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Market penetration modeling of high energy efficiency appliances in the residential sector

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ABSTRACT

The aim of this research is to model the market penetration of energy efficient appliances in the residential sector. The analysis focuses on six major appliances – refrigerators, freezers, clothes washers, clothes dryers, and ranges – to forecast their market penetration and market share during the years 2012–2050. Models were developed for each category using 22 years of historical data related to population, household income, immigration, and appliance price. These variables were selected based on the statistical tests of twelve macroeconomic variables. The market shares of high efficiency appliances were analyzed based on the related capital costs, operating costs, lifetime, and incentive. The results show that in Alberta the market penetration growth rate of dishwashers is higher than that of all other appliances, with a projected 30.52% increase between 2012 and 2050. The modeling results also indicate that the average annual energy consumption by refrigerators will decrease from 560.9 kWh in 2012 to 460.8 kWh in 2050, and this decrease indicates an annual energy efficiency improvement of 0.47%. In addition, the effect of an incentive on adopting high energy efficiency appliances and ultimately on energy efficiency improvement in Alberta is more effective for dishwashers and clothes washers.

1. Introduction

The improvement of energy efficiency in the energy demand sector has key impacts on energy consumption and GHG mitigation [1]. Forecasting the overall energy efficiency for the energy sector is the function of a series of variables including technical and economical parameters affecting the market penetration of high energy efficiency technologies [2]. Modeling the penetration of high energy efficiency equipment in the energy demand sectors is critical not only to analyze the energy demand of future years but also to manage the policies formulated by public or private organizations to achieve energy or environmental targets [3].

Energy intensity in the residential sector of Alberta, a province in Canada, was 148.52 GJ per household in 2011, 38% more than the national average of 107.75 GJ [4]. The province of Alberta has the highest per household energy consumption among the provinces [5]. Energy intensity by appliance in Alberta was 17.01 GJ per household in 2011, which put this province second in the country after Manitoba [5] and was 25.2% higher than the average of the other provinces and territories in energy consumption by appliance. The total stocks of appliances per household in Alberta were 21.7, which was 2.25% lower than Canada's average [6].

In Alberta, 49% of refrigerators have the ENERGY STAR® label, which is a consumer icon in the Canadian marketplace [7]. The ENERGY STAR product label identifies products that are qualified as high efficiency [8]. These products have higher energy efficiency than regular ones and are considered energy efficient [9]. Under an agreement with the U.S. Environmental Protection Agency (EPA), Natural Resources Canada (NRCan) administers and monitors the ENERGY STAR name and symbol in Canada. It should be mentioned that, as of the time of this study, there are no ENERGY STAR standards formulated for ranges [10]. The history of specification differences between ENERGY STAR and regular appliances shows that ENERGY STAR appliances have 20–30% more energy efficiency than regular ones [10]. The shares of ENERGY STAR use for dishwashers, freezers, and clothes washers are 42%, 23%, and 50%, respectively, all of which are higher than Canada's average values (37%, 22%, and 48%, respectively) [11].

Market penetration and market share models could provide insights into the penetration rates of efficient household appliances based on basic parameters and historical data [12]. Market

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Nomenclature

a	Constant coefficient in each developed model and varies for variables
AAE	Absolute average error
Adjusted R^2	*Adjusted R-Squared* is useful to analyze the fitting degree when the number of actual data is relatively high
APH	appliances per household
app_cpi	Appliance CPI
b	Constant coefficient in each developed model and varies for variables
c	Constant coefficient in each developed model and varies for variables
CAD	Canadian dollar
CC_i	The capital cost of item i
CPI	Consumer price index
d	Constant coefficient in each developed model and varies for variables
elec_cpi	Electricity CPI
ε	The residual value in each point
F-statistic	Function statistic test
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoule, equal to 10^9 J
Income_hh	Household income
kWh	kiloWatt-hour
nat_mig	National migration
NEMS	National Energy Modeling System
NRCan	Natural Resources Canada
OC_i	The operating cost of item i
popu	Population
Prob. a	Probability or "the *p-value" of coefficient "a"*
Prob. b	Probability or "the *p-value" of coefficient "b"*
Prob. c	Probability or "the *p-value" of coefficient "c"*
Prob. d	Probability or "the *p-value" of coefficient "d"*
Prob. e	Probability or "the *p-value" of coefficient "e"*
Prob. F statistic	Probability of function statistic test
R^2	*R-squared which* analyzes the fitting degree of actual data by the developed model
StatCan	Statistics Canada
U.S.	United States of America
UEC	Unit energy consumption
unempl-rate	Unemployment rate
urban	Urbanization
$Weight_i$	The weight of item i
x	The macroeconomic variable effective in market penetration modeling
x1	Variable used in market penetration modeling
x2	Variable used in market penetration modeling
x3	Variable used in market penetration modeling

penetration refers to the number of people who buy a specific product in a period of time, and market share is the percentage of the market accounted for by a specific product [13]. There is limited research on the assessment of market penetration through comprehensive models. A few studies on the impact of some methods of improving average energy efficiency have been done, for instance on labeling, incentives for purchasing high efficiency appliances, and pricing policy [14–17]. Market penetration modeling based on econometrics and time series analysis combined with cost models has not been done for high energy efficiency appliances. Hence, the main objective of this paper is to assess the market penetration and market shares of energy efficient appliances by developing a comprehensive framework based on econometrics and time series analyses combined with cost models.

2. Method

The method used in this study was to develop data-intensive models to estimate of the market penetration of residential sector appliances over a time period. The developed models used a number of macroeconomic and technical parameters. Fig. 1 shows the steps involved in developing the framework. The model is described in more detail in the sections that follow.

Statistical data and time series information of appliances for Alberta were extracted from publically available resources including NRCan [5] and StatCan [11]. Some of the key parameters considered are: population, household income [6], electrification, urbanization, consumer price index (CPI) [6], international and inter-provincial immigration to Alberta [18], unemployment rate [19], and people's awareness of the benefits of high energy efficiency appliances [20]. Other parameters, such as look, color, and style, which affect the adoption of appliances, were not considered in this study.

2.1. Market penetration modeling

There are different means of modeling the market penetration of energy technologies. These include subjective methods-based models, cost models, time series models, and econometrics diffusion models [21]. No one approach can be used for all circumstances. Models that are more complex make more reliable results, but they usually need more data [22]. Subjective estimation methods are used if there is little or no historical data available for related technology [13]. Market surveys are recommended if available categorized data is not enough. In case of those technologies which costs and economic factors are available, cost estimation models are suggested [23]. For those technologies with two types of adopters (innovators and imitators), diffusion models could be a good option [24]. For market penetration of new technologies which are related to a set of other factors including economic variables, econometric models could have reliable results but they need statistical analysis [25]. Due to the availability of appliance data in Alberta's residential sector, econometric diffusion models were selected for market penetration forecasting.

In econometric diffusion models, all variables affecting market penetration are analyzed. Average values of the related variables such as price of the appliance or energy consumption by the appliance were used.

To analyze the variables' effects on the market penetration of different appliances, individual variable probability tests were done using the least square method and based on Pearson's correlation (Equation (1)) [26]:

$$Ln(APH) = a + b \times Ln(x) \quad (1)$$

where

APH is appliances per household;