Time-Saving Innovations and Canadian Household Energy Use

Vera Brenčič and Denise Young

April 2008

CBEEDAC 2008–RP-02-DRAFT

Executive Summary

Time and energy are major inputs into the production of household goods and services. The introduction of time-saving innovations allows households to change their activity patterns and to reallocate their time across competing activities. As a result, the market penetration of time-saving technologies for general household use will be expected to have a two-fold impact on energy use in the residential sector. Firstly, increased use of time-saving technologies for basic household needs and maintenance (cooking, cleaning) will lead to a direct impact on energy use, as many time-saving technologies are more energy-intensive than technologies that require larger time commitments. Secondly, increased use of time-saving technologies allows household members to increase the amount of the activity that is undertaken (for example, when cooking requires less time, more meals may be prepared at home) or to spend more time undertaking other household production activities or leisure activities (watching TV, reading, exercising) which may or may not be energy-intensive. In this project, we will use the Canadian Survey of Household Energy Use data from 2003 to explore the extent to which time-saving technological devices have entered into Canadian household use and, via regression analysis, to examine the extent to which ownership of products that embody time-saving innovations impacts activities and energy use at the household level.

Table of Contents

List of Tables

1: Introduction

Recent decades have seen the introduction of a variety of new household appliances, as well as improvements in previously existing technologies. Many of these technological innovations, such as those embodied in "Energy Star®" appliances, lead to more energy- efficient provision of household services, such as refrigerating foods and cleaning clothes, without affecting the way in which household members 'interact' with the technology. Other innovations that have been widely adopted by households, such as the use of microwaves for cooking, offer substantial time savings to households who opt for this technology over other methods of preparing meals. In addition, households today have access to new technologies providing services that were not available to previous generations. Devices such as computer gaming systems and DVD players that have been introduced into the market and have been increasingly adopted by households provide energy-intensive options for leisure activities.

The relationship between household energy use and technological change is complex. In this study, we focus on the relationship between time-saving technologies (such as microwave ovens and dishwashers) and household energy use. There are two basic channels through which energy use may be affected when households adopt time-savings technologies. Firstly, many of these technologies are more energy-intensive than alternative technologies. Using an electric or gas clothes dryer, for example, uses more energy than hanging clothes to dry. Cleaning an oven manually uses less energy than making use of an oven's built-in 'self-cleaning' feature. Although microwave ovens use more energy than conventional ovens while in operation, they tend to use less energy per meal, given that they cook foods more quickly.[1]

Secondly, time-savings appliances free up time for household members; time that may be reallocated to additional activities. Among other possibilities, this reallocation of time may lead to an increase in the frequency of use of appliances in order to produce more household services and/or an increase in time spent in energy-using leisure activities such as watching TV or playing computer games. To the extent that time is reallocated to energy-using activities, residential energy use will increase.

[1] http://www.aceee.org/consumerguide/cooking.htm

In order to examine the extent to which these various impacts are present in the energy usage patterns of Canadian households, we look at household-level data from the 2003 Survey of Household Energy Use (SHEU – 2003) conducted by Statistics Canada on behalf of Natural Resources Canada (Office of Energy Efficiency, 2006). Along with information on energy use and socioeconomic characteristics of households, this survey includes questions on the ownership and frequency of use for a variety of household appliances as well as other electronic equipment such as TVs, VCRs, DVD players and computers. This allows us to look at the impact of time-saving technologies on (i) the allocation of time to household work and home-based leisure activities; and (ii) household energy use.

The plan of the paper is as follows. In Section 2, we discuss the major issues related to household energy use and technological innovations. Section 3 provides an overview of the relevant portions of the SHEU-2003 data. The results of our statistical analysis of the relationships of time use and of energy use with the ownership of time-saving devices are presented in Section 4. A general discussion of these results follows in Section 5. Section 6 concludes.

2. Appliances and Household Energy Use

With the current state of technology, households often have several options regarding how to perform basic household production tasks. Dishes can be washed by hand, or they can be washed in a dishwasher. Meals can be cooked, among other ways, in conventional ovens, on stove tops, in microwave ovens, or in slow cookers. Clothes can be dried by hanging them in the open air or in an electric or gas clothes dryer. The choice of technology will affect both the amount of time that must be devoted to any particular task and the amounts of purchased energy inputs that are required.

If we consider cooking as an example, the use of a microwave oven saves time over the use of other technologies. And, although a microwave oven uses more energy per minute of operation than a conventional oven, the reduced amount of time required will generally lead to lower energy costs per meal cooked. Whether or not there will be an overall reduction in energy inputs when a household switches away from other methods of preparing meals and towards the use of microwave ovens will depend on how the time saved from microwave cooking is reallocated. Some of the time saved may be used to increase the number of hot meals prepared at home. Some of the time may be used to increase the production of other household services such as dish-washing and laundry. And some of the time may be used for leisure activities within or outside of the home, and these leisure activities may or may not require energy inputs.

Models of appliance use that incorporate these sorts of 'time rebound' effects have been proposed by Binswanger (2002), Jalas (2002) and Sorrell and Dimitropoulos (2008). These time rebound effects are analogous to the more familiar 'energy rebound' effects whereby increased energy efficiency leads to lower marginal (energy) costs of obtaining final services from appliances and therefore increases the demand for appliance use. When this energy rebound effect is present, technological innovations that lead to increased energy-efficiency will not lead to the magnitudes of energy savings that are predicted in engineering-based studies that assume that appliances will be used with the same intensity both before and after new technologies are adopted (Khazzoom, 1986; Sorrell, 2007; Sorrell and Dimitropoulos, 2008).

Although models of 'time rebound' effects vary in the details and the extent to which the relationships are formalized, Binswanger (2002), Jalas (2002) and Sorrell and Dimitripoulos (2008), following the general framework of Becker (1965), treat time as one of several inputs into the production of household services and leisure activities. Both Binswanger (2002) and Sorrell and Dimitropoulos (2008) set up formal household production function models. In these models, households receive utility from consuming a bundle of 'n' individual services, such as prepared meals, loads of clean clothes, and leisure activities produced in the home. Each service that is produced and consumed within the household requires time, purchased energy, and other purchased inputs. Sorrell and Dimitripoulos (2008) explicitly add capital (appliance) stocks and their attributes into the production functions such that:

$$S_i = f_i(t_i, e_i, k_i(A_i), x_i) \quad for \;\; i = 1, \ldots, n \tag{1}$$

where S_i = household service i;

t_i = the time devoted to the production of household service i;
e_i = the amount of purchased energy devoted to the production of household service i;
k_i = the capital equipment devoted to the production of household service i;
A_i = a measure of the attributes embodied in the capital used for the production of household service i; and
x_i = a vector of additional purchased inputs devoted to the production of household service i.

The set of attributes, A_i, embodied in the capital may include, among other things, the ease of use of an appliance or the prestige associated with owning a particular model. In many cases, the set of attributes embodied in a piece of household capital equipment (such as a microwave oven or dishwasher, for example) will be a function of the age of the equipment, as more 'options' are often made available in the most recent models.

In the models of Binswanger (2002) and Sorrell and Dimitropoulos (2008), households maximize utility, assumed to be dependent solely on the bundle of household services consumed, where the utility function is given by:

$$U = U(S_1, S_2, \ldots, S_n) \quad where \;\; U' > 0, \;\; U'' < 0 \qquad (2)$$

and they are subject to a budget constraint of the form[2]:

$$V + T_w P_w \geq \sum_{i=1}^{n} (P_e e_i + P_x x_i + \delta_k k_i) \qquad (3)$$

where V = the household's non-wage income;
T_w = the time spent in the labour market ($T - \sum_{i=1}^{n} t_i$, where T is total time available for labour market and/or household production activities);
P_w = the opportunity cost of time (possibly the average wage rate) for the household;
P_e = the price of energy faced by the household;
P_x = a vector of prices for the additional purchased inputs; and
δ_k = the discount factor, such that $P_k = \delta_k k(A)$ represents annualized capital costs.

[2] The model of Binswanger (2002) does not include the V or $\delta_k k$ terms.

In this utility-maximizing framework, changes in appliance technology that affect the time required to produce one of the final products, S_i, will lead to changes in the composition of the utility-maximizing bundle of household services. That is, the reduction in the time cost of producing one service will change the time cost relative to the other input costs for this service. This will result in a new bundle of utility-maximizing services, selected according to the new cost conditions. The new bundle of services will entail a different set of underlying input demands (for time and energy) than was previously required.

For example, suppose that S_i represents the provision of clean dishes. A household who purchases a dishwasher (k_i, embodying a set of attributes A_i that will include a set of available options for washing and rinsing cycles, etc.) can clean dishes with a smaller time commitment, and therefore a smaller time cost, than previously. With less time required to do dishes, the household may decide to watch more TV (S_j). Or it may decide to use some of the extra time that is available to increase the amount of home cooking (S_l) and thereby create more dishes that need to be washed (S_i). These would be 'time rebound' effects. The overall reallocation of time will affect the amount of purchased energy necessary to produce the new bundle of serves.

The extent to which time is reallocated and energy purchases change are an empirical matter. Preferences, the opportunity cost of time and the price of energy all vary across households. The relative costs of time and energy faced by a particular household will influence the type of technology used. It is expected that those with higher incomes will be more likely to substitute away from high time cost technologies towards low time cost (and often high energy cost) options. The available possibilities for trading off time for energy inputs will vary according to the type of service.

The empirical work of Jalas (2002) is based on a less formal 'diagrammatic' model that is in the same general class of utility-maximizing models as Binswanger (2002) and Sorrell and Dimitropoulos (2008). Jalas (2002), however, considers time-saving activities involving third parties (such as ordering goods via the internet and having them delivered, or contracting out repairs to a commercial enterprise). In his study, Jalas (2002) uses Finnish time-use survey data from 1987-1988 combined with 1990 household expenditure survey data for 2-person Finnish households and 1990 Finnish input-output tables. These data are used to calculate the direct energy requirements for household activities that require direct energy inputs, and the indirect energy requirements embodied in the production and distribution of purchased consumption goods. From these data, Jalas (2002) is able to obtain a rough estimate of what will happen to energy use as time is reallocated across activities. Any reallocation of time that leads to a scaling down of activities that have higher (lower) than average energy intensities should lead to lower (higher) overall energy requirements, under the assumption that the time saved is reallocated to activities with 'average' energy requirements. Therefore, Jalas (2002) predicts that a decrease of time allocated to cultural events, reading, using home electronics or cleaning and organizing should lead to higher energy use. Similarly, a decrease in the amount of time allocated to common household production activities such as clothes and dish washing and cooking should lead to lower overall energy use.

With the exception of Jalas (2002), there has been very little empirical research on the impacts of time-saving appliances. Kellert (2006) looks at some impacts of the ownership of time-saving appliances on overall household energy use in Canada, but does not examine the question of their impacts on time allocation. Schipper *et al* (1989) do look at the role of time in energy demand, but not in the context of technological innovations. They note that, controlling for income and appliance ownership, how individuals allocate their time will have an influence on overall personal energy use. A comparison of US time-use diary information from 1975 and 1985 indicates that allocation of time to various activities changed over the intervening decade, with less time spent at home. They also note, based on 1985-86 energy use data, that home activities tended to be much less energy-intensive than travel and somewhat less energy-intensive than time spent obtaining services outside of the home.

2.1 Studies of Household Energy Use

Although empirical evidence examining the relationship between time allocation and energy use is scant, there does exist a substantial literature on the impacts of energy-saving technological change on household energy use. Much of this literature focuses on the aggregate long-term impacts of the introduction of energy-saving technological innovations into the marketplace. In these models, energy-efficiency gains in household appliances such as clothes washers, clothes dryers, dishwashers, refrigerators, and freezers are incorporated into the residential sector component of multi-sector energy demand models. (Brown *et al*, 2001; Geller *et al*, 1998; Interlaboratory Working Group, 2000; Koomey *et al*, 1999; Koomey *et al*, 2001; Meyers *et al*, 2003; Meyers *et al*, 2005). These multi-sector models, of which the residential sector constitutes only one component, rely on assumptions regarding the behaviour of households regarding the purchase and intensity of use of appliances and other energy-using home products.

Much of the assumed underlying behaviour in these aggregated models is based on engineering and empirical studies that use household-level data to estimate the impact of appliance ownership and use on residential energy demand. Many of these household-level models of energy demand use the conditional demand analysis framework of Parti and Parti (1980) wherein regression analysis is used to estimate the energy use attributable to individual household appliances. In these studies, residential energy demand is modeled as a function of appliance ownership (which is considered to be exogenous in these cross-sectional studies as appliance ownership is fixed in the short run) and a set of control variables that varies across studies according to data availability. Where available, the control variables usually include (i) energy prices, (ii) socioeconomic characteristics of the household such as income, education levels, marital status, hobby preferences and household size, (iii) physical characteristics of the residence such as square footage, construction materials and insulation, and (iv) environmental factors such as location and/or heating and cooling degree days. (Munley *et al*, 1990; Branch, 1993; Bauwens *et al*, 1994; Biesiot and Noorman, 1999; Weber and Perrels, 2000; Larsen and Nesbakken, 2004).

There are several results of interest from these studies. Biesiot and Noorman (1999) find that with rising incomes and falling real energy prices, in spite of energy-saving technological improvements that have led to lower energy requirements for a given amount of household services, energy saving behaviour has not been encouraged in the Netherlands. They also find significant differences in energy demand for single vs. multiple person households. Munley *et al* (1990) find that, for a sample of renters in the US, whether or not households are responsible for making their own utility payments has an impact on residential energy demand. Larsen and Nesbakken (2004) note a much lower ownership rate for time-saving appliances such as dishwashers and clothes dryers than for other major household appliances in Norway. Bauwens *et al* (1994) find it important to interact demographic variables with appliance ownership variables for Australia. This result is similar to the findings of Weber and Perrels (2000) who note that the extent to which income matters in determining appliance ownership varies across individual appliances for a set of European countries.

In our present study, we extend the modeling of the demand for energy in the provision of household services by taking into consideration the extent of ownership and use of time-saving appliances. First, we look at the impact of time-saving device ownership on the allocation of time to household production and leisure activities. Then we consider the impact of time-saving device ownership on energy use. Before proceeding to our empirical models, we provide a brief overview of our data and its main characteristics.

3. Data

In our analysis we draw on two data sources. First, we use data from the Survey of Household Energy Use (SHEU - 2003) that was conducted in 2004 by Statistics Canada. In addition to surveying Canadian households about the characteristics of their dwellings and activities undertaken at home that may have implications for the household energy use, Statistics Canada also obtained estimates of household energy consumption directly from the households' suppliers of electricity, natural gas, heating oil, and propane. The survey's initial sample consisted of 6,433 households but was reduced to 4,551 households after accounting for non-responses and the fact that some household dwellings turned out to be incompatible with the purpose of the SHEU – 2003 survey (e.g., summer residences were excluded). The samples we use in our regressions were further reduced due to missing information for some of the variables included in the regressions.

Since we are interested in assessing the impact of households' adoption of time-saving innovations on the households' allocation of time and energy use it is important that we include among the explanatory variables energy prices. We obtained energy price data for electricity and natural gas corresponding to each household's place of residence from the Canadian Building Energy End-Use Data and Analysis Centre (CBEEDAC).[3] The prices we observe correspond to average prices of the relevant local providers and pertain to the 2003 calendar year.

4. Empirical approach

4.1 Time rebound effect

To understand the relationship between a household's adoption of time-saving innovations and their residential energy consumption we are first interested in assessing how households use time they save from their adoption of time-saving innovations. In particular, we examine the relation between a household's adoption of time-saving appliances and household allocation of time along two dimensions: (i) the amount of time the households decide to allocate to household production (i.e., household chores); and (ii) the amount of time households decide to allocate to energy-using home-based leisure (i.e., leisure activities that entail the use of various home electronic devices or 'leisure appliances').

Many household appliances represent time-saving innovations. We refer to these appliances as time-saving appliances (TSA). While the adoption of a TSA reduces the amount of time a household needs to complete a given household chore, the use of a TSA may not reduce the total amount of time a household allocates to TSA use or to chores in general. Since time saving innovations make the completion of household chores that require time cheaper in terms

[3] http://www.ualberta.ca/~cbeedac/

of time costs, their adoption may actually end up increasing the amount of time a household allocates to completing chores. Following Sorrell (2007), we define a direct time rebound effect as an increase in the frequency of chores (or time allocated to completing households chores) a household undertakes on account of the household's TSA adoption. This can be expressed in terms of an equation as:

$$\text{frequency of } TSA_i \text{ use} = \alpha_0 + \sum_{j \neq i} \alpha_j \text{ use of } TSA_j + \alpha' X + u \qquad (4)$$

A positive sign for α_j suggests that a household's ownership of TSA *j* (e.g., a dishwasher) is positively associated with the amount of time the household allocates to the use of TSA *i* (e.g., a microwave). A positive association between TSA adoption and the frequency of TSA use is consistent with a notion that a household uses some of the time saved from TSA adoption for household chores, through an increased frequency of TSA use. The literature refers to this relation as a time rebound effect. To estimate the presence of a direct time rebound effect we therefore need: (i) a definition of what constitutes an adoption of a TSA; and (ii) a measure of the frequency of TSA use or the amount of time allocated to TSA use.

SHEU - 2003 provides two key insights that are of interest for this study. First, households are asked direct questions that pertain to their use and ownership of several TSAs (microwave ovens, self-cleaning features for stoves, dishwashers, washing machines, clothes dryers). A microwave is a TSA since it can be used, among other things, in place of waiting for frozen food to defrost in the refrigerator, heating up food on stove tops, or baking in a conventional oven. Similarly, a dishwasher saves time in comparison to washing dishes by hand. A washing machine and a clothes dryer in the home save time one would otherwise spend driving to a commercial laundry or waiting for clothes to dry out in the open. The adoption of a stove with a self-cleaning feature can also save time that would otherwise be spent on cleaning the stove after use. Second, the households are asked how frequently they use TSAs in an average week. More specifically, the survey asks:

- *In an average week, how many minutes do you use your microwave oven?*

- *In an average week, how many loads of dishes do you do?*
- *In an average week during the summer, how many loads of laundry do you wash?*
- *In an average week during the winter, how many loads of laundry do you wash?*
- *In an average week during the summer, how many loads of laundry do you dry in the clothes dryer?*
- *In an average week during the winter, how many loads of laundry do you dry in the clothes dryer?*

While a household's TSA adoption may to lead the reallocation of time to chores through TSA use, the household may also reallocate the time saved by using a TSA to home leisure activities, leisure activities outside of the home, or to work. We will refer to these changes in the household's pattern of time use as an indirect rebound effect. From the SHEU - 2003 survey we cannot observe whether or not any saved time is allocated to activities outside of the house, but we do have some information on a household's allocation of time to leisure activities that entail the use of home leisure appliances. Time allocated to leisure appliance use is inferred from the households' answers to the following questions:

- *In an average week, how many hours do you have your personal computer turned on?*
- *In an average week, how many hours do you use your personal computer?*
- *In an average week, how many hours do you have your television set turned on?*
- *In an average week, how many hours do you have your VCR turned on?*
- *In an average week, how many hours do you have your DVD player turned on?*
- *In an average week, how many hours do you use your stereo?*

To infer the presence and magnitude of the indirect rebound effect with respect to time we are interested in the following equation:

$$Time\ allocated\ to\ leisure\ appliance\ use_i \ = \ \beta_0 + \sum_j \beta_j\ use\ of\ TSA_j + b'X + u \qquad (5)$$

A positive sign for β_j would suggest that a household ownership of a TSA *j* (e.g., dishwasher) is positively associated with the time the household spends using a leisure appliance *i* (e.g., watching TV).

The presence of either direct or indirect time rebound effects suggests that the adoption of TSA should be positively associated with the amount of time allocated to TSA use or use of other appliances (e.g., leisure appliances). Importantly, two additional predictions follow. First, we expect the time rebound effect to be of smaller magnitude when households use older models of a given type of TSA. For instance, a more recent model of a TSA is likely more time efficient either because it can perform a household chore quicker or because it can perform a greater variety of chores. This argument motivates inclusion of TSA's age as a control variable. Second, the time rebound effect is expected to be larger among high income households since these households are likely to be further away from satiation in their consumption of time allocated to home production or leisure activities (Sorrell, 2007; Sorrell and Dimitropoulus, 2008). This argument motivates the inclusion of interaction terms between TSA use and household income in our models. In particular, by including the interaction we allow for the association between the TSA adoption and time allocation to differ across households with less than 40,000 CAD annual income and households with annual income exceeding 40,000 CAD.

Clearly, a household's adoption of one or more TSAs is not the only determinant of how many hours household members spend watching television or how many loads of clothes are washed in an average week. We therefore include several additional explanatory variables that are likely to affect the households' time allocation. These variables can be categorized into five groups. The first group consists of variables that identify household characteristics: household size, number of household members under 18, household income, a dummy variable for whether there was someone home all day, number of weeks the dwelling is unoccupied during the year, a set of provincial dummy variables, and a dummy variable for whether a dwelling was in an urban rather than a rural area. The second group of variables measures TSA characteristics: whether a TSA was already in a dwelling when a respondent moved in the dwelling, TSA capacity characteristics (when available), and TSA age. The third group consists of variables that capture physical dwelling characteristics (year dwelling was built, dwelling type), while the fourth group includes the price of electricity. The last group consists of other control variables that capture factors such as a household's propensity to undertake energy-saving investments: total number of household improvement undertaken in 2003 or planned for 2004, total number of ENERGY STAR qualified products in the household. Summary statistics for the major variables are reported in Table 1.

4.2 Time rebound effect and residential energy use

Time saving innovations that are embodied in TSAs may not only affect how households allocate their time across work, home production, and leisure but they also likely affect the households' energy consumption. For instance, additional time the households gain from adopting TSAs may be used to increase the use of appliances that require energy. However, to the extent that TSA adoption significantly alters households' allocation on other margins (e.g., time allocated to work, time spent outside the home), TSA adoption may lead to reduced residential energy consumption. To assess the implications of TSA adoption for the household's residential energy consumption we consider the following relationship:

$$\textit{Energy use per sq.ft. of heated dwelling area} = \gamma_0 + \sum_j \gamma_j \textit{ use of } TSA_j + g'X + u \qquad (6)$$

We consider separately the household's consumption of two types of energy: electricity and natural gas. While the SHEU – 2003 survey also provides information about the household's use of propane and heating oil, we do not make use of this information for several reasons. First, we do not observe prices for heating oil and propane. Since the price of an energy source is likely an important determinant of the household's energy consumption, failure to control for the price in the case of propane and heating oil consumption would likely result in biased estimates. Second, it is difficult to come up with an example whereby the household may allocate additional time on account of the TSA adoption to activities that result in a change in residential consumption of propane or heating oil (except to the extent that more or less 'thermal comfort is required as household members reallocate time to additional household chores or in-home leisure activities). The last reason for restricting our interest to the household's electricity and natural gas consumption is related to the data. Given that heating oil and propane are only used by a relatively small subset of households, the available sub-sample that we have available to assess the relation between the TSA adoption and propane or heating oil use is very small.

Several additional variables are included to control as much as possible for various other determinants of residential energy use. The first group of variables identifies the number of household appliances in use in a dwelling that require electricity. These variables pertain to refrigerators, freezers, personal computers, television sets, VCRs, DVD players, video game systems, satellite dishes, component stereo systems, compact stereos, telephones, and answering machines. For some of these appliances (refrigerators and freezers) we observe and hence construct variables for the size of the appliance and the appliance age. Importantly, for some of the household appliances we are also able to infer whether the appliances are used in a manner that is likely to affect energy consumption. For instance, we observe whether the use of a dish washer is such that dishes tend to be dried with heat on, whether hot water is used for most clothes washing and rinsing, and whether a clothes dryer has a moisture detector.

Another set of variables pertains to the households' use of heating and cooling appliances. These variables identify whether a household owns a central air-conditioner, number of hours per week a central air-conditioner is turned on for cooling, number of window or room air-conditioner a household owns, number of hours per week a room (window) air-conditioner is turned on for cooling, whether a household owns a central ventilator, number of ceiling fans in use, and hours per week ceiling fans are in use for heating or cooling. A variable is also constructed to identify the number of heating degree days. To identify characteristics of the households' heating appliances we construct variables that identify whether electricity is used for heating, the number of wood fireplaces, and the number of gas fire places in a dwelling.

A separate set of variables identify the household's use of lighting fixtures. These variables measure the number of different lights in use (halogen bulbs, compact fluorescent lights, fluorescent light, security lights, ordinary light bulbs), and the number of hours lights are on per day. In addition, we construct several variables that pertain to the households' use of water: whether a household owns a water cooler, whether a water tank is in use, whether electricity is used for a hot water tank, a dummy variable for a swimming pool, and a dummy for whether electricity is used for a pool heater. Remaining explanatory variables include variables that identify: whether a dwelling has a garage, total dwelling heated area in squared feet, whether air leaks or drafts were noticed, and whether electricity (natural gas) is used to operate a stove or furnace.

5. Evidence

5.1 Preliminary analysis

We start our analysis by examining the average energy consumption, the average hours per week allocated to leisure appliance use, and the average frequency of TSA use separately for households in different percentiles of the distribution based on the intensity of TSA adoption. These are presented in Table 2. We measure the intensity of TSA adoption as the number of TSAs adopted by a household. In addition, we report the average energy consumption separately for households in different percentiles of the distribution based on the intensity of TSA use and the intensity of leisure appliance use.

Three findings are interesting. First, not surprisingly, we find that the frequency of TSA use is higher for households who adopt more TSAs. For instance, while households that fall in the bottom 25^{th} percentile of the sample based on the number of adopted TSAs use their TSAs on average about 19 times a week, households that fall in the top 25^{th} percentile use their TSA on average about 25 times a week. In contrast, households that adopted relatively more TSAs tend to allocate less time to the use of leisure appliances. While households that fall in the bottom 25^{th} percentile of the sample based on the number of adopted TSAs allocate on average about 138 hours per week to using leisure appliances, households who fall in the top 25^{th} percentile allocate about 5 fewer hours. Interestingly, households with more TSAs tend to on average consume less electricity and natural gas per sq ft of heated dwelling area. Households that fall in the bottom 25^{th} percentile of the sample based on the number of adopted TSAs consume about

0.036 (0.077) gj of electricity (natural gas) per sq ft compared to 0.027 (0.056) gj consumed by households that fall in the top 25th percentile.

Second, households that use TSAs more frequently tend to use more electricity per sq ft of heated dwelling area. There appears to be no clear association between the frequency of TSA use and energy consumption. For instance, households that fall in the bottom 25th percentile of the sample based on the frequency of TSA use consume about 0.029 (0.058) gj of electricity (natural gas) per sq ft compared to 0.030 (0.054) gj consumed by households that fall in the top 25th percentile respectively. Third, time allocated to using leisure appliances appears not to be correlated with electricity use but is negatively related to natural gas use. While households that fall in the bottom 25th percentile based on time allocated to using leisure appliances consume about 0.029 (0.062) gj of electricity (natural gas) per sq ft, households that fall in the top 25th percentile consume 0.030 (0.056) gj electricity (natural gas) per sq ft.

5.2 Household TSA adoption and time use

Our preliminary analysis suggests that there appears to exist a positive direct rebound effect and a negative indirect rebound effect with respect to household adoption of time-saving innovations. Since there are likely other factors that affect the household's allocation of time and energy consumption in addition to a household's TSA adoption we now turn to our regression results. In Tables 3 and 4 we report the results from Ordinary Least Squares regressions that pertain to the households' allocation of time along two dimensions: Table 3 reports determinants of the households' frequency of TSA use while Table 4 reports results that pertain to the determinants of the amount of time the households allocate to leisure appliance use. In both cases heteroskedasticity-robust standard errors are reported in parentheses.

Several findings are of particular interest. First, there appears to exist a strong and persistent positive association between a household's adoption of TSAs and the frequency of the household's TSA use. In particular, we find that a household's adoption of a microwave is associated with an increase in the number of loads of laundry washed or dried in an average week, regardless of the season. The same pattern extends to the adoption of any other TSA, with the exception of stove with a self-cleaning feature. We find that the adoption of a clothes dryer or a stove with a self-cleaning feature is positively associated with the amount of time a household allocates to the use of a microwave as well as to the number of times the dishwasher is loaded in an average week. The only negative association we find is that between washing machine adoption by high income households and the intensity of dishwasher use. This negative relationship, however, is only significant at a ten percent level.

The second interesting finding in Table 3 pertains to differences in the association between the TSA adoption and intensity of TSA use across households depending on income levels. Note that, to the extent high income households have less time to allocate to either household production or leisure activities compared to low income households, we would expect the positive association between the TSA adoption and the frequency of TSA use to be of greater magnitude for high income households. Sorrell (2007, page 21), for instance, succinctly described a similar argument in the context of the energy rebound effect. In particular, Sorrell notes: “direct rebound effect from improvements in the energy efficiency of household heating systems should decline rapidly once whole-house indoor temperatures approach the maximum level of thermal comfort. One important implication is that direct rebound effect will be higher among low income groups, since these are further from satiation in their consumption of many energy services.”

In the case of TSA adoption we would therefore expect that high-income households are further away from satiation in their consumption of time spent in off-work activities compared to low-income households. We expect to observe an increase in the rebound effect as income increases. This argument motivates the inclusion of interaction terms for TSA adoption and household income. The evidence in Table 3 is mixed. We find that in eleven cases the positive association between a TSA adoption and frequency of TSA use is greater for households whose income exceeds 40,000 CAD compared to households whose income is less than 40,000 CAD. In five cases, however, the positive association is reversed (i.e., is greater for low income households compared to high income households) or similar in magnitude for the low and the high income households.

For instance, during the winter months low (high) income households who own a dishwasher wash about 0.6 (0.9) more loads of laundry in an average week (or about 2.4 and 3.6 more loads per month) compared to households that do not own a dishwasher. This represents about 10 (16) percent greater intensity of washing machine use in an average week for households that own a dishwasher compared to those who do not. Similarly, low (high) income households that own a dishwasher dry about 0.5 (0.7) more loads of laundry in an average winter week (or about 2.0 and 2.1 more loads per month) compared to households that do not own a dishwasher. This represents about 9 (13) percent greater intensity of clothes dryer use in an average week for households that own a dishwasher compared to those that do not during the winter. A similar pattern extends to the summer months.

Furthermore, high income households with a clothes dryer use a microwave about 11 minutes more in an average week compared to households that do not own a clothes dryer. This represents about 22 percent greater intensity of a microwave use in an average week for high income households that own a clothes dryer compared to those that do not. High income households that own a clothes dryer also clean about 1.182 more loads of dishes per week compared to households that do not own a clothes dryer. This represents about 31 percent greater intensity of a dishwasher use in an average week for high income households that own a clothes dryer compared to those that do not. Low (high) income households with a clothes dryer also wash about 1.689 (1.415) more loads of clothes compared to households without clothes dryer during the winter. The magnitude is slightly smaller during summer months. Microwave adoption, similarly, is associated with about 17 (15) percent greater intensity of a washing machine use during the winter for high (low) income households. A similar magnitude is found for the summer months. Microwave use is also associated with about 18 (13) percent greater intensity of clothes dryer use during the winter for high (low) income households.

Importantly, if the association between the TSA adoption and the frequency of TSA use measures a time rebound effect, we would also expect that the age of a given TSA matters. For instance, a more recent model of a TSA may be more time efficient either because it can perform a given household chore more quickly or because it can perform a greater variety of household chores. From the SHEU - 2003 survey we can infer the age of all TSAs included in the survey except microwaves. Interestingly, we find that households with an older dishwasher tend to use the dish washer less frequently during an average week. Households with an older dish washer also use their washing machines less frequently regardless of the season and use a clothes dryer less frequently during the winter. We also find that households with older clothes dryer tend to use their dishwashers, washing machines, and clothes dryers less frequently. Households with an older stove, on the other hand, allocate more time to using a microwave. The latter association is significant only at a ten percent level.

In addition to results that are of interest in terms of assessing the presence of a time rebound effect, there are several other interesting findings. The price of electricity, for instance, is positively associated with the frequency of TSA use. This result may be a bit surprising as the TSAs we consider tend to use electricity. However, the association may be indicative of the households' substitution away from using electricity intense appliances (such as a stove, an oven, or washing dishes by hand) to using less electricity intense TSAs (such as a microwave or a dish washer) when facing higher electricity prices. As expected, we find that both the household's size and composition matter. The number of household members and the number of household members under the age of 18 are both positively associated with the frequency of TSA use. We also find that households that own their own dwelling use clothes dryers less frequently in an average week during the winter compared to households that do not own their dwelling.

To summarize, the results discussed thus far suggest that the households' adoption of TSA tends to be positively associated with the frequency of TSA use. The positive association tends to be of greater magnitude for high income households compared to low income households in about two thirds of all cases. We also find that the association between the TSA age and frequency of TSA, if significantly different from zero, tends to be negative. These findings are consistent with the presence of a direct time rebound effect: on account of the TSA adoption, households allocate some of the saved time to more frequent use of TSAs.

We next wish to identify the presence and magnitude of the indirect time rebound effect. In particular, we want to infer whether the households' TSA adoption is not only associated with changes to the households' allocation of time to home production but also households' allocation of time to leisure activities.

Table 4 is similar to Table 3 except that rather than reporting results that pertain to determinants of intensity of TSA use, Table 4 reports results that pertain to determinants of the amount of time households allocate to leisure activities involving the use of various sorts of home electronics devices or leisure appliances. Again, several findings are particularly interesting. Perhaps most important is an observation that if the association between the TSA adoption and time allocated to leisure appliance use is statistically different from zero, the association is positive in two thirds of cases (e.g., while eight coefficients are positive, four are negative). We find that the adoption of a microwave is positively associated with the number of hours allocated to DVD player or computer use but only for low income households. For instance, low income households with a microwave have a DVD player turned on (use computer) for 2.8 (13.4) more hours per week compared to households without a microwave. This represents about 67 (70) percent greater allocation of time to DVD player and PC use. Microwave adoption is also positively associated with the number of hours allocated to watching television but only for high income households. High income households with a microwave have their TV sets on for about 8.4 more hours (23 percent) in an average week compared to households without a microwave.

Dishwasher adoption is also found to be positively associated with the amount of time allocated to VCR use and computer use, but only for high income households. For instance, high income households with a dishwasher allocate about 2.5 (10.0) more hours compared to households without a dishwasher to using a VCR (a PC). This represents about 42 (17) percent greater use of a VCR (a PC). A clothes dryer, on the other hand, is positively associated with the number of hours households allocate to watching television for high income households and the number of hours households allocate to DVD player use for low income households. In particular, a low (high) income household with a clothes dryer has a DVD player (TV set) turned on for 3.9 (11.2) more hours per week compared to a household without a clothes dryer. This represents about 95 (30) percent greater allocation of time to DVD player and PC use.

TSA age does not appear to matter in terms of predicting the amount of time the households in our sample allocate to using leisure appliances except in two cases. We find that the older the dishwasher or clothes dryer, the less time is allocated to using a personal computer or a DVD player, respectively. While time allocated to television and computer use is positively associated with household size, household size is negatively associated with time allocated to stereo system use. The number of household members under 18 years of age is positively associated with time allocated to DVD player and VCR use. Households that own their own dwelling appear to allocate less of their time to watching television. Dwelling ownership, however, does not appear to affect the amount of time households allocate to using other leisure appliances.

5.3 Household TSA adoption and residential energy consumption

The results discussed thus far suggest that a household’s adoption of TSAs tends to be associated with an increase in the frequency of TSA use and with an increase in time allocated to using in-home leisure appliances. Hence, we would expect that TSA adoption will also result in greater residential energy consumption as both the TSA and leisure appliances we consider tend to require electricity. However, to the extent that TSA adoption also significantly alters household time allocation on other margins (e.g., time households allocate to work or time households spend outside their homes), TSA adoption may actually end up reducing total residential energy consumption. In this section, we wish to identify the sign and the magnitude of the association between the TSA adoption and residential energy use. In Table 5 we report results that pertain to determinants of households’ intensity of residential energy consumption; i.e., household’s consumption of electricity and natural gas per sq ft of the household’s heated dwelling area.

The results in Table 5 are quite interesting. We find that of the TSAs we consider only two are significantly associated with the household’s energy consumption. In particular, the adoption of a microwave by high income households or the adoption of a washing machine by low income households is negatively associated with electricity consumption. None of the TSAs have a significant impact on residential natural gas consumption. Furthermore, we find that the price of the natural gas has a negative effect on the households' natural gas consumption. The price of electricity does not appear to affect household electricity consumption.

The results also suggest that an increase in the number of household members is associated with greater electricity and natural gas consumption. An increase in the number of household members less than 18 years of age has a negative effect on the household's electricity consumption but no effect on the residential natural gas consumption. These latter results are consistent with findings reported in Biesiot and Noorman (1999) as they pertain to the association between household size and energy consumption in the Netherlands. While Munley *et al* (1990) find that dwelling ownership impacts energy consumption our findings suggest otherwise. In our sample dwelling ownership does not appear to have any effect on residential electricity or natural gas consumption.

In addition to results reported in Table 5, we also considered several alternative specifications (available from the authors on request). We obtain similar results when we consider energy consumption rather than energy consumption per sq ft of heated dwelling area. When we do not interact TSA adoption with household income, we find that only one TSA we consider is associated with energy consumption. The one exception is the adoption of a washing machine, which is negatively associated with natural gas consumption.

5.4 Discussion of results[4]

Household preferences versus time rebound effect: One concern might be that the relation between the TSA adoption and the frequency of TSA use measures differences in the household's lifestyle or preferences rather than a time rebound effect. For instance, households with many TSAs may have adopted TSAs because they plan to engage more in household production and hence use more frequently all appliances of which some are TSAs. These households stand to save more time from adopting TSAs and hence face greater gains from TSA adoption. To some extent, we control for such differences across households by including an

[4] In this section we discuss results that are not reported in the paper to preserve space. These results are available upon request from the authors.

indicator variable for whether there is someone at home all day and a variable that measures the number of weeks no one is in a dwelling. Consistent with our concern, we find that households where someone is always at home tend to use microwaves and dishwashers more frequently. However, no differences in the use of a washing machine or clothes dryer exist between households that have someone at home all day and households that do not have someone at home all day.

To explore further the relevance of this alternative explanation, we use the fact that in SHEU – 2003 we observe how frequently households use one other appliance that is not a TSA: a stove. If households who adopt TSAs are more likely to allocate more time to household production, than we would expect that TSA adoption is not only positively associated with a frequency of TSA use but also with time allocated to using other home appliances such as stoves. When we regress the frequency of stove use on dummy variables that identify household's adoption of various TSAs we do not tend to find any positive associations. One exception is the adoption of a washing machine. Microwave adoption is negatively associated with the frequency of stove use, while a self-cleaning stove feature and a dishwasher are not associated with the frequency of stove use.

Definition of household income: Rather than using household income we constructed a new variable that measures household income per household member over 18 years of age. The results are slightly different from the pattern that would be consistent with our thesis suggested by the time rebound effect. In the latter specification, we do find that the households' adoption of a stove with a self-cleaning feature is associated with an increase in the households' electricity (natural gas) consumption but only for low (high) income households. We also find that microwave adoption is positively associated with natural gas consumption, but only for low income households.

Econometric model: Note that all our dependent variables in Tables 3 and 4 are count variables that take strictly positive values. To account for this feature of our variables we estimate a Poisson model in place of the Ordinary Least Squares model. Results that pertain to the association between TSA adoption and intensity of TSA use remain the same. However, we observe a less convincing pattern of larger impacts for high income households. Results that pertain to TSA age and intensity of TSA use are also found to be consistent with those reported in the paper.

6. Concluding remarks

By the time of the SHEU-2003 survey, we can observe that many time-saving appliance (TSA) have been adopted by Canadian households. In this paper, our interest lies in assessing the implications of this on household allocation of time and residential energy consumption. Drawing on several insights provided in the SHEU – 2003, we find that household TSA adoption tends to be associated with a more frequent TSA use, an association we refer to as a direct time rebound effect. In addition, we find that households not only appear to adjust their allocation of time to home production due to TSA adoption but also adjust their allocation of time to leisure activities. We find some evidence indicating that TSA adoption is also associated with an increase in the amount of time households allocate to using leisure appliances. While we find that TSA adoption does appear to change how households allocate their time and, in particular, change time allocation in favor of using appliances that entail energy, we do not find that TSA adoption results in an increase in residential energy consumption.

Importantly, in our analysis we do not capture substitution for activities taking place outside of the home. For instance, the households may allocate time saved from a TSA adoption to work related activities, leisure activities that take place outside the home, or to household chores beyond those reported in the SHEU – 2003. Hence our analysis likely underestimates the magnitude of the time rebound effect that arises from the households' TSA adoption. Moreover, that the TSA adoption may have a considerable effect on the households' allocation of time along the margins we do not observe, could help explain why we do not find strong association between the TSA adoption and the households' residential energy consumption.

References

Bauwens, L, D Fiebig, and M Steel (1994), Estimating End-Use Demand: A Bayesian Approach, *Journal of Business and Economic Statistics*, 12, 221-231.

Becker, G S (1965), A Theory of the Allocation of Time, *The Economic Journal*, 75, 493-517.

Biesiot, W and K J Noorman (1999), Energy Requirements of Household Consumption: A Case Study of the Netherlands, *Ecological Economics*, 28, 367-383.

Binswanger, M (2002), Time-Saving Innovations and Their Impact on Energy Use: Some Lessons from a Household Production-Function Approach, 'Series A' Working Paper, Solothurn University of Applied Science Northwestern Science.

Branch, E R (1993), Short Run Income Elasticity of Demand for Residential Electricity Using Consumer Expenditure Survey Data, *Energy Journal*, 14, 111-121.

Brown, AB, M D Levine, W Short, and JG Koomey (2001), Scenarios for a Clean Energy Future, *Energy Policy* 29, 1179-1196.

Geller, H, S Nadel, R N Elliot, M Thomas, and J DeCicco (1998), Approaching the Kyoto Targets: Five Key Strategies for the United States. Washington, D.C.: American Council for an Energy-Efficient Economy.

Interlaboratory Working Group (2000), Scenarios for a Clean Energy Future (Oak Ridge, TN; Oak Ridge National Laboratory and Berkely, CA; Lawrence Berkely National Laboratory), ORLN/CON-476 and LBNL-44029.

Jalas, M (2002), A Time Use Perspective on the Materials Intensity of Consumption, *Ecological Economics*, 41, 109-123.

Kellert, C (2006), Time-Saving Devices and Their Impact on Electricity Use in the Home, unpublished MA research project, Department of Economics, University of Alberta.

Khazzoom, J D (1986), An Econometric Model Integrating Conservation Measures in the Residential Demand for Electricity, JAI Press: Greenwich, Connecticut.

Koomey, J G, S A Mahler, C A Webber, and J E McMahon (1999), Projected Regional Impacts of Appliance Efficiency Standards for the US Residential Sector. *Energy Policy* 24, 69-84.

Koomey, J G, C A Webber, C S Atkinson, and A Nicholls (2001), Addressing Energy-Related Challenges for the US Buildings Sector: Results from the Clean Energy Futures Dtudy. *Energy Policy* 29, 1209-1221.

Larsen, B M and R Nesbakken (2004), Household Electricity End-Use Consumption: Results from Econometric and Engineering Models, *Energy Economics*, 26, 179-200.

Meyers, S, J E McMahon, M McNeil, and X Liu (2003), Impacts of US federal energy efficiency standards for residential appliances. *Energy – The International Journal*, 28, 755-767.

Meyers, S, J E McMahon, and M McNeil (2005), Realized and Prospective Impacts of U.S. Energy Efficiency Standards for Residential Appliances: 2004 Update. Lawrence Berkely National Laboratory Report LBNL-56417, Berkely, CA.

Munley, V G, L W Taylor, and J P Formby (1990), Electricity Demand in Multi-family, Renter-Occupied Residences, *Southern Economic Journal*, 57, 178-194

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

Parti, M and C Parti (1980), The Total and Appliance-Specific Conditional Demand for Electricity in the Household Sector, *Bell Journal of Economics*, 11, 309-321.

Schipper, L, S Bartlett, D Hawk and E Vine (1989), Linking Life-Styles and Energy Use: A Matter of Time?, *Annual Review of Energy*, 14, 273-320.

Sorrell, S (2007), The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Savings from Improved Energy Efficiency, Report for the Technology Policy Assessment function of the UK Energy Research Centre, Sussex Energy Group, University of Sussex, Brighton.

Sorrell, S. and Dimitropoulos (2008), The Rebound Effect: Microeconomic Definitions, Limitations and Extensions, *Ecological Economics,* forthcoming.

Weber, C and A Perrels (2000), Modelling Lifestyle Effects on Energy Demand and Related Emissions, *Energy Policy*, 28, 549-566.

Table 1: Summary Statistics

Variable name	SHEU - 2003 Sample size (1)	Sample mean (2)
Frequency of TSA use		
microwave use (in minutes per average in a week)	4308	50.719
loads of dishes (average in a week)	2530	3.805
loads of laundry washed (average in a week during summer)	4128	5.493
loads of laundry washed (average in a week during winter)	4125	5.515
loads of laundry dried (average in a week during summer)	3916	5.180
loads of laundry dried (average in a week during winter)	3917	3.624
Time spent on leisure appliance use		
hours TV on (average in a week)	4497	36.804
hours VCR on (average in a week)	3794	3.484
hours DVD player on (average in a week)	2362	4.322
hours stereo in use (average in a week)	4551	0.836
hours personal computer on (average in a week)	3009	58.399
hours personal computer in use (average in a week)	2947	19.911
TSA adoption		
1 if use microwave and 0 otherwise	4551	0.948
1 if use dishwasher and 0 if not	4551	0.557
age of a dishwasher (in years)	2355	8.383
1 if washing machine used and 0 if not	4550	0.908
age of the washing machine (in years)	3887	8.897
1 if use clothes dryer and 0 if not	4551	0.861
age of clothes dryer (in years)	3702	9.835
1 if stove self-cleaning	4513	0.403
age of stove (in years)	3981	10.693
Household characteristics		
household size	4551	2.648
household members age under 18	4551	0.629
1 if household income is less than $40000	3464	0.419
1 if household owns dwelling	4550	0.787
Prices		
electricity price	4551	0.079
average natural gas price	4545	6.843
Energy consumption		
electricity (gj) heating and cooling per squared feet of dwelling heating area	4550	0.032
natural gas (gj) total both cycles per squared feet of dwelling heating area	2280	0.064

Note: All available (non-missing) observations for a given variable are used.

Table 2: Energy use/time allocation by TSA adoption and use

Sample restricted by:	Average electricity use per sq. feet of dwelling heating area (in gj) (1)	Average natural gas use per sq. feet of dwelling heating area (in gj) (2)	Average frequency of TSA use per week (in number of loads) (3)	Average intensity of LA use (in hours) (4)
Intensity of TSA adoption				
bottom 5th percentile of all households	0.039	0.095	0.000	157.000
bottom 25th percentile of all households	0.036	0.077	18.928	138.024
bottom 50th percentile of all households	0.034	0.068	24.711	133.743
top 25th percentile of all households	0.027	0.056	25.320	132.648
top 5th percentile of all households	0.027	0.056	25.320	132.648
Intensity of TSA use				
bottom 5th percentile of all households	0.028	0.058		
bottom 25th percentile of all households	0.029	0.058		
bottom 50th percentile of all households	0.029	0.060		
top 25th percentile of all households	0.030	0.054		
top 5th percentile of all households	0.030	0.048		
Intensity of LA use				
bottom 5th percentile of all households	0.031	0.062		
bottom 25th percentile of all households	0.029	0.062		
bottom 50th percentile of all households	0.029	0.059		
top 25th percentile of all households	0.030	0.056		
top 5th percentile of all households	0.033	0.059		

Notes: Intensity of TSA adoption is defined as the number of TSAs a household uses in an average week. Intensity of TSA use is defined as the frequency of TSA use in an average week (in number of loads) where use of a microwave is excluded. Intensity of Leisure Appliance (LA) use is defined as the number of hours spent in an average week using leisure appliances (TV, VCR, DVD player, stereo system, personal computer).

Table 3: Household TSA adoption and frequency of TSA use

	TSA ownership and frequency of TSA use OLS					
	microwave in use (minutes) per week	number of dishwasher loads per week	winter - loads of laundry per week	summer - loads of laundry per week	winter - loads dried per week	summer - loads dried per week
	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Explanatory variables:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
1 if microwave used by <40k income household		0.660	0.842	0.976	0.700	0.182
		(0.446)	(0.304)***	(0.308)***	(0.401)*	(0.339)
1 if microwave used by >40k income household		0.315	0.921	0.920	0.939	0.604
		(0.484)	(0.437)**	(0.486)*	(0.432)**	(0.347)*
1 if dishwasher used by <40k income household	-2.964		0.583	0.667	0.497	0.556
	(3.696)		(0.290)**	(0.296)**	(0.299)*	(0.250)**
1 if dishwasher used by >40k income household	0.311		0.864	0.602	0.681	0.461
	(3.013)		(0.265)***	(0.264)**	(0.275)**	(0.244)*
1 if washing machine used by <40k income household	-7.030	-0.887			3.654	2.810
	(7.319)	(0.821)			(1.851)**	(1.184)**
1 if washing machine used by >40k income household	-12.461	-1.218			4.633	3.290
	(10.297)	(0.652)*			(0.546)***	(0.509)***
1 if clothes dryer used by <40k income household	3.605	0.385	1.689	1.096		
	(5.666)	(0.627)	(0.360)***	(0.390)***		
1 if clothes dryer used by >40k income household	11.046	1.182	1.415	1.124		
	(6.243)*	(0.420)***	(0.597)**	(0.517)**		
1 if self-cleaning stove used by <40k income household	2.584	0.460	0.040	0.176	0.127	0.276
	(3.320)	(0.210)**	(0.254)	(0.258)	(0.255)	(0.236)
1 if self-cleaning stove used by >40k income household	4.109	0.186	-0.285	-0.243	-0.199	0.157
	(2.376)*	(0.140)	(0.199)	(0.192)	(0.198)	(0.179)

age - dishwasher (years)	0.111	-0.067	-0.035	-0.034	-0.028	-0.018
	(0.190)	(0.008)***	(0.014)**	(0.014)**	(0.015)*	(0.013)
age - washing machine (years)	0.024	0.003	0.002	-0.016	0.000	-0.001
	(0.179)	(0.010)	(0.013)	(0.013)	(0.013)	(0.012)
age - clothes dryer (years)	0.129	-0.016	-0.039	-0.016	-0.056	-0.041
	(0.174)	(0.009)*	(0.011)***	(0.012)	(0.012)***	(0.012)***
age of stove (years)	0.216	0.012	0.001	-0.001	-0.002	0.003
	(0.123)*	(0.008)	(0.009)	(0.009)	(0.010)	(0.008)
1 if household income is less than $40000	4.167	-0.238	-0.397	-0.409	0.897	0.302
	(8.599)	(0.856)	(0.763)	(0.754)	(1.910)	(1.296)
electricity price	448.571	0.259	30.543	24.821	29.561	25.014
	(176.058)**	(11.793)	(13.767)**	(13.012)*	(14.302)**	(13.428)*
household size	3.107	0.635	1.146	1.089	1.096	0.646
	(1.124)***	(0.079)***	(0.109)***	(0.105)***	(0.112)***	(0.100)***
household member age under 18	3.290	0.261	0.651	0.491	0.584	0.252
	(1.511)**	(0.102)**	(0.149)***	(0.147)***	(0.152)***	(0.135)*
1 if dwelling owned by a household member and 0 if not	-0.235	-0.109	-0.487	-0.348	-0.750	-0.307
	(4.778)	(0.303)	(0.349)	(0.356)	(0.356)**	(0.293)
Constant	-9.492	2.302	-2.841	-1.532	-5.704	-3.072
	(19.160)	(1.353)*	(1.510)*	(1.451)	(1.735)***	(1.583)*
Mean of dependent variable	49.856	3.764	5.557	5.541	5.216	3.608
Observations	2761	1690	2692	2690	2563	2564
R-squared	0.05	0.27	0.29	0.26	0.27	0.20

Notes: Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%. Control variables not reported in the table: dummy variables for year dwelling built, dummy variables for type of dwelling, dummy variables for province, dummy variable for whether some one always at home, number of weeks no one at home, dummy variable if urban dwelling, number of improvement undertaken in 2003 or planned in 2004, number of energy star appliances in the household, dummy variables for whether a time saving appliance already in a dwelling when household moved in, dummy variables for capacity of a clothes dryer and a washing machine.

Table 4: Household TSA adoption and time spent on leisure appliance use

	TSA ownership and intensity of leisure appliances' use OLS					
	television - hours turned on per week	vcr - hours turned on per week	dvd player - hours turned on per week	stereo system - hours used per week	computer - hours turned on per week	computer - hours used per week
	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Explanatory variables:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
1 if microwave used by <40k income household	3.240	2.133	2.781	-2.085	25.283	13.413
	(4.576)	(1.314)	(1.228)**	(4.277)	(15.097)*	(2.648)***
1 if microwave used by >40k income household	8.393	-2.240	0.948	0.998	-0.492	0.762
	(2.709)***	(5.215)	(0.658)	(4.418)	(12.348)	(3.056)
1 if dishwasher used by <40k income household	-5.700	-2.381	-3.067	-0.531	10.356	-1.834
	(2.629)**	(1.428)*	(1.932)	(2.153)	(6.974)	(2.855)
1 if dishwasher used by >40k income household	-2.454	2.549	-0.211	-0.381	10.026	1.690
	(1.907)	(1.030)**	(0.577)	(1.994)	(4.810)**	(1.741)
1 if washing machine used by <40k income household	-1.169	-6.888	-3.520	6.334	-7.398	0.816
	(4.475)	(4.641)	(1.532)**	(4.430)	(13.433)	(5.790)
1 if washing machine used by >40k income household	-8.636	2.686	-0.308	6.039	-15.379	1.628
	(6.882)	(2.439)	(2.075)	(5.796)	(17.944)	(7.406)
1 if clothes dryer used by <40k income household	4.989	4.505	3.944	0.007	5.789	-1.553
	(3.911)	(2.801)	(1.508)***	(4.183)	(10.238)	(5.053)
1 if clothes dryer used by >40k income household	11.179	-0.083	0.560	1.184	17.462	-3.814
	(3.810)***	(1.999)	(0.821)	(4.851)	(10.739)	(5.777)
1 if self-cleaning stove used by <40k income household	4.025	1.362	2.456	-0.927	2.961	2.423
	(2.661)	(1.625)	(2.366)	(2.220)	(6.448)	(2.784)
1 if self-cleaning stove used by >40k income household	-3.049	0.456	-0.466	-0.914	-3.009	-0.131
	(1.314)**	(0.970)	(0.548)	(1.404)	(3.629)	(1.172)

age - dishwasher (years)	0.101	-0.032	0.002	0.034	-0.345	-0.232
	(0.118)	(0.076)	(0.038)	(0.118)	(0.324)	(0.088)***
age - washing machine (years)	-0.131	0.056	0.006	0.102	-0.448	-0.003
	(0.118)	(0.112)	(0.034)	(0.099)	(0.313)	(0.103)
age - clothes dryer (years)	0.085	-0.001	-0.081	-0.031	0.167	0.025
	(0.111)	(0.107)	(0.028)***	(0.091)	(0.299)	(0.105)
age of stove (years)	-0.061	0.079	0.026	-0.020	-0.109	0.103
	(0.077)	(0.061)	(0.029)	(0.085)	(0.206)	(0.078)
1 if household income less than $40000	9.130	2.174	-0.972	0.934	-25.496	-12.562
	(6.387)	(5.352)	(2.288)	(6.683)	(24.550)	(6.059)**
electricity price	51.482	-39.378	24.241	175.218	433.654	4.282
	(99.152)	(52.055)	(31.434)	(126.200)	(271.580)	(80.791)
household size	3.956	-0.094	-0.325	-1.958	5.126	2.809
	(0.688)***	(0.343)	(0.336)	(0.730)***	(1.812)***	(0.610)***
household member age under 18	-1.069	0.784	0.988	1.132	-1.095	-0.581
	(0.993)	(0.442)*	(0.465)**	(0.864)	(2.223)	(0.830)
1 if dwelling owned by a household member and 0 if not	-9.055	2.222	-0.158	0.542	-7.535	0.163
	(4.453)**	(1.485)	(0.795)	(2.557)	(7.914)	(2.545)
Constant	10.325	5.392	1.161	3.159	2.113	7.963
	(11.295)	(7.141)	(4.208)	(13.304)	(31.611)	(10.017)
Mean of dependent variable	36.889	6.052	4.158	15.029	57.949	19.086
Observations	2857	2438	1590	2515	1981	1937
R-squared	0.10	0.02	0.04	0.02	0.06	0.06

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%. Control variables not reported in the table: dummy variables for year dwelling built, dummy variables for type of dwelling, dummy variables for province, dummy variable for whether some one always at home, number of weeks no one at home, dummy variable if urban dwelling, number of improvement undertaken in 2003 or planned in 2004, number of energy star appliances in the household, dummy variables for whether a time saving appliance already in a dwelling when household moved in, dummy variables for capacity of a clothes dryer and a washing machine.

Table 5: Household TSA adoption and residential energy consumption

	Energy consumption per squared feet of dwelling heating area and TSA use	
	OLS	
	Log electricity use (in gj)	Log natural gas use (in gj)
	Coefficient (S.E.)	Coefficient (S.E.)
Explanatory variables:	**(1)**	**(2)**
1 if microwave used by <40k income household	-0.008	0.098
	(0.092)	(0.089)
1 if microwave used by >40k income household	-0.179	0.037
	(0.081)**	(0.088)
1 if dishwasher used by <40k income household	0.049	-0.012
	(0.056)	(0.052)
1 if dishwasher used by >40k income household	-0.029	0.041
	(0.042)	(0.042)
1 if washing machine used by <40k income household	-0.316	-0.185
	(0.170)*	(0.163)
1 if washing machine used by >40k income household	0.249	-0.199
	(0.294)	(0.157)
1 if clothes dryer used by <40k income household	0.093	-0.101
	(0.080)	(0.087)
1 if clothes dryer used by >40k income household	0.030	0.030
	(0.099)	(0.097)
1 if self-cleaning stove used by <40k income household	-0.014	0.061
	(0.051)	(0.045)
1 if self-cleaning stove used by >40k income household	-0.010	0.028
	(0.032)	(0.028)
age - dishwasher (years)	-0.000	0.001
	(0.003)	(0.002)
age - washing machine (years)	-0.002	-0.004
	(0.002)	(0.002)*
age - clothes dryer (years)	-0.002	0.001
	(0.002)	(0.002)
age of stove (years)	-0.001	0.004
	(0.002)	(0.002)**
1 if household income less than $40000	0.272	0.100
	(0.307)	(0.194)

electricity price	-1.408	
	(2.362)	
natural gas price		-0.090
		(0.009)***
household size	0.082	0.039
	(0.018)***	(0.014)***
household member age under 18	-0.035	-0.023
	(0.021)*	(0.018)
1 if dwelling owned by a household member and 0 if not	-0.112	-0.124
	(0.070)	(0.080)
Constant	-4.521	-1.392
	(0.383)***	(0.243)***
Mean of dependent variable	0.029	0.059
Observations	2107	1121
R-squared	0.58	0.49

Notes: Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%. Control variables not reported in the table: see notes to Table 4 and pages 14 and 15.

CBEEDAC
Department of Economics

University of Alberta

8-14 Tory Building

Edmonton, Alberta

Canada

T6G 2H4