Evolution of Residential Electricity Demand by End-Use in Québec 1979-1989: A Conditional Demand Analysis

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This paper presents some of the main conclusions of a temporal analysis of three large-scale electricity demand surveys (1979, 1984 and 1989) for the Québec residential sector with a regression method called Conditional Demand Analysis (CDA). The study allows a number of conclusions about certain electricity consumption trends by end-uses from 1979 to 1989 by household type and by vintage category. For instance, the results indicate that decreasing electricity consumption between 1979 and 1984 for a typical dwelling equipped with an electric space heating system was mainly related to a large decline in net heating consumption. Overall, our results suggest that some permanent energy savings have been realized by a typical household equipped with an electric heating system, due to improvements in standards and changes in consumer behaviour. These energy saving were partly offset by increased electricity consumption due to the purchase of new appliances and an increase in the demand for hot water.

Cet article présente les principales conclusions d'une analyse temporelle de l'évolution de la consommation d'électricité par ménage et par usage au Québec pour la période 1979 à 1989. Cette étude repose sur l'analyse de trois importants sondages réalisés par Hydro-Québec en 1979, 1984 et 1989. La méthode utilisée est l'analyse conditionnelle de la demande. Nos résultats montrent notamment qu'il y a eu d'importantes économies d'électricité dans le domaine du chauffage des locaux principalement pendant la première période, i.e 1979 à 1984. Il est assez clair que cette économie de chauffage s'est réalisée pour tous les types de logements, anciens comme neufs. Pour la période 1984 à 1989, les économies de chauffage ont été moins importantes en moyenne et ont correspondu principalement à une modification structurelle du stock, les maisons nouvelles étant plus efficaces que les anciennes. En même temps, nous constatons que les économies de chauffage et que le progrès technologique au niveau des équipements ménagers ont été partiellement annulées par l'augmentation de la consommation moyenne d'électricité liée aux équipements ménagers et au chauffage de l'eau. Le climat économique favorable a incité les consommateurs, non seulement à s'acheter plus équipements, mais également à choisir des équipements plus gros.

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The authors gratefully acknowledge the financial support of Hydro-Québec.

1. Introduction

For the past two decades, Canadian governments (federal and provincial) and utilities have sought to affect consumer decisions on heating fuel choice and to change consumer behaviour in order to reduce energy consumption. For instance, in Québec building codes changed considerably between 1970 and 1982, resulting in improved building materials, increased insulation and lower air infiltration. During the same period, several energy incentive programs were in effect, which led householders to retrofit their houses and improve the efficiency of their heating systems. Technical progress and more demanding standards in the United States and Canada also led to the production of more efficient energy-using appliances.

The analysis of average energy consumption per household in Québec (Figure 1) appears to show that these actions have been effective. Indeed, annual average energy consumption per household dropped from 41.75 MWh in 1979 to 29.76 MWh in 1984. A slight rebound then occurred, reaching a peak of 31.40 MWh in 1989. By 1993, however, energy consumption per household had fallen again, 28.60 MWh. This reduction in consumption can be partly attributed to the increased penetration of electric space heating, which is more efficient than fuel systems: from 8% of the total stock in 1972 to 68% in 1989. In fact, annual average electricity consumption per household in Québec, has grown considerably

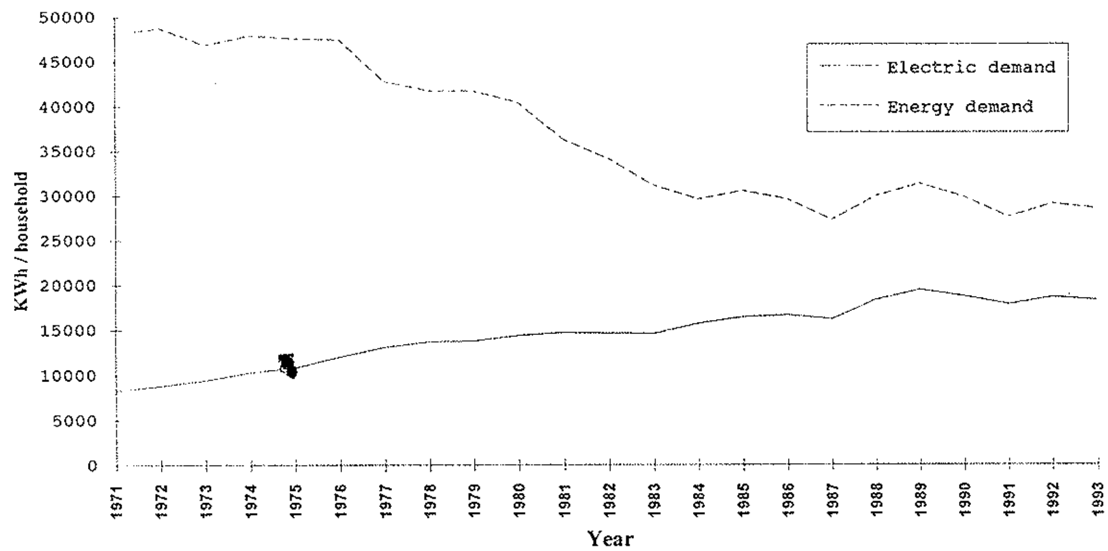

Figure 1: Average energy consumption by household — Québec residential sector (1971-1993)

since the early 1960s: from 4.63 MWh in 1961 to 14.40 MWh in 1979, and finally reaching 18.31 MWh in 1993.

Behind these aggregate data and curves, many questions are raised. Which factors really affected the evolution of energy consumption by end-use? Is it possible to obtain better estimates of unit energy consumption (UEC) by end-use and by class of dwelling stock (or socio-economic categories) in order to shed more light on time trends? These issues are particularly important in energy forecasting and for those who have to estimate the effects of energy incentive programs.

In addition, the heightened environmental concerns of the 1990s force utilities to improve their estimates of UEC in order to justify investments in demand-side management (DSM) programs.

This paper presents some of the main conclusions of a temporal analysis of three large-scale surveys (1979, 1984 and 1989) of the residential sector using a regression method called Conditional Demand Analysis (CDA). This study, sponsored by Hydro-Québec, allows us to draw a number of conclusions about some trends in electricity consumption by end-uses from 1979 to 1989, by household type and by vintage category. For instance, analysis of the data reveal that falling electricity consumption between 1979 and 1984 for a typical dwelling equipped with an electric space heating system is mainly related to a substantial decline of net heating consumption (about 38%). However, since electricity consumption by other end-uses (appliances, water-heaters, etc) has increased significantly, the decline in **net** heating consumption, defined as the energy provided by the space heating system, can be related to other variables. Cross effects of heat gains provided by free sources and behaviour changes are probably the main factors behind this decline. As a corollary, these results for electricity demand partly explain the large decrease of average energy consumption by household between 1979 and 1984.

2. Methodology

Historically, UEC estimates have been based on two main approaches: engineering estimates and metering programs. Of the two, metering is the more precise approach, since it allows the real energy consumption of a given type of equipment may be measured. However, because metering is generally too expensive to permit coverage of a significant sample for a broad range of end-uses or problems, its use is usually limited to understanding a specific problem, (e.g., air infiltration rates).

Engineering estimates are used in simulation models in which they are related to technical information about equipment types (standards, size, insulation, efficiency, type of system, etc.) and other variables (e.g., weather data) that can influence utilization. These simulation models are sufficiently precise to give estimates of UEC from a technical point of view, but exclude considerations linked to consumer behaviour. For example, it is relatively easy to calculate the average energy consumption of a refrigerator if we know its type and technical characteristics (e.g., frost-free, number of doors, size, age). It is less easy to consider behavioral factors, such as how many times per week the door is opened, or how important is the income of the household in determining the rate of utilization of the appliance.

To deal with some of these problems, many authors have proposed the use of engineering estimates in conjunction with regression methods in order to take account of both technical parameters and socioeconomic variables, such as energy prices, household attributes, behavioral factors, income, etc. An advantage of regression methods is their relatively low cost.

One such approach, conditional demand analysis (CDA), was proposed by Parti and Parti (1980). The CDA approach was initially designed to infer monthly or annual residential end-use consumption from billing records. However, as evidenced by the large number of studies included in a recent EPRI survey (1989), the approach has been used for a number of other purposes, such as estimating income and price elasticities for end-use consumption, evaluating the impacts of utility incentive programs, and assessing energy consumption trends for forecasting purposes.

Two Canadian electric utilities have recently applied CDA to the residential sector: Hydro-Québec and Manitoba Hydro (Kellas, 1993). This paper presents some results of the Hydro-Québec study.

3. Theoretical Issues in CDA

The basic CDA equation as proposed by Parti and Parti (1980) relates electricity consumption, denoted by E, to exogenous and dummy variables that are correlated to an appliance of type i. The resulting linear function can be written as: where

$$E = \sum_{i=0}^{N} \overline{E}_i [A_i] + \sum_{i=0}^{N} \sum_{j=1}^{M} b_{ij} [(V_j - \overline{V}_{(ij)}) * A_i]$$

A_i, i = 0,...N, takes on the value one for those households possessing the *i*th appliance and is zero otherwise. For some end-uses, it is sometimes interesting to set A at the number of appliances, for example, 2 refrigerators;

N is the number of appliances considered in the model;

V_j is a vector of exogenous variables, j = 1,... M;

$\overline{V}_{(ij)}$ are the average values of the M exogenous variables in households that possess equipment of type i.

E is regressed on the variables in the square brackets. By using this procedure, the coefficients of the appliance dummy variables are our estimates of the average electricity consumed in using those appliances in the households that own them. Hence, $\overline{E}_i$ is the average electricity consumed in using appliance type i. When i = 0, $\overline{E}_0$ is the average electricity consumed in using unspecified appliances, mostly small appliances and lighting. In a similar manner, V_{0j} are the average values of explanatory variables for unspecified appliances.

The b_{ij} are the coefficients that capture the impact of variable j on electricity consumption for end-use i. They also represent variations of electricity consumption across households based on having or not having appliance i, conditioned by the specific effects of variables in vector V.

The regressions were done with SAS software.[1] All the R-squares were between 0.55 and 0.7, which accords with other CDA studies, such as that reported on in EPRI (1989). Mallow's Cp was also used as a quality criterion. Finally, all the tests H_0: $b_{ij} = 0$ were significant to a level of 5% or 10%.

For each appliance, a wide number of

1/ The stepwise procedure with the MAXR option was used in conjunction with the REG procedure.

exogenous variables, in the vector V, were tested. The main significant variables are presented in Table 1. Most of these significant variables are related to demographic characteristics (number of persons, age) and technical characteristics of the dwelling or the appliance. Degree days were used to normalize the variable E. As in most other studies, we were not successful in calculating price elasticities. However, interesting results were obtained with regression by income category.

Detailed methodology and resulting models for the Québec case are described in Perron and Lafrance (1991, 1992).

4. The Samples

Our study was based upon three very detailed household surveys (42000 in 1979, 24000 in 1984, 46000 in 1989), which allowed us to study three different categories of households:

- single-family dwellings;
- duplexes, triplexes and buildings of four to nine apartments; and
- buildings of 10 apartments or more.

Since climate affects consumption habits, we decided to study the 1984 and 1989 survey data by bi-monthly periods. To capture the effects of changes in construction standards, which could involve nonlinear relationships, the single-family dwelling category was divided into vintage blocks:

- 1960 and earlier;
- 1961-70;
- 1971-80; and
- 1981 and later.

for the 1979 survey, since the consumption data by bi-monthly periods were not available, the analysis was done on an annual basis for the following vintage blocks:

- 1965 and earlier;
- 1966-70; and
- 1971 and later.

5. Results

5.1 Water Heaters (Single-Family Dwellings)

As shown in Table 2, there was a substantial increase in electricity consumption for heating

Table 1: Exogenous variables which appear significant

End-use	· Exogenous variables which frequently appear significant
Space heating	· Degree-days · Space area · Number of persons · Wood cord purchase · Income
Water heating	· Number of persons · Size of the water heater · Teenage rate · Dishwasher and pool bath possessions · Inlet water temperature by season · Income
Cooling	· Degree-days · Space area · Income · Number of persons
Appliances	· Number of persons · Income · Lighting hour by season

Table 2: Hot water (Single dwelling, Annual electricity consumption)

UEC by dwelling vintage category	1979[3]	1984	1989	Evolution 1984-89
kWh/household[1]				
· 1960-less	3187	3678	3940	7.1%
· 1960-1970	3983	4775	3846	-19.5%
· 1970-1980	7248	5327	5456	2.4%
· 1980-more	---	---	6324	---
· Total	4726	4588	4960	8.1%
kWh/person[1]				
· 1960-less	905	1171	1363	16.4%
· 1960-1970	1021	1353	1221	- 9.8%
· 1970-1980	2035	1488	1595	7.2%
· Total	1320	1349	1558	15.5%
kWh/person[2]	---	1247	1420	13.9%

(1) Every appliance using hot water is considered.
(2) Dishwashers, whirlpool baths and washing machines are not considered.
(3) In 1978, the vintage blocks are 1965-less, 1965-70, 1970-78.

water from 1984 to 1989, 8.1% per household or 15.5% per person. This is partly due to the increased usage of dishwashers and whirlpool baths, especially in houses built most recently. Recent data on the water-tank stock also indicates increased usage of the 270 litre water tank, rather than the 175 litre tank as observed in the past. Note that even when we subtract the consumption for dishwashers and whirlpool baths, we still have a 13.9% increase per person, which can only mean that important changes in consumer behaviour have occurred. In fact, we have estimated a minimal increase of 150 kWh per person. In other words, electricity consumption related to showers and baths per person seems to have increased over time. It is, however, impossible to distinguish the impact of the decreasing number of persons per household on hot water needs per person.

Another useful result for electricity forecasting is the variation of electricity consumption for water heating according to the building vintage category and the age of occupants. Greater consumption in younger buildings (1970 and later) compared to older vintage categories reflects two phenomena.

1) Penetration rates of appliances by vintage of building stock using hot water are related to household income. Table 3 suggests the importance of household income for hot water consumption. Clearly, regressions by category of income suggest that electricity consumption is proportional to household income.

2) Families in new housing stock are larger, with more teenagers. In old stock, people are older and children are no longer at home. An analysis of electricity consumption for water heating in the 1984 and 1989 surveys, for the stock built in 1960-1970 and the stock built in 1970-1980, provides evidence for this. For instance, for the building stock constructed between 1970 and 1980, 55% of the dwellings had persons 6–17 years of age in 1984; in 1989, this rate was 75% for the same category of houses. Since this variable is significant in the model and since hot water consumption was higher in 1989, two conclusions are evident: hot water consumption is dependent on the ages of consumers, and, in load forecasting, it seems important to study the evolution of the household by the age of occupants.

Table 3: Relative importance of electricity consumption for hot water heating by income class, household and vintage category (1989)

Single dwelling construction vintage	$30,000	$30000 <> $50000	$50000
1960 and less	1.0	1.19	1.49
1960-1970	1.0	1.08	1.12
1970-1980	1.0	1.04	1.13

Looking at the results for 1979, consumption for heating water, in the categories 1960 or earlier and 1961-70, is reasonable in both cases, since electricity consumption per person is lower than the estimates obtained for 1984 and 1989. However, the results do not follow the same pattern in the 1971-78 category, which may be related to less precise data for the 1979 survey.

5.2 Consumption for Space Heating (Single-family Dwellings)

5.2.1 COMPARISON OF 1984 AND 1989 SURVEYS

The results for the 1989 survey show interesting differences from those of 1984 (Table 4). For instance, the analysis of conventional space heating systems by dwelling vintage class seems to confirm the relation between decreasing electricity consumption and more severe construction standards over time. One of the important results of this study is a better understanding of electricity consumption by type of heating system. Baseboards are a more efficient system than central hot air or water systems, which may be mainly explained by two technical points. First, with a baseboard system, it is easier to control temperature by room, which brings about a lower average temperature for the total space heated. Surveys done by Hydro-Québec confirm that costumers take care to reduce temperature at night (77% of households in 1990, 82% in 1993). Secondly, a central system generally results in more air infiltration than a static system, which results in higher energy consumption for heating. A corollary is that, since electric baseboard systems are more and more popular in Québec, we can

Table 4: Space heating (Single dwelling, Annual electricity consumptions) kWh/household

System	1960-less	1960-1970	1971-1980	1980-more	Avg.
Hot water					
79	24,064	21,603	20,259	—	22,750
84	14,027	15,018	11,261	—	13,570
89	15,501	14,993	10,843	9,016	13,975
Hot air					
79	21,250	16,486	14,423	—	16,226
84	13,379	12,247	11,953	—	12,538
89	13,484	13,324	11,169	12,376	12,642
Baseboard					
79	19,787	19,796	16,768	—	17,528
84	11,337	11,925	11,130	—	11,265
89	10,964	11,414	9,779	8,887	9,873
Heat pump					
79	—	—	—	—	—
84	9,510	10,962	9,923	—	10,131
89	11,532	8,803	7,927	10,862	9,966
Dual fuel					
79	—	—	—	—	—
84	3,658	4,101	3,785	—	3,852
89	7,614	6,837	6,148	7,427	6,968
Auxiliary (baseboard)					
79	—	—	—	—	—
84	2,587	2,158	1,877	—	2,288
89	2,155	1,878	—	—	1,286
Average consumption					
79	19,808	19,792	16,666	—	18,781
84	11,863	12,180	11,177	—	11,676
89	11,720	11,886	9,897	9,292	10,658

assume that we will see some energy savings for this reason over the long term.

More specifically, if we look at the average consumption for baseboard heating in 1984 and 1989, we see a 12% reduction in 1989, which is essentially related to the reduction of heating consumption in the 1971-80 vintage block. We also have observed decreasing consumptions of the other space heating systems in the category 1971-80, but with a less important reduction. We believe that this reduction in average consumption by electric baseboard systems is also linked to the more recent construction of houses (1981-88), which are apparently more efficient. However, if we look at heating consumption per unit area (Table 5), the total energy consumption of the household does not vary much according to the dwelling construction date, since the average size of recently built houses is larger. In addition, cross effects caused by heat gain through lighting and electric appliances is higher in recent stock.

For the electric hot water, hot air and electric board systems, average heating consumption is comparable in 1984 and 1989. In fact, a difference of less than 3% is observed in consumption due to electric hot water and hot air systems.

Table 6 outlines a number of interesting results for heat pump and dual heating systems. (Note that the shares of heat pump and dual systems were negligible before 1984.) For the single-family dwelling case, UEC estimates for heat pumps, dual systems and electric systems reveal that the performance of heat pumps and dual systems are much lower than expected. Hence, the average COP estimate is 1.25, rather than the 1.6 as proposed by the publicity. For the dual system, the share of electricity in the total fuel requirement for a single family dwelling is much closer to 55% than 80%, as expected for this type of system. These results are observed for all types of construction vintages. A detailed analysis can be found in Perron and Lafrance (1994).

5.2.2 COMPARISON OF 1979, 1984 AND 1989 SURVEYS

From 1979 to 1984, results show an important reduction of electricity consumption for space heating. For instance, for the single-family dwelling category, the observed reduction is 37.8% between 1979 and 1984. As an initial hypothesis, it seems normal to conclude that this reduction is related to the context of oil market developments in the 1970s and to federal and provincial energy policies focused during that period on consumer choices in regard to heating fuels and saving energy.

We cannot, however, attribute the reduction only to the incentive programs that were in effect,

Table 5: Net electricity saving for the space heating (Single dwelling)

Dwelling vintages	≤60	60-70	70-80	≥80	Avg.
kWh/household					
1979	19,808	19,792	16,667	—	18,781
1984	11,863	12,180	11,177	—	11,676
1989	11,720	11,886	9,897	9,292	10,226
gain from					
79 to 84	40.1%	38.5%	32.9%	—	37.8%
79 to 89	40.8%	39.9%	40.6%	—	45.5%
83 to 88	1.2%	2.4%	11.4%	—	12.4%
kWh/ft²					
1984	9.81	8.52	9.48	—	9.38
1989	10.0	9.25	7.73	6.75	8.02
gain	- 2.0%	- 8.5%	18.5%	—	14.5%

Note: Surface areas are defined by classes. However, most of the houses have 1000 to 1500 square feet, which means that they are almost all in the same surface class. Note also that there is no variable related to surface area in the 1979 survey.

Table 6: Consumption Ratios

Dwelling vintages	≤60	60-70	70-80	≥80	Avg.
Heat pump[a]					
84	.71	.89	.83	—	.81
89	.85	.66	.71	.88	.79
Dual fuel[b]					
84	.27	.33	.31	—	.31
89	.56	.51	.55	.60	.55

[a] (heat pump consumption)/hot air consumption
[b] (dual fuel consumption)/hot air consumption

even though it is clear that consumer behaviour did change. The observed reduction in the average ambient indoor temperature is a good example of such change. However, those results do not allow us to distinguish the importance of energy conservation programs from other factors. For example, we also have to consider the cross effects of heat gain provided by greater usage of electrical equipment, lighting and a higher hot water consumption. It should not be forgotten that the results in the area of space heating presented above relate to the net consumption of electricity for space heating, which means that they reflect the energy used by the heating system and do not account for heat losses by appliances, lighting, hot water, etc.

At 12.4%, the reduction in electricity consumption for space heating between 1984 and 1989 was smaller. While an energy saving trend was general for the all categories of dwelling vintage in the period 1979-1984, the reduction in the second period may be attributed to a normal change in the structure of the stock. Hence the 12.4% reduction is mainly related to the shell-efficiency gain of the newer stock.

5.3 Appliances, Lighting and Miscellaneous Equipment

When electricity consumption for appliances and lighting are summed and analyzed as a whole, the evolution for the period 1984-1989 is interesting (Table 7). The observed UEC increases for miscellaneous types of appliances are remarkable, especially for the dwelling stock built after 1960. Economic growth in this period was high and households clearly bought more electric equipment. They traded older equipment for bigger versions which were even less efficient; the frost-free refrigerator is a good example. They chose bigger houses, which increased the need for lighting. They installed a new pool, a second TV, and so on. In sum, technical progress and energy efficiency have been partly offset by an increased demand related to a favourable economic context.

It should be noted that data limitations precluded the inclusion of a separate category for the electricity used by auxiliary space heating systems (electric heaters) in the estimations for the 1979 survey.[2] This may have caused a mistake in the interpretation of the UEC estimate for the appliance-lighting group. However, despite this, it appears clear that electricity consumption for this grouping did not increase significantly between 1979 and 1984. Based on this conclusion and on our discussions about space heating and water heating, it appears that the net reduction in the need for net space heating is the main factor explaining the reduction in average elec-

2/ Auxilliary space heating systems were likely included in 'miscellaneous uses' in this survey.

Table 7: Annual electricity consumption for various appliances. Average kWh/household by single-family dwelling vintage category

Appliances	≤1960	1960-1970	1970-1980	≥1980
Central cooling				
1984	1174	1163	988	—
1989	954	1750	1752	1662
Pool				
1979	2386	2180	950	—
1984	1543	1966	1420	—
1989	1880	1797	1769	1803
Miscellaneous appliances				
1979	8507	8888	8502	—
1984	7835	8497	8735	—
1989	9446	11451	11352	9759

Table 8: Average annual electricity consumption (kWh/household[1])

	1979	1984	1989
Space heating[2]			
• single dwelling	18,781	11,676	10,658
• plex+apartment	11,292	7,148	5,967
Water heater			
• single dwelling	4,726	4,588	4,960
• plex+apartment	3,278	2,777	3,288
Miscellaneous			
• single dwelling	8,901	8,635	11,000
• plex+apartment	5,876	5,866	5,860
Total			
• single dwelling	32,408	24,899	26,618
• plex+apartments	20,446	15,791	15,158

1. Dwelling equipped with an electric heating system.
2. Dual fuel system not considered.

tricity consumption for households equipped with an electric space heating system (Table 8).

In regard to miscellaneous end-uses, one has to note the importance of electricity consumption for pool pumps, which, after space heating and hot water heating, is the third most important UEC in a house. Simply by installing a timer, one can save one-half of the energy consumed.

Our estimates relating to energy consumed by cooling systems and auxiliary space heating systems (electric baseboards and wood stoves) illustrate the advantage of using the CDA approach. Especially for the wood stove, engineering methods are quite imprecise in this area, since it is difficult to derive measures of the real efficiency of the equipment and to model consumer behaviour.

6. The Usefulness of the CDA Method

In our view, the application of the CDA approach to the Québec case produces results that underline the originality and appeal of such a method. As in earlier studies, the method seems useful:

- to estimate unit consumption by end-uses; in our case, the UECs related to space heating, water heating and such specific equipment as auxiliary systems, pool pumps, and cooling systems, appear reasonable;
- to analyze energy use over time at a relatively cheap cost;
- to relate socio-economic variables (income, age of consumers, etc) to electricity consumption.

For the particular case of Québec, the method also permits:

- a better knowledge of seasonal electricity consumption patterns by end-use; and
- an estimation of energy use by category of income and by dwelling vintage class.

As with other studies, we also note that the method is not perfect. For instance, for several end-uses, there is multicollinearity caused by a high correlation across explanatory variables and bi-monthly electricity consumption. An example of the sort of problem caused by this is the difficulty in separating, within the estimation process, the energy consumed for refrigeration from that consumed by small appliances. Since all households are likely to own a refrigerator, A_i always takes on the value 1 in both cases, and separate estimates cannot be obtained. The problem is especially important in the Québec data because of a high rate of ownership of household electrical appliances. The only way to deal with this kind of problem is to improve the surveys of technical characteristics of each type of equipment (for example, in order to have more knowledge about the size of appliances used).

The comparisons of these CDA results with those of Hydro-Québec calculated with a simulation method show similarities (e.g., for electricity consumption due to water heating) but also discrepancies (as in the case of space heating consumption and the other UECs summed as a whole). The main discrepancies are tied to our estimates of electricity sales for heating, which are lower than those of Hydro-Québec, while the sales for other end-uses together are higher.

It is clear that the estimates obtained with regression methods do not always correspond to reality, since they can catch up the effects actually associated with other parameters that are not included in the set of variables in the regression. For example, in regard to the space heating UEC, it is possible that the model does not distinguish a grey zone between real net space heating and the contribution of heat from free sources. In other words, the UECs for space heating are maybe lower than in reality. On the other hand, the differences between space heating systems (baseboard, forced air, heat pumps, etc) are caught up correctly. Thus the method is still useful to do follow-up consumption studies or in forecasting. A study done with REEPS (see Perron, Lafrance and Roy, 1994), with these CDA data used as input, shows that the final long-term electricity forecast for the residential sector is comparable to the result obtained by Hydro-Québec with other UEC estimates used in the past.

In general, then, while no methods is perfect, the CDA method is useful and complementary to simulation methods and metering programs.

7. Concluding Comments

Focusing here on the data analysis, rather than on the method used, the results for 1979, 1984 and 1989 give us insights on trends in end-use consumption of electricity in the residential sector in Québec. For instance, a substantial drop in the annual average electricity consumption by household related to space heating was observed from 1979 to 1984 (about a 38% reduction). This important decrease in the need for space heating in the first period is related to energy saving in all dwelling vintage categories, both newer and old stock. These results show that energy savings have been realized both from the improvement in construction standards and from the actions of consumers (behavioral changes and retrofit investments).

For the following period, 1984-1989, the 12% reduction for space heating may be attributed mainly to the efficiency gain of the newer stock of housing. The analysis by system type reveals that the baseboard systems are more efficient compared to other types. The UEC estimates for heat pumps and dual systems also show that the performance of heat pumps and dual systems are much lower than expected. Hence, the mean heat pump COP estimate is 1.25 rather than 1.6, as suggested by the advertising. For the dual system, the electricity share in total energy requirement is much closer to 55% than 80%. Finally, those CDA results suggest that the cross effects of heat gain related to free sources are probably more important than was previously thought because of significant increases in consumption for other uses.

The increase in electricity consumption for heating water appears more important in the second period of the study: from 1984 to 1989, an 8.1% increase by household is observed. But the 15.5% increase per person appears more significant. This is partly due to the increased household share of dishwashers and whirlpool baths, and to the increased share of bigger water tanks, especially in the most recently built houses. But even when the consumption of those end-uses are subtracted, we still have a 13.9% increase per person, which can only mean that important changes in the consumer's behaviour have occurred. According to our results, the relationship between hot water need and the incomes and ages of electricity consumers is clear and should be considered in any load forecast.

We estimated a substantial increase in demand for appliance services and lighting from 1984 to 1989 in the single dwelling category. This phenomenon is clearly explained by the increased ownership of personal appliances, but also by the replacement of old appliances with bigger and less efficient ones.

Overall, our results suggest that some permanent energy savings have been realized by typical households equipped with an electric heating system at the beginning of the 1980s, which is related to standard improvements and changes in consumer behaviour. But, at the same time, these energy saving were partly offset by the increasing electricity consumption related to purchases of appliances and the rising demand for hot water.

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