

Measuring the Rebound Effect as a Result of a Residential Fuel-Switching Program

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Rebound effect deserves attention when evaluating impacts of some DSM programs. For some DSM programs, ignoring the rebound effect may result in a biased cost-benefit analysis,

This paper addresses the rebound effect associated with a residential fuel switching program at Public Service Company of Colorado. The rebound effect occurs after an electric-to-gas conversion when costs of space and hot water heating are reduced by about 70%. As a result of the program, participants turned up thermostat settings in their homes and reduced the use of supplemental heat.

In this study, we use a statistical model to measure the increase in comfort in participants' homes in terms of energy use. The empirical results indicate that participants increased their energy use (comfort levels) by 61%. Included in this 61% is a 4.9% decrease in the use of supplemental heat. The study results convinced us that the value of the increase in comfort should not be ignored in the evaluation of residential fuel switching programs.

Introduction

Today, more and more DSM program evaluators address explicitly behavioral changes as part of the impact evaluation (Nadel, 1993). For some DSM programs, the non-energy impact can be a significant contributor to the program's net benefit, and should not be ignored (Haynes, et al., 1993, and Manual, et al., 1993). For example, if the value of the increased comfort in participant homes is ignored when evaluating a residential program, the cost-effective analysis can be biased.

This paper addresses the behavioral impact of a residential program where space and hot water heating were converted from electric to natural gas at Public Service Company of Colorado (PSCo). Increases in home comfort level resulting from a DSM program is an example of the so-called rebound, take-back, or snap-back effect (EPRI, 1991). In other words, savings on energy bills from a DSM project may be partially reinvested by program participants to purchase more comfort or warmth, as energy services have become less expensive. Residential customers, for example, may adjust their thermostats after a weatherization program, because space heating as a commodity has become less expensive. Studies (Nadel, 1993, EPRI, 1991, Hirst 1987, and Tonn, et al., 1987) found evidences of rebound effect in DSM programs involving space heating measures.

For a DSM program with a primary focus on energy efficiency improvement, the rebound effect is difficult to isolate from the total impact as the "take-back" amount is not observable. This is because the observed energy use change is a combination of energy savings from efficiency improvements and increased energy consumption due to the lower price of energy services.

Fuel switching programs provide a unique opportunity to study the rebound effect. The primary objective of a fuel switching program is not to improve the energy efficiency of the house shell; rather, it is to assist program participants with switching to a more economical fuel and therefore reducing electric use. Thus, any change observed in total energy (electric plus gas) use is attributable to behavioral factors. The impact associated with behavioral changes can be measured as the rebound effect.

PSCo'S fuel switching program. PSCo is the largest utility in the State of Colorado serving electric, gas, and steam to over one million customers. A primary objective of PSCo'S DSM programs is to reduce electric demand and use. Among various types of DSM programs considered by PSCo, a few fuel switching programs were designed to encourage participants to switch from using electricity to using natural gas, a less expensive fuel. In PSCo'S service territory, the costs of using natural gas

(\$0.34/ccf) are about 30% of using electricity (\$0.07/kWh) for space heating.

In 1990, PSCo offered its first 50 megawatt bidding program, which contained a residential fuel switching project in a Denver suburb. The project, awarded to an energy services company, included space and hot water heating conversions from electric to natural gas in 160 residential homes. There was no other gas usage before the conversion as gas pipelines were not available to the area. The majority of the 160 conversions were done in the 1991/92 heating season. Most participants converted both space and hot water heating systems through the program, which resulted in an average, non-peak demand reduction of 12.8 kW per home. All the participants in the sample replaced their electric baseboards with gas furnaces. No heat pumps or solar systems were replaced.

In this study, we intend to measure the increase in residence comfort level associated with the heating conversion in terms of increased energy use. The paper is organized as follows: the next section provides a theoretical discussion about the program impact on a residence's comfort level and presents the general approach of our study. The following sections contain a qualitative analysis of program impact, provide a statistical analysis of energy use changes after the conversion, present the study results, and finally, conclude the paper.

Theoretical Discussion

Residential customers are interested in a fuel switching program only when they think they gain financial benefits and convenience in producing warmth. Under certain circumstances, residents may participate in a program even if it is financially neutral to them, because the program provides convenience in heating. The rebound is most likely to happen when the net financial benefit is greater than zero. From a participant perspective, the costs of a fuel switching project are the initial investment beyond utility's rebates and the inconvenience of going through the conversion process. The total benefit, on the other hand, consists of lower fuel costs, a potential increase in house value, and the convenience. The convenience is realized by avoiding the time-consuming hassle of using supplemental heat and not having to adjust thermostats from time to time in different living areas¹. In sum, rebound may occur due to two factors: a) lower fuel prices for heating, and b) reduced use of supplemental heat. Furthermore, we believe the magnitude of the rebound effect is positively related to the magnitude of the net benefits from the conservation measure.

The concept of rebound can be defined from either a utility or total energy perspective. From a utility

perspective, utilities are interested in the amount of takeback in terms of energy observed from utility's billing record. Thus, rebound should include the increased energy use due to substitution of other energy forms, such as wood, kerosine, and solar, which are not supplied by a utility as primary energy sources. Nadel (1993) argues: "This . . . could be interpreted as takeback — giving up an inferior good for a more convenient form of heating." On the other hand, from a total energy use perspective, the concept of rebound represents the increased amount of energy use taking into account energy supplied both by utilities and by other heating systems. In the context of this study, the key is whether we should include in the rebound effect the amount of energy substituted from supplemental heating sources to natural gas as a result of the conversion.

In this study, we define rebound or takeback from the utility perspective. Figure 1 illustrates our definition of the rebound effect associated with the PSCo program.

In Figure 1, a_0 and a_0 represent the non-heating related electric use, and we assume they stay the same, before and after the program. Before the conversion (PART=0), a_1 represents the electric use for space and water heating, and a_2 indicates energy provided by supplemental heat (the exact amount in terms of therm is not known). After the conversion (PART=1), a_3 stands for the natural gas use for space and water heating, and a_2 represents the amount of energy provided by supplemental heat sources. As indicated by the graph, after the conversion, we have higher energy use on heating (a_3) than before the conversion (a_1) from utility's billing record. The difference is the sum of a_{31} and a_{32} , which is by our definition the rebound effect. Note, a_{31} represents the portion of rebound associated with the increase in comfort level, whereas a_{32} stands for the portion of rebound associated with reduced supplemental heat.

Our general approach is to model the total household energy use² and to derive the changes in the total energy use by comparing the uses before and after the measure installation.

In this study, we neither develop a sophisticated model for home energy use, nor for house heating. For a comprehensive discussion on modeling house heating, see Scott (1980). Our simple model assumes that the total energy an individual home consumes is determined by several factors, such as prices of fuels of all types, household income, occupancy, weather, square footage, etc.

Obviously, household income is a key constraint to energy use. Because the electric heating bill is a sizable portion of an average family income, we believe many families living in electric heated homes trade their comfort to a

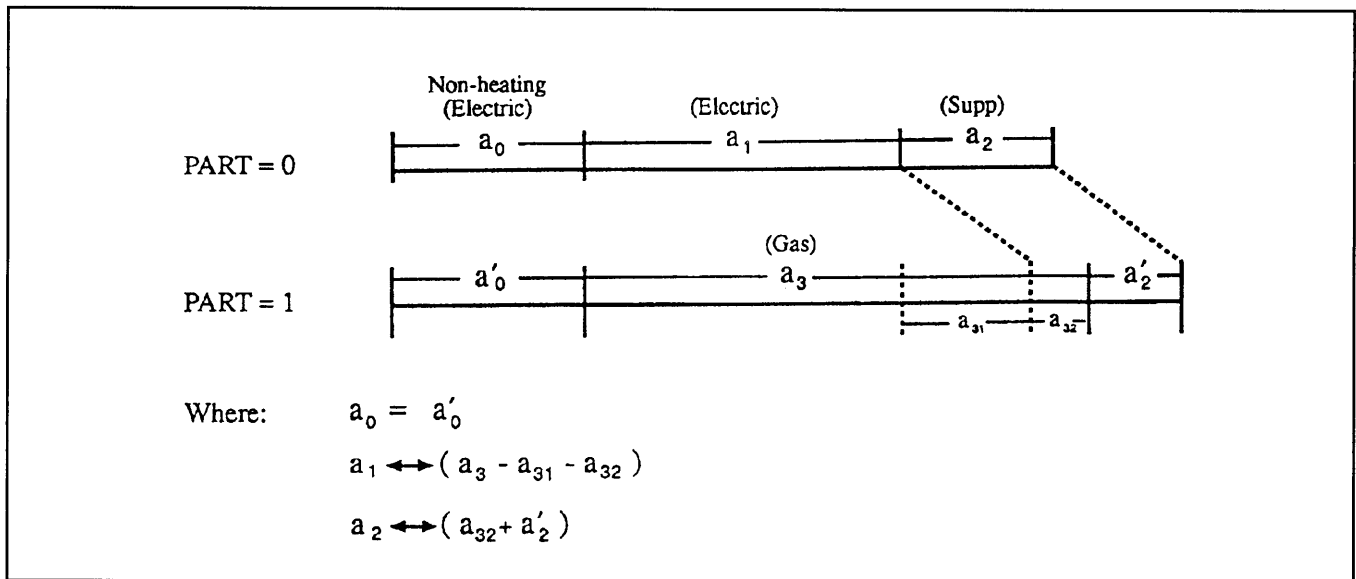


Figure 1. Rebound Effect in the Context of the PSCo Program

certain extent for lower energy bills. For this very reason, after the conversion, families with lower gas heating bills are likely to enjoy a higher level of warmth in their homes by using more energy.

Electric heated homes are more likely than gas heated homes to use different heating options, as electric space heating is very expensive. Most residents in electric homes examine other options, such as wood stoves, wood fire places, solar water heaters, and portable heating units using either kerosene or electricity, etc. A “rational” resident will compare all the options in terms of cost, comfort, and convenience. The resident will choose the best combination of options that balances costs, convenience and comfort.

To measure the impact of the project on participants’ comfort level, we conducted a two-step analysis. The first step was a qualitative analysis in which we identified the issues associated with energy use and specified the theoretical model by screening utility billing data, reviewing engineering audit data, and conducting focus groups and participant surveys. The second step is a statistical analysis of billing data where the rebound effect is quantified in terms of increased energy use.

Qualitative Analysis

Qualitative analysis is a necessary step toward any quantitative analysis. In our case, we first developed a theoretical model based on the discussion above. We then explored the model’s validity through qualitative analysis. The qualitative analysis started with a review of billing data to confirm that there is an decrease in electric use. After we determined the decrease in electric use was

apparent, focus groups were arranged to explore the rationale behind fuel conversion and therefore confirm our basic assumptions. From the results of the focus groups, we developed a telephone survey for all of the households who participated in the program. The purpose of this telephone survey was to gather data for the qualitative analysis.

The primary reason for analyzing the billing history data was to observe if there is a decrease in electric use and an increase in natural gas use after the measure was installed. Other reasons for analyzing the data were to confirm conversion dates and to ensure that the quality of billing data was good enough to conduct regression analyses. The review of the billing data confirmed our expectations. In addition, the analysis of the data showed the average annual saving from the fuel switching was \$291 or almost \$60 each heating month. The savings realized by converted households were approximately 19% of the previous annual bill. The \$291 average annual savings was a simple average across participants and was adjusted with a simple index of heating degree days (HDD). Note, the rebound effect is imbedded in these financial savings.

The next step in the qualitative analysis was to conduct focus groups. There were two objectives addressed in the focus groups. The first was to understand the rationale behind the household decision making process to switch fuels and to confirm the theoretical model we had developed. The other objective was to develop a quality telephone survey which was administered to all of the participants.

The focus groups results supported our hypotheses that residents felt uncomfortable and inconvenienced living

in electric heated homes and were very concerned about high electric bills in the winter. Participants stated they turned down or even turned off thermostats to overcome expensive electric bills. When conversions were completed, some participants told of the relief they found in turning their thermostats up to what they believed to be a comfortable level. Most of the participants at the discussion used alternative heating sources before the conversion. They indicated they would likely not continue to use their alternate heating systems now that they had natural gas for heating, because other systems were not convenient to use. The focus group results also confirmed that participants perceived an increase in home value after the switching. Many believed that the increase in home value was greater than the cost of the conversion.

A telephone survey was developed from the focus groups results and the data needs of the model. The survey asked for home demographics such as income, education, age and number of occupants. The survey gathered information on the presence of supplemental heating devices in the home during pre and post conversion periods, usage levels of the supplemental heating in terms of dollars during both time periods. Other questions were asked about type of household appliances, the customer satisfaction, and other items of this nature.

The survey results showed wood stoves to be the most popular supplemental heating option. The average costs of supplemental heat are \$85 and \$34 before and after conversions, respectively. A possible reason supplemental heating costs did not drop to zero might be that it was still cheaper to use certain form of supplemental heat. We did not explore this issue.

Statistical Analysis

An econometric model was designed to analyze the rebound effect associated with the program. The model was developed to explain variation in total energy use, i.e. the sum of gas and electric use expressed in therm. Intuitively, if there is no rebound effect or increase in resident's comfort level, there should be no significant changes in total energy use before and after a conversion.³ In other words, since there is no efficiency improvement in the fuel switching process, the decrease in therm in electric use should be equal to the increase in gas use after adjusting gas use for combustion losses in the absence of any rebound effect.

The regression model, which utilizes a pooled time series and cross-section (longitudinal or panel) data set, is as follows:

$$THM = \alpha_0 + \alpha_2 SQFT \times HDD + \alpha_3 OCCP + \alpha_4 SUPP \times HDD + \alpha_5 PART \times CKW \times HDD + \epsilon$$

where

- THM: utility recorded average daily total energy use, gas plus electric, in therm for home *i* in billing⁴ period *t*
- HDD: average daily HDD with 650 F reference temperature for home *i* in period *t*
- Y: household income for home *i*
- SQFT: square-footage of home *i*
- OCCP: number of people live in home *i*
- SUPP⁵: dollar amount spent on supplemental heat before or after conversion for home *i*
- PART: conversion dummy variable for home *i* in period *t*; it equals 0 before conversion, and equals 1 after conversion
- CKW: kilowatts converted through the program for home *i*

The model implies the variation in total energy use is determined by the variation in income, house size, weather, occupancy, and the level of supplemental heat use. Most importantly, the model is used to detect whether the conversion has any impact on the total energy use. The coefficient of the last term, α_5 , is expected to be zero if there is no rebound effect, or greater than zero if a rebound in energy use occurs.

The model utilizes a longitudinal data set and controls simultaneously the variation both across program participants and over time. In fact, variables such as household income, house size and occupancy vary only across participants but not over time. The weather variable, HDD, varies mainly over time. The dollar amount spent on supplemental heat differs from before to after the conversion for each individual home, and also varies from one participant to another.

The average daily energy consumption is expected to be positively related to household income, house size, heating degree days and occupancy, and to be negatively related to the dollar amount spent on supplemental heat.

In the model, SQFT interacts with HDD implying that square-footage should only affect the amount of energy used for space heating, which is a function of heating degree days. In addition, the conversion dummy variable, PART, is interacted with kW converted, CKW, and heating degree days, HDD. This implies the magnitude of the rebound effect, if any, varies with the number of KW converted in different homes and weather conditions.

Similarly, SUPP also interacts with HDD as supplemental heat use has insignificant or no effect on the total energy use when heating degree days approach zero. SUPP does not include dollar amount spent on portable electric space heaters. Thus, the rebound effect related to the reduced use of portable electric heaters is not estimated.

Note, the rebound effect is explicitly captured in two separate terms, the fourth and fifth terms of the model. The estimator of α_4 captures the rebound effect associated with reduced use of supplemental heat, whereas the estimator of α_5 captures the rebound effect associated with higher thermostat settings.

Data and Results

The conversion project had 160 participants, of which 100 home owners were interviewed on the telephone. After screening monthly billing data and survey data, the final data set used for the regression analysis contained 64 participants and on average, each customer had eight months pre and nine months post billing periods. Customers' monthly billing data were collected in a way so that both pre- and post-periods contained a full heating season, as well as non-heating months.

The dependent variable, the average daily energy consumption, THM, is calculated by converting both electric and gas use into therm, and adding the two terms together. Before being converted to therm, gas use in ccf is discounted by 20% to adjust for combustion losses. We assumed the efficiency of gas furnaces is 80% (PSCo, 1992), and the efficiency of electric baseboards is 100%. Electric use in kwh and natural gas use in ccf are converted into therm according to the following equations:

kwh to therm:

$$\begin{aligned} 1 \text{ therm} &= 100,000 \text{ Btu} \\ 1 \text{ kwh} &= 3,413 \text{ Btu} \\ \Rightarrow 1 \text{ kwh} &= 0.03413 \text{ therm} \end{aligned}$$

ccf to therm:

$$\begin{aligned} 1 \text{ therm} &= 100,000 \text{ Btu} \\ 1 \text{ ccf} &= 82,900 \text{ Btu} \\ \Rightarrow 1 \text{ Ccf} &= 0.829 \text{ therm} \end{aligned}$$

The total monthly energy use in therm is then divided by the number of days in the corresponding billing period to obtain the average daily total energy use, which becomes the dependent variable, THM⁶.

The regression results are shown in Table 1. In Table 1, the mean values of the interactive terms are products of the mean of each variable. For example, the average annual HDD over the past fifteen years is 5801 in the Denver area, and the average daily HDD is 15.9 (=5801/365). The average SQFT is 1766 ft². Thus, the mean value of the term SQFT*HDD is 28,079. In addition, as previously stated, the average amount spent on supplemental heating before and after the conversion is \$85 and \$34 respectively. The mean of SUPP*HDD, 541 (=34*15.9) is based on the post-conversion dollar amount spent. Finally, the average kW converted per home is around 12.8 kW. Thus, the mean value of PART*CKW*HDD is 203.5 (=12.8*15.9).

Based on the estimated model, the average daily energy use per home increased from 1.40 therm before the conversion to 2.26 therm after the conversion. The pre-installation consumption, 1.40 therm, is calculated by setting the pre-supplemental use to \$85, instead of \$34, and the participation variable, PART, to zero:

Table 1. Results of Regression Analysis

Variables	$R^2 = 0.62 \quad n = 1125$		Var. Mean	Product
	Estimated Coefficient	T-Ratio		
CONSTANT	$\alpha_0:0.620$	3.39	1	0.62
Y	$\alpha_1:0.0000011$	0.35	43,828	0.05
SQFT*HDD	$\alpha_2:0.000017$	21.87	28,079	0.48
OCCP	$\alpha_3:0.10$	2.84	3.6	0.36
SUPP*HDD	$\alpha_4:-0.00008$	-6.91	541	-0.04
PART*CKW*HDD	$\alpha_5:0.0039$	29.96	203.5	0.79
THM			2.6	2.26

$$\begin{aligned}
 1.40 &= 0.62 + 0.05 + 0.48 + 0.36 - \\
 &\quad -0.00008*85*15.9 \\
 &= 0.62 + 0.05 + 0.48 + 0.36 - \\
 &\quad -0.11.
 \end{aligned}$$

Similarly, the 2.26 therm post-use is derived by adding the last column of Table 1:

$$\begin{aligned}
 2.26 &= 0.62 + 0.05 + 0.48 + 0.36 - \\
 &\quad -0.04 + 0.79.
 \end{aligned}$$

Thus, the rebound effect in terms of increased total energy (gas plus electric) use is equivalent to 0.86 (2.26-1.40) therm, which is a 61% (0.86/1.40) increase compared to the pre-use. In other words, an average home owner would use 61% more energy after the conversion to make his/her home more comfortable, simply because they now use a less expensive fuel and a more convenient system for space heating.

This increase can be further broken down into two separate components, the decrease in supplemental heating and the increase in indoor comfort level.

As shown in Table 1, the estimated coefficient of α_4 has a negative sign with a t-ratio of -6.91. This result implies that when supplemental heat use decreases, the total daily average energy use increases. Using the estimated equation, we see the amount of supplemental heat use decreases from 0.11 therm to 0.04 therm from before to after conversion, a decrease of 0.07 therm. In other words, we see the proportion of supplemental heat use decreases from 7.7% (0.11/1.40) to 1.9% (0.04/2.26) after the conversion.

In addition, the increase in energy use after the conversion is statistically significant, i. e. the estimated α_5 is a positive value, 0.0039, with a t-ratio at 29.96. This can be interpreted as an average increase in energy use of 0.79 (0.0039*15.9*12.8) therm, using an average daily HDD of 15.9, and 12.8 kW worth of electric demand converted in an average home. This increase in energy use represents the second part of the rebound effect, which is most likely a result of high indoor temperature settings.

The decrease in supplemental heat represents about 8.1% (0.07/0.86) of the total increase in energy use after conversions. Therefore, of the increase in total energy use, 61% or 0.86 therm per day, 8.1% or 0.07 therm is due to reduced alternative heat use and 91.9% is due to the increase in warmth level inside a house. Both components increase the comfort and convenience of residents' lives.

The estimated coefficient of income has a positive sign, but is not statistically significant with the t-ratio at 0.35.

This may be due to the poor quality of survey data obtained on family income, which participants are reluctant to provide. The other two variables, square footage (SQFT) and occupancy (OCCP) are shown with positive signs and significant t-ratios, as expected from our early theoretical discussion.

Summary

This study attempts to assess the increase in comfort level in participant homes as a result of a residential fuel switching program at PSCO. Our statistical analysis indicates the rebound effect, or the increase in comfort level, is a significant 61%, within which a small portion is due to the reduced use of alternative heat sources. After the conversion, program participants adjusted their home thermostats to comfortable levels, minimized the inconvenience associated with using supplemental heat, and possibly increased the consumption of other energy end-uses.

This preliminary work has room for improvement. For example, the increase in total energy use measured by this analysis is only a rough estimate rather than an accurate measurement of the rebound effect. As mentioned above the increased electric use of furnace fans should be taken into consideration. In addition, part of the total energy use increase may be involuntary for some participants as they no longer have as much control over temperature settings in various areas of home. If this is true, that "involuntary" portion should not be included in the rebound effect.

We believe the rebound issue should be addressed in impact evaluations of DSM programs, especially fuel switching programs. Although, as indicated by this study, the total energy use may increase at the end-use level as a result of a fuel switching program, the program may still have a positive net benefit from a broader perspective, which is not the focus of this study.

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Endnotes

1. Most electric heating systems in PSCO service territory provide residents with thermostat control of different living areas in a house, whereas gas heating

cannot provide individual room control as effectively. However, program participants in our focus groups indicated, that given the cost difference, they would rather use gas systems even through they now have less control on heating different areas.

2. The total energy use is that captured by the utility billing records. We are incapable of capturing the amount of energy provided through solar, wood, and other supplemental heating systems. So the notion of total energy hereafter represents only the sum of electric and natural gas recorded by utility.
3. Electricity consumed by furnace fans was ignored in the analysis. If considered, it would reduce the magnitude of the rebound effect. A furnace fan consumes about 400 kWh per year in Colorado (PSCo, 1992).
4. Monthly billing periods.
5. SUPP is an indicator for the level of supplement heat use before and after the conversion. It is not a function of HDD for any specific billing period t.
6. The reason for deriving average daily use rather than using the billing period total is to improve the accuracy of calculating rebound effect after the coefficients are estimated. This is because billing periods do not contain the same number of days.

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