j (i.e., a measure of the number the number of appliances in age group t_j that are 'at risk' of being replaced); in LIMDEP, this is measured as $R_j = X_j – C_j/2$;

X_j = the number of observations that exit (i.e., the number of appliances in the age group t_j that are replaced at that age);

S_j = the survival rate (i.e., the cumulative proportion of appliances surviving); this is measured as $[1-(X_{j-1}/ R_{j-1})]S_{j-1}$, where $S_1=1$; and

s.e.(S_j) = $S_j \sqrt{\sum_{k=1}^{j-1} (Q_k /(R_k (1-Q_k)))}$ is the standard error of the empirical survival rate.

3.2.1 Refrigerators

We consider two cases for refrigerators. In the first instance we look at patterns pertaining to the case where any replacement is considered an 'exit', regardless of whether or not the original appliance had failed. We see from Table 7 that we have data on the ages of 1820 refrigerators that were replaced before the survey and 775 'original' refrigerators that were still in use at the time of the survey. Of these 2595 appliances, 100 were replaced at an age of 3 years or less (X_{t1}) and 115 of the 'original' refrigerators were in this same 3 years of less age category (C_{t1}). By definition, the survival proportion for the first age category is 1 (since all refrigerators survive for at least 0 to 3 years). This survival proportion, which is depicted in Figure 2a, falls to 0.96 (or 96%) for ages of 4 or 5 years, and remains at over 0.8 (or 80%) until we reach ages of 16 to 20 years or older. Note that the drop of the survival rate to below 0.95 (or 95%) by the time we reach 6 to 10 years constitutes the fastest drop in survivals at the lower age ranges for all of the appliances considered. By the time we reach the largest age category, the survival rate for refrigerators has dropped to a little over 0.20. The only appliance with a lower survival rate in this age grouping is clothes washers.

In Table 8 and Figure 3a we present the survival rates for refrigerators that 'exit' due to failure. In this case, we have 884 refrigerators that exit and 980 'original' appliances. The 980 'original' appliances include some of the refrigerators that 'exited' according to our first definition, but are known to be still in use in the household.[4] As would be expected, compared with our previous results, the survival rates are higher in each of the age categories. The survival rates for refrigerators in the 21 to 25 year age range are almost 40% higher and for the 26 years of more range over 67% higher than those where 'exit' is defined as replacement for any reason. These results have important implications for household energy use, as many refrigerator replacements result in the energy use of the new (and probably larger) refrigerator being added on to the energy use of an older energy inefficient model.

3.2.2 Other Appliances

Freezers exhibit the highest longevity of all of the household appliances considered. The empirical survival rate for freezers reported in Table 9 and depicted in Figure 4a does not drop below 0.95 until we reach the *16 to 20 year* age range and falls only to .76 by the time we reach the *26 years or more* category. For the remaining appliances (dishwashers, clothes washers and dryers), the survival rates that appear in Tables 10-12 and Figures 5a-7a are greater than 0.95 for age ranges up to 10 years old, and fall steadily for the older age ranges. Survival rates for clothes washers drop more quickly than those for dishwashers and dryers. For dishwashers and dryers, the survival rate is still above .3 by the time we reach the *26 year or more* category.

Overall, these results indicate that the linear survival curves used in energy demand modeling exercises may be reasonably accurate for the lower age ranges. However, the linear survival curves used for other countries would overestimate the replacement rates of appliances in the older age ranges in Canada, leading to underestimates of the number of older appliances in use and overestimates of energy savings that can be expected in any given period from appliance replacement.

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[4] For some but not all of the refrigerators that were replaced for a reason other than 'failure' we know whether or not they are still in use in the home.

3.3 Heterogeneity of Empirical Survival Rates

All of the retirement and survival statistics provided so far have been purely descriptive and are of limited direct use for policy makers who may wish to evaluate the feasibility of measures that could be put in place to target factors affecting the timing of appliance replacements. It may be the case, for example, that appliance survival rates are sensitive to household income. If so, this would provide some scope for inducing earlier appliance replacement in lower income households via programs such as targeted subsidies.

One approach to determining whether or not appliance replacement rates differ across broad groupings of households is to test for homogeneity across stratifications of the data. The LIMDEP software provides two such tests, a log-rank test and the Generalized Wilcoxon test (Greene 2002). If the null hypothesis of homogeneity is rejected, this indicates that appliance replacement rates vary significantly across sub-groups of households in the sample.

For each appliance, we test for homogeneity based on stratifications established according to household size, household location and household income.[5] Based primarily on the categories available in the data set, we divide household size into 4 categories (1-2 persons, 3-4 persons, 5-6 persons, 7 or more persons), location into 5 regions (Atlantic, Quebec, Ontario, Prairies, British Columbia) and income into 5 categories ('less than $20000', '$20000-$39999', '$40000-$59999', '$60000-$79999', and '$80000 or more').

The results of the homogeneity tests can be found in the final row of Tables 7 through 12. From Tables 7 and 8, we see that survival curves for refrigerators based on an exit being defined as a replacement, where replacements due to failure and discretionary replacements are pooled together, vary significantly across household size, household location, and household income. When an exit is defined as appliance failure, none of these factors are significant. These results are not surprising, given that higher income and larger families are more likely to 'replace' a refrigerator while retaining it for use as a secondary appliance.

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[5] Since data on household income is incomplete, some observations are dropped for the latter stratification.

For the remaining four appliances, all replacement rates are sensitive to income. Replacement rates for clothes washers and dryers vary across household size. Sensitivity of replacement rates to location appears to only apply to refrigerators, clothes washers, and possibly freezers.

Although these homogeneity tests can provide some information about the likelihood of success for targeted policies aimed at increasing the turnover of appliances, they do not allow for easy quantification of the extent to which replacements are affected by household characteristics. Another way to look at these impacts is through a parametric specification of our survival rates. In the next section we consider parametric survival and hazard curves in order to examine the impacts of demographic factors on appliance replacement rates. We also use limited dependent variable models (Probit and Logit) to examine the determinants of the decision by many households to continue to use (instead of discard) a refrigerator after the purchase of a newer model.

4. Econometric Models of Appliance Replacement Decisions

4.1 Parametric Duration (Survival) Analysis

A parametric analysis of appliance survival requires the selection of an appropriate functional form. In the energy demand studies cited in Section 2, appliance duration is modeled in terms of 'survivals.' Parametric studies of appliance duration can be couched in terms of either 'survivals' or in terms of a related concept: 'hazards'.

In the context of household appliances, the survival function, $S(t)$ is defined as the probability that an appliance will last at least t years before failure/replacement. Technically, the survival function is simply $1-F(t)$, where $F(t)$ is the cumulative distribution function (CDF) for the random variable 'appliance duration'. The hazard rate is a measure of the likelihood that an appliance will fail (or be replaced) at age t, given that it has survived to an age of at least t. Mathematically, the hazard rate is defined as $h(t) = f(t)/S(t)$, where $f(t)$ is the probability density function (PDF) corresponding to F(t).[6] Given the relationships between the survival function and the corresponding CDF, PDF and hazard functions, once a functional form has been selected for any one of these functions, the remaining three functions can easily be derived.

The shape of the empirical hazard function, which can be constructed from the raw data (see Greene 2002), can help to narrow down the choice of functional forms for the parametric hazard. When a hazard function is upward sloping, this feature is referred to as positive duration dependence. In this case, the likelihood that an appliance will fail at age t, conditional on having survived up to age t, increases with t. A downward sloping hazard function exhibits negative duration dependence. While an 'exponential' specification implies a flat hazard, a 'Weibull' specification can exhibit either positive or negative duration dependence (but not both), and a 'log-logistic' or 'log-normal' specification will lead to a 'hill-shaped' hazard that exhibits positive duration dependence for small t, and negative duration dependence for large t (Greene 2003).

An examination of the empirical hazards for the major household appliances covered in the SHEU-2003 data set (Figures 2b-7b) shows that most of them exhibit purely positive duration dependence. The one exception is in the case of dishwashers, where the empirical hazard is hill-shaped. Therefore, we can rule out an exponential functional form for all of the appliances considered. For refrigerators, freezers, clothes washers and dryers we will use Weibull specifications. For dishwashers we will also consider 'log-logistic' and 'log-normal' specifications of the hazard and survival functions.

All three hazard specifications considered in our empirical specifications (Weibull, log-logistic and log-normal) can be most compactly expressed in terms of their associated survival functions:

Weibull: $S(t) = \exp[(-\lambda t)^p]$;

log-logistic: $S(t) = 1/[1+ (\lambda t)^p]$.;

log-normal: $S(t) = \Phi[-p\ln(\lambda t)]$ where Φ represents the normal CDF.

[6] The hazard rate can also be expressed as $-d\ln S(t)/dt$. See Greene (2003).

In each specification, the survival function is defined in terms of two basic parameters. The parameter p is a scale parameter, while the parameter λ is a location parameter. The effects of household income and other household characteristics can be entered into the specification by making λ a function of these 'covariates.' If we let x_i be the vector of characteristics corresponding to household i, they can be entered into the survival function by specifying the location parameter as: $\lambda_i = \exp[-x_i'\beta]$.

The interpretation of the parameters on the household characteristics differs from the case of a linear regression model. The parameters (β) do not directly represent the impacts of the individual household characteristics on the life-span of a household appliance. For the particular specifications considered in our application, it can be shown that (Greene 2003):

for a Weibull hazard: $E[\, t \mid x_i] = \exp[x_i'\beta]\, \Gamma[(1/p) +1]$; and

for a log-logistic or log-normal hazard: $E[\, \ln(t) \mid x_i] = x_i'\beta$;

In the case of the Weibull specification, the impact of the k^{th} household characteristic on the conditional mean of the life-span of an appliance is a multiple of the associated parameter β_k , while for the other specifications, the impact of the k^{th} household characteristic on the conditions mean of the log of duration, ln(t), is given by β_k.

In our study, the set of household characteristics that we include in the vector x_i can be divided into 3 groups. We control for location with a set of provincial dummies (the excluded province is British Columbia) and an urban/rural dummy (urban=1). We control for income / lifestyle with a set of income category dummies (the excluded category is under $20000), a set of dwelling-type dummies (the excluded type is single detached), and a dummy for whether or not the dwelling is owner-occupied (somebody at home on a typical weekday =1). We also control for the demand for appliance services in the household through the inclusion of household size, the number of children in the household, and a dummy for whether or not there is usually somebody at home during the day in the set of covariates.

Table 13 reports the results for a Weibull hazard / survival specification for all appliances except dishwashers. Table 14 presents the results for dishwashers. Once we control for other characteristics (which is not the case for our data stratifications in Section 3), the only appliances whose survivals are sensitive to income are refrigerators (when looking at time to replacement regardless of whether or not the appliance has 'failed') and clothes washers. In both cases, households with higher incomes are likely to replace these appliances at earlier ages than those with very low incomes. And for most income categories, the absolute size of the coefficient (and therefore the effect) increases with the income category, indicating that this tendency to replace appliances earlier increases with the level of income. The one exception is the highest income level category in the case of clothes washers.

It is interesting to note that for the case of clothes washer replacements, in all cases the respondent indicated that the appliance was replaced after 'failure'. The fact that replacements after failure are income sensitive may reflect the fact that appliance 'failure' can be a subjective evaluation that takes into account, among other things, the cost of repair to correct the 'failure'. Those with lower incomes may be willing to pay a repair bill that requires a lower cash outlay than is needed for replacement, while those with higher incomes may elect to simply replace the appliance. The fact that this phenomenon is not observed for all appliances may be related to the costs and feasibility of repairs, the cost of replacement, and the expected post-repair lifetime of the appliance. These are all factors that are likely to vary across appliance type.

For all appliances except refrigerators, the larger the household, the lower is the expected age at replacement. This result is of greater statistical significance (5% vs 10%) for clothes washers and dryers, two appliances that tend to be used more intensively by larger households. For clothes washers, this effect is partially offset if the household composition includes more children. In households where somebody is generally home during the day, dryers tend to be replaced at older ages, possibly due to an increased tendency to use other, more time intensive methods to dry clothes in some of these households.

The following is a summary of the statistically significant (at 10% or less) variables (excluding provincial dummies) and the sign of their impacts on age of failure / replacement :

Appliance	*Significant covariates*
Refrigerator (replaced)	income (-), mobile home (-), owner-occupied (+),
Refrigerator (failed)	owner-occupied (+)
Freezer	mobile home (-), urban (+), household size (-), no. of children (+)
Dishwasher	owner-occupied (-), household size (-)
Clothes Washer	income (-), urban (+), household size (-), no. of children (+)
Dryer	at-home (+), household size (-)

Overall, the results indicate that the household characteristics that affect the decision to replace an appliance vary across the five appliances considered in our study. For some appliances (refrigerators and clothes washers) replacement behaviour is income-sensitive. The most common factor influencing appliance replacement decisions appears to be demographics, as larger households tend to (need to?) replace appliances at more frequent intervals than smaller households. The policy implications of these results will be discussed in Section 5.

4.2 Binary Choice Models for 'Second' Refrigerators

One phenomenon that the hazard/survival analysis cannot capture is the decision of some households to continue to use an appliance (namely, refrigerators) after 'replacement' of an older model. While most households do not continue to use an older-model refrigerator once a newer, more energy efficient model has been purchased, there is a sizable minority of households who do keep an older fridge for 'secondary' use. In the SHEU-03 data, of the 1070 households who replaced a refrigerator and for whom there is sufficient information provided to determine whether the appliance was discarded or kept for future use, almost one-quarter of households kept the older model refrigerator in their home.

In order to determine whether there are particular circumstances in terms of factors such as income or demographics that influence the decision to keep a 'replaced' refrigerator for secondary use, we consider binary choice models of the form:

$$E(Y \mid x_i) = \text{Prob}\,(Y_i = 1 \mid x_i) = F(x_i'\beta)$$

where Y_i = 1 if a household keeps a 'replaced' refrigerator for secondary use
0 if a household waits until 'failure' before replacing a refrigerator; and
x_i is a vector of household characteristics which may affect this decision.

We consider both the Logit [$F(x_i'\beta) = \exp(x_i'\beta) / (1 + \exp(x_i'\beta))$ i.e., the logistic CDF] and Probit [$F(x_i'\beta) = \Phi(x_i'\beta)$ i.e., the normal CDF] specifications.

As with the hazard / survival models, the coefficients on the household characteristics do not provide a direct measure of the impact of the individual characteristics on the probability of keeping an older refrigerator once it has been 'replaced.' For household characteristics that are measured continuously, these impacts or 'marginal effects' can be computed as the derivative of $F(x_i'\beta)$ with respect to that characteristic (evaluated at the estimates of β and the sample means of the variables).

For characteristics that are captured through the use of dummy variables, the 'marginal effect' can be evaluated as difference in the probability of keeping an older refrigerator after 'replacement', $F(x_i'\beta)$, evaluated when the characteristic is present (dummy variable equals 1) and when the characteristic is not present (dummy variable equals 0), where these probabilities are measured at the estimates of β, with all other variables measured at their sample means (see Greene 2002, 2003). The results from the Probit and Logit equations, including the marginal effects corresponding to all variables that have statistically significant impacts on the decision to keep an 'old' refrigerator after 'replacement,' are reported in Tables 15 and 16.

Our results are robust to the choice of (Logit vs Probit) specification. Both regressions are significant overall; the same characteristics have significant impacts in both regressions; and the marginal effects are similar in each case, but slightly larger for the Probit model. The results indicate that income is an important factor in the decision to continue to use an older refrigerator that has been ‘replaced’ by a more energy efficient model. Compared to the base group of low income (<$20000) households, the probability of keeping a ‘replaced’ refrigerator increases by about .1 for those in the $20000-$39999 or $40000-$59999 income ranges. For those in the highest income category, the probability increases by an even larger amount, approximately .14 to .15. The case of households in the $60000-$79999 range for income is an anomaly, with no significant difference in probabilities compared to the low-income base case.

We also find that those who live in apartments are the least likely to hold on to an older refrigerator, most likely due to space constraints. And, households living in an owner-occupied residence are more likely to keep an old refrigerator after buying a new one than other households. Finally, there seems to be an increased tendency to hold onto old ‘replaced’ refrigerators in Quebec when compared to households in other provinces.

While these results do indicate that there may be some identifiable factors that influence the decision to retain an old refrigerator for energy use, and the regressions are significant, we see from Table 16 that the Logit and Probit models do not do well in terms of predicting this behaviour in individual households. From the subset of the data that we are using for our binary choice analysis, we know that 250 households kept their refrigerator after replacement, and 820 households did not. Based on a criterion whereby our models predict that a household will keep a refrigerator if the estimated probability, $F(x_i'\beta)$, evaluated at that household’s set of characteristics is greater than .5, the Logit (Probit) model predicts that only 10 (7) of the households would keep a refrigerator.

5. Policy Implications

The results from our empirical analysis indicate that there are identifiable factors that influence that age at which an appliance is replaced. Dishwashers tend to be replaced at younger ages than other appliances. While this leads to relatively quick introductions of new models into household use, this advantage may be offset by the increased use of materials and energy in the production and transportation of these appliances unless there are major technological gains in terms of the energy efficiency of dishwashers.

While the age at replacement is not sensitive to income for most appliances, households with higher incomes tend to replace refrigerators and clothes washers at a lower age than low-income households. This implies that there may be some scope for policies that provide incentives for lower income households to replace these appliances with more energy efficient models, leading to lower residential energy use. The success of these policies, especially in the case of refrigerators, would depend on whether or not households select larger refrigerators with more energy-using features as replacements for their older models and whether or not households truly replace a refrigerator or instead continue to operate the older appliance along with the newer model in their homes.

6. Conclusions

The appliance replacement patterns for Canadian households differ from those assumed in most models of residential energy demand. The linear survival curves used in these models would overestimate the replacement rates of appliances in the older age ranges in Canada. This would lead to underestimates of the number of older appliances in use and overestimates of energy savings that can be expected in any given period from appliance replacement. These replacement patterns, however, are not set in stone. An examination of the relationship between replacement rates and household demographics indicates that it would be possible to introduce policies that would induce households to replace some appliances earlier. If the decrease in residential energy demand from earlier replacement more than offsets the social costs of an increased use of energy and materials in the production and transportation of these appliances, there could be a net benefit from such policies.

References

Bos W (1993) "SMUD's refrigerator graveyard – conditions of the deceased" *Home Energy* 10, 18-19.

Cutler S and F Ederer (1958) "Maximum Utilization of the Life Table in Analyzing Survival" *Journal of Chronic Disorders* 699-712.

Greene W (2002) *LIMDEP Version 8.0 Econometric Modeling Guide (vol.2)* Plainview, NY: Econometric Software, Inc

____________ (2003) *Econometric Analysis (5th edition)* Upper Saddle River, NJ: Prentice-Hall.

Hwang R.J., F.X. Johnson, R.E. Brown, J.W. Hanford and J.G. Koomey (1994) "Residential Appliance Data, Assumptions and Methodology for End-Use Forecasting with EPRI-REEPS 2.1" Working Paper, Energy Environment Division, Ernest Orlando Lawrence Berkely National Laboratory, UC Berkely.

Kim H.C., G.A. Keoleian and Y.A. Horie (2006) "Optimal household refrigerator replacement for life cycle energy greenhouse gas emissions and cost" *Energy Policy* 34, 2310-2323.

Koomey J.G., S.A. Mahler, C.A. Webber and J.E. McMahon (1998) "Projected Regional Impacts of Appliance Efficiency Standards for the US Residential Sector" Working Paper, Energy Analysis Programs, Ernest Orlando Lawrence Berkely National Laboratory, UC Berkely.

Lu W. (2006) "Potential energy savings and environmental impact by implementing energy efficiency standard for household refrigerators in China" *Energy Policy* 34, 1583-1589.

Office of Energy Efficiency (2005), "Energy Consumption of Major Household Appliances Shipped in Canada: Trends for 1990-2003" Ottawa: Natural Resources Canada.

___________ (2006a), "The State of Energy Efficiency in Canada" Ottawa: Natural Resources Canada.

___________ (2006b), "2003 Survey of Household Energy Use (SHEU) Detailed Statistical Report" Ottawa: Natural Resources Canada.

Truttmann N. and H. Rechberger (2006) "Contribution to resource conservation by reuse of electrical and electronic household appliances" *Resources Conservation & Recycling* (in press)

APPENDIX 1: FIGURES

Figure 1: Linear Survival Curve for Average Appliance Age of 21

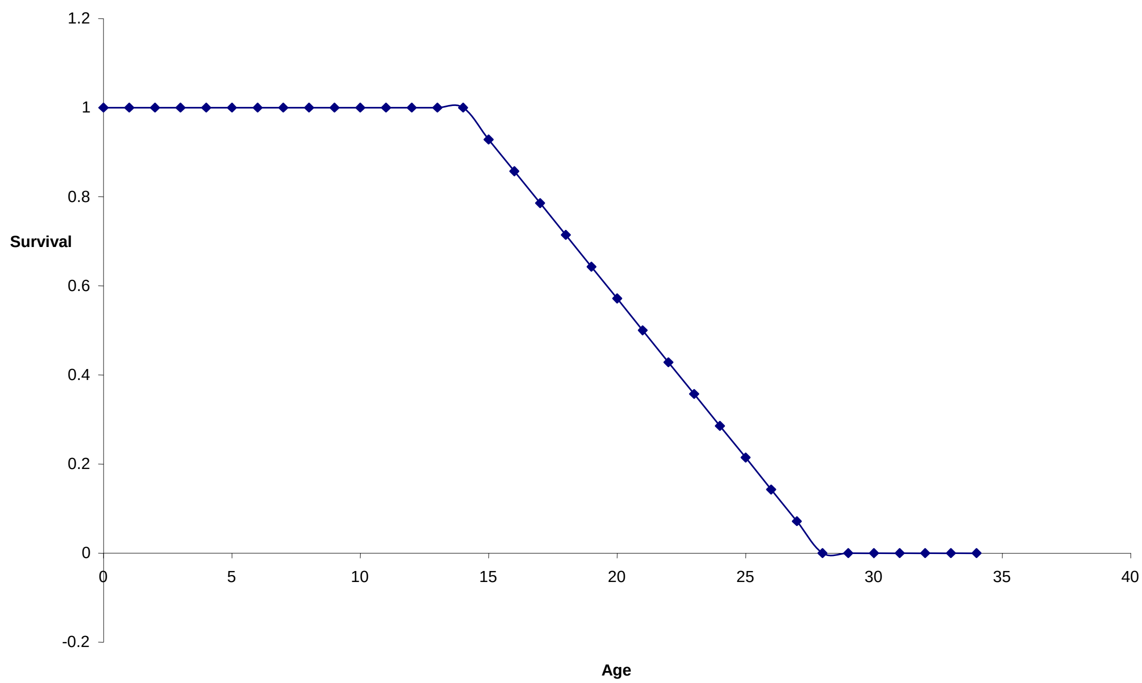


Figure 2a: Empirical Survival Curve for Refrigerators (Replacement)

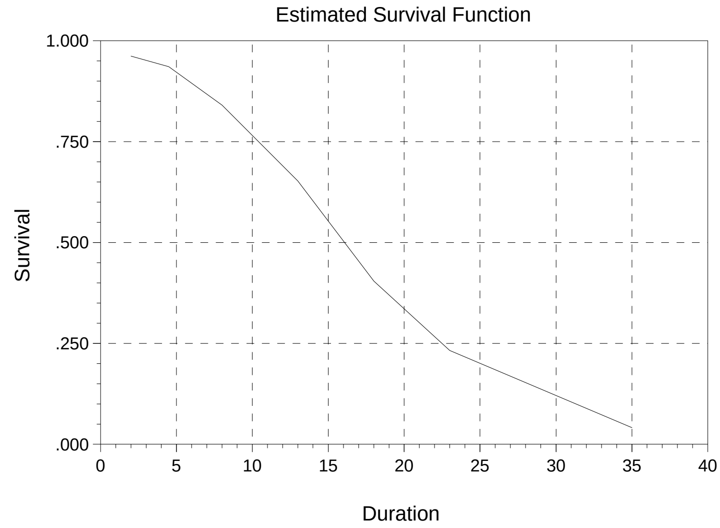


Figure 2b: Empirical (Kaplan-Meier) Hazard Function for Refrigerators (Replacement)

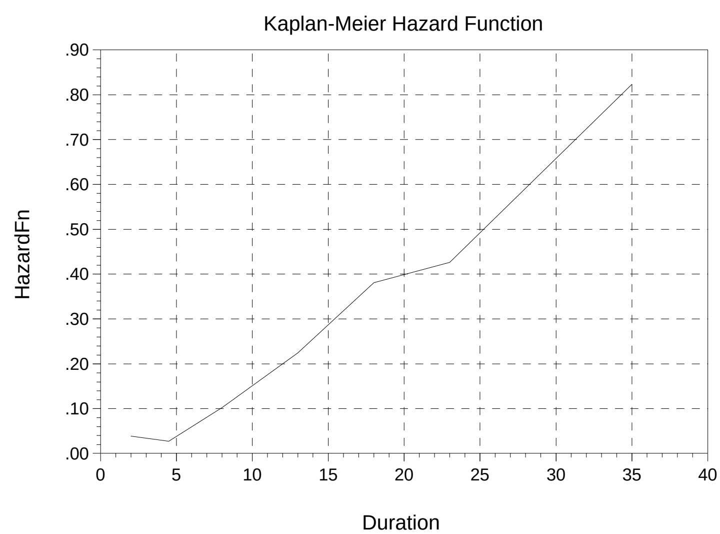


Figure 3a: Empirical Survival Curve for Refrigerators (Failure)

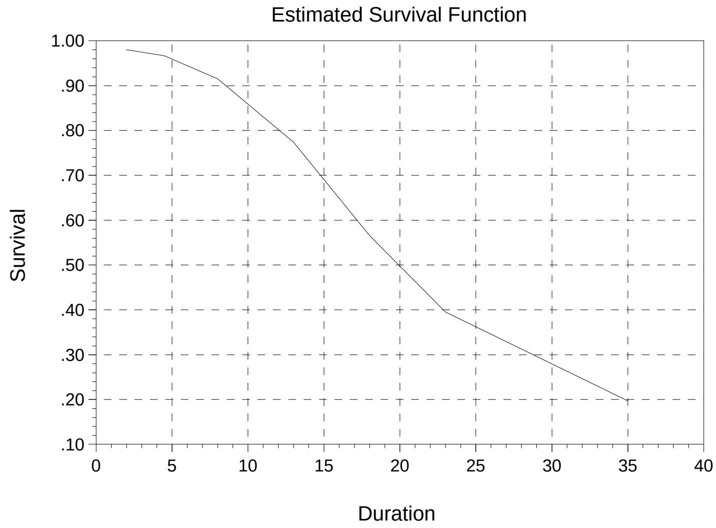


Figure 3b: Empirical (Kaplan-Meier) Hazard Function for Refrigerators (Failure)

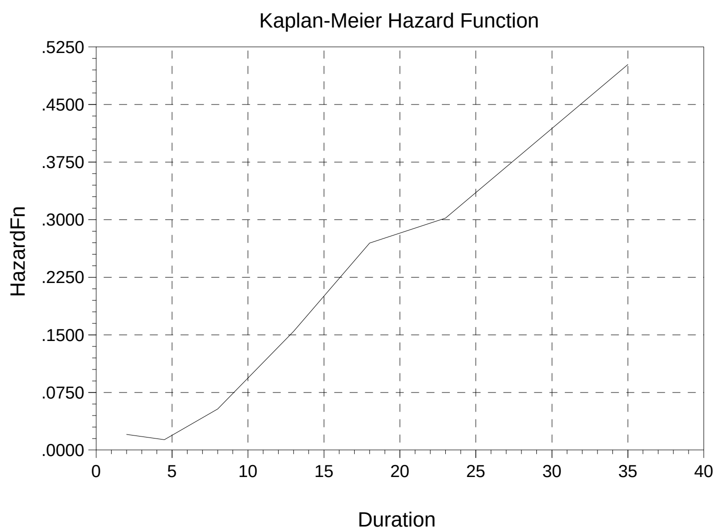


Figure 4a: Empirical Survival Curve for Freezers

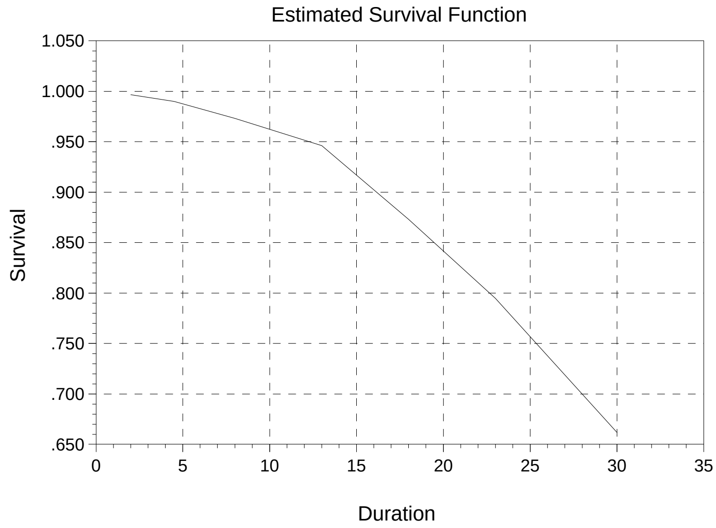


Figure 4b: Empirical (Kaplan-Meier) Hazard Function for Freezers

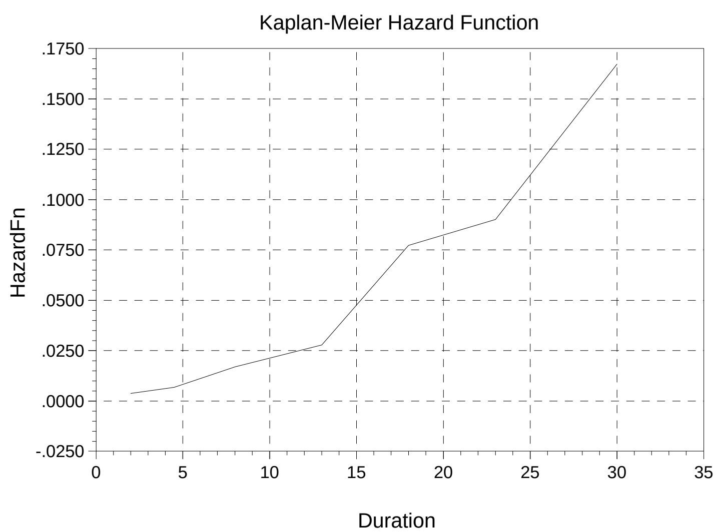


Figure 5a: Empirical Survival Curve for Dishwashers

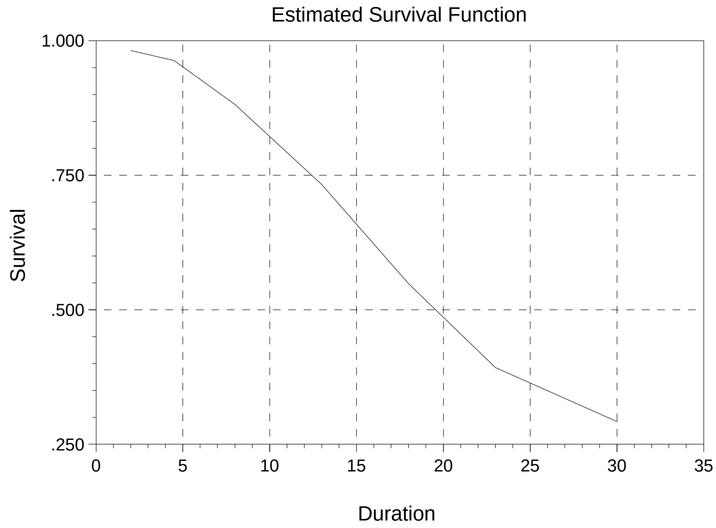


Figure 5a: Empirical (Kaplan-Meier) Hazard Function for Dishwashers

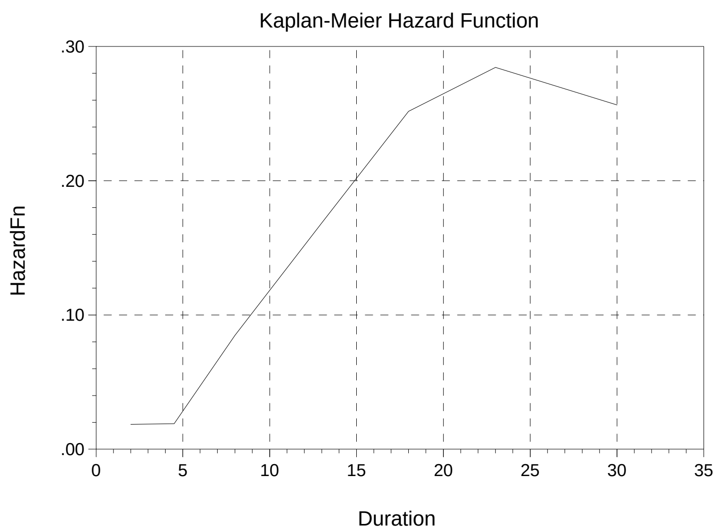


Figure 6a: Empirical Survival Curve for Clothes Washers

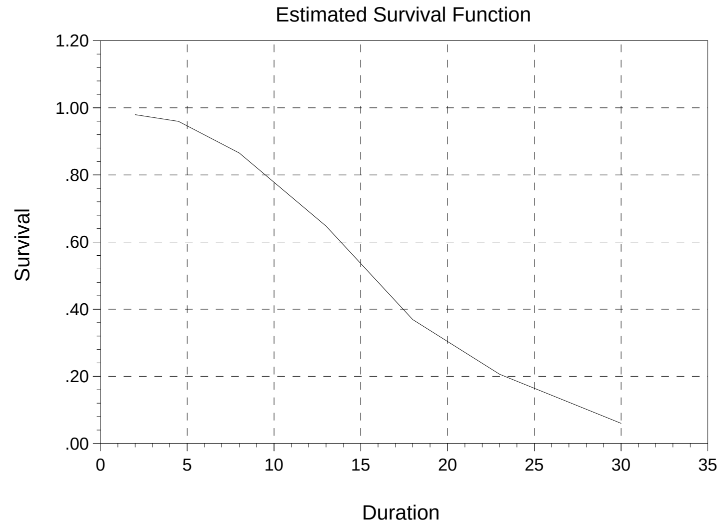


Figure 6b: Empirical (Kaplan-Meier) Hazard Function for Clothes Washers

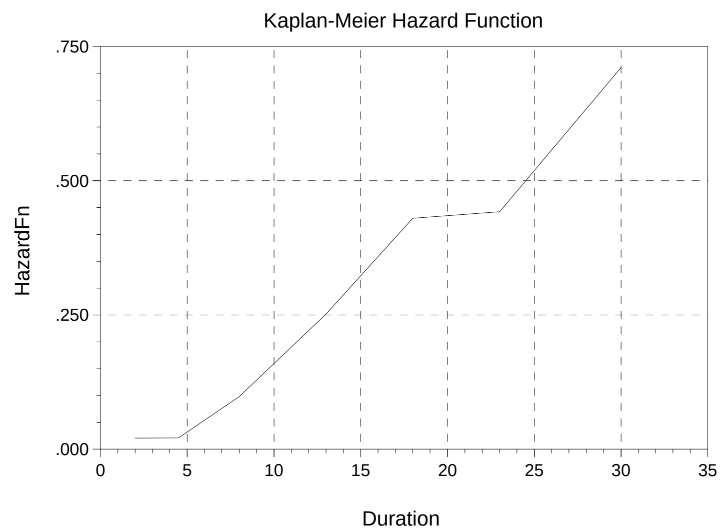


Figure 7a: Empirical Survival Curve for Dryers

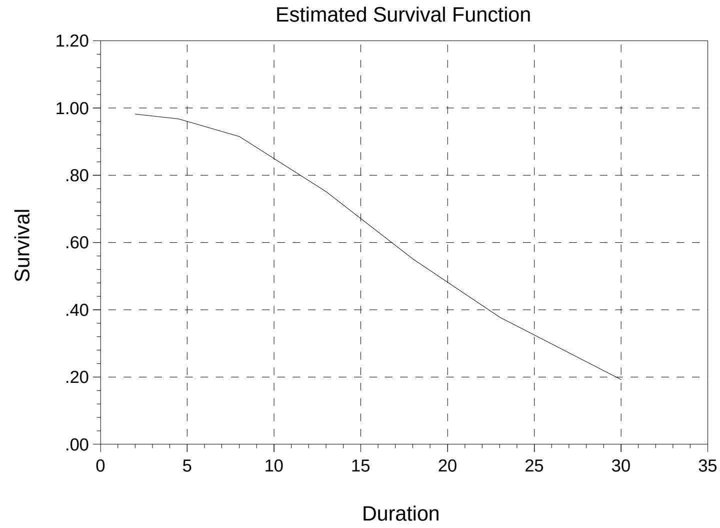
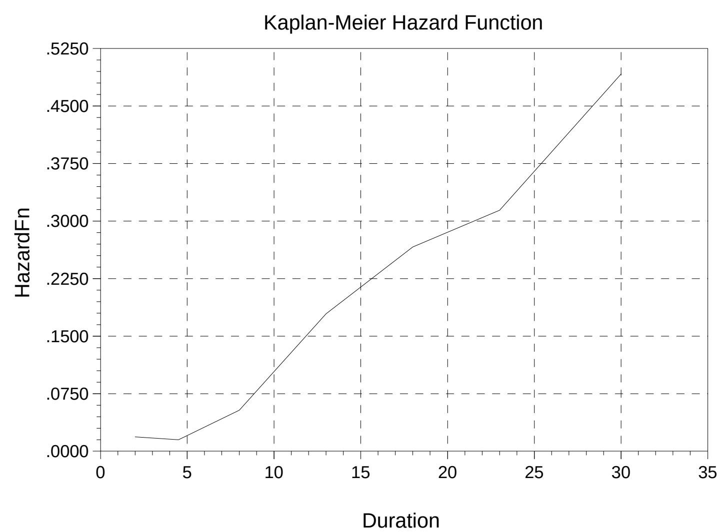


Figure 7b: Empirical (Kaplan-Meier) Hazard Function for Dryers



APPENDIX 2: TABLES

Table 1: Approximately, how old was your previous refrigerator?

Approximate Age	Frequenc y	Percent	Cumulative Percent
3 years or less	100	5.5	5.5
4 to 5 years	64	3.5	9.0
6 to 10 years	228	12.5	21.5
11 to 15 years	407	22.4	43.9
16 to 20 years	477	26.2	70.1
21 to 25 years	279	15.3	85.4
26 years or more	265	14.6	100.0
Total	1820	100.0	

Table 2: Approximately, how old was your previous refrigerator? (not working when replaced)

Approximate Age	Frequenc y	Percent	Cumulative Percent
3 years or less	38	4.3	4.3
4 to 5 years	23	2.6	6.9
6 to 10 years	86	9.7	16.6
11 to 15 years	203	23.0	39.6
16 to 20 years	249	28.2	67.8
21 to 25 years	154	17.4	85.2
26 years or more	131	14.8	100.0
Total	884	100.0	

Table 3: Approximately how old was your previous freezer?

Approximate age	Frequency	Percent	Cumulativ e Percent
3 years or less	8	2.8	2.8
4 to 5 years	13	4.6	7.5
6 to 10 years	31	11.0	18.5
11 to 15 years	39	13.9	32.4
16 to 20 years	78	27.8	60.1
21 to 25 years	53	18.9	79.0
26 years or more	59	21.0	100.0
Total	281	100.0	

Table 4: Approximately how old was your previous dishwasher?

Approximate age	Frequency	Percent	Cumulative Percent
1: 3 years or less	22	6.7	6.7
2: 4 to 5 years	19	5.8	12.6
3: 6 to 10 years	74	22.7	35.3
4: 11 to 15 years	95	29.1	64.4
5: 16 to 20 years	75	23.0	87.4
6: 21 to 25 years	31	9.5	96.9
7: 26 years or more	10	3.1	100.0
Total	326	100.0	

Table 5: Approximately, how old was your previous washer?

Approximate age	Frequency	Percent	Cumulative Percent
1: 3 years or less	45	3.6	3.6
2: 4 to 5 years	41	3.3	6.9
3: 6 to 10 years	178	14.3	21.2
4: 11 to 15 years	341	27.4	48.6
5: 16 to 20 years	362	29.1	77.7
6: 21 to 25 years	164	13.2	90.9
7: 26 years or more	113	9.1	100.0
Total	1244	100.0	

Table 6: Approximately, how old was your previous dryer?

Approximate age	Frequency	Percent	Cumulative Percent
1: 3 years or less	36	4.6	4.6
2: 4 to 5 years	26	3.3	7.8
3: 6 to 10 years	86	10.9	18.7
4: 11 to 15 years	221	28.0	46.7
5: 16 to 20 years	209	26.5	73.2
6: 21 to 25 years	125	15.8	89.0
7: 26 years or more	87	11.0	100.0
Total	790	100.0	

Table 7: Life Table for Refrigerators (Exit = replaced)

Approximate age (t_j)	Entered (N_j)	Censored (C_j)	At risk (R_j)	Exited (X_j)	Survival (S_j)
3 years or less (t_1)	2595	115	2537	100	1.0000 (.000)
4 to 5 years (t_2)	2380	76	2342	64	0.9606 (.004)
6 to 10 years (t_3)	2240	194	2143	228	0.9343 (.005)
11 to 15 years (t_4)	1818	157	1739	407	0.8349 (.008)
16 to 20 years (t_5)	1254	122	1193	477	0.6396 (.010)
21 to 25 years (t_6)	655	54	628	279	0.3839 (.011)
26 years or more (t_7)	322	57	293	265	0.2133 (.010)
N= 2595 Number exiting = 1820 Number censored = 775			Homogeneity tests p-values (Log-Rank; Wilcoxon): region (0.000; 0.000) household size (0.001; 0.007) income (0.000; 0.017) *		

Notes: Values in parentheses are estimated standard errors
* uses only observations where income is known (N=2405)

Table 8: Life Table for Refrigerators (Exit = failure)

Approximate age (t_j)	Entered (N_j)	Censored (C_j)	At risk (R_j)	Exited (X_j)	Survival (S_j)
3 years or less (t_1)	1864	116	1806	38	1.0000 (.000)
4 to 5 years (t_2)	1710	78	1671	23	.9790 (.003)
6 to 10 years (t_3)	1609	207	1505	86	.9655 (.004)
11 to 15 years (t_4)	1316	189	1221	203	.9103 (.007)
16 to 20 years (t_5)	924	165	841	249	.7590 (.011)
21 to 25 years (t_6)	510	95	462	154	.5344 (.014)
26 years or more (t_7)	261	130	196	131	.3565 (.015)
N= 1864 Number exiting = 884 Number censored = 980			Homogeneity tests p-values (Log-Rank; Wilcoxon): region (0.190; 0.331) household size (0.647; 0.553) income (0.872; 0.645) *		

Notes: Values in parentheses are estimated standard errors
* uses only observations where income is known (N=1726)

Table 9: Life Table for Freezers

Approximate age (t_j)	Entered (N_j)	Censored (C_j)	At risk (R_j)	Exited (X_j)	Survival (S_j)
3 years or less (t_1)	2157	196	2059	8	1.0000 (.000)
4 to 5 years (t_2)	1953	105	1900	13	.9961 (.001)
6 to 10 years (t_3)	1835	396	1637	31	.9893 (.002)
11 to 15 years (t_4)	1408	358	1229	39	.9706 (.004)
16 to 20 years (t_5)	1011	344	839	78	.9398 (.006)
21 to 25 years (t_6)	589	183	497	53	.8524 (.011)
26 years or more (t_7)	353	294	206	59	.7616 (.015)
N=2157 Number exiting = 281 Number censored = 1876			Homogeneity tests p-values (Log-Rank; Wilcoxon): region (0.105; 0.078) household size (0.527; 0.504) income (0.008; 0.078) *		

Notes: Values in parentheses are estimated standard errors
* uses only observations where income is known (N=1977)

Table 10: Life Table for Dishwashers

Approximate age (t_j)	Entered (N_j)	Censored (C_j)	At risk (R_j)	Exited (X_j)	Survival (S_j)
3 years or less (t_1)	1192	170	1107	22	1.0000 (.000)
4 to 5 years (t_2)	1000	108	946	19	.9801 (.004)
6 to 10 years (t_3)	873	235	755	74	.9604 (.006)
11 to 15 years (t_4)	564	171	478	95	.8664 (.012)
16 to 20 years (t_5)	298	114	241	75	.6944 (.018)
21 to 25 years (t_6)	109	39	89	31	.4783 (.024)
26 years or more (t_7)	39	29	24	10	.3126 (.029)
N=1192 Number exiting = 326 Number censored = 866			Homogeneity tests p-values (Log-Rank; Wilcoxon): region (0.398; 0.381) household size (0.505; 0.218) income (0.003; 0.039) *		

Notes: Values in parentheses are estimated standard errors
* uses only observations where income is known (N=1103)

Table 11: Life Table for Clothes Washers

Approximate age (t_j)	Entered (N_j)	Censored (C_j)	At risk (R_j)	Exited (X_j)	Survival (S_j)
3 years or less (t_1)	2176	159	2096	45	1.0000 (.000)
4 to 5 years (t_2)	1972	118	1913	41	0.9785 (.003)
6 to 10 years (t_3)	1813	279	1673	178	0.9576 (.004)
11 to 15 years (t_4)	1356	173	1269	341	0.8557 (.008)
16 to 20 years (t_5)	842	109	787	362	0.6259 (.012)
21 to 25 years (t_6)	371	48	347	164	0.3382 (.013)
26 years or more (t_7)	159	46	136	113	0.1783 (.011)
N=2176 Number exiting = 1244 Number censored = 932			Homogeneity tests p-values (Log-Rank; Wilcoxon): region (0.056; 0.000) household size (0.001; 0.002) income (0.001; 0.000) *		

Notes: Values in parentheses are estimated standard errors
* uses only observations where income is known (N=2035)

Table 12: Life Table for Dryers

Approximate age (t_j)	Entered (N_j)	Censored (C_j)	At risk (R_j)	Exited (X_j)	Survival (S_j)
3 years or less (t_1)	1940	150	1865	36	1.0000 (.000)
4 to 5 years (t_2)	1754	119	1694	26	.9807 (.003)
6 to 10 years (t_3)	1609	290	1464	86	.9656 (.004)
11 to 15 years (t_4)	1233	227	1119	221	.9089 (.007)
16 to 20 years (t_5)	785	178	696	209	.7295 (.012)
21 to 25 years (t_6)	398	96	350	125	.5104 (.015)
26 years or more (t_7)	177	90	132	87	.3281 (.016)
N=1940 Number exiting = 790 Number censored = 1150			Homogeneity tests p-values (Log-Rank; Wilcoxon): region (0.634; 0.328) household size (0.015; 0.000) income (0.012; 0.000) *		

Notes: Values in parentheses are estimated standard errors
* uses only observations where income is known (N=1818)

Table 13: Parametric Hazards: Weibull

	Refrigerators (replaced)	*Refrigerators (failed)*	*Freezers*	*Clothes Washers*	*Dryers*
constant	3.0064*** (.0770)	3.1013*** (.1020)	3.6424*** (.1468)	3.2231*** (.0771)	3.3413*** (.1082)
Provincial Dummies					
NFLD	-.0557 (.0680)	-.1543* (.0816)	-.3110*** (.1072)	-.1266** (.0556)	-.0254 (.0818)
PEI	-.0372 (.1093)	-.0812 (.1971)	-.0512 (.1959)	-.0828 (.1462)	-.3027** (.1252)
NS	.0449 (.0619)	.0136 (.0864)	-.0511 (.1230)	-.0477 (.0594)	-.0558 (.0729)
NB	.0931 (.0649)	.0319 (.0838)	.0197 (.1263)	-.0117 (.0580)	-.0361 (.0776)
QUE	-.0007 (.0469)	.0239 (.0647)	-.0348 (.0987)	-.0527 (.0449)	-.0737 (.0619)
ONT	.0404 (.0471)	-.0311 (.0644)	-.0736 (.0911)	-.0398 (.0440)	-.0702 (.0581)
MAN	.1583** (.0678)	.0522 (.0831)	.0022 (.1259)	.0662 (.0753)	.1096 (.0878)
SASK	.1338* (.0762)	.1222 (.1017)	.1686 (.1346)	.0112 (.0733)	-.0408 (.0882)
AB	.0623 (.0590)	.0330 (.0813)	-.0885 (.0990)	.0272 (.0539)	-.1254* (.0681)
Income Dummies					
$20000-$39999	-.0534 (.0590)	-.0351 (.0506)	-.0343 (.0815)	-.0838* (.0435)	.0253 (.0568)
$40000-$59999	-.0926** (.0434)	-.0334 (.0547)	.1646* (.0955)	-.1015** (.0462)	.0092 (.0583)
$60000-$79999	-.1312*** (.0490)	-.0828 (.0654)	.1141 (.1063)	-.1184** (.0514)	-.0315 (.0649)
$80000 or more	-.1485*** (.0466)	-.0454 (.0623)	.0367 (.0967)	-.0894* (.0482)	-.0082 (.0611)
Dwelling type dummies					
Double	-.0083 (.0569)	-.0684 (.0715)	-.2007 (.1388)	.0832 (.0541)	.1546 (.0940)
Row or terrace	.0989 (.1043)	.0051 (.1394)	.0940 (.2157)	.0388 (.1120)	.0419 (.1272)
Duplex	.0443 (.0694)	.0917 (.1047)	.1097 (.2114)	.0736 (.0822)	.2005* (.1142)
Low-rise apartment	.0996 (.0613)	.0248 (.0750)	-.1008 (.1582)	-.0222 (.0658)	-.0019 (.1039)
Mobile Home	-.2286* (.1281)	-.2348 (.1681)	-.3113** (.1339)	.0514 (.0986)	.0373 (.1079)
Other dummies					
Urban	-.0251 (.0287)	-.0032 (.0362)	.1144** (.0570)	.0768*** (.0269)	.0146 (.0358)
at-home	.0059 (.0118)	.0349 (.0336)	.0002 (.0447)	.0353 (.0252)	.0898*** (.0338)
owner-occupied	.1306** (.0537)	.1672*** (.0629)	.1282 (.1160)	-.0373 (.0536)	-.0299 (.0788)
Household size variables					
size	-.0070 (.0155)	-.0087 (.0192)	-.0538* (.0313)	-.0588*** (.0131)	-.0648** (.0178)
no. of children	-.0308 (.0201)	-.0175 (.0271)	.0890* (.0470)	.0370** (.0184)	.0386 (.0236)
scale parameter					
p	2.3641*** (.0422)	2.5085*** (.0619)	2.6415*** (.1146)	2.5729*** (.0545)	2.5244*** (.0656)
N	2405	1726	1977	2035	1818
log-likelihood	-1719.17	-1072.00	-607.08	-1152.07	-1010.68
LR (overall)	82.46***	34.36*	48.12***	73.58***	58.08***

Notes: Values in parentheses are estimated standard errors.
***, **, and *, denote significance at the 1% , 5%, and 10% levels, respectively.

Table 14: Parametric Hazards: Dishwashers

	log-logistic	*log-normal*	*Weibull*
constant	3.4261*** (.2396)	3.4627*** (.2608)	3.6747*** (.2442)
Provincial Dummies			
NFLD	-.1213 (.1936)	-.1256 (.2224)	-.1150 (.1716)
PEI	-.0231 (.2860)	-.1764 (.2651)	.0240 (.2976)
NS	-.0521 (.1633)	-.1010 (.1857)	-.0579 (.1474)
NB	.0977 (.1704)	.1117 (.1937)	.0803 (.1599)
QUE	-.0216 (.1161)	-.0320 (.1318)	.0847 (.1044)
ONT	-.0137 (.1149)	-.0732 (.1248)	.0011 (.1048)
MAN	-.0304 (.1667)	-.1159 (.1752)	-.0134 (.1484)
SASK	-.1761 (.1603)	-.2173 (.1838)	-.1046 (.1348)
AB	-.0407 (.1307)	-.0344 (.1518)	-.0284 (.1180)
Income Dummies			
$20000-$39999	.1601 (.1269)	.1875 (.1455)	.1023 (.1127)
$40000-$59999	.0232 (.1263)	.0237 (.1408)	-.0379 (.1142)
$60000-$79999	.0412 (1428)	.1179 (.1657)	-.0679 (.1279)
$80000 or more	-.0254 (.1337)	-.0161 (.1551)	-.1136 (.1199)
Dwelling type dummies			
Double	-.0052 (.1945)	-.0903 (.1698)	-.0479 (.1891)
Row or terrace	.1710 (.2900)	.2690 (.3409)	.2261 (.3094)
Duplex	-.0174 (.2086)	-.1028 (.2161)	-.0684 (.2241)
Low-rise apartment	.3466 (.2234)	.4802 (.2672)	.2992 (.2250)
Mobile Home	.3614 (.3578)	.5177 (.4744)	.3394 (.3389)
Other dummies			
Urban	.1102 (.0698)	.0827 (.0805)	.0748 (.0609)
at-home	.0489 (.0703)	.0454 (.0808)	.0559 (.0614)
owner-occupied	-.4069** (.1793)	-.3607* (.1888)	-.4613** (.1962)
Household size variables			
size	-.0729* (.0376)	-.0810* (.4458)	-.0494 (.0332)
no. of children	.0663 (.0482)	.0751 (.0533)	.0452 (.0441)
scale parameter			
p	2.6160*** (.1088)	1.3047*** (.0462)	2.2194*** (.0938)
N	1103	1103	1103
log-likelihood	-549.62	-571.28	-541.19
LR (overall)	42.86***	42.00***	46.6***

Notes: Values in parentheses are estimated standard errors.
***, **, and *, denote significance at the 1% , 5%, and 10% levels, respectively.

Table 15: Discrete Choice Estimates: Refrigerators

	Logit		Probit	
	Coefficient	***Marginal Effect***	***Coefficient***	***Marginal Effect***
constant	-3.8732*** (.7143)		-2.1845** (.3679)	
Provincial Dummies				
NFLD	-.7414 (.5121)	-----	-.3770 (.2768)	-----
PEI	-.0727 (.8669)	-----	-.0546 (.5015)	-----
NS	-.0200 (.4353)	-----	-.0160 (.2516)	-----
NB	-.7075 (.5140)	-----	-.4019 (.2834)	-----
QUE	.6456* (.3397)	.0972	.3767* (.1995)	.1088
ONT	.1292 (.3385)	-----	.0800 (.1974)	-----
MAN	-.0459 (.4543)	-----	-.0240 (.2629)	-----
SASK	.6127 (.4568)	-----	.3683 (.2714)	-----
AB	-.0839 (.4165)	-----	-.0434 (.2410)	-----
Income Dummies				
$20000-$39999	.6457** (.3126)	.0981	.3827** (.1723)	.1114
$40000-$59999	.6175* (.3352)	.0977	.3649* (.1865)	.1094
$60000-$79999	.5839 (.3593)	-----	.3280 (.2026)	-----
$80000 or more	.8701** (.3481)	.1406	.5053*** (.1963)	.1533
Dwelling type dummies				
Double	-.3958 (.3713)	-----	-.2259 (.2150)	-----
Row or terrace	-1.2585 (1.0840)	-----	-.6711 (.5511)	-----
Duplex	.2644 (.4521)	-----	.1375 (.2680)	-----
Low-rise apartment	-1.2532** (.5786)	-.1224	-.7184** (.2945)	-.1457
Mobile Home	-29.699 (14E+05)	-----	-7.0847 (19E+04)	-----
Other dummies				
Urban	-.1372 (.1767)	-----	-.0693 (.1038)	-----
at-home	.0860 (.1673)	-----	.0494 (.0987)	-----
owner-occupied	1.7096*** (.5661)	.1521	.8842*** (.2676)	.1703
Household size variables				
size	.1362 (.0948)	-----	.0809 (.0556)	-----
no. of children	.0115 (.1255)	-----	.0029 (.0749)	-----
N	1070		1070	
log-likelihood	-534.93		-535.03	
LR (overall)	93.53***		93.34***	

Notes: Values in parentheses are estimated standard errors.
Marginal effects are only shown for significant variables.
***, **, and *, denote significance at the 1% , 5%, and 10% levels, respectively.

Table 16: Discrete Choice Prediction Success: Refrigerators

LOGIT	**Predicted**				***PROBIT***	**Predicted**		
Actual	**0**	**1**	**Total**		**Actual**	**0**	**1**	**Total**
0	814	6	*820*		**0**	816	4	*820*
1	246	4	*250*		**1**	247	3	*250*
Total	*1060*	*10*	**1070**		**Total**	*1063*	*7*	**1070**

Note: Threshold value for predicting success (Y=1) = 0.5

CBEEDAC
Department of Economics
University of Alberta
8-14 Tory Building
Edmonton, Alberta
Canada
T6G 2H4
cbeedac@ualberta.ca