COMPACT FLUORESCENT LIGHTS (CFLs) IN CANADA

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Abstract

Compact fluorescent lights (CFLs) use between one-quarter and one-third as much electricity as incandescent bulbs to provide the same amount of light. Yet, according to the 2003 Survey of Household Energy Use (SHEU03), CFLs are present in only 31.4% of homes in Canada, and even in these houses, CFLs represent less than 14% of total lighting. Of course, CFLs are not necessarily desirable or appropriate in all situations where incandescent lights are currently used. In this paper, features of CFL use in Canada are examined, and factors that might explain their pattern of usage are evaluated.

CFL use is found to be higher in British Columbia and in Alberta than in Ontario, although use there is still much higher than in Quebec and the Maritime provinces. CFLs are more likely to be found in urban dwellings, in houses that are owner-occupied, in single-detached and in row or terrace housing, in homes with a garage, in homes built more recently, and in larger houses. Generally, CFL use increases with the size of the household and with income. Despite its electricity-saving properties, there is only weak evidence that average electricity consumption falls as the number of CFLs in a household increases.

To take account of the possibly offsetting effects of several of these factors, a probit model explaining the decision of a household to use at least one CFL is estimated using the SHEU03 data. Key variables that have significant positive effects on the probability of a household using CFLs include a larger total number of lights, higher electricity consumption, an older house, living in row housing, and living in Alberta or British Columbia. However, CFL use is significantly negatively affected by having a greater number of incandescent lights, more lights switched on for three hours or longer, a larger heated area, or living in Quebec. Although income was found to have no significant effect, this remains a subject of further research.

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1. Introduction

Due to the different method that they use to produce light, compact fluorescent lights (CFLs) use between one-quarter and one-third as much electricity as incandescent bulbs to provide the same amount of light. According to the most recent (2003) Survey of Household Energy Use (SHEU03), at least one CFL is used in 31.4% of homes in Canada, and in these CFL-using households, an average of 4.38 CFLs are used along with 2.69 halogen lights, 3.08 fluorescent lights, and 20.74 incandescent lights. Remaining households use on average 2.08 fluorescent lights, 2.05 halogen lights, and 20.90 ordinary light bulbs. Obviously if all remaining incandescent bulbs in Canada were to be replaced with CFLs, significant energy savings could be achieved. However, CFLs are not necessarily appropriate or desirable in all situations where incandescent bulbs are currently used, and even in cases where they are suitable, consumers may be reluctant to us them for a variety of reasons. Indeed, even in households that use CFLs, the average number of CFLs is greatly outweighed by the average number of incandescent lights. Given this context, the purpose of this paper is to examine the current penetration of CFLs in Canada, to determine the relative importance of the factors that explain this usage, and hence to assess the potential energy savings of CFLs in the residential sector in Canada.

The structure of the remainder of this paper is as follows. Section 2 contains background information about CFLs. Factors influencing CFL use that have been identified in other studies are outlined in Section 3, while a comparison of the life-cycle costs of CFLs and incandescent lights is provided in Section 4. Analysis of the information pertaining to CFLs that is contained in the SHEU03 dataset, including the penetration of CFLs in the residential sector in Canada and how this differs by region and various other characteristics of households, is presented in Section 5. Based on this analysis and the findings of other studies, in Section 6 a discrete choice model of CFL usage, designed to determine the importance of different factors in explaining a household's decision to use CFLs, is formulated. Estimation results are described in Section 7, while Section 8 contains a summary and conclusions.

2. Background

Compact fluorescent lights (CFLs) use between one-quarter and one-third as much electricity as incandescent bulbs to provide the same amount of light. CFLs are available in many different sizes, shapes and wattages. Common shapes include quad tube lamps, which consist of two curved tube sections, “swirling shape” CFLs, and circline-shaped CFLs. Circline-shaped CFLs are ideally suited for lamps with shades as they fit under the shade and distribute light evenly. Originally, consumers could not dim CFLs, but manufacturers have now devised special CFLs that can be dimmed using dimmer switches. CFLs have a standard screw base similar to incandescent lamps. CFLs utilize electronic ballasts to reduce flicker, improve power usage and reduce the start up time for the light; these electronic ballasts are lighter and quieter than the alternative, magnetic ballasts (Wood, 1996). According to *Consumer Reports Magazine*, compact fluorescents have a break in period of 100 hours, with brightness levels stabilizing after this period of use (Consumer Reports, 1999).

Compact fluorescent lights are more energy efficient than incandescent lights due to the different method that they use to produce light. Regular incandescent light bulbs create light by heating a filament inside the bulb; the heat makes the filament white hot, producing visible light. Consequently, much of the energy used by incandescent lamps is dissipated as heat. In contrast, CFLs, as do all fluorescents, contain a gas which when excited by electricity produces invisible ultraviolet (UV) light. The UV light hits the phosphor coating on the inside of the lamp producing visible light. CFLs do not use heat to create light and thus they require far less energy than incandescent lights to produce a given amount of light (measured in lumens). A comparison of the Wattage of select incandescent lights along with the equivalent CFL wattage for a given lumen level is provided in Table 1.

TABLE 1: Comparison of Incandescent and Compact Fluorescent Lamps

Incandescent	***CFL***	***Lumens***
40 watt	9 watt	>450
60 watt	13-15 watts	>800
75 watt	20 watt	>1100
100 watt	26-29 watts	>1600
150 watt	38- 42 watts	>2600

Source: General Electric Company (2005) (http://www.gelighting.com/na/business_lighting/faqs/cfl.htm) and United States Environment Protection Authority and United States Department of Energy (2005) (www.energystar.gov/index.cfm?c=cfls.pr_cfls)

While there are no special rules regarding the disposal of CFLs, environmental agencies such as the U.S. Environmental Protection Agency (United States, 2005) recommend that the lights be disposed of at recycling stations. CFLs contain a very small amount of mercury that, while not considered hazardous, should be disposed of in an environmentally intelligent manner. According to Polsby (1994), the amount of mercury in CFLs is, however, less than the amount of mercury emitted by the generation of the greater power needs of regular lamps. The author notes that Minnesota, California, Wisconsin, and Florida, along with European countries such as Germany, Sweden, Belgium, Netherlands and Switzerland, have special disposal programs for fluorescent lights.

It is particularly advantageous to use CFLs in locations where the lights remain on for prolonged periods of time (The Gazette, 1993). A light that is used infrequently will take a very long time to pay back the extra fixed costs associated with the purchase of the CFL. According to Friedmann et al (1995), incandescent lights that are used for more than two to four hours a day are ideally suited for replacement by CFLs. These authors found that the best CFL introduction opportunities occurred where energy consumption is the greatest. Each time a CFL is turned on and off a slight amount of its lighting ability is eroded, so that lights that are turned on and off frequently, or those that are only lit for short periods of time, are not ideally suited to the use of CFLs (Canada Mortgage and Housing Corporation, 2005). This may change in the future as CFLs become better able to cope with being turned on and off without adversely affecting luminescence or service life. In the past CFLs took anywhere from a few seconds to a few minutes to warm up, however advances in ballast technology – specifically the extensive use of electronic ballasts – has reduced warm up times to a couple of seconds (The Gazette, 1993).

According to Byrne (1994), many compact fluorescent lights are unsuitable for outdoor use in cold climates. Many CFL packages warn that the light should only be used on outdoor fixtures that are enclosed so that the CFL can warm up to a level sufficient for reasonable operation. In general, however, Byrne (1994) notes that newer models of CFLs are less temperature sensitive than were earlier models.

3. Factors Influencing CFL Usage

Probably the main reason for using CFLs is the potential energy (electricity) savings that they can provide. In aggregate terms, Friedmann and associates calculated, in 1994, that Mexico could reduce its peak load demand by 78 MW and reduce total annual electricity generation by 135 Gwh, if all incandescent lights that were used for more than 4 hours a day were replaced with CFLs. In the context of South Africa, Van Horen, Simmonds, and Parker (1998) noted that even though lighting contributes a small amount to peak load electricity demand, since its utilization coincides with cooking, space heating and water heating which contribute more to peak load usage, CFLs were being examined to see if their use could contribute to a lowering of peak-load electricity demand.

According to Friedmann et al (1995), consumer-specific reasons for using CFLs include reduced energy consumption, concern for the environment, and better lighting. Factors that led to negative perceptions regarding CFLs included high initial cost and quality concerns. These authors found that the number of lights in the dwelling, the number of bedrooms, the existence of a garage, and the number of hallways all influenced CFL penetration rates. Other important factors included the number of light fixtures in the kitchen, living room, and dining room, as well as the time in the day that the lights are used and the duration of their use. A research study by the Canada Mortgage and Housing Corporation (2005) (CMHC) found that CFLs were best suited to hallways, kitchens, stairwells, and exterior lights. The CMHC study found that CFLs are ideal for light fixtures that are switched on for more than 1 or 2 hours per day.

Kumar, Jain and Basal (2003) examined factors that influenced CFL use in India. They distributed a questionnaire to 900 individuals that asked questions regarding the respondent's age, educational attainment, income, lighting needs, and CFL awareness. Respondents were also asked what measures would improve their acceptance of CFLs. The study found that advertisements regarding CFLs raised awareness of the advantages of CFLs especially among higher income groups. Advertising also increased usage among consumers with high levels of education, although the increase was less than for highly educated groups. Awareness levels were found to be highest with professionals and lowest among the sales professions. Perhaps unsurprisingly, Kumar et al. discovered that those respondents who used more electricity also used more CFLs, indicating that respondents with the most to gain from saving electricity adopted CFLs more readily.

Factors that hindered CFL adoption, according to Kumar et al. (2003), included the cost of the CFL, inadequate information about CFL features, and lack of knowledge concerning CFL availability. With CFL prices dropping in Canada and with large retailers such as Wal-Mart, Home Depot and IKEA selling CFLs, only the second of these factors appears to be relevant for CFL adoption in Canada. In the Indian survey, respondents stated that endorsement of CFLs by reputed institutions, unconditional two-year guarantees by manufacturers, and usage of CFLs by government agencies would help increase respondents' positive views of CFLs.

Even among those most receptive to using CFLs in India, such as high-income earners, CFL usage was low. Indian consumers were concerned about the lighting levels of CFLs, which prompted the authors to recommend that manufacturers recommend higher wattage CFLs than were being suggested. To increase CFL acceptance, Kumar et al (2003) also recommended that government and industry increase their advertising and that the advertising should focus on the positive implications of using CFLs. For example, in Canada the advertising could focus on the energy savings, lower electricity bills and the less environmentally harmful nature of CFL usage. Kumar et al also suggested that government and industry undertake other initiatives such as trade shows, point of purchase displays and no-obligation trial offers. However, with CFL prices dropping, the effect of no obligation trial offers in reducing the risks and costs of CFL purchase would appear to be less significant.

Finally, Kumar et al. (2003) identified five factors that generally influence the adoption of any new energy innovation. The first factor was relative advantage – whether the innovation is better than existing options, and whether consumers perceive the innovation to be superior to existing options. The second factor is compatibility – whether the innovation fits with consumer needs. The third issue is complexity – whether consumers can readily understand and use the new product. Another important issue was "trialability" – the ease with which the innovation can be tried, and whether there are large upfront costs that may hamper these trials. The final factor to consider relates to the new products' observability – whether the superior aspects of the energy innovation easily be observed.

Menanteau and Lefebrve (1998) examined the factors that affect CFL adoption in the residential sector. They determined that public policies play an important role in the expansion of niche markets. They recommended that public policies should be implemented to increase product awareness and improve product performance. Specifically, they comment that the dominant market position of incandescent lights makes it hard for new products such as CFLs to "break into" the lighting market. Improvements in performance and reductions in costs made incandescents the market standard, and eventually increases in performance and lower costs will increase market penetration for CFLs. The authors conclude that the longer lifetimes, increased energy efficiency and absence of heat for CFLs do not count as much, in the eyes of consumers, as do brightness, instantaneousness, and the low price of incandescent lights. Initially, consumers did not like the "cold" colour emitted by fluorescent lights, however Mentaneau and

Lefebrve note that the lighting companies' research and development have made strides toward improving colour rendering to make CFLs more "warm". The most important barrier to CFL adoption was cost. At the time of the study the price of a CFL was about 20 times higher than the average incandescent bulb, currently, in Canada, the ratio between CFL cost and incandescent bulb cost is 10.

The life cycle cost advantage of CFLs over incandescent lights is clear. According to Mentaneau and Lefebrve (1998), the problem is that consumers tend not to think in life cycle cost terms as they pertain to electrical appliances. Rather, consumers are highly sensitive to up-front costs. Lack of information concerning life cycle costs hinder the adoption of new products such as CFLs. In practice, according to these authors, consumers do not always seek the best solution, but rather they seek the solution that gives them the best overall satisfaction given product availability, imperfect information and financial capacity. In the past, lack of compatibility with existing fixtures also inhibited CFL adoption. Unlike the case now, CFLs were not always compatible with existing light sockets, which affected consumers' initial reactions to CFLs. Even though consumers did not initially adopt CFLs based on economic efficiency criteria, many organizations in the commercial sector, such as hotels, realized cost savings by replacing incandescent lamps with CFLs. Market penetration into the commercial sector did allow manufacturers to improve CFL performance and reduce costs.

Lund (2005) considers the inertia against change to be large for energy technologies. Market factors that affect the penetration rate of new energy technologies, according to Lund, include the availability of information, cost and risk associated with the new product, public financing and standards, how companies perceive the new technologies (opportunity or threat), volume and size effects (size of companies, number of users, and market volume). Non-energy factors that influence adoption include; colour rendering, productivity benefits and financial benefits. These factors had a high degree of influence on new energy technology adoption. Lund found that mass production in China reduced CFL prices and contributed to the CFL penetration rate increasing by 24% per year. Market penetration is, according to Lund, time dependent. Current market share is dependent on past market share.

Urge-Vorsatz and Hauff (2001) examined the successful penetration of CFLs into the Hungarian marketplace. During the early 1990s, few households in Hungary owned a CFL, although by 1997 one-fifth of households used at least one CFL. This ranks Hungary among the top eight countries in Europe in terms of CFL penetration, considerably below Germany, The Netherlands, and Denmark, where 50%, 56%, and 46%, respectively, of homes owned at least one CFL in 1995, but much higher than in the U.S. where, in 1999, only between 10% and 15% of houses had at least one CFL.

Based on a 1997 survey of 2400 Hungarian households that evaluated CFL ownership, awareness, purchasing behavior and barriers to CFL market success, Urge-Vorsatz and Hauff (2001) discovered a high positive correlation between education levels and CFL use. They also found weaker positive correlations between CFL ownership and income and between CFL ownership and household size. Urbanites were more likely to use CFLs than were people living in rural areas. Consumers 60 years of age and older were the least likely to be aware of the advantage of CFLs. The authors were not aware of any single nationwide government program that contributed to the rapid penetration of CFLs into the Hungarian marketplace. Rather, market participants initiated the majority of all CFL awareness programs. In the authors' opinion, the high CFL awareness in Hungary was a result of the fierce competition between the three main CFL manufacturers. Vigorous competition contributed to CFL price decreases (although the prices of incandescent lamps also decreased), while a 35% real increase in electricity prices in 1995 – and continued but smaller real electricity price increases subsequently – increased the sales of energy saving products including CFLs.

CFL aesthetics had a moderate effect on the CFL purchasing decision for 36% of Hungarian survey respondents. Many respondents thought CFLs were modern and fashionable. In-depth interviews revealed that financial savings were not the only – or even the main – motivation for buying CFLs. However, for most survey participants, there was a strong correlation between awareness of the economic benefits of CFLs and CFL usage. According to Urge-Vorsatz and Hauff (2001), the biggest barriers to CFL adoption were high initial cost and lack of information regarding CFLs. Consumers often confused wattage with illumination and thus they saw the higher wattage on incandescent lamps as indicating greater brightness. Consumers did not realize that lumens were the more appropriate measurement of brightness. The authors conclude that "high initial cost" problems are indicative of liquidity constraints, oversensitivity to initial costs, and a lack of understanding on the part of consumers about the economic benefits of CFLs.

Martinot and Borg (1998) studied the experiences of eight countries with energy efficient lighting programs. They found, unsurprisingly, that CFL price decreases have helped increase CFL sales. In addition, an increase in the number of manufacturers that are producing CFLs has contributed to price decreases as competition increased. There were 1000 Chinese CFL manufacturers in 1997 compared to 500 two years earlier. Martinot and Borg identify three key factors that aid the expansion of energy efficient lighting programs: raising consumer awareness, the existence of effective distribution channels, and improvements in product quality. Direct subsidies were found to be less important as CFL prices dropped and as the CFL market matured. According to these authors, the elements of a cost effective CFL adoption strategy include: (1) a lack of subsidies – which is understandable in light of dramatic CFL price decreases, (2) a focusing of program objectives on energy efficiency, and (3) high marketing and distribution cost effectiveness.

Martinot and Borg (1998) also identified four barriers to CFL market expansion that appear to be relevant to Canada: lack of information by consumers about CFL benefits, the high initial cost of CFLs compared with alternative lighting options, early product failure and poor product quality, and intangible consumer preferences such as aesthetics. In Poland, consumer awareness of the environmental benefits of CFLs led to more CFL use. In contrast, Urge-Vorsatz and Hauff (2001) found that, in Hungary, environmental issues were unimportant in CFL adoption.

Finally, Martinot and Berg also detected a positive correlation between household income and CFL usage.

4. Comparison of Life Cycle Costs for CFLs and Incandescent Lights

To provide an estimate of the electricity savings that could be achieved by replacing an incandescent light by a CFL, we compare the capital and operating costs of a 60-Watt incandescent bulb and a 13-Watt CFL. As shown in Table 1, the 13-Watt CFL provides the same amount of lumens as the 60-Watt incandescent light. We focus on 60-Watt incandescent lights since in the SHEU03 dataset, discussed in the next section, this is the median bulb used more than 3 hours per day. The literature has found that lights on for 2 hours or more are ideal for replacement with CFLs.

The parameters used in the calculation are shown in Table 2. A variety of costs for electricity are used, ranging from $0.06 per kWh to $0.14 per kWh, and real discount rates of 5%, 7% and 10% are used, along with the 15% rate recommended by Kooreman (1995) as being appropriate for discounting savings related to energy conservation devices. The total costs are compared over the 9.132-year lifetime of the CFL, during which time it is assumed that 10 incandescent bulbs would be used.

TABLE 2: Characteristics of Light Bulbs Used in Cost Comparison

Characteristic	CFL	Incandescent
Bulb	13 Watt	60 Watt
Lifetime: hours / years	10,000 hours / 9.132 years	1,000 hours / 0.913 years
Total Bulbs used / 9.132 yrs	1	10
Purchase cost per bulb[1]	$2.33	$0.21
Daily/Annual usage	3 hours / 1,095 hours	3 hours / 1,095 hours
Discount Rate	5%, 7%, 10%, 15%	5%, 7%, 10%, 15%
Cost of electricity per kWh	$0.06, $0.08, $0.10, $0.12, $0.14	$0.06, $0.08, $0.10, $0.12, $0.14

[1]Based on purchase price at Wal-Mart, Fort Saskatchewan, Alberta, March 2006, excluding taxes.

TABLE 3: Comparison of CFL and Incandescent Light Capital and Operating Costs

Cost of electricity	CFL			Incandescent		
	Capital	Operating	Total	Capital	Operating	Total
5% discount rate						
$0.06/kWh	$2.33	$6.29	$8.62	$1.73	$29.05	$30.78
$0.08/kWh	$2.33	$8.39	$10.72	$1.73	$38.73	$40.46
$0.10/kWh	$2.33	$10.49	$12.82	$1.73	$48.41	$50.14
$0.12/kWh	$2.33	$12.59	$14.92	$1.73	$58.09	$59.82
$0.14/kWh	$2.33	$14.68	$17.01	$1.73	$67.77	$69.50
7% discount rate						
$0.06/kWh	$2.33	$5.82	$8.15	$1.62	$26.85	$28.47
$0.08/kWh	$2.33	$7.76	$10.09	$1.62	$35.80	$37.42
$0.10/kWh	$2.33	$9.70	$12.03	$1.62	$44.75	$46.37
$0.12/kWh	$2.33	$11.63	$13.96	$1.62	$53.70	$55.32
$0.14/kWh	$2.33	$13.57	$15.90	$1.62	$62.65	$64.27
10% discount rate						
$0.06/kWh	$2.33	$5.21	$7.54	$1.46	$24.03	$25.49
$0.08/kWh	$2.33	$6.94	$9.27	$1.46	$32.04	$33.50
$0.10/kWh	$2.33	$8.68	$11.01	$1.46	$40.05	$41.51
$0.12/kWh	$2.33	$10.41	$12.74	$1.46	$48.06	$49.52
$0.14/kWh	$2.33	$12.15	$14.48	$1.46	$56.07	$57.53
15% discount rate						
$0.06/kWh	$2.33	$4.40	$6.73	$1.26	$20.32	$21.58
$0.08/kWh	$2.33	$5.87	$8.20	$1.26	$27.09	$28.35
$0.10/kWh	$2.33	$7.34	$9.67	$1.26	$33.86	$35.12
$0.12/kWh	$2.33	$8.80	$11.13	$1.26	$40.64	$41.90
$0.14/kWh	$2.33	$10.27	$12.60	$1.26	$47.41	$48.67

Note: 10 incandescent bulbs are purchased over the same period that one CFL is used. These incandescent bulbs are assumed to be purchased as needed.

Table 3 shows the present values of the capital and operating costs of the different types of light bulbs using the parameters in Table 2, and calculated over the lifetime of the CFL of approximately 9 years. Even using a very low cost of electricity ($0.06 per kWh) and a high discount rate (15%), there is a difference of almost $15 ($21.58-$6.73), or approximately $1.62 per year in present value terms, per CFL. So a household that replaced 10 of their 60-Watt incandescent bulbs with 10 x 13-Watt CFLs would obtain the same lighting and would save approximately $16 per year in present value terms over the lifetime of the CFLs. Of course, with higher electricity prices, the savings are considerably higher, rising to approximately $36 per CFL over its 9-year lifetime if electricity costs $0.14 per kWh and the discount rate is 15%. Using a more typical discount rate of 7%, and an electricity price of $0.10 per kWh, the savings are similar, at just over $34 per CFL.

Overall, the driving factor in the cost savings with CFLs is the reduction in electricity use. Regardless of the discount rate, the electricity price represents between 94% and 97% of the costs of using incandescent lights, whereas for a CFL this percentage is considerably lower, ranging between 65% and 82% at a discount rate of 15% and between 73% and 86% at a discount rate of 5%. Even though there is a difference in capital costs, which are higher using a CFL, this difference is relatively small when compared to the electricity savings that are obtained using a CFL. Indeed, these savings with a CFL are so substantial that even if electricity were to cost only 1c/kWh, using the parameters in Table 2, a CFL would still be cost effective in present-value terms, even at a discount rate of 15%, costing $3.06 versus $4.65 for incandescent lights over the approximate 9 year lifetime of the CFL.

5. CFL Use in Canada

The Survey of Household Energy Use (SHEU), conducted in Canada in 2004, collected data on household characteristics, appliance usage, and energy use in 2003. A total of 4551 households were surveyed directly, representing 11,169,389 households across Canada. Among the questions asked of households were several pertaining to their use of lighting, including how many of each of several specified types of light bulbs – including CFLs – were used. In this section we analyze CFL usage by Canadian households, and how this is related to various household characteristics and energy use.

Within the directly surveyed households, 31.4% have at least one CFL. After accounting for the differing numbers of households that each surveyed household represents within Canada, weighted CFL usage, countrywide, is 31.8%. However, this obscures quite distinct variation in CFL usage from province to province, as can be seen in Table 4.

TABLE 4: Percentage of Households with at Least One CFL, by Province

Province	Directly Surveyed Households	All Canadian Households
Newfoundland	14.6	14.4
Prince Edward Island	25.5	20.6
Nova Scotia	23.2	24.3
New Brunswick	21.4	24.5
Quebec	21.4	24.2
Ontario	33.6	32.9
Manitoba	28.8	24.6
Saskatchewan	24.6	27.2
Alberta	38.5	40.5
British Columbia	49.3	46.7
CANADA	31.4	31.8

As Table 4 shows, British Columbia has the highest proportion of households, almost 50%, using at least one CFL, with Alberta second at around 40%, and Ontario third at 33%.

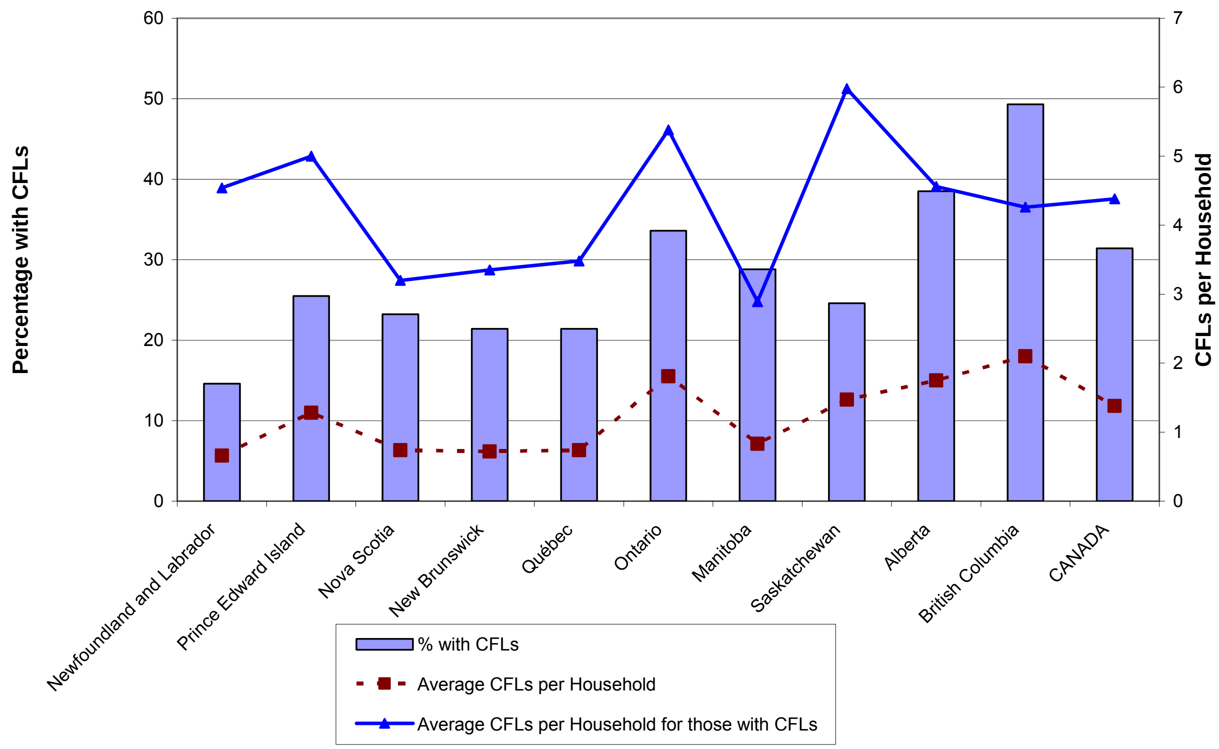
CFL usage in all other provinces is below 30%, with the lowest rate of approximately 14% occurring in Newfoundland.

Of course, some households may use several CFLs, while others use only a small number. This is illustrated in Table 5, where the values in the second and third columns show the average number of CFLs per household, including those households that do not have any CFLs. These values show that Canada wide, households use on average 1.4 CFLs, ranging from approximately 0.6 to 0.7 in Newfoundland and Nova Scotia, to 1.89 and 1.97 in Alberta and British Columbia, respectively. However, focusing attention just on households that use at least one CFL, the results shown in the last two columns of Table 5 are quite different, especially when viewed in conjunction with the values in Table 4. Overall, the average number of CFLs per household, for households that have at least one CFL, is 4.4. A similar average is observed in Newfoundland, while Alberta is slightly above this average and British Columbia is slightly below. Here, the largest average number of CFLs per household, for households that have at least one CFL, is between 5 and 6, and occurs in Saskatchewan and Ontario. Figure 1 provides a graphical depiction of the values in Tables 4 and 5 for the directly sampled households.

TABLE 5: Number of CFLs per Household, by Province

Province	All Households		Households with CFLs	
	Direct Sample	Canada	Direct Sample	Canada
Newfoundland and Labrador	0.66	0.64	4.54	4.44
Prince Edward Island	1.28	1.01	5.00	4.87
Nova Scotia	0.74	0.65	3.20	2.69
New Brunswick	0.72	0.85	3.35	3.47
Québec	0.74	0.78	3.48	3.23
Ontario	1.81	1.76	5.38	5.36
Manitoba	0.83	0.70	2.89	2.83
Saskatchewan	1.47	1.39	5.98	5.11
Alberta	1.75	1.89	4.56	4.65
British Columbia	2.10	1.97	4.26	4.22
CANADA	1.38	1.41	4.38	4.42

Figure 1: CFL Use in Canada



Apart from variation across regions, CFL use also differs according to various aspects of the dwelling. As the second column in Table 6 shows, houses in urban areas are more likely to have at least one CFL than those located in rural regions – which is consistent with the findings in the literature – while CFLs are almost twice as likely to be in use in houses that are owned compared to in houses that are rented. In terms of the type of dwelling, low-rise apartments and duplexes are less likely to have at least one CFL, especially compared to single detached homes, row or terrace houses, or mobile homes. One reason for the lower use of CFLs in apartments and rented housing may be that with a typical CFL lasting about 10,000 hours, apartment dwellers and/or renters who move more frequently than homeowners may not realize the full cost benefits of using CFLs. Houses with garages are more likely to have CFLs, as are houses that were built more recently. Finally, in terms of dwelling size, larger houses – in terms of heated area – are also more likely to have at least one CFL than houses that have less than 1,200 heated square feet. In fact, at 2,026.2 square feet, the average heated area of houses with at least one CFL is approximately 200 square feet larger than for houses without any CFLs (1,808.4 square feet).

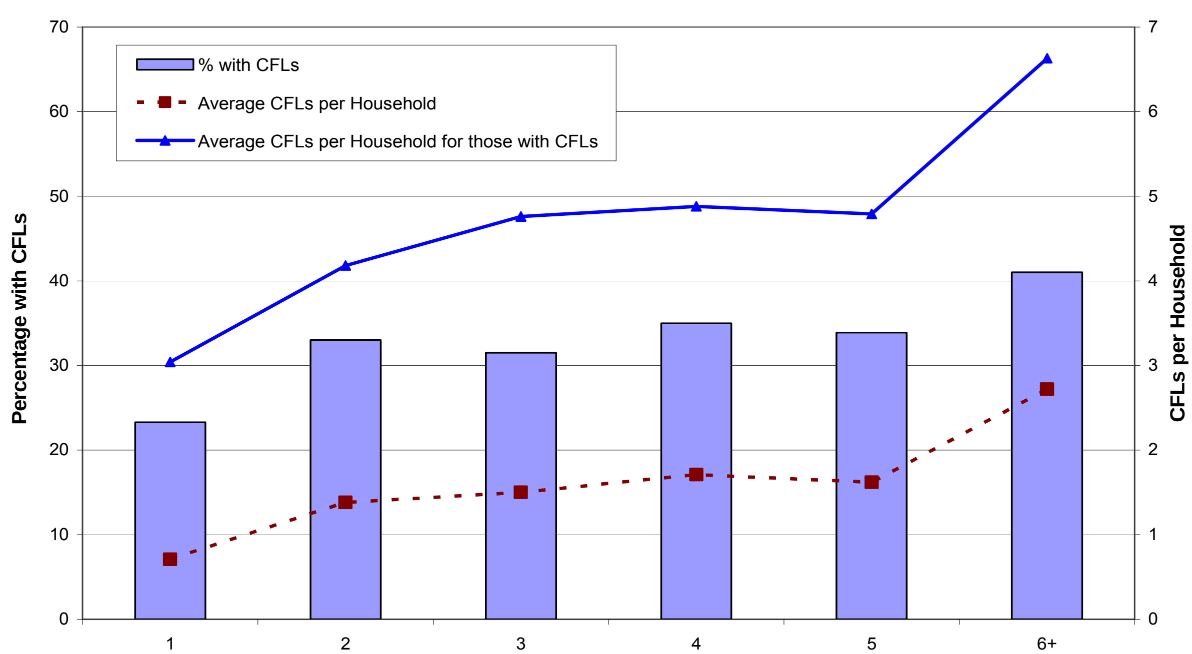
TABLE 6: CFL Use and Dwelling Characteristics

Type of Dwelling	% with CFLs	Number of CFLs	
		All Households	Households with CFLs
All	31.4%	1.38	4.38
Urban	32.3%	1.45	4.49
Rural	28.2%	1.11	3.92
Owned	34.8%	1.58	4.54
Not Owned	19.1%	0.63	3.31
Single Detached	34.8%	1.64	4.70
Double	26.9%	0.89	3.30
Row or Terrace	34.4%	1.42	4.13
Duplex	25.5%	0.82	3.22
Low-rise Apartment	17.0%	0.49	2.86
Mobile Home	30.6%	0.91	2.98
Garage	38.9%	1.87	4.80
No Garage	28.7%	1.18	4.11
Built 1900-1950	29.8%	1.21	4.05
Built 1951-1975	31.8%	1.38	4.34
Built 1976-1990	35.1%	1.63	4.65
Built 1991-2003	36.2%	1.67	4.61
Up to 1200 sq ft	26.3%	0.96	3.66
1201 – 2000 sq ft	36.0%	1.58	4.38
2001 – 2500 sq ft	34.7%	1.50	4.32
More than 2500 sq ft	39.1%	2.20	5.63

The final two columns of Table 6 show the number of CFLs present in households with particular dwelling characteristics. Interestingly, for homes that have at least one CFL, owned houses have on average only one more CFL than those that are rented. However, single detached houses that have at least one CFL have on average almost two more CFLs in use than low-rise apartments that have at least one CFL. For houses with at least one CFL, while there is little difference in the number of CFLs per house based on year of construction, houses comprising over 2,500 square feet of heated area are likely to have two more CFLs that houses that have 1,200 square feet or less of heated area.

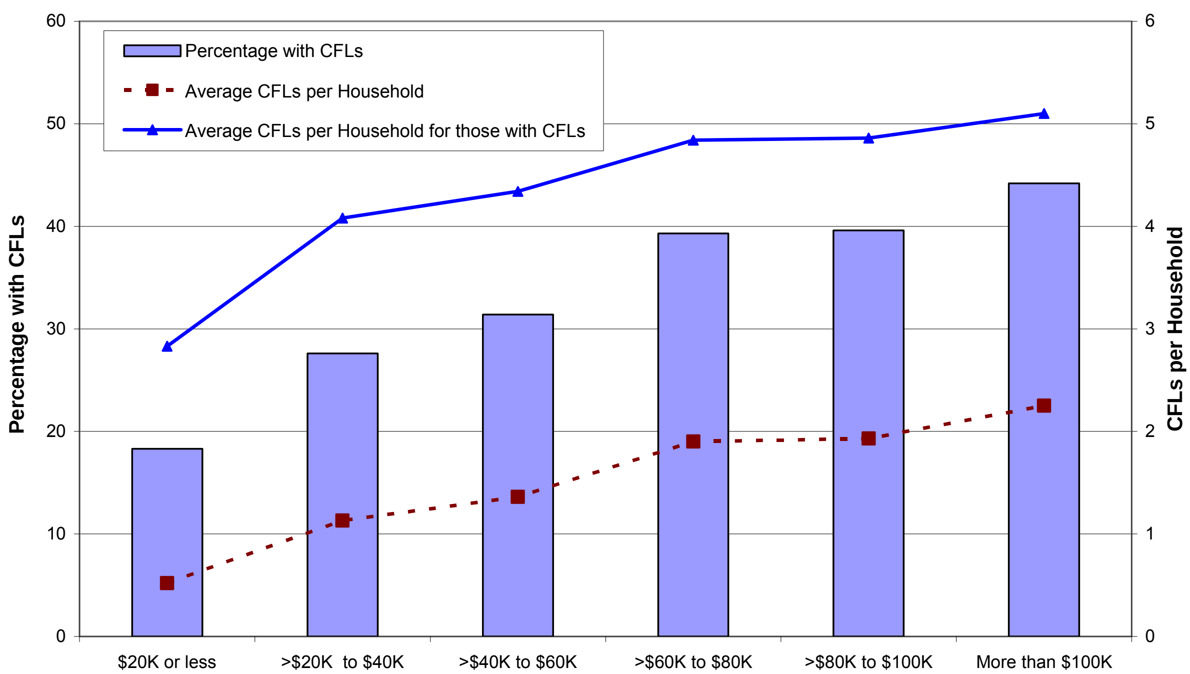
As well as dwelling characteristics, CFL use differs according to the characteristics of the household itself. Figure 2 shows how CFL use differs according to household size. Of households that comprise only one person, only 23.3% have at least one CFL. For households with between two and five members, CFLS are present in between 31.5% and 35% of the sample. For households with six or more members, this figure increases to 41%. Similarly, for households with at least one CFL, the average number of CFLs increases with household size, ranging from just over 3 for one-person households, to between four and five for households with between two and five members, and to 6.63 for households with six or more members.

Figure 2: CFL Use and Household Size



Although SHEU03 asked questions about household income, almost 25% of surveyed households did not provide direct information on income. For households that did provide this information, the average household income for those with no CFLs was just below $55,000, while the average income for those with at least one CFL was almost $68,000, suggesting that CFL use increases with income. Since a number of households with no detailed income information did confirm a range in which their household income lies, this range information can be used in conjunction with the actual income data provide by other households to examine how CFL use varies according to income for approximately 90% of the sampled households.[1] These findings are shown in Figure 3.

Figure 3: CFL Use and Income

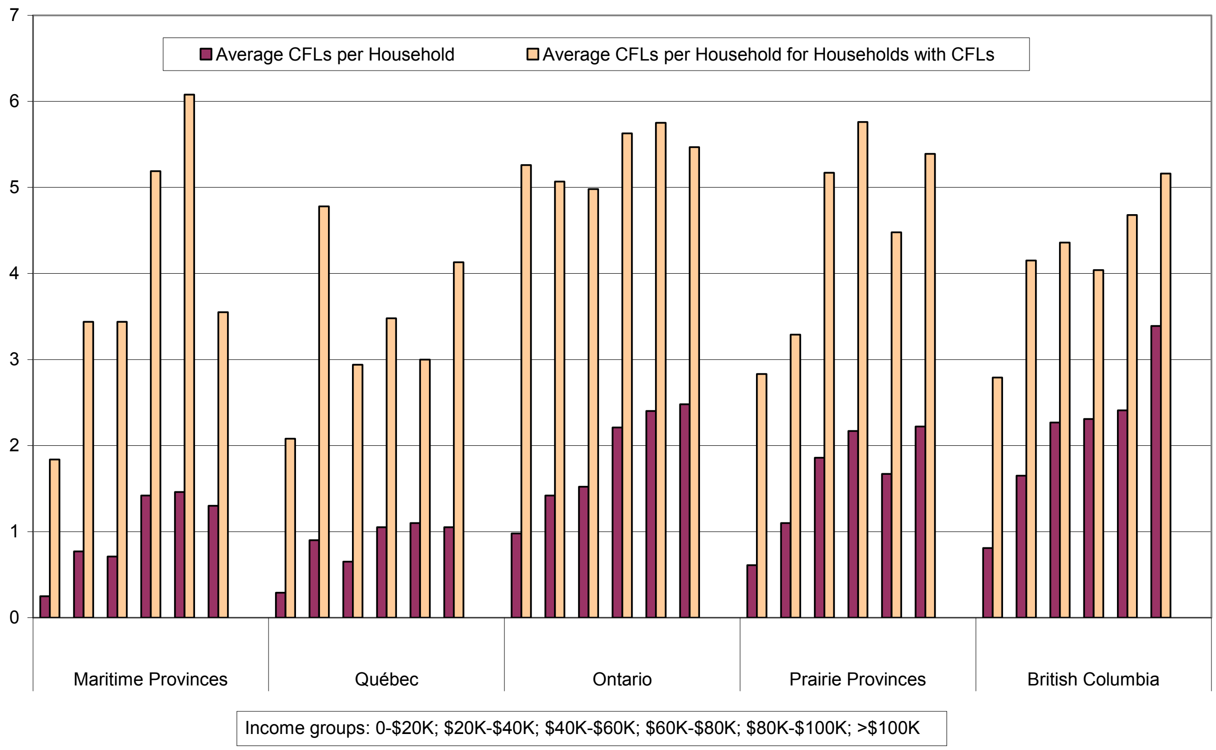


[1] Some households indicated that their income was in the open-ended range of "higher than $80,000". However, inclusion of this data prevents an examination of how CFL use differs for incomes in the range $80K to $100K and those over $100K, and CFL usage behaviour in these two income groups does appear to differ.

As Figure 3 shows, there is quite distinct evidence of increased CFL use with higher income. Over 44% of households with incomes exceeding $100K have at least one CFL, compared to less than 20% of households earning $20K or less, and just over 30% for households earning between $40K and $60K in 2003. Households in the highest income group have on average 2.25 CFLs, which is over four times as many as the average number of CFLs per household in the lowest income group, and 65% higher than the average number for the group with incomes between $40K and $60K. However, once a household has made a decision to use at least one CFL, the differences in the average number of CFLs according to income group do not differ nearly as substantially. As shown in Figure 3, for households using at least one CFL, those in the lowest income group use 2.83 CFLs on average, while those with incomes between $40K and $60K use 4.34 on average, and those in the highest income group use an average of 5.1 CFLs. While confirming the tendency for CFL use to increase with income, this result suggests that the key issue in increasing overall use of CFLs might be to induce households just to to try one CFL.

The relationship between income and CFL use appears to apply generally across regions, as shown in Figure 4. Here, due to the relatively small number of households in some income groups in particular provinces, it was necessary to separately aggregate the Maritime provinces (Newfoundland, Nova Scotia, Prince Edward Island, and New Brunswick), and the Prairie provinces (Manitoba, Saskatchewan, and Alberta). In general terms, Figure 4 confirms that the direct relationship between income and CFL use that was observed in Figure 3 applies in each of the different regions of Canada, although the strength of the relationship may differ from region to region. One interesting observation in Figure 4 is that in Ontario, for households that have at least one CFL, there is relatively little variation across income groups in the number of CFLs that they use.

Figure 4: Average Number of CFLs by Income Group by Province



In terms of types of light bulbs, households have many choices, and in view of the earlier discussion of the advantages and disadvantages of CFLs, it would not be expected that households would use CFLs in all light fixtures. SHEU03 survey participants were asked how many light bulbs of several different types were present in their dwelling. For those households that knew the number of each type of light bulb, Table 7 lists the average number of light bulbs of each type that were present. In addition, the last two columns of this table indicate how these average numbers differed for households that had at least one CFL and for those households with no CFLs.

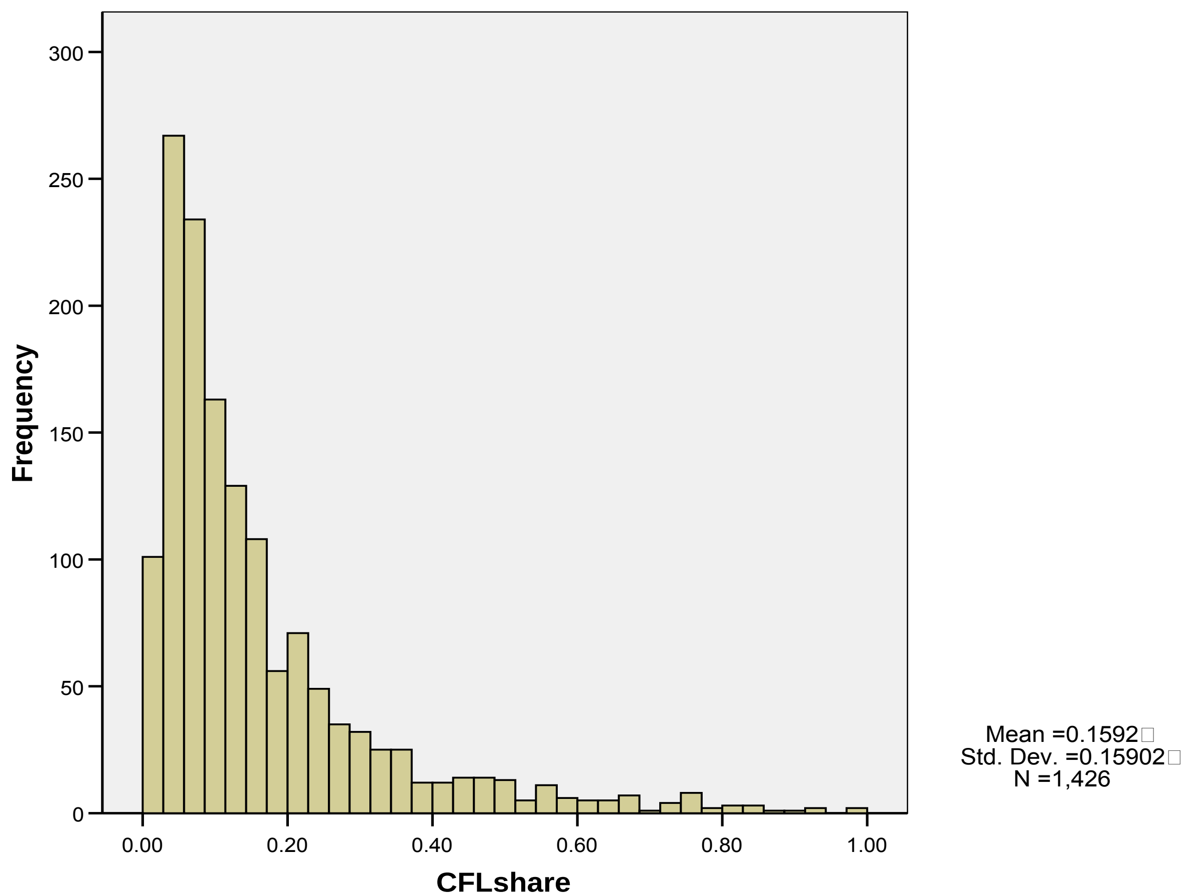
TABLE 7: Types of Light Bulbs Present in Dwellings

Type of Light Bulb	Average Number of Light Bulbs per Household		
	All Households	Households with CFLs	Households with no CFLs
Incandescent	20.86	20.74	20.92
Fluorescent	2.39	3.08	2.08
Halogen	2.25	2.69	2.05
CFL	1.38	4.38	
Security	0.63	0.90	0.51
ALL	27.51	31.79	25.56
Switched on for3 hours or more daily	2.24	2.02	2.34

One of the interesting findings in Table 7 is that households with at least one CFL generally have approximately six more total light bulbs on average than other dwellings. The average number of ordinary (incandescent) lights differs by only 0.2 between the two types of dwellings, but households with CFLs tend to have more or each other type of light bulb – fluorescent, halogen, security, and of course CFL – than households that do not have CFLs. However, in the overall sample, apart from security lights, CFLs are the least used lighting choice with on average1.38 bulbs per household. Households on average have approximately one more fluorescent bulb and one more halogen bulb than the number of CFLs, and approximately 15 times as many incandescent bulbs. The last row of Table 7 shows the average number of lights that are switched on for three hours or more each day in the different types of households. In view of the finding, discussed earlier, that CFLs tend to save more energy when switched on for longer periods, it might have been expected that households with CFLs would have more lights switched on for longer periods, but this is not the case in the SHEU03 data.

Since CFLs may not be appropriate in all situations, it is interesting to examine the proportion of light bulbs that are CFLs rather than some other type. For all households (that know the numbers of lights of each type that they have), on average only 5% of light bulbs are CFLs. However, this number is largely affected by the fact that the majority of houses have no CFLs. Focusing just on dwellings that have at least one CFL, on average almost 16% of their light bulbs are CFLs, although there is quite wide variation in this proportion across households, as is shown in Figure 5.

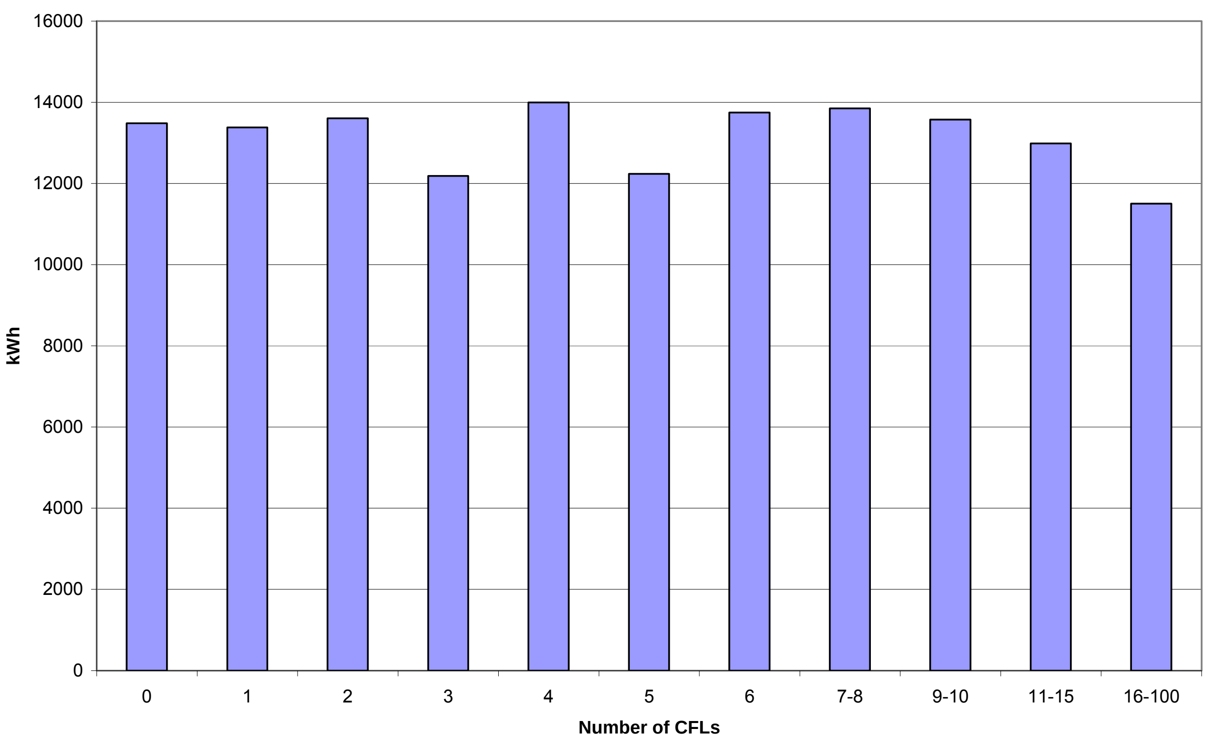
Figure 5: Share of CFLs in Dwellings where CFLs are Present



Since one of the main reasons for using CFLs rather than an alternative type of light bulb concerns the expected energy savings, it is instructive to examine the extent to which electricity use differs according to whether households utilize CFLs. Of course, the average number of CFLs in use in any dwelling is relatively low (4.38 on average per household with at least one

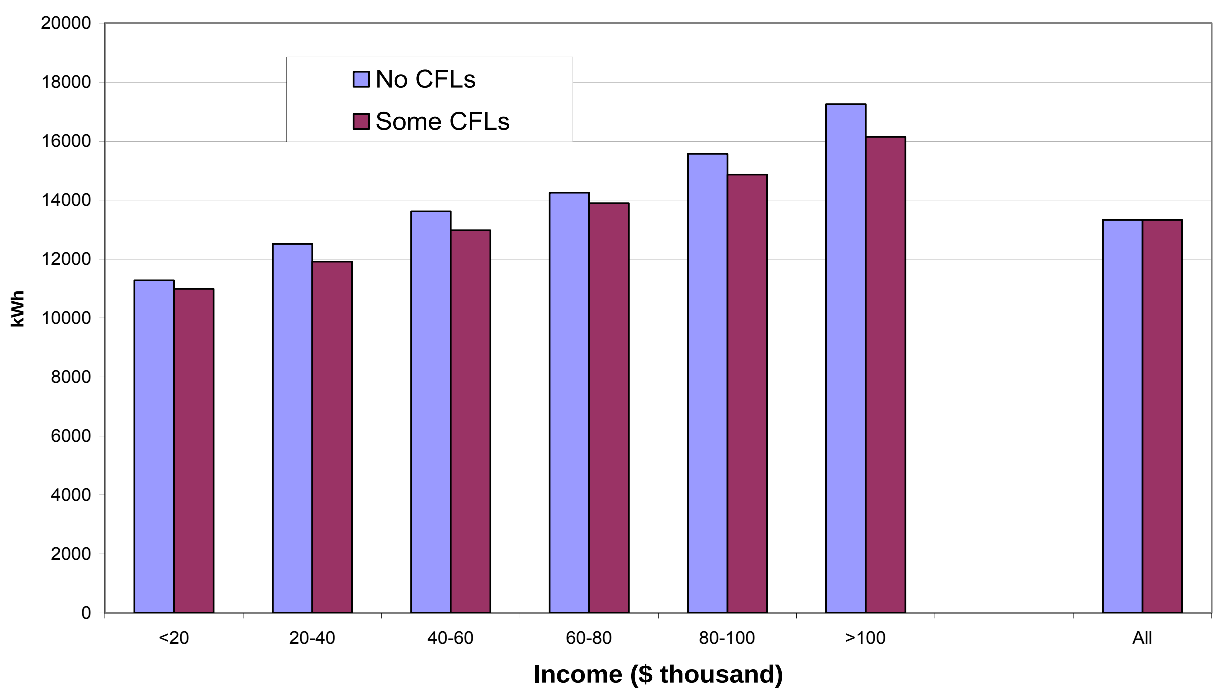
CFL), so that it would not be anticipated that large reductions in electricity use would be observed in households that have CFLs. Nevertheless, to the extent that CFL use may be part of an overall energy-use reduction strategy in particular households, it might be possible to detect lower electricity use in households that utilize CFLs even though this is not solely due to the use of CFLs. Some high-level evidence of this is provided by the SHEU data, where the average electricity use for households without any CFLs is 13,482 kWh, while households that have at least one CFL have average electricity use of 13,284 kWh, a difference of only 1.5%. As Figure 6 shows, there is at best only weak evidence that average electricity consumption falls as the number of CFLs in a household increases.

Figure 6: Average electricity consumption



Since electricity use would presumably differ with a number of other factors, such as income, in Figure 7 average electricity consumption is shown for each of the six income groups used previously, according to whether or not the household has any CFLs. As expected, average electricity consumption increases relatively steadily as income increases, for both households that have at least one CFL and those that have no CFLs. For each income group, average electricity use is lower – by between 2.5% and 6.5% – for households that have at least one CFL compared to the remaining households. Interestingly, when the sample is limited in this way to households that provided their income or income range information, across all households (the last two bars in Figure 7) the average difference in electricity use for households with CFLs and households with no CFLs disappears entirely.[2]

Figure 7: Electricity Consumption (kWh) by Income and CFL Use



[2] Even though average electricity use is higher for households without any CFLs in each income group, since there are different numbers of household in each income group that do and don't have CFLs, the overall average of electricity consumption need not be smaller for households that have CFLs. Almost 44% of households that have CFLs are in the top three income groups, but only just over 28% of households with no CFLs are in these three groups.

One drawback of the analysis so far is that in examining the effect of any particular factor on CFL use, no account is taken of the confounding effects of various other factors. In the next section a model of the decision to use at least one CFL is developed and subsequently estimated in order to determine which factors have important roles once the effects of changes in other variables are held constant.

6. Modelling the Decision to Use CFLs

There are three potentially interrelated decisions for the household to make concerning CFLs – whether to use any at all, if so how many to use, and in which situations or locations to use CFLs in place of other types of lighting. The literature on CFLs identifies a number of variables that may be related to CFL usage generally, although not necessarily to any particular one of the three decisions. Here we focus on the first decision, of whether to use any CFLs in the dwelling, and leave the second question for subsequent analysis. The third question would require detailed information on where CFLs are located in the dwelling, which is not available in SHEU03.

In modeling the decision of whether or not to use any CFLs, we utilize a probit model which has the general form:

$$CFL_i^* = \beta_1 + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + e_i ,$$

where CFL_i^* is an unobserved variable that measures the intensity of desire by the household to use CFLs,

$X_{2i}, X_{3i}, \cdots, X_{ki}$ are a set of k explanatory variables that affect the desire to use CFLs,

e_i is a random error term, assumed to be normally distributed with mean zero and constant variance, σ^2,

$\beta_1, \beta_2, \cdots, \beta_k$ are unknown parameters,

and the subscript *i* denotes the different households in the sample.

If the intensity of desire of the household to use CFLs is sufficiently high, it will be observed that the household uses at least one CFL. This is reflected in the second part of the model:

$$HASCFL_i = \begin{cases} 1 & if \quad CFL_i^* > 0 \\ 0 & otherwise \end{cases},$$

where $HASCFL_i$ is a qualitative (dummy) variable that equals 1 if the household uses at least one CFL.

In terms of the explanatory variables for the model, the literature focuses on two major categories of variables that describe CFL usage. The first relates to dwelling characteristics, while the second relates to household characteristics such as income and education levels. Friedman et al. (1994) identified several dwelling characteristics that were related to CFL ownership, including the number of lights in the home, the existence of a garage, the number of hallways, and the number of bedrooms in the dwelling. The SHEU03 data contain information concerning the number of lights in the dwelling and the existence of a garage, so these variables were in included in our analysis. While there is no direct information in the data set on the number of bedrooms and hallways, the dwelling size heated area in square feet is available and is included in the model on the basis that a house with more bedrooms and hallways would generally have a larger heated area. However, dwelling size is an imperfect measure in the sense that CFLs may not be ideal in all locations in a home, and a dwelling size may be larger without additional bedrooms and hallways, or other locations that may be well suited to CFL use. Nevertheless, the occupants of a larger house – or one with more lights – would likely incur greater expenditures on lighting, and therefore may have more incentive, or just be more willing, to experiment with non-incandescent or "non-traditional" lights.

To capture the idea that some houses, or locations within houses, may be better-suited than others for CFLs – possibly in terms of their usage patterns – another variable included in the model is the total number of lights that were switched on for more than three hour per day, and the age of the dwelling. Also, based on the results in Table 5 in the previous section that indicate that CFL use differs according to the type of housing, dummy variables for the different housing types are included in the model, with single-detached housing treated as the base case. Finally, and again based on the findings in Table 5, which showed that owners are more likely to use CFLs than renters (possibly because in some rental situations electricity costs are included in the rental rate, in which case energy savings would not necessarily accrue to the renters), a dummy variable that indicates whether or not the dwelling was owned by the occupying household is also included in the model.

Kumar, Jain & Basal (2003) focused on household and individual factors that influenced CFL usage, such as age, educational attainment, income, CFL awareness, and occupation. Unfortunately, other than income – which is included in the model here – information on these variables is not contained in the SHEU03 data set. In view of the analysis in the previous section, an additional variable pertaining to household characteristics that was included in the model is household size, on the basis that larger households may use more lighting and may benefit more from the electricity-saving features of CFLs. For similar reasons, the household's total consumption of electricity is also included as an explanatory variable in the model.

Menanteau & Lefebvre (1998) commented on the dominance of incandescent lights in the lighting market. To capture the possibility that consumers may be more likely to try CFLs in lighting fixtures that are not "dedicated" to, or regularly filled with, an incandescent bulb, the number of incandescent lights in use in the household is also included in the model. The inclusion of this variable also reflects the possibility that there may exist a certain degree of consumer inertia in the adoption of "new" light technologies. This consumer inertia was confirmed by Lund (2005).

In this report, we have added a third major category to explain CFL ownership, location. Canada is a diverse country with a relatively decentralized government. Since cultures and attitudes as well as government programs and other factors such as weather – including hours of sunshine – differ from one province to another, provincial dummy variables were added to the model with Ontario being the base case. For instance, BC Hydro, the electricity provider in British Columbia, instituted a lighting rebate program, which encouraged the adoption of CFLs. According to BC Hydro's 2005 annual report, BC Hydro distributed 1.8 million CFLs to 650,000 customers between 2002 and 2004, although it is not known how many of these are in use. In addition, we added a dummy variable indicating whether the household lived in an urban or rural area. The analysis of the SHEU03 data in the previous section revealed some variation in CFL ownership across provinces as well as between rural and urban households. Lighting specialty shops and big box retailers are the most prevalent sellers of CFLs so that in 2003, rural households may not have had the same access to CFLs as did urban households.

The complete list of variables used in the model is presented in Table 8. Unfortunately, complete data are not available on all the variables for all households in the sample. For example, as noted earlier, detailed income information is missing for over 20% of the original sample of 4551 households. In addition, some households do not know what types of lights they have, or how many are switched on for three hours or more in an average day, while other households are unaware of the age of their dwelling or its size.[3] The inclusion of the variable indicating whether the household has a garage also causes some operational difficulties, as many households were not asked this question because of the type of residence in which they lived, such as an apartment. For the analysis reported here, the sample is limited to those households

[3] In some cases, the surveyed households are renting the dwelling, in which case supplementary information is sometimes available from the property owners. This information has not been included in the analysis reported here, but is planned to be used in subsequent analysis.

that actually answered "yes" or "no" to this question.[4] Finally, although survey participants were asked for electricity consumption information, or for permission to access this from their electricity supplier, in some cases this information was not forthcoming. In these cases, electricity consumption was imputed to these households by Statistics Canada, and in the analysis reported here these imputed values are treated as though they are equal to actual electricity consumption by these households, although the merits of so doing are unclear.[5] Summary statistics for the variables used in the model, for the remaining sample of 2470 households, are shown in the last three columns of Table 8.

[4] By recoding the responses of households that were not asked this question as "no", the sample size would be increased and would include representation of apartments which are excluded under the current coding of responses to the garage question. Furthermore, the variable would still reflect those households that explicitly have a garage as opposed to a parking area (indoor or outdoor) for which they are most likely not directly responsible for lighting decisions. It is proposed to examine this issue in subsequent empirical analysis.

[5] In subsequent empirical analysis, the effects on the results of omitting these observations with imputed electricity consumption will also be examined.

TABLE 8: Variables Included in the Probit Model

Variable	Description	Minimum	Maximum	Average
HASCFL	=1 if household has at least one CFL; =0 otherwise	0	1	0.36
ALLLIT	Total number of lights in the dwelling	1	171	31.17
INCAN	Number of incandescent lights in the dwelling	0	100	23.37
TOTLIT3	Number of lights that are switched on for 3 or more hours per day	0	25	2.47
AREA	The size (heated area) of the dwelling in square feet	15	54450	1461.55
GARAGE	=1 if the household has a garage; =0 otherwise	0	1	0.51
HAGE	Age of the dwelling	0	103	33.71
OWN	=1 if the dwelling is owned by the household; =0 otherwise	0	1	0.93
URBAN	=1 if the dwelling is in an urban area; =0 otherwise	0	1	0.77
ELEC	Annual electricity consumption, in kWh	144	169716	14232.65
INCOME	Annual household income	0	1250000	66228.37
HHSIZE	Size of the household	1	9	2.83
NFLD	=1 if the household is in Newfoundland and Labrador; =0 otherwise	0	1	0.05
PEI	=1 if the household is in Prince Edward Island; =0 otherwise	0	1	0.01
NS	=1 if the household is in Nova Scotia; =0 otherwise	0	1	0.06
NB	=1 if the household is in New Brunswick; =0 otherwise	0	1	0.05
QUE	=1 if the household is in Quebec; =0 otherwise	0	1	0.17
MAN	=1 if the household is in Manitoba; =0 otherwise	0	1	0.05
SAS	=1 if the household is in Saskatchewan; =0 otherwise	0	1	0.04
ALB	=1 if the household is in Alberta; =0 otherwise	0	1	0.15
BC	=1 if the household is in British Columbia; =0 otherwise	0	1	0.16
DOUBLE	=1 if the house is double housing; =0 otherwise	0	1	0.06
ROW	=1 if the house is row or terrace housing; =0 otherwise	0	1	0.05
DUPLEX	=1 if the house is a duplex; =0 otherwise	0	1	0.03
MOBILE	=1 if the house is a mobile home; =0 otherwise	0	1	0.04

7. Empirical Results

Estimation of the probit model using the variables listed in Table 8, for the sample of 2740 households, weighted using the sample weights specified in SHEU03, via Maximum Likelihood Estimation using the LIMDEP software, yielded a maximized log likelihood value of -1447.69. This is significantly greater than the log likelihood function using none of the explanatory variables, of -1629.86, the Likelihood Ratio (LR) statistic of 2(-1447.69-(-1629.86)) = 364.34 exceeding the critical chi-square value with 24 degrees of freedom of 36.42. [6] However, while the overall model is significant, and correctly predicted 71% of the CFL usage of the 2470 households (89% correct predictions for those with no CFLs and 39% correct for those with at least one CFL), which is considerably better than the naïve model,[7] a number of explanatory variables did not appear to have significant explanatory power.

Since none of the coefficients on the four maritime provinces (Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and New Brunswick) were individually significant, and since each of these provinces has relatively few households, they were amalgamated into a single dummy variable for the maritime provinces (denoted MARITIME). This variable was significant at the 10% level, and its inclusion in place of the four separate provincial dummy variables had no significant impact on the log likelihood (reduction of only 0.28) or on the proportion of correct predictions. Since, of the dwelling-type dummy variables, only the variable denoting row housing was significant (at 10%), the other three dwelling-type variables were tested for joint significance using a LR test, were found to be insignificant (the

[6]A Likelihood Ratio test involves first estimating the log likelihood value for the unrestricted model (that is, the model as specified), and then obtaining the restricted log likelihood value by re-estimating the model with the coefficient(s) on the variables of interest set to their hypothesized values. The LR statistic, which is then obtained as twice the difference between the unrestricted log likelihood value and the restricted log likelihood value, has a chi-square distribution with degrees of freedom equal to the number of restrictions.

[7] The naïve model predicts the most common outcome (here, not having a CFL) for each household. Since 64.4% of the households in the sample do not have any CFLS, this model would be correct for 64.4% of the households.

log likelihood decreased by a further 0.25 to -1448.22, and the proportion of correct predictions marginally improved), and were omitted from subsequent consideration. Although not all remaining variables are significant at a 10% or higher level, this form of the model was used for subsequent analysis since further operations, as described below, could affect these individual significance levels.

One of the econometric issues that may arise with estimation of probit models using survey data of the type used here is that the errors may be heteroskedastic (have non-constant variances) in which case the maximum likelihood estimators are inconsistent, and the usual standard errors will be inappropriate. Consequently, it is important to test for heteroskedasticity in the probit model, and to allow for any such heteroskedasticity in the estimation procedure. Here, we test for and allow heteroskedasticity of the form:

$$Var(e) = \exp(\gamma_1 Z_{1i} + \gamma_2 Z_{2i} + \cdots + \gamma_p Z_{pi})^2,$$

where $Z_{1i}, Z_{2i}, \cdots, Z_{pi}$ are a set of p explanatory variables that affect the variance of the error term. As candidates for these variables, we consider all the continuous variables in the probit model. Estimation of the model allowing for heteroskedasticity of the specified form yields a log likelihood that can be used in conjunction with the log likelihood for the model without any heteroskedasticity in a LR test of whether there is evidence of heteroskedasticity related to the specified variables. The results from this analysis are shown in Table 9.

Table 9: Results of Heteroskedasticity Tests

Variable(s) in heteroskedasticity (het) function	Log Likelihood	t-statistics on het function variables	LR statistic for het	Proportion of Correct Predictions		
				ALL	No CFL	CFL
none	-1448.22			0.71	0.89	0.31
AREA	-1424.49	5.98**	47.46**	0.70	0.88	0.38
INCAN	-1445.94	1.97†	4.56*	0.71	0.90	0.38
TOTLIT3	-1443.80	2.76**	8.84**	0.71	0.90	0.38
ELEC	-1427.52	5.76**	41.4**	0.72	0.91	0.37
ALLLIT	-1361.43	9.16**	173.58**	0.72	0.86	0.46
HHSIZE	-1447.51	1.18	1.42	0.71	0.89	0.38
HAGE	-1446.75	1.76†	2.94†	0.65	1.00	0.01
ALLLIT AREA TOTLIT3	-1360.524	8.91** -0.84 -1.03	175.4** 1.82 (a)	0.72	0.86	0.46

Notes: ● **, *, and † indicate significance at the 1%, 5%, and 10% levels, respectively.
● Except where otherwise indicated, the LR statistic is a test of heteroskedasticity of the specified form versus no heteroskedasticity.
● (a) indicates a test of heteroskedasticity of the specified form (involving three variables) versus heteroskedasticity just involving ALLLIT, as in row 6.
● Income was also tried as a variable in the variance function, but in this case the model did not converge.

As the results in Table 9 indicate, there is clear evidence of heteroskedasticity. What is unclear from the separate tests is the exact form of the heteroskedasticity, since all variables individually except HHSIZE are significant at the 10% level or higher in the variance function, although INCAN and AGE only show moderate evidence of heteroskedasticity. However, when the significant variables were jointly included in the variance function, it appears that the heteroskedasticity is predominantly associated with ALLLIT, as the last row of Table 9 shows. Inclusion of additional variables with ALLLIT in the variance function has no significant effect on the log likelihood compared to just including ALLLIT by itself, and also has no effect on the ability of the model to correctly predict CFL use overall or for each of the two groups, CFL-users and non-CFL users. Therefore, in the preferred model, the variance is specified to depend only on ALLLIT.

Since the coefficients in the probit model indicate the effect of a change in each explanatory variable on CFL_i^*, which is an unobserved variable that measures the intensity of desire by the household to use CFLs, they are of limited direct usefulness. However, they can be used to calculate the marginal effects, that is, the effects of a change in each explanatory variable on the probability of using at least one CFL. These marginal effects, evaluated at the average values of the explanatory variables, are displayed in Table 10.[8]

As can be seen from the marginal effects in Table 10, there are a number of variables that have significant effects on the probability that a household will use at least one CFL. The most significant effect is for ALLLIT, indicating that, holding all other factors constant, a household with more lights in total has a greater probability of having CFLs, with the probability increasing by 0.032 for each additional light. However, this effect is almost exactly offset by the significant negative marginal effect for the INCAN variables, which indicates that having one more incandescent light, holding all other variables (including the total number of lights) constant, will decrease the probability of having a CFL by 0.035. Therefore the net effect of having one more light that is incandescent (summing the marginal effects for ALLLIT and INCAN) on the probability of having at least one CFL is zero. In other words, if a household was to purchase one more light (not a replacement) that was incandescent, they are unlikely to have any CFLs.

[8] Note that for the variable ALLLIT, which also appears in the variance function, the marginal effect includes its direct effect and its effect through the variance function. For details, see Greene (2005, pp. 680-682).

TABLE 10: Marginal Effects for the Preferred Probit Model Specification

Variable	Marginal Effect	Standard Error
constant	-0.1549**	0.0578
URBAN	0.0030	0.0204
OWN	0.0153	0.0242
HAGE	0.0006†	0.0003
HHSIZE	0.0082	0.0064
AREA	-0.00002†	0.00001
INCAN	-.0353**	0.0034
INCOME	-0.0000003	0.0000002
TOTLIT3	-0.0089*	0.0037
ALLLIT	0.0322**	0.0023
ELEC	0.000002*	0.000001
GARAGE	-0.0043	0.0168
ROW	0.0647*	0.0300
MARITIME	-0.0333	0.0335
QUE	-0.0712**	0.0259
MAN	-0.0152	0.0402
SAS	0.0310	0.0427
AB	0.0768**	0.0264
BC	0.0697*	0.0297

Note: **, *, and † indicate significance at the 1%, 5%, and 10% levels, respectively.

Other variables that have significant marginal effects are TOTLIT3, ELEC and ROW (at the 5% level) and AREA and HAGE (at the 10% level). Holding everything else constant, higher electricity use increases the probability of using at least one CFL, as does residing in row housing (as opposed to residing in a single detached dwelling). However, having more lights that are switched on for three hours or more – where CFLs would be effective at saving energy –

reduces this probability, although only by less than 0.01 per light. An increase of one year in the age of a house increases the probability of having a CFL by 0.0006, while the probability of using a CFL decreases by 0.02 for every additional thousand square feet of heated area, again holding everything else constant. In terms of regional effects, the probability of using CFLs is significantly higher (than the base case of Ontario) in Alberta and BC, by between 0.07 and 0.08, and is significantly lower by a similar amount in Quebec. The effects for the other regions are not significant.

Of interest also are the variables that have no significant effect on the probability of using at least one CFL. These include living in an urban location, whether the house is owned or rented, the household size, and whether the dwelling has a garage. Income also does not have a significant effect on the likelihood of using CFLs – holding all other effects constant – and its coefficient is negative, which is somewhat surprising. On the one hand, higher income may mean that electricity costs are perhaps less important, so that there is a reduced incentive to save energy, but on the other hand – to the extent that higher income is associated with higher education – it might be expected that this would be associated with an increased level of awareness of the energy-saving possibilities and responsibilities. Unfortunately the non-significance of income – whatever its sign – may be due to the reduced sample size that is necessitated when actual income data is used, so that in subsequent analysis it may be worth considering the use of income groups, which will increase the size of the usable sample.

Overall, the preferred model is significant, and correctly predicts 72% of household use or non-use of CFLs. For households that do not use CFLs (64% of the sample), the model predicts this feature correctly in 86% of the cases, while for households that do use at least one CFL, the model predicts this correctly in 46% of the cases.

8. Summary and Conclusions

Compact fluorescent lights (CFLs) use between one-quarter and one-third as much electricity as incandescent bulbs to provide the same amount of light, and are particularly advantageous for use in locations where lights remain on for prolonged periods. Yet, based on the data in SHEU03, CFLs are present in only just over 31 of homes in Canada, and even in these houses, CFLs are generally vastly outnumbered by incandescent light bulbs, representing less than 14% of total lighting.

The identification of factors that affect CFL use has been the subject of several papers in the literature. A number of possible reasons for – and against – CFL use have been suggested, based on surveys and other information. Positive factors include reduced energy consumption, concern for the environment, and the desire for better lighting. Negative factors include high initial cost and quality concerns. Although the life cycle cost advantage of CFLs over incandescent lights is clear – calculated in this paper to be as much as $34 over the approximately 9-year life of a CFL using a 7% discount rate and a cost of 10c/kWh for electricity – some authors have argued that consumers tend to think in terms of initial cost rather than life-cycle costs for electrical appliances, including lighting. Inertia has also been identified as a factor that works against the substitution of CFLs for incandescent lights. In terms of household characteristics, higher education, income, household size and location in an urban environment have all been found – to varying degrees – to be associated with CFL usage.

Using data pertaining to 2003 collected in the Survey of Household Energy Use, we find that CFL use is highest in British Columbia, and relatively high also in Alberta and Ontario, but much less in Quebec and the Maritime provinces. The average number of CFLs across all households in Canada is 1.4, although households that have at least one CFL have on average 4.4

of them. CFLs are more likely to be found in urban dwellings, in houses that are owner-occupied, in single-detached and in row or terrace housing, in homes with a garage, in homes built more recently, and in larger houses. Generally, CFL use increases with the size of the household and with income. Interestingly, for households that have at least one CFL, there appears to be a smaller amount of variation in the number of CFLs as income increases. This might suggest that the key issue with increasing penetration of CFLs is to convince households to just try one. However, even in households that have at least one CFL, on average only 4.38 out of 31.79 total lights are CFLs. This may reflect the finding, frequently raised in the literature, that CFLs are not necessarily desirable or appropriate in all situations where incandescent lights are currently used.

With only an average of 4.4 CFLs per household in households that have at least one CFL, it would not be expected that electricity consumption would be noticeably smaller in households with CFLs. However, to the extent that CFL use may be part of an overall energy-use reduction strategy in particular households, it might be possible to detect lower electricity use in households that utilize CFLs even though this is not solely due to the use of CFLs. Within the SHEU data, and not controlling for the effects of income, house size, or any other factors, the average electricity use for households with at least one CFL is 1.5% lower than for households that have no CFLs. While there is only weak evidence that average electricity consumption falls as the number of CFLs in a household increases, electricity consumption within each income group is found to be marginally lower on average in households that have at least one CFL. This highlights the importance of controlling for the effects of other variables when evaluating the effects of particular factors on CFL use. To accomplish this, a probit model of the decision of a household to use at least one CFL is estimated using the SHEU03 data.

Estimation of a probit model of the decision to use at least one CFL, allowing for heteroskedasticity related to the total number of lights in the house, revealed that households that have more lights are significantly more likely to use a CFL. This result is consistent with the findings of Friedman et al (1994). In contrast, the more incandescent lights a household owns, the less likely they are to own a CFL. Perhaps households that are the biggest incandescent light users are resistant to lighting alternatives or perhaps they have, as Lund (2005) noted, a great deal of consumer inertia when it comes to adopting new lighting technologies.

The size (area) of the household's dwelling had a very small negative effect on CFL ownership, which, if dwelling size is a proxy for number of bedrooms and hallways, does not support the findings of Friedman et al (1994). However, the effect of this variable is quite small and it is only significant at a 10% level. In addition, the existence of a garage was found here to have no significant effect on CFL use, which also contradicts Friedman et al's results. While these authors reported that lights that are switched on for between 2 and 4 hours per day are ideally suited for CFLs, the probit model results here indicate that, holding everything else (including electricity usage) constant, an increase in the number of lights that are on for three or more hours a day has a significant negative effect on the likelihood of using at least one CFL. This may indicate that households that have lights on for more than three hours per day are unaware of the benefits of CFL usage, including the electricity savings they could realize. Informing them of the benefits of CFLs may induce them to substitute towards this type of lighting, since they are among those who would realize the largest benefits from CFL use.

In terms of other explanatory factors, the relationship between income and the probability of CFL ownership is slightly negative, but is insignificant. However, the probability of CFL usage significantly increases in older houses, in row housing (compared to single detached dwellings), and as the amount of electricity consumed by the household increases. Finally, in terms of regional effects, compared to the base case of Ontario, households in Quebec are 7% less likely to use CFLs, while those in Alberta and British Columbia are approximately 7% more likely to use them.

Overall, the analysis here suggests that there is scope for much more widespread use of CFLs in Canada. In part the issue is to convince households to try at least one CFL, although the limited use – on average – in households that use at least one CFL, suggests that the factors that limit more intensive use of CFLs in these households also need to be thoroughly investigated. This would likely require data on the locations in houses where CFLs are used, along with their usage patterns relative to other types of lights. Unfortunately, this is very detailed information that would require a much more narrowly focused survey than SHEU03. It is also unfortunate that education information is not available in SHEU03, since education has been linked – more strongly than income – to household energy-savings decisions, and to the extent that increased education affects CFL use, a strong role for pro-active advertising programs may be suggested. In the analysis here, income likely acts to some extent as an imperfect proxy for education, and although this variable was not found to be significant, the reluctance of many survey participants to reveal their income limits the usefulness of this variable through its effect on reducing the usable sample size. Possibly the effects of this variable can be examined in more detail by combining specific income data with information on income groups, or perhaps by utilizing non-survey information based on household location. These remain as tantalizing subjects for ongoing and future research.

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