THE TAKE BACK EFFECT: FACT OR FICTION ?

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INTRODUCTION

Economists and other analysts have postulated that savings from efficiency measures are reduced as consumers use some of the money they save from energy efficiency measures to purchase increased comfort or convenience by operating energy-consuming equipment more intensely (*e.g.* increased hours of operation, higher temperature settings or increased lighting levels). Similarly, consumers who purchase energy efficient equipment might purchase larger units or units with more features. This effect has been called the *takeback, snapback, rebound*, and *Khazzoom* effect. The latter term is named after Daniel Khazzoom, whose 1980 paper (Ref. 21) is perhaps the first publication dealing with this issue.

Since this time, an extensive literature on the takeback effect has developed, including several theoretical works and a number of empirical studies. Many of the theoretical works are summarized by Keating (Ref. 20) and will not be discussed here. Instead, the focus of this paper is to examine empirical studies on the takeback effect.

Empirical studies on the takeback effect have generally relied on three different types of data:

1. Survey data in which customers are asked about how they use energy consuming equipment including, for example, data on temperature setpoints and operating hours.

2. Empirical measurements of behavioral variables that affect energy use such as measurements of thermostat settings, indoor temperature, hot water temperature, and average length of showers.

3. Statistical analyses in which behavioral effects are inferred from data on energy use, energy and equipment prices, indoor and outdoor temperatures, survey data, engineering models, and other sources.

Each of these data types have strengths and weaknesses. Survey data are easy to collect but may be inaccurate due to poor recall of past behavior, a desire to please the interviewer, or a desire to provide socially acceptable answers. Empirical measurements of behavioral variables can often provide the most accurate data, but collecting this data usually requires extensive effort and expense. Due to these difficulties, most empirical measurements focus on only one or two variables and not a wide range of variables that might be relevant. Furthermore, empirical measurements are not always precise -- measurement errors can and do occur. Statistical analyses can provide more accurate data than surveys without the effort and expense of empirical measurements. However, statistical inferences are only as good as the data and models on which they are based, and these links are sometimes tenuous. Statistical analyses range in quality from studies in which statistically significant influences are attributed to specific behavioral variables to studies in which differences between engineering estimates and impact evaluation results are attributed to specific or vague behavioral factors, with little or no empirical basis. While the former can provide solid evidence of takeback, the latter provides only circumstantial evidence of takeback. The strengths and weaknesses of the different approaches should be kept in mind as the results of different studies are reviewed.

For this review, 42 different studies were examined. Twenty-eight of the studies pertain to the residential sector including 15 which deal with space heating, eight with air conditioning, five with water heating, five with lighting, and two with refrigerators (totals do not add up because several studies cover more than one end-use). Three of the studies cover commercial and industrial lighting and eleven cover industrial process measures in individual plants. Each of these studies are discussed below. Results are organized by sector and end-use.

RESIDENTIAL SECTOR

Space Heating

The issue of takeback for residential space heating measures is the subject of at least 15 studies. These studies include consumer surveys, statistical analyses, and measurements of indoor temperature and thermostat setpoints. The results of these studies paint a consistent picture -- takeback with residential space heating measures is generally very limited. Results of these studies are summarized in Table 1. Most of these studies attempt to quantify takeback in terms of changes in average indoor temperature or thermostat setting between the pre- and post weatherization periods. If consumers use energy savings to purchase improved comfort, this is most likely to result from increases in thermostat settings. A total of 12 quantified estimates of changes in thermostat setpoints or indoor temperature are available from nine different studies (several studies provide two estimates based on different methods or time periods). Results vary from a 0.5° F decrease in setpoint to a 0.9° F increase in setpoint. The median result is a 0.25° F increase. To put this increase into perspective for cities with an average 40° F outdoor temperature during the heating season (e.g. Detroit, MI and Albany, NY), a 0.25° F increase in indoor temperature will increase annual energy use for heating by just under 1%.

While the average customer in these studies shows little, if any, change in setpoint, all of the studies have found that some individual customers increase their setpoint and some decrease their setpoint.

Increases in setpoint or temperature can be due to takeback or to increased capacitance of a home after weatherization. Capacitance refers to the fact that when buildings are weatherized, they take longer to cool when thermostats are set back, thus average interior temperatures over the course of a day will be higher for the same thermostat setpoint regime. Work by Miller (Ref. 25) indicates that under identical setpoint regimes, capacitance can increase average interior temperature by a full degree Fahrenheit.

Table 1. Summary of Takeback Studies on Residential Space Heating

Study	Refer-ence	Method	Sample Size	Avg. Temp. Change	Control Group	Notes
Dinan	4	Measure temperature	254	0.5	No	Temp.increase 0.8 for low-income homes. Much of increase may be due to thermal capacitance.
Ternes & Stovall	34	Mearure temperature	185	0.1	No	Largest temperature increase at 5 a.m.
Ternes et al.*	33	Monitor t-stat Measure temp.	15 15	0.3 -0.1	Yes Yes	Median temperature reported instead of average
Wiehl et al.*	36	Monitor thermostat	8	0.9	No	Majority of temperature increase was @ night. After weatherization households manipulated thermostats less.
Hirst & White	18	Statistical analysis	242	0.4 1st yr. 1.0 2nd yr.	Yes Yes	
Goldberg & Fels*	9	Statist.analysis	243	0.3	No	Median temperature reported instead of average.
Nadel*	26	Survey	15	-0.5	No	Related survey questions found that after weatherization houses were less drafty and residents more comfortable.
Nadel & Meyer*	27	Survey	54	0.2	No	
Nadel & Heineman*	28	Survey Measure temp.	52 38	-0.3 -0.2	Yes Yes	
Brown & White	3	Survey	1300	Negative	No	16% of participants changed their winter thermostat setting; more households lowered their thermostats than raised them.
Hall	11	Survey	132	Not available	Yes	Nearly equal proportions of test & control houses reported they raised space heating temps. & lowered cooling temps.
ARG	1	Survey	352	Not available	No	2% of respondents said they set thermostats higher and 53% were more comfortable after weatherization.
Dubin et al.	5	Statistical analysis	252	Not available	Yes	Savings from weatherization and heating system improvements may be reduced by 8-12% due to takeback.
Hirst, Tonn & White	17 35	Survey Metered wood stove used	Not provided 32	Not available	Unclear No	In 1st year after weatherization, use of wood declined by 0.4 cords. Some decline in wood use (equivalent to 300 kWh) due to partial switching from wood to electric heat.

* Households in study were low-income.

Decreases in setpoint can be due to increased awareness of the benefits of energy conserving behavior, or can be due to the fact that many people are more comfortable in weatherized buildings, even when interior temperatures remain unchanged. Personal comfort is affected by many factors including air temperature, drafts, interior humidity, and the temperature of walls and windows. Weatherization often reduces drafts, increases wintertime humidity (because tightening buildings reduces the infiltration of dry exterior air), and increases the temperature of walls and windows (due to the affects of insulation and improved glazing), all of which tend to increase occupant comfort. For example, a series of studies by the Massachusetts Audubon Society (Refs. 26, 27, and 28) found that after weatherization, the average program participant found that their home was less drafty and more comfortable. Similarly, 53% of the participants in the New England Electric System Electric Space Heating program reported that they were more comfortable after weatherization, even though only 2% of the participants said they increased their thermostat after program participation (Ref. 1).

Another interesting finding from these studies is how takeback behavior relates to household income level. Some observers have speculated that takeback may be more pronounced for low-income households than for higher income households because low-income households may not be able to afford the level of comfort they desire. Work by Dinan (Ref. 4) supports this hypothesis. In her study low-income households increased interior temperatures by an average of 0.8° F while higher income households increased interior temperatures by an average of approximately 0.2° F. On the other hand, results of six studies that evaluated low-income weatherization programs (noted with an asterisk in Table 1) found a median increase in thermostat setpoint or interior temperature of only 0.5° F, scarcely different than the median of all the studies listed in Table 1.

The discussion thus far has focused on changes in thermostat settings. Takeback can also occur by increasing the amount of space that is heated (heating formerly unheated rooms) or by decreasing the use of wood or coal stoves and increasing the use of electric or gas heat. Regarding the first issue, a survey by Hall (Ref. 11) found that nearly identical proportions of test and control group homes changed the number of rooms that were heated. However, the direction of change was not reported.

Regarding the second issue, evaluations of the Hood River Conservation Project (Refs. 17 and 35) found that reductions in electricity used for space heating were less than expected, largely because after weatherization, households increased the proportion of space heating energy supplied by electricity and decreased the proportion supplied by wood. This fuel-switching was estimated to reduce electricity savings by approximately 300 kWh/year, which reduced savings by about 9% relative to what savings would have been without fuel-switching. This fuel-switching could be interpreted as takeback -- giving up an inferior good for a more convenient form of heating. However, the amount of takeback in Hood River was relatively small, and is likely to be even less of a problem in other areas because use of wood heat was particularly high in the Hood River area (almost 60% of program participants used wood in whole or in part to heat their homes).

Air Conditioning

Eight studies have examined takeback with respect to air conditioning, including three studies on weatherization and five studies on improved-efficiency air conditioners. For both types of measures, takeback can occur if air conditioners are operated more frequently and/or interior temperatures are lowered. Also, takeback can occur if incentives encourage consumers to purchase more or larger air conditioners than they otherwise would have.

With regard to weatherization measures, two studies are based on surveys and one on statistical analysis. A survey of participants in General Public Utilities' (GPU) RECAP program (Ref. 3) found that 11% of participants reported changing their thermostat setting after weatherization, equally divided between those who raised and lowered their setpoint. On the other hand, 10% of the participants in New England Electric System's (NEES) Electric Space Heat Program reported that after weatherization they ran the air conditioner longer or set it cooler (Ref. 1). No data were collected on raising the setpoint or decreasing the hours of operation. Finally, Dubin et al. (Ref. 5) conducted a complex statistical analysis on a weatherization and high efficiency air conditioner/heat pump program operated by Florida Power & Light. The statistical model employed in the study included energy consumption, energy prices, engineering estimates of savings, and survey data. Based on this model, the authors conclude that very little takeback took place in the summer months when outdoor temperatures are very high (takeback estimates were 1-2% of the energy savings that would otherwise result) but that significant, though limited, takeback took place in spring and summer when temperatures and the need for air conditioning were more modest (takeback estimates were as much as 13% of anticipated energy savings).

With regard to high efficiency air conditioners, four statistical analyses and two surveys are available. A survey of participants in Pacific Gas & Electric Companies' (PG&E) Central Air Conditioner Rebate Program, asked participants if they used their new high-efficiency air conditioner more often or less often than the unit it replaced. Of the respondents, 55% indicated no change in use patterns, 22% said use increased, and 23% said use decreased (Ref. 7). The second survey, conducted on Wisconsin Power & Light's (WP&L) Buysmart program found that 7-8% of air conditioning program participants reported that without the rebate, they would not have purchased an air conditioner at this time. Furthermore, 8-9% of air conditioning program participants reported that due to the influence of the rebate, they purchased a larger room or central air conditioner than if no rebate were offered (Ref. 22). Respondents who answered yes to the first question may have also answered yes to the second question, and hence the answers to these two questions cannot be summed.

Only one of the statistical analyses directly addresses the issue of takeback. Using a modeling approach similar to that used by Dubin et al. (described above), Hausman (Ref. 12) examined the interactions between energy use and room air conditioner efficiency in the 1970s. The study concluded that for each 1% increase in Energy Efficiency Ratio (EER), use of air conditioners increased by 0.26%. However, the study compared homes with and without high efficiency air conditioners and did not examine changes in consumer behavior after the efficient air conditioner was purchased. Thus, instead of inferring takeback, one could hypothesize that consumers who operate air conditioners for long periods of time are more likely to purchase high efficiency air conditioners than consumers who operate air conditioners less frequently.

The other three statistical analyses only indirectly address takeback. All three studies are impact evaluations of air conditioner rebate programs in which pre- and post-rebate electric consumption is analyzed relative to a control group of non-participants. In a study conducted by Wisconsin Electric Power Company (WEPCo), energy savings for both central air conditioners and room air conditioners were negative (energy use increased after rebate). These findings were significant with 90% confidence. The author speculates that perhaps operating hours increased, particularly in Wisconsin's temperate climate where use of air conditioning is rarely required (Ref. 30). No data to support this hypothesis were provided. Similarly, WP&L conducted an impact evaluation on its Buysmart rebate program and also found negative savings (Ref. 29). However, the negative savings were largely due to consumers who purchased air conditioners for the first time, including both consumers whose purchase decisions were and were not influenced by the rebate. The impacts of program-induced purchases cannot be separated from purchases that were not program induced, and hence conclusions about takeback cannot be made. Finally, in a study conducted by PG&E (Ref. 6), energy savings measured in an impact evaluation were only 63% of the savings predicted by engineering estimates. Based on a "quick and inconclusive" review of load research data for air conditioners, the author concludes that the discrepancy may be due to an error in the assumed operating hours and that typical operating hours may be lower than was assumed.

In summary, one study (GPU) found no evidence of takeback, two studies (Dubin et al. and the WP&L survey) found evidence for limited takeback, one study (WEPCo) found circumstantial evidence for takeback, and four studies (NEES, Hausman, PG&E and the WP&L impact evaluation) were inconclusive. Clearly more work is needed on this issue, but some takeback may be occurring. Evidence indicates that takeback may be more likely in moderate climates (*e.g.* Wisconsin) and in moderate temperature months (*e.g.* spring and fall in Florida) where use of air conditioning can be considered optional rather than mandatory.

Water Heating

Studies on takeback and water heating efficiency measures primarily address low-flow showerheads, although two studies address rebates for efficient water heaters. A total of five studies are available including two studies that include in-home measurements, three that use consumer surveys, and one that relies on analysis of electric bills before and after measure installation (numbers do not total because one study uses two different types of data).

For low-flow showerheads, takeback would occur if consumers take longer or hotter showers with a low-flow showerhead than with a higher-flow showerhead. Data on both issues were collected in a U.S. Department of Housing and Urban Development (HUD) study (Ref. 24) in which water use, flow rates, water temperature, and shower duration were monitored for a sample of 286 showerheads. The study found that "nonconserving" (greater than 3 gpm) and "low-flow" (3 gpm or less) showerheads were used for an identical 4.8 minutes per shower. With the low-flow models, average water temperature was 1° F higher.

Similar findings were reached in an evaluation of PG&E's Showerhead Coupon Program (Ref. 16). In an on-site survey, program participants reported that showerheads rebated through the program were used for an average of 7.64 minutes/shower, slightly less than either non-program showerheads in participant households (8.19 minutes/shower) or showerheads in non-participant households (8.62 minutes/shower). When asked directly whether program showerheads were used for more or less time than the showerheads they replaced, 15% said showers were now shorter and 5% said they were now longer. On-site measurements of shower temperature were also made; average temperatures for all three groups were within 0.4° F of each other. Statistically significant differences between the groups could not be discerned.

Thus, both the HUD and PG&E studies show that little or no takeback occurred. Additional support for this finding is provided by a survey of participants in NEES's Electric Space Heat Program, a program which included low-flow showerheads. In a survey of program participants, only 4% indicated they took longer showers (Ref. 1). Data on the proportion of participants who took shorter showers were not collected.

Regarding rebates for high efficiency water heaters, a survey by WP&L on the water heater portion of their Buysmart program reported some indications of takeback. In the survey (Ref. 22), 8% of participants reported that without the rebate they would not have purchased a water heater "of this kind" and 7% indicated that the rebate induced them to purchase a larger water heater. With regards to the first issue, since nearly all houses have only one water heater, it is highly unlikely that the program would cause a homeowner to purchase a second water heater. A more likely interpretation of the data is that consumers purchased a different type of water heater than they otherwise would have (the survey was unclear by what was meant by "of this kind"). With regards to the second issue, larger water heaters are slightly less efficient than smaller water heaters, but trading up one size usually only decreases efficiency (and hence increases energy use) by only 1%. Thus, the takeback implied by the WP&L survey results is unlikely to result in any significant increase in energy use.

Lighting

An increasing number of DSM programs are promoting use of compact fluorescent lamps. Takeback could occur with these lamps if lamps are left on longer or are brighter than the lamps that were replaced. Five studies address this first issue and one study addresses the second issue.

Thus far, changes in lamp operating hours have only been measured through customer surveys; to our knowledge physical measurements of lamp operating hours before and after retrofit have yet to take place. Surveys on changes in lamp operating hours after compact fluorescent lamps are installed have been conducted by PG&E, Boston Edison (BE), and NEES (two studies) (Refs. 8, 19, 10 and 1). Results of these studies indicate that 8-32% of the compact fluorescent bulbs are used more often and 2-12% are used less often than the bulbs they replaced. Both the PG&E and BE studies collected data on operating hours per lamp and calculated an average change in lamp operating hours; for PG&E and BE compact fluorescent lamps were used an average of 5% and 12% more than the bulbs they replaced. Thus, these surveys all indicate that some takeback occurs, but takeback effects are modest.

The PG&E study also collected data on lamps that were replaced when compact fluorescent lamps were installed. Two types of compact fluorescent lamps were distributed -- an 18 W lamp and a 27 W lamp. These are designed as replacements (based on equivalent light output) for 75 W and 90 W incandescent lamps, respectively. Survey results found that on average the 18 W and 27 W lamps displaced 74 W and 88 W lamps respectively, indicating that takeback effects were minimal (Ref. 8).

Indirect support for these findings of minimal takeback effect comes from a 1990 impact analysis of NEES' Energy Fitness Program -- a program that primarily installs compact fluorescent lamps in participating homes. For the evaluation, electricity consumption of program participants before and after participation was compared to a control group of nonparticipants. For the 1990 program, net energy savings averaged 295 kWh/home. Engineering estimates of the savings, which incorporate survey data on free riders and field data on lamp operating hours and premature removal of lamps, indicate savings of 311 kWh/home (Ref. 10). After considering the confidence interval around the savings estimate ($\pm$ 116 kWh at 90% confidence), it appears that little, if any, takeback occurred.

On the other hand, an impact evaluation of the 1991 program found savings of 143 kWh/home (with a 90% confidence interval of $\pm$ 65 kWh), nearly 50% less than the engineering estimate of 297 kWh. Reasons for this large discrepancy are unclear and could be due to difficulties discerning small savings from whole-house billing data, increased removal of lamps following the survey, errors in operating hour estimates, and/or greater takeback than indicated by all of the other studies discussed above (Ref. 10).

Refrigerators

Takeback with more efficient refrigerators could occur if purchasers of more efficient refrigerators purchase larger models or models with additional energy-consuming features. Surveys by PG&E and WP&L on their refrigerator rebate programs address these issues.

In the PG&E survey (Ref. 15), both program participants and a control group of nonparticipants who recently purchased refrigerators were surveyed. The survey found that participants were somewhat less likely than nonparticipants to purchase ice makers and thru-the-door service (20-29% versus 29-52% depending on the feature). Nonparticipants purchased slightly larger refrigerators than participants (20.9 versus 20.0 ft^3). In comparing their new units to their old units, a larger proportion of nonparticipants reported that they increased unit size or the number of features. For example, the average size increase was 1.8 ft^3 for participants versus 2.6 for nonparticipants. These findings all tend to indicate that no takeback occurred. On the other hand, 6% of the participants indicated that due to the program, they purchased a larger refrigerator and 10% indicated the program influenced their decision to purchase more features. This finding indicates a small takeback effect.

In the WP&L survey (Ref. 22), 6% of program participants reported that without the rebate they would not have purchased a refrigerator of this kind and 5% indicated that the rebate induced them to purchase a larger refrigerator. As discussed above under water heaters, without further clarification of what is meant by "of this kind," the first question cannot be interpreted. Responses to the second question indicate that a small amount of takeback may be occurring.

Considering all questions in both surveys, it appears that if any takeback is occurring, the takeback is very limited.

COMMERCIAL AND INDUSTRIAL SECTORS

Lighting

Studies on takeback with lighting in the commercial and industrial sectors are very limited. Takeback can occur if program participants increase the operating hours of their lights or if light output is increased. Regarding operating hours, a survey of participants in NEES' Small C&I Program (a direct installation program for lighting) found that 90% of participants reported no change in lamp operating hours, 5% reported an increase, and 5% reported a decrease (Ref. 14).

Regarding lighting levels, two evaluation studies address this issue, one on WP&L's Bright Ideas for Businesses Program and one on BPA's Industrial Lighting Incentive Program. The WP&L study (Ref. 13) included a participant survey in which 33% of participants reported that they increased their lighting levels and 7% reported that they decreased lighting levels after participating in the program. Answers to this question were entered into a multiple regression analysis that sought to explain changes in electricity use. For large commercial and industrial customers, the lighting level reduction variable was not a useful addition to the regression equation. For small and medium-sized customers, the lighting level reduction variable was a useful addition to the equation. For these buildings, for all seven of the measures studied, changes in lighting levels were found to decrease energy savings including five measures (ballasts, fluorescent lamps, delamping, motors, and other non-lighting measures) for which this variable was statistically significant at the 95% confidence level. While these findings might be expected for ballasts and lamps, for the other three measures, these findings are counterintiutive. It is possible that answers to this question are correlated with other variables that were not in the regression equation. Thus, while this study indicates that some takeback may have occurred in this program, results are far from conclusive. According to program staff, customers were allowed to receive rebates for new lighting loads. Many customers with high intensity discharge lighting systems, which are used for outdoor lighting and interior lighting in industrial facilities, took advantage of this feature. Subsequently, program rules were tightened to make new lighting loads ineligible for rebates (Ref. 23).

The BPA program was a pilot program designed to upgrade high-bay industrial and warehouse lighting. The program promoted the installation of new fixtures. Since lighting in most of the participating facilities was considered substandard, participants were allowed and encouraged to increase lighting levels. As a result, lighting levels increased by an average of 36%, but even with these increased lighting levels, lighting loads were reduced by an estimated 50% (Ref. 37). Thus, a substantial amount of takeback did occur, although this takeback was anticipated and was therefore accounted for in the incentive structure of the program; incentives depended on load reductions relative to the old lighting system -- as light levels increased, load reductions and incentives decreased.

Industrial Process

Industrial DSM is often touted as an economic development strategy: by making plants more efficient, it is argued, the plant will become more competitive, and production levels may increase. Increased production is a form of takeback. To our knowledge, the only studies which have addressed this issue in a systematic and empirical fashion are a set of eleven evaluations on process efficiency improvements in eleven plants that participated in BPA's Energy Savings Plan Program (Ref. 2). The plants represented a range of industries including lumber, paper, food processing, cold storage, air separation, petroleum, chemical, and fabricated metals. Of the eleven evaluations; one indicated that production has increased 12% as a result of the efficiency measures installed (Ref. 31) and one indicated that the firm plans to increase production in the future (Ref. 32). The other nine evaluations found no increase in production. Thus, this small sample of eleven tends to indicate that, on average, only limited takeback with industrial process measures can be expected.

CONCLUSIONS

The Research findings summarized here indicate that takeback can occur, but it is not a widespread phenomenon. Instead, takeback is a localized phenomenon, largely limited to several specific end-uses. For residential space heating, a total of 15 studies indicate that little if any takeback is likely. For residential lighting takeback, in the form of increased operating hours, can increase energy use of compact fluorescent lamps by approximately 10% relative to what use would have been if operating hours remained unchanged. For industrial process measures, based on a very small sample size, increases in plant production levels following efficiency improvements may increase energy use by an average of about 2% above what use would have been if production levels did not change. For residential water heating, there is no evidence of takeback. Data for the other end-uses studied are inconclusive, but tend to indicate that takeback is unlikely for residential refrigeration, may occur for residential air conditioning, and probably will occur for industrial lighting as a result of increases in lighting levels. For commercial lighting, data are too limited to reach even preliminary conclusions. While this study indicates that much is known about takeback, additional research would be useful which is directed at end-uses where substantial questions remain. Among the end-uses that should be targeted are commercial lighting, other commercial end-uses (which were not included in any of the studies examined here), and residential air conditioning.

ACKNOWLEDGEMENTS

Support for this work was provided by grants from the Energy Foundation and the Pew Charitable
Trust. Helpful comments on a draft version of this paper were provided by Eric Hirst, Ken Keating, Ralph Prahl and Ed Vine.

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