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Time-Saving Innovations, Time Allocation, and Energy Use: Evidence from Canadian Households

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Abstract

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 is expected to have a two-fold impact on energy use in the residential sector. Firstly, increased use of time-saving technologies for basic household chores (cooking, cleaning) can 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 chores or leisure activities (watching TV, reading, exercising) which may or may not be energy-intensive. In this paper, we use Canadian Survey of Household Energy Use data from 2003 to estimate the extent to which ownership of products that embody time-saving innovations impacts time allocation and energy use at the household level.

Key words: time rebound effects, residential energy use, household production

SECTION 1: Introduction

Recent decades have seen the introduction and wide adoption 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, such as dishwashers, offer substantial time savings to households who opt for these technologies over more labour-intensive methods of performing the same task. 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 provide energy-intensive options for leisure activities.

The relationship between household energy use and technological change is complex. In this paper, we focus on the relationship between time-saving technologies and household energy use. There are two basic channels through which energy use may be affected when households adopt time-saving technologies. Firstly, many of these technologies are more energy-intensive than their alternatives. Using an electric or gas clothes dryer, for example, uses more energy than hanging clothes to dry. Secondly, time-saving 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 (referred to subsequently as direct time rebound effects) and/or an increase in time spent in energy-using leisure activities such as watching TV or playing computer games (indirect time rebound effects). To the extent that time is reallocated to energy-intensive activities in the home, residential energy use will increase as households adopt time-saving appliances.

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 that embody time-saving innovations as well as other electronic equipment such as TVs, VCRs, DVD players and computers used to engage in leisure activities. This allows us to look at the impact of time-saving technologies on (i) the allocation of time to household production and home-based leisure activities (i.e., time rebound effects); and (ii) household energy use.

This paper contributes to the literatures on rebound effects related to technological innovations and on household time use. Rebound effects have been considered primarily in terms of energy inputs, where the focus has been on the extent to which energy-saving technological innovations affect energy use. In our analysis, following the general approaches found in Binswanger (2002), Jalas (2002) and Sorrell and Dimitropoulos (2008), we extend the scope of the empirical rebound effect literature by examining how a household's ownership of appliances that embody time-saving innovations affects time use and subsequently energy use. The findings in this paper also contribute to the literature on household time use in two respects. Firstly, this literature has attributed, in part, the observed drop in the amount of time households allocate to household chores over the last few decades to technological improvements in the production of household chores (Aguiar and Hurst, 2007; Hamermesh, 2007). Evidence in this paper is consistent with the notion that the adoption of household appliances embodying time-saving innovations changes household allocation of time to both leisure and home production activities. Secondly, evidence in Gronau and Hamermesh (2008, pp. 567) suggests that households allocate extra time they save when substituting towards goods-intensive activities to an increase in the variety of activities these households engage in. Our findings suggest that households allocate part of the extra time made available when adopting time-saving household appliances to an increase in the frequency of many household activities.

The plan of the paper is as follows. In Section 2, we provide a framework for our empirical analysis and discuss the empirical literature related to household time use, energy use and technological innovations. Section 3 provides a brief overview of our data sources. Our empirical examination of time rebound effects is presented in Section 4. The results related to determinants of residential energy use are provided in Section 5. Section 6 concludes.

SECTION 2: Time-saving innovations and household behaviour

With the current state of technology, households often have several options regarding how to perform basic household chores. Dishes can be washed by hand, or they can be washed in a dishwasher. 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 chore and the amount of 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 embodied in conventional ovens, stove tops, or slow cookers. 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 is reallocated. Some of the time saved may be used to increase the number of hot meals prepared at home. Some may be used to increase the production of other household services such as dish-washing and laundry. And some may be used for leisure activities within or outside of the home. 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 before and after new technologies are adopted (Khazzoom, 1986; Sorrell, 2007; Sorrell and Dimitropoulos, 2008).[1]

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 and Sorrell and Dimitropoulos set up formal household production function models wherein 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 produced and consumed within the household requires time, purchased energy, and other purchased inputs. Sorrell and Dimitripoulos explicitly add capital (appliance) stocks and their attributes into a household's production functions such that:

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

where S_i denotes 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.

[1] Energy-efficiency gains in household appliances such as clothes washers, clothes dryers, dishwashers, refrigerators, and freezers are incorporated into the residential sector component of many multi-sector energy demand models. Some such examples are studies by Brown et al. (2001), Geller et al. (1998), Interlaboratory Working Group (2000), Koomey et al. (1999), Koomey et al. (2001), Meyers et al. (2003), and Meyers et al. (2005). More recently, Davis (2008) exploits a field trial in which trial participants received high energy-efficient clothes washers as a replacement for their old clothes washers. Using data on the participants' use of clothes washers prior and after the replacement, the author examines the extent to which the gains from increased energy efficiency of clothes washers were offset by increased utilization of the washers.

The set of attributes, A_i, embodied in the capital may include, among other things, the ease of use of a particular model. In many cases, the set of attributes embodied in a piece of household capital equipment (such as a 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 these models, households maximize utility, which is assumed to depend solely on the bundle of household services consumed, where the utility function is given by:

$$U = U\left(S_1, S_2, ..., S_n\right) \text{ where } U' > 0, U'' < 0 \tag{2}$$

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

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

where V denotes 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 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 $\delta_k \sum_{i=1}^{n} k_i\left(A_i\right)$ represents annualized capital costs.

In this 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 and relative to the time costs associated with other services. This will result in a new bundle of utility-maximizing services, selected according to the new cost conditions, that will result in a new set of input demands (for time and energy).

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

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 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, household members may decide to watch more TV (S_j). Or they may opt to use some of the extra time made 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 services. The extent to which time is reallocated and energy purchases change is 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. 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. Jalas 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 uses Finnish time-use survey data from 1987-88 combined with 1990 household expenditure survey data for two-person households and 1990 input-output tables. The 1990 data are used to calculate the direct energy requirements for household activities and the indirect energy requirements embodied in the production and distribution of purchased consumption goods. 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 any time saved is reallocated to activities with 'average' energy requirements. Jalas predicts that 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, 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) 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. The authors 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.

There are also studies such as Gronau and Hamermesh (2008) and Hamermesh (2007) that look at time-use data. These studies document, among other things, changes in the allocation of time to and time intensity of home production activities over the last few decades. But in the absence of information on appliance use for the individuals in their samples, these studies must leave to conjecture the extent to which time-saving appliances, referred to in this literature as labour-saving or time-saving technical progress, underlie time allocation decisions for household chores (Hamermesh, 2007, pp. 861; Burda et al., 2008, pp. 55).

In this paper, 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 appliance ownership on the allocation of time to household production and leisure activities. Then we consider the impact of time-saving appliance ownership on energy use. Before proceeding to our empirical models, we briefly describe our data sources.

SECTION 3: Data description

The choice of technology at the household level may have a significant effect on overall energy use. Note that, in Canada, the residential sector used about 11.8 percent of total energy in 2003, accounting for 28.4 percent of total electricity consumption and 26.5 percent of total natural gas consumption.[3] Of total residential energy use, 14 percent was allocated to the use of household appliances. The energy used for appliances was primarily (97.3 percent) electricity. Of the total residential energy used for household appliances, 1.6, 1.4, 18.3, and 18.4 percent were attributed to the use of a dishwasher, a clothes washer, a clothes dryer, and a stove range, respectively. An even larger portion, 29.8 percent, of the energy used by household appliances was attributed to microwaves, TVs, cable boxes, VCRs, stereo systems, and computers.

In order to investigate residential energy use at a micro-economic level, we draw on two data sources. First, we use data from the Survey of Household Energy Use (SHEU - 2003). The survey, conducted by Statistics Canada in 2004, asked Canadian households several questions about the characteristics of their dwellings and about activities the households undertook at home. Households were asked direct questions pertaining to their use and ownership of several appliances that embody time-saving innovations: microwave ovens, self-cleaning features for ovens, dishwashers, washing machines, and clothes dryers. Furthermore, households were asked how frequently they use these appliances in an average week (for details, refer to Office of Energy Efficiency, 2006).

Although the SHEU - 2003 survey does not provide information on a household's allocation of time to activities outside of the home, it does provide information on a household's allocation of time to leisure activities that entail the use of home leisure appliances. For instance, we observe the number of hours a household spent in an average week using TVs, VCRs, DVD players, stereos, and PCs.

We use this information to examine the relation between a household's adoption of appliances that embody time-saving innovations and a household's allocation of time along two dimensions: (i) the

[3] Source: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_tables.cfm (Office of Energy Efficiency, Natural Resources Canada). Consumption of electricity and natural gas represented about 83.3 percent of the total residential energy use in 2003. In the sample of households surveyed in SHEU-2003 that we use in our analysis, an average household used about 49.2 GJ of electricity and 112.9 GJ of natural gas.

amount of time allocated to household production (direct time rebound effect); and (ii) the amount of time allocated to using home leisure appliances (indirect time rebound effect).

In addition, Statistics Canada also obtained data on household energy use directly from the households' suppliers of electricity, natural gas, heating oil, and propane. We use this information to assess the impact of households' adoption of time-saving innovations on energy use. The SHEU-2003 data are supplemented with energy price data for electricity and natural gas corresponding to each household's place of residence that we obtained from the Canadian Building Energy End-Use Data and Analysis Centre (CBEEDAC).[4] The prices correspond to average prices of the relevant local providers and pertain to the 2003 calendar year. For a complete list of variables used in our study, please refer to the notes in Tables 2 through 4.[5] Summary statistics for key variables are reported in Table 1.

<Insert Table 1>

SECTION 4: Evidence on time rebound effects

Following Sorrell (2007), we define a direct time rebound effect as an increase in the frequency of (or the amount of time allocated to completing) household chores undertaken by a household resulting from a household's adoption of household appliances that incorporate time-saving innovations, which we refer to as time-saving appliances (TSA). This can be expressed in terms of an equation as:

$$\textit{frequency of } TSA_i \textit{ use} = \alpha_0 + \sum_{j \neq i} \alpha_j \textit{use of } TSA_j + a' X + u \,, \tag{4}$$

where X is a vector of control variables (see notes to Table 2 for a complete list of control variables). A positive sign on α_j suggests that a household's ownership of TSA_j (e.g., a dishwasher) is positively associated with the amount of time a household allocates to the use of TSA_i (e.g., a microwave oven),

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4 http://www.ualberta.ca/~cbeedac/

5 The SHEU - 2003'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.

which is consistent with a notion that a household allocates some of the extra time released upon TSA adoption to increasing the frequency of TSA use.

A 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 indirect time rebound effects. Our estimation of in-home indirect time rebound effects is based on the following equation:

$$time\ allocated\ to\ leisure\ appliance\ use_i = \beta_0 + \sum_{j \neq i} \beta_j use\ of\ TSA_j + b'X + u\ , \qquad (5)$$

where X denotes a vector of control variables (see notes to Table 3). A β_j different from zero is consistent with the notion that adoption of a time-saving appliance affects time allocation. The presence of time rebound effects suggests that the adoption of a time-saving appliance is positively associated with the amount of time allocated to using leisure appliances in the home.

Importantly, two additional predictions follow. First, we expect time rebound effects to be of a smaller magnitude when households use older models of time-saving appliances. For instance, a more recent model of a time-saving appliance is likely to be more time efficient either because it can perform a household chore more quickly or because it can perform a greater variety of chores than older models. Second, time rebound effects may be of a larger magnitude among high income households as they are likely to be further away from satiation in their use of time allocated to home production or leisure activities (Sorrell, 2007; Sorrell and Dimitropoulus, 2008). On the other hand, since high income households likely face higher time costs (wage rate) they may choose to allocate a greater portion of the time made available by the adoption of a time-saving appliance to activities outside the home (work). Because of these differences across high and low income households we allow for the association between the adoption of a time-saving appliance and household time use to differ across low and high income households.

Direct time rebound effects

In Table 2 we report the results from Ordinary Least Squares regressions that pertain to determinants of the households' frequency of TSA use. The categories of TSA adoption considered for the *use of* TSA_j variables are dishwashers, washing machines without an accompanying clothes dryer, washing machines with an accompanying clothes dryer, and self-cleaning ovens. Virtually all households in the sample own a microwave (see Table 1). Therefore, it is not possible to examine the impact of microwave adoption on the allocation of time to household chores using our data set. Despite the high penetration rate of some household appliances, heterogeneity in the intensity of use (amount of time households allocate to using these appliances) is still considerable and thus worth investigating. For instance, while some households rely almost entirely on microwaves to prepare meals, other households make substantial use of stoves. In Table 2, and all the tables that follow, heteroskedasticity-robust standard errors are reported in parentheses.[6]

<Insert Table 2>

Table 2 suggests that there exists a strong and positive association between a household's adoption of time-saving appliances and the frequency of use of appliances. The ownership of a dishwasher is positively associated with the frequency of a household's use of a washing machine and clothes dryer (columns 3 and 4). The adoption of an oven with a self-cleaning feature is positively associated with the amount of time a household allocates to using a microwave as well as to the number of times the dishwasher is loaded in an average week (columns 1 and 2). The only negative association we find is that between washing machine adoption by high income households and the intensity of dishwasher use (column 2). This negative relationship, however, is only significant at a ten percent level.

[6] Alternative specifications that model the discrete nature of our dependent variables in Tables 2 and 3 (i.e., Tobit models for the amount of time allocated to the use of a microwave oven and leisure appliances and Poisson models for the frequency of use of other appliances) provide qualitatively similar results. Instrumental variable regressions were also performed to deal with endogeneity problems, but this avenue was hampered due to the dearth of suitable instruments. These results are available upon request.

The second interesting finding in Table 2 pertains to differences across low income and high income households.[7] In particular, we find that a positive association between appliance adoption and frequency of appliance use exists for both high and low income households. The magnitude of the identified association is also economically important. For instance, when it comes to dishwasher ownership we find that, during 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 (column 3). This represents about 11 (16) percent greater intensity of washing machine use in an average week for households that own a dishwasher compared to those that 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 2.8 more loads per month) compared to households that do not own a dishwasher (column 4). This represents about 10 (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.[8]

If the association between the adoption of a time-saving appliance and the frequency of time-saving appliance use measures time rebound effects, we would also expect that the age of a time-saving appliance matters. A more recent model of a time-saving appliance may be more time efficient either because it can perform a household chore more quickly or because it can perform a greater variety of household chores. Results in Table 2 suggest that households with older dishwashers or clothes dryers tend to use these appliances less frequently during an average week (columns 2 and 4). Evaluated at the sample means (Table 1), the corresponding elasticity in each case is approximately -0.15. For several

[7] We define a low income household as a household with an annual income of less than 40,000 CAD. We also consider low income households as those with an annual income of less than (i) 10,000 CAD; or (ii) 10,000 CAD per household member over 18 years of age. The results we get from these alternative specifications are consistent with those reported in the paper but primarily for high income households.

[8] Unless otherwise noted, results that pertain to the frequency of use of either a clothes washer or a clothes dryer extend to summer months. The results for summer months are available upon request.

appliances there are significant "cross-elasticities" of use with respect to age. Households with an older dishwasher use their washing machines less frequently regardless of the season and use a clothes dryer less frequently during the winter (columns 3 and 4). Households with older clothes dryers tend to use their dishwashers and washing machines (columns 2, 3) less frequently. In all of these cases, the elasticities are small, ranging from -0.04 to -0.07. Households with an older stove, on the other hand, allocate more time to microwave use (column 1). This association is statistically significant from zero only at a ten percent level and the corresponding elasticity is approximately 0.05.

Overall, the results in Table 2 suggest that the households' adoption of time-saving appliances tends to be positively associated with the frequency of time-saving appliances use. The positive association tends to be significant for high income and for low income households. We also find that the association between the time-saving appliance's age and the frequency of time-saving appliance use, if different from zero, tends to be negative. These findings are consistent with the existence of direct time rebound effects.[9] The negative coefficients on the age variables for dishwashers and clothes dryers may also be indicative of standard energy rebound effects. Given that there have been substantial improvements in energy efficiency for these appliances over past decades, these newer appliances are less costly to operate and used more frequently than older models. In contrast to Davis (2008), the coefficients on the age variables do not provide any evidence of standard energy rebound effects for clothes washers in our sample.

The results in Table 2 reveal other interesting findings. The price of electricity, for instance, is positively associated with how frequently all time-saving appliances except dishwashers are used in a household in an average week. This result may be somewhat surprising as the time-saving appliances we consider tend to use electricity. However, the association may be indicative of the household's

[9] We have also considered a specification that treats a PC as a time-saving appliance rather than a leisure appliance. We find that the ownership of a PC is positively associated with the frequency of use of some appliances and negatively associated with the frequency of use of other appliances.

substitution away from using electricity intense appliances (such as a stove, an oven, or washing dishes by hand) to using less electricity intense time-saving appliances (such as a microwave or a dishwasher) when electricity prices are higher. We also find that both household 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 use for all time-saving appliances considered. This finding as it pertains to microwave oven use is consistent with Crossley and Lu (2004) who, using Canadian time use data, find that time intensity in food preparation increases with household size. Finally, households that own their dwelling use clothes dryers less frequently in an average week during winter compared to households that do not own their dwelling.

<u>Indirect time rebound effects</u>

Table 3 reports results pertaining to the determinants of the amount of time households allocate to in-home leisure activities involving the use of various home electronics devices or leisure appliances. Time-saving appliance adoption is associated, at times positively and at times negatively, with the amount of time households allocate to leisure activities in the home. Dishwasher use is positively associated with the amount of time allocated to VCR use, but only for high income households. For instance, high income households with a dishwasher allocate about 2.5 more hours (42 % more time) compared to households without a dishwasher to using a VCR in an average week (column 2). Low income households without a dishwasher have their televisions turned on for about 5.5 more hours (15% more time) per week than similar households who own a dishwasher (column 1). Both low and high income households with washing machines and clothes dryers tend to have their stereo systems on for approximately one more hour per day (about 41 to 46% more time) than those without a clothes dryer and a washing machine (column 4). High income households with clothes dryers and washing machines also tend to have their VCRs on for about a half hour more (53% more time) per day, while those with a self-cleaning oven have their TVs on for about a half hour less (8% less time) per day (columns 2 and 1, respectively).

<Insert Table 3>

The age of a time-saving household appliance 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. Evaluated at the sample means from Table 1, the elasticity of DVD use with respect to the age of a clothes dryer is -0.19 and the elasticity of personal computer use with respect to dishwasher age is -0.10 (columns 3 and 5).

Additional results show that the amount of time allocated to television and PC use (columns 1 and 5) is positively associated with household size, while household size is negatively associated with the amount of time allocated to stereo system use (column 4). We also find that the number of younger members in a household is positively associated with the number of hours a DVD player and a VCR are in use (columns 2 and 3). Home owners also appear to allocate less time to watching TV (column 1). Finally, the price of electricity does not appear to affect the use of leisure appliances.

SECTION 5: Time-saving technologies and residential energy use

The results thus far suggest that a household's adoption of time-saving appliances affects household allocation of time to both home production and in-home leisure activities. Hence, the adoption of time-saving innovations may also result in an increase in the residential energy use as both time-saving appliances and leisure appliances that we consider require purchased energy inputs (electricity or natural gas). However, to the extent that the adoption of time-saving appliances also significantly alters household time allocation on other margins (e.g., time households allocate to work or activities outside their homes), the adoption may actually end up reducing total residential energy use (and possibly increasing energy use outside of the home).[10] To assess the implications of adoption of time-saving appliances for a household's residential energy use we estimate the following relationship:

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

[10] Drawing on time use data for several countries, Burda et al. (2008) find a strong negative association between the amount of time households allocate to household production and the amount of time households devote to market work.

We consider separately the household's use of two types of energy: electricity and natural gas. In our analysis we draw on household-level models of energy demand where residential energy demand is modeled as a function of appliance ownership (considered to be exogenous in 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. X in (6) denotes a vector of control variables for other factors that may affect residential energy use (see notes to Table 4). In our selection of controls we draw on related studies that, where available, include as controls (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 (e.g., Parti and Parti, 1980; Munley et al., 1990; Branch, 1993; Bauwens et al., 1994; Biesiot and Noorman, 1999; Weber and Perrels, 2000; Larsen and Nesbakken, 2004).

In Table 4, we report results that pertain to determinants of household use of electricity and natural gas per square ft of heated dwelling area while controlling for observable household and dwelling characteristics. Only two time-saving appliances are statistically significantly associated with a household's energy use, and these effects only apply to low income households. In particular, the adoption of a washing machine by low income households is negatively related to electricity use (column 1), while in low income households where a dryer is also used, less electricity and natural gas is used (columns 1 and 2).

<Insert Table 4>

Several other results in Table 4 are of interest. The price of natural gas has a negative effect on the households' natural gas use. The price of electricity does not affect electricity use. The results also suggest, consistent with findings for the Netherlands in Biesiot and Noorman (1999), that an increase in the number of household members is associated with greater electricity and natural gas use. In our sample, dwelling ownership does not appear to have any effect on residential energy use. To the extent that households who own their dwellings are more likely to pay their own utility bills, this latter finding differs from Munley et al. (1990). Using a sample of renters in the U.S., the authors find that whether or not households are responsible for making their own utility payments has an impact on residential energy demand.

SECTION 6: Conclusion

The SHEU-2003 survey reveals that many time-saving appliances have been adopted by Canadian households. In this paper, our interest lies in assessing the implications of this observation on household allocation of time and residential energy use. Drawing on data from the SHEU – 2003 survey, we find that a household's adoption of time-saving appliances tends to be associated with a more frequent use of time-saving appliances, an association we refer to as direct time rebound effect. In addition, we find that households not only appear to adjust their allocation of time to home production as they adopt a time-saving appliance but also adjust the amount of time they allocate to using home leisure appliances. While we find that time-saving appliance adoption does appear to change how households allocate their time and, in particular, adjust time allocation in favour of using appliances that require energy inputs, we do not find evidence that would suggest that adoption of a time-saving appliance results in an increase in residential energy use.

These results are interesting on two accounts. First, the results extend the scope of the empirical rebound effect literature by documenting how a household's ownership of appliances that embody time-saving innovations impact time use and subsequently energy use. The related literature has been primarily concerned in assessing the extent to which energy-saving technological innovations affect energy use. Second, the results are also interesting in light of the literature on time use. In the absence of information on appliance use, this literature must leave to conjecture the extent to which time-saving appliances underlie time allocation decisions that pertain to household chores. The results we discuss in this paper support the view of this literature; i.e., we find that a household's adoption of time saving appliance (or labour-saving technical progress) is associated with the pattern of a household's use of time.

Importantly, from a policy perspective, it is of interest to know about the nature of the relationship between the ownership of time-saving technologies and residential energy use even if the relation happens to be weak. It should be noted that our analysis likely understates the magnitude of time rebound effect that arises from the households' adoption of a time-saving appliance and its implication for the energy use on two accounts. First, given that new household appliances such as plasma TVs and digital cable boxes use substantially more power than older models, the results that we have based on households' decisions in 2003 may understate the impacts of household appliances on electricity use in more recent years.

Second, in our analysis we do not capture substitution for activities that are taking place outside of the home. For instance, households may allocate time they save from adopting a time-saving appliance to work-related activities, to leisure activities that take place outside the home, or to household chores beyond those considered here. That time-saving appliance adoption may have a considerable effect on the households' allocation of time along the margins that we do not observe, could help explain why we do not find a strong association between time-saving appliance adoption and household residential energy use. Given the findings of Schipper et al (1989) and Jalas (2002) that many activities outside of the home are relatively more energy-intensive, detailed data on household allocation of time outside of the home and its relation to the adoption of time-saving innovations could provide further interesting insights regarding household time allocation and energy use.

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Table 1: Summary statistics

SHEU - 2003			
Variable name	**Sample mean**	**Variable name**	**Sample mean**
Household use of time-saving appliances		**Frequency of time-saving appliance use**	
1 if use microwave and 0 otherwise	0.948	microwave use (in minutes on average per week)	50.719
1 if use dishwasher and 0 if not	0.557	loads of dishes (average per week)	3.805
age of a dishwasher (in years)	8.383	loads of laundry washed (average per week during summer)	5.493
1 if washing machine used and 0 if not	0.908	loads of laundry washed (average per week during winter)	5.515
age of the washing machine (in years)	8.897	loads of laundry dried (average per week during summer)	5.180
1 if use clothes dryer and 0 if not	0.861	loads of laundry dried (average per week during winter)	3.624
age of clothes dryer (in years)	9.835		
1 if oven self-cleaning	0.403		
age of stove (in years)	10.693		
Time spent on leisure appliance use		**Household characteristics**	
hours TV on (average per week)	36.804	household size	2.648
hours VCR on (average per week)	3.484	household members age under 18	0.629
hours DVD player on (average per week)	4.322	1 if household income is less than $40000	0.419
hours stereo in use (average per week)	0.836	1 if household owns dwelling	0.787
hours personal computer in use (average per week)	19.911		
Prices		**Energy use**	
electricity price (in $ per gj)	0.079	electricity (gj) heating and cooling per squared feet of dwelling heating area	0.032
average natural gas price (in $ per gj)	6.843	natural gas (gj) total both cycles per squared feet of dwelling heating area	0.064

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

Table 2: Household time-saving appliance adoption and frequency of time-saving appliance (TSA) use

	microwave in use (minutes) per week	number of dishwasher loads per week	loads of laundry washed per week (winter)	loads of laundry dried per week (winter)
	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Explanatory variables:	**(1)**	**(2)**	**(3)**	**(4)**
1 if dishwasher used by <40k income household	-3.145		0.631	0.529
	(3.697)		(0.286)**	(0.297)*
1 if dishwasher used by >40k income household	0.562		0.868	0.691
	(3.003)		(0.265)***	(0.276)**
1 if only washing machine used by <40k income household	-9.557	-0.787		
	(7.402)	(0.818)		
1 if only washing machine used by >40k income household	-6.584	-1.207		
	(8.829)	(0.652)*		
1 if washing machine with clothes dryer used by <40k income household	-4.458	-0.351		
	(5.692)	(0.542)		
1 if washing machine with clothes dryer used by >40k income household	1.390	-0.030		
	(7.111)	(0.514)		
1 if self-cleaning oven used by <40k income household	2.665	0.471	0.049	0.103
	(3.328)	(0.209)**	(0.253)	(0.255)
1 if self-cleaning oven used by >40k income household	4.173	0.188	-0.281	-0.197
	(2.375)*	(0.140)	(0.198)	(0.198)
age - dishwasher (years)	0.106	-0.067	-0.035	-0.028
	(0.190)	(0.008)***	(0.014)**	(0.015)*
age - washing machine (years)	0.016	0.004	0.001	0.001
	(0.179)	(0.010)	(0.013)	(0.013)
age - clothes dryer (years)	0.136	-0.016	-0.038	-0.057
	(0.174)	(0.009)*	(0.011)***	(0.012)***
age of stove (years)	0.225	0.012	0.001	-0.003
	(0.123)*	(0.008)	(0.009)	(0.010)
1 if household income is less than $40000	8.516	-0.038	-0.232	-0.305
	(8.050)	(0.688)	(0.265)	(0.281)
electricity price	444.003	0.376	30.531	29.524
	(175.851)**	(11.793)	(13.754)**	(14.304)**
household size	3.146	0.641	1.164	1.115
	(1.124)***	(0.079)***	(0.108)***	(0.112)***
household member age under 18	3.252	0.256	0.640	0.573
	(1.511)**	(0.102)**	(0.150)***	(0.152)***
1 if dwelling owned by a household member and 0 if not	0.066	-0.109	-0.493	-0.743
	(4.778)	(0.302)	(0.349)	(0.355)**
Constant	-12.451	2.585	-0.546	-0.196
	(19.090)	(1.265)**	(1.395)	(1.447)
Mean of dependent variable	49.820	3.764	5.557	5.223
Observations	2758	1690	2692	2559
R-squared	0.05	0.27	0.29	0.27

Notes: (i) Robust standard errors in parentheses. (ii) * significant at 10%; ** significant at 5%; *** significant at 1%. (iii) 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 improvements 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 3: Household time-saving appliance (TSA) adoption and allocation of time to leisure appliance use

	TSA ownership and time allocated to leisure appliance 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	PC - hours used per week
	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Explanatory variables:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
1 if dishwasher used by <40k income household	-5.550	-1.906	-2.938	-0.551	-1.656
	(2.640)**	(1.353)	(1.927)	(2.155)	(2.854)
1 if dishwasher used by >40k income household	-2.082	2.490	-0.181	-0.384	1.655
	(1.891)	(1.016)**	(0.576)	(1.999)	(1.736)
1 if only washing machine used by <40k income household	-1.082	-3.206	-2.836	6.497	0.055
	(4.618)	(2.702)	(1.489)*	(4.530)	(6.468)
1 if only washing machine used by >40k income household	-2.870	2.915	0.105	5.338	1.749
	(4.512)	(2.479)	(2.247)	(6.021)	(7.367)
1 if washing machine with clothes dryer used by <40k income household	4.310	-0.476	0.745	6.142	-0.413
	(3.533)	(2.451)	(1.714)	(2.814)**	(3.874)
1 if washing machine with clothes dryer used by >40k income household	5.741	3.178	0.510	6.899	-2.132
	(3.754)	(1.665)*	(2.100)	(3.691)*	(5.015)
1 if self-cleaning oven used by <40k income household	4.115	0.665	2.477	-0.970	2.410
	(2.660)	(1.487)	(2.353)	(2.229)	(2.786)
1 if self-cleaning oven used by >40k income household	-2.953	0.371	-0.455	-0.920	-0.125
	(1.313)**	(0.965)	(0.548)	(1.405)	(1.171)
age - dishwasher (years)	0.098	-0.021	0.002	0.034	-0.230
	(0.119)	(0.076)	(0.038)	(0.118)	(0.088)***
age - washing machine (years)	-0.135	0.079	0.005	0.101	-0.008
	(0.119)	(0.110)	(0.034)	(0.099)	(0.103)
age - clothes dryer (years)	0.083	-0.030	-0.082	-0.030	0.026
	(0.112)	(0.104)	(0.028)***	(0.091)	(0.105)
age of stove (years)	-0.053	0.063	0.028	-0.020	0.102
	(0.076)	(0.059)	(0.029)	(0.085)	(0.078)
1 if household income less than $40000	7.134	4.840	0.712	-2.194	-0.385
	(4.059)*	(2.141)**	(2.009)	(3.550)	(5.861)
electricity price	38.244	-55.885	22.477	175.428	9.763
	(98.771)	(49.489)	(31.414)	(126.175)	(80.624)
household size	4.052	-0.067	-0.337	-1.960	2.807
	(0.691)***	(0.354)	(0.336)	(0.733)***	(0.610)***
household member age under 18	-1.180	0.768	0.992	1.128	-0.568
	(0.995)	(0.446)*	(0.465)**	(0.864)	(0.831)
1 if dwelling owned by a household member and 0 if not	-8.983	1.975	-0.184	0.581	0.134
	(4.448)**	(1.468)	(0.798)	(2.562)	(2.554)
Constant	16.312	4.736	2.000	4.483	7.996
	(10.975)	(5.284)	(4.129)	(12.632)	(9.877)
Mean of dependent variable	36.822	5.990	4.145	15.039	19.093
Observations	2853	2435	1588	2513	1935
R-squared	0.09	0.02	0.04	0.02	0.06

Notes: (i) Robust standard errors in parentheses. (ii) * significant at 10%; ** significant at 5%; *** significant at 1%. (iii) Control variables not reported in the table: refer to notes in Table 2.

Table 4: Household time-saving appliance (TSA) adoption and residential energy use

	Energy use per squared feet of dwelling heating area and TSA use	
	Log electricity use per squared feet (in gj)	Log natural gas use per squared feet (in gj)
	Coefficient (S.E.)	Coefficient (S.E.)
Explanatory variables:	**(1)**	**(2)**
1 if dishwasher used by <40k income household	0.046 (0.056)	-0.011 (0.052)
1 if dishwasher used by >40k income household	-0.028 (0.042)	0.040 (0.042)
1 if only washing machine used by <40k income household	-0.418 (0.162)***	-0.200 (0.177)
1 if only washing machine used by >40k income household	0.256 (0.291)	-0.200 (0.157)
1 if washing machine with clothes dryer used by <40k income household	-0.282 (0.151)*	-0.289 (0.165)*
1 if washing machine with clothes dryer used by >40k income household	0.285 (0.278)	-0.173 (0.125)
1 if self-cleaning oven used by <40k income household	-0.019 (0.050)	0.062 (0.045)
1 if self-cleaning oven used by >40k income household	-0.011 (0.032)	0.028 (0.028)
age - dishwasher (years)	-0.000 (0.003)	0.001 (0.002)
age - washing machine (years)	-0.002 (0.002)	-0.004 (0.002)**
age - clothes dryer (years)	-0.002 (0.002)	0.001 (0.002)
age of stove (years)	-0.001 (0.002)	0.004 (0.002)**
1 if household income less than $40000	0.510 (0.287)*	0.157 (0.170)
electricity price	-1.241 (2.358)	
natural gas price		-0.090 (0.009)***
household size	0.083 (0.018)***	0.040 (0.014)***
household member age under 18	-0.036 (0.021)*	-0.023 (0.018)
1 if dwelling owned by a household member and 0 if not	-0.102 (0.070)	-0.125 (0.080)
Constant	-4.724 (0.375)***	-1.358 (0.223)***
Mean of dependent variable	0.029	0.059
Observations	2105	1120
R-squared	0.58	0.49

Notes: (i) Robust standard errors in parentheses. (ii) * significant at 10%; ** significant at 5%; *** significant at 1%. (iii) Control variables not reported in the table: see notes to Table 2 and a series of variables that identity a number (when available, also size and age) of appliances in a dwelling, use of appliances for heating and cooling, number of heating days, use of lighting fixtures and appliances that pertain to water management, whether a dwelling has a garage, the size of the heating area, and whether drafts or air leaks noticed..

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