The Rebound Effect: Large or Small?

Steven Nadel

August 2012

An ACEEE White Paper

529 14th Street NW, Suite 600, Washington, DC 20045
Phone: (202) 507-4000 • Twitter: @ACEEEDC
Facebook.com/myACEEE • www.aceee.org

Contents

Abstract

As the energy efficiency of products, homes, and businesses improves, it becomes less expensive to operate them. The rebound effect is a postulate that people increase their use of products and facilities as a result of this reduction in operating costs, thereby reducing the energy savings achieved. Periodically over the years, some analysts raise questions about the rebound effect, arguing that it is a major factor that needs to be accounted for when analyzing energy efficiency programs. This paper is written in "question and answer" format and is designed to summarize what we know, what we do not, and—given what we know—how large the rebound effect is likely to be.

We find that there are both direct and indirect rebound effects, but these tend to be modest. Direct rebound effects are generally 10% or less. Indirect rebound effects are less well understood but the best available estimate is somewhere around 11%. These two types of rebound can be combined to estimate total rebound at about 20%. We examined claims of "backfire" (100% rebound) and they do not stand up to scrutiny.

Overall, even if total rebound is about 20%, then 80% of the savings from energy efficiency programs and policies register in terms of reduced energy use. And the 20% rebound contributes to increased consumer amenities (for example, more comfortable homes) as well as to a larger economy. These savings are not "lost" but put to other generally beneficial uses.

Acknowledgments

Helpful comments on a draft of this paper were provided by Jonathan Koomey (Stanford University) and Therese Langer, Maggie Molina, Naomi Baum, Skip Laitner, and Neal Elliott (ACEEE). Renee Nida edited the manuscript. To them I am grateful.

Introduction

Periodically over the years, some analysts raise questions about the rebound effect, arguing that it is a major factor that needs to be accounted for when analyzing energy efficiency programs.[1] This paper is designed to address questions about the rebound effect, what we know, what we do not, and—given what we know—how large the rebound effect is likely to be. We concentrate on information about the United States and not other countries.

Q. What is the rebound effect?

A. As the energy efficiency of products, homes, and businesses improves, it becomes less expensive to operate them. The rebound effect is a postulate that people increase their use of products and facilities as a result of this reduction in operating costs, thereby reducing the energy savings achieved. The most extreme position is that rebound can wipe out all of the energy savings caused by the efficiency gains, a phenomenon labeled backfire.

For example, if a 20% improvement in residential space heating actually results in only an 18% drop in natural gas consumption, the rebound effect would equal 10%.[2] The 2% of expected energy savings missing from the total savings realized is the extra energy consumed by the new, more efficient furnace because the household residents changed their habits, such as boosting the setting on their thermostat.

Q. Is there a single rebound effect or several?

A. Different authors have suggested different types of rebound effects, but these boil down to two general types—direct and indirect.

Direct rebound is the impact of a purchase of an efficient product by the purchaser's use of that product. For example, a car buyer may drive an efficient car more often than an inefficient one or a homeowner who weatherize his/her house may use a portion of the savings to increase the temperature in the house in the winter to increase comfort.

Indirect rebound, on the other hand, reflects the impact of re-spending the money that consumers and businesses save from improved energy efficiency. It can also include the fact that as factories and other parts of the economy get more efficient, production costs may be lower, freeing up funds to expand the factory. Also, if production costs are lower, demand for products can increase. An example of the former is a household that cuts its heating bill and takes back a little of the savings on higher thermostat settings, but then spends the money saved on eating out or buying a new flat screen

---

[1] The first such reference is to a paper written in 1865 by William Stanley Jevons called *The Coal Question*. In the 1980s the concept was suggested by Daniel Khazzoom (1980) and was sometimes called the *Khazzoom Effect*. In the past few years papers claiming substantial rebound effects have been written by Sorrel (2007), Owen (2010), Jenkins et al. (2011), and Michaels (2012), among others. Counterarguments have been advanced by Goldstein et al. (2011), Koomey (2011), and Afsah and Salcito (2012), among others.

[2] Calculated as (20 – 18) / 20 * 100% = 10%.

television. An example of the latter is that efficiency improvements in aluminum smelting can reduce the price of aluminum thereby fostering increased aluminum sales that, requires additional energy consumption in its production.

Q. What are the most plausible estimates of the size of the direct rebound effect?

A. There have been more than 100 studies published that attempt to estimate direct rebound effects for specific energy efficiency programs and policies. Many of these are evaluations of individual programs. These studies indicate that direct rebound effects will generally be about 10% or less. In the paragraphs below we summarize some of the key findings by end-use.

Passenger Vehicles: More efficient vehicles cost less per mile for fuel, which can spur some car owners to drive longer distances. They could also potentially use some of the fuel savings to buy a larger car or even a second car. Many studies have been conducted and, interestingly, recent studies have found smaller rebound effects than older studies. For example, the National Highway Traffic Safety Administration and the Environmental Protection Agency (NHTSA and EPA 2010) discuss a series of papers by Small and Van Dender that found an average rebound effect of 22.2% over the 1966-2001 period, 10.7% over the 1997-2001 period, and 6% over the 2000-2004 period. Based on a thorough review of these and other recent studies, NHTSA and EPA (2010) estimate that rebound for passenger vehicles in response to new fuel economy rules will be about 10%.

Space Heating: Greening et al. (2000) and Sorrell (2007) both estimated 10-30% rebound for space heating, citing several studies they reviewed. This rebound includes behavioral effects (e.g., increasing thermostat setpoints) and technical effects (e.g., portions of the house are warmer after weatherization). However, examination of the underlying papers does not support the high end of this range, at least for most households in the United States. A more likely range is 1-12%, with rebound effects sometimes higher than this range for low-income households who could not afford to adequately heat their homes prior to weatherization.[3]

Space Cooling: Nadel (1993) examined eight studies that looked at rebound (called "takeback" in the paper) for air conditioning. This paper reports that "one study found no evidence of takeback, two

[3] In the Greening et al. paper, four U.S. studies are listed. For one, they note 8-12% rebound while for another they note 1-3%. The other two were studies of consumer responses to changes in energy prices, not to responses following weatherization. But as Greene (2010) has shown for automobile fuel economy, the elasticities for prices and efficiency can be statistically different from each other. In the case of Sorrell, he lists five U.S. evaluation studies with rebound numbers. Three of these are from the same project in the town of Hood River, Oregon, with rebound estimates of 5% from temperature data and 5%, 20%, and 25% based on electricity billing data and "complicated assumptions" for which the original authors urge caution. Also part of the effect in Hood River was a fuel switching effect—some participants used less wood heat and increased their use of electric heat. The same authors estimate 11% rebound in a study in a different region, again with a caution about "complicated assumptions." The final study estimated a 40% rebound but this was a study on low-income homes in a mild climate—both factors that can lead to higher than average rebound (rebound in low-income homes is discussed in the text; moderate climates are discussed in the Space Cooling section). Sorrell also cites several econometric studies that calculate price elasticity, not responses following weatherization. In sum, the most widely applicable estimates of rebound in these studies range from 1-12%.

studies found evidence for limited takeback, one study found circumstantial evidence for takeback, and four studies were inconclusive." The paper concludes: "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." For example, Dubin et al. (1986) conducted a statistical analysis on a high efficiency air conditioner/heat pump program operated by Florida Power & Light. Based on this model, the authors conclude that very little rebound took place in the summer months when outdoor temperatures are very high (rebound estimates were 1-2% of the energy savings that would otherwise result) but that significant, though limited, rebound took place in spring and summer when temperatures and the need for air conditioning were more modest (rebound estimates were as much as 13% of anticipated energy savings)[4].

Residential Lighting and Appliances: Nadel (1993) looked at five lighting studies and concluded that consumers modestly increase operating hours after they install efficient lights, with a range of 5-12% greater operating hours. Greening et al. (2000) use the same range. For water heating, Nadel also found five studies and these found little evidence of rebound. For example, two studies involving low-flow showerheads found no increase in the length of showers after the new showerheads were installed.[5] For refrigerators, Nadel looked at two studies and concluded that "it appears that if any takeback is occurring, the takeback is very limited." Greening et al. echo this finding. Finally, Sorrell (2007) discusses work by Davis on a study involving high-efficiency clothes washers. The study found that following purchase of high-efficiency clothes washers the pounds of clothes washed increased by about 5%. It is unclear to what extent this increase is due to the higher efficiency of the new washers or to their larger capacity per load.

Summary: While there is some uncertainty, particularly for space heating and air conditioning, available evidence indicates that direct rebound effects will generally be 10% or less. Estimates of higher direct rebound effects are primarily based on studies on consumer responses to changes in energy prices, but as shown by Greene (2010) for vehicles this is different from consumer response to changes in energy efficiency. There is a need for a study on home weatherization that attempts to separate out price and rebound effects to see if they are similar or different. Rebound is probably higher for weatherization of low-income homes since prior to weatherization some of these households could not afford to keep their homes as warm as they would have liked.

[4] [4] Greening et al. (2000) cite this study and also one by Hausman. However, as described by Nadel (1993): "the [Hausman] 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."

[5] Greening et al. (2000) estimate 10-40% rebound but this appears to be based on one econometric study by Hartman that looked at price and income elasticities for a hypothetical water heater wrap and solar water heating program. As discussed in Footnote 3 of this paper, price elasticities are different from the rebound effect.

Q. What is the range of estimates on the indirect rebound effect and which are most plausible?

A. There is substantial uncertainty about the size of indirect rebound effects and more careful studies are needed. From the evidence that is available, the most likely estimate is that indirect rebound effects are on the order of 11%, increasing both energy use and the level of economic activity. This 11% means that if a set of policies reduce a country's energy use by 10%, after indirect rebound is accounted for, actual energy savings will be only 8.9%.[6]

This 11% rebound estimate comes from a study by Barker and Foxon (2008) that used a sophisticated macroeconomic model to examine the impact of a number of United Kingdom energy efficiency policies over the 2000-2010 period. The study estimated that indirect rebound was 11% by 2010, with higher effects (15%) in energy-intensive industries and lower effects for commerce (5%), road transport (6%) and households (10%). Unfortunately, there are no similar studies of the U.S., although such a study would be useful.

Other studies, using different methodologies, come up with different answers, both higher and lower. For example, Laitner et al. (2012) examine energy efficiency opportunities out to 2050. In their advanced scenario, they estimate that energy use can be reduced by 42% in 2050 relative to a business-as-usual reference case. Using an input-output model of the U.S. economy, they estimate that these efficiency savings will increase U.S. GDP in 2050 by 0.3% above the reference case. If this extra GDP growth requires the same amount of energy per dollar of GDP as the rest of the economy, the rebound would be only 0.7%.[7] On the one hand money saved from efficiency can be reinvested in the economy. On the other hand, the efficiency investments pull capital that would have been invested elsewhere. The net effect is a small macroeconomic rebound. However, Laitner et al. posit that this estimate likely underestimates the indirect rebound to some degree because there are attendant non-energy or productivity enhancing impacts that they did not model that may boost the economy more than 0.3%.

At the high end, a variety of Computable General Equilibrium (CGE) models have been used to estimate indirect rebound effects. Sorrell (2007) summarizes eight such studies, none in the United States. Rebound estimates range from 37% to more than 100%. However, as described in detail by Sorrell, CGE models have a number of limitations. According to Sorrell, such models are "based upon a number of standard neo-classical assumptions (e.g., utility maximization; perfect competition; constant returns to scale in production, etc.) that are poorly supported by empirical evidence. In particular, the possibility of "win-win" policies, such as those aimed at encouraging energy efficiency, may be excluded if an economy is assumed to be at an optimal equilibrium."

Several additional lines of reasoning can be used to reject rebounds approaching 100%. First, returning to the Laitner et al. study, in order for rebound to eliminate all of the savings estimated, assuming 5% direct rebound, indirect rebound would have to increase U.S. energy use by 49

---

[6] 10% savings * (100% - 11% rebound) = 8.9% savings after rebound.
[7] 0.3% higher energy use / 42% energy savings = 0.7% rebound.

quadrillion Btu.[8] If this extra energy use was at the same energy per dollar GDP ratio as the rest of the economy, the U.S. economy would be $25 trillion bigger (2009 $), an increase of 69% relative to the business-as-usual base case. While as energy efficiency advocates we would love to be able to claim that energy efficiency could grow the economy by 69%, such claims are not plausible.

Second, we can look at the fact that energy is about 7% of total GDP in the U.S.[9] If money saved through energy efficiency is respent, we would expect about 7% of this money to ultimately be used to purchase energy. It would be a little higher than 7% if this respending were in energy-intensive portions of the economy (e.g., this was among Barker and Foxon's findings, contributing to their estimate of 11% indirect rebound).

Third, we can look at look at evaluations of energy efficiency programs in the industrial sector. The industrial sector is a more complicated sector for exploring rebound than the residential sector or passenger vehicles. Energy efficiency investments reduce costs, which can allow sales and hence production and energy use to increase. For much of the industrial sector, energy costs are a very small portion of production costs (e.g., 2% on average[10]) and reductions in energy use will not be great enough to appreciably affect production costs. But for some energy-intensive industries (e.g. aluminum, steel, chemicals) energy costs are more significant and it is possible for decreases in energy costs to affect sales. This could happen for a single plant, with some of the extra production offset by reductions at a less efficient plant, or if the savings were large enough, it could affect an entire industry, albeit again with some offsets (e.g. if sales of aluminum increased, there might be some declines in steel or plastics). In terms of actual data, Nadel (1993) reviewed a set of eleven evaluations of specific industrial efficiency improvements at individual plants. Of the eleven evaluations, nine found no change in production, one indicated that production had increased 12% as a result of the efficiency measures installed and one indicated that the firm plans to increase production in the future (although it was unclear if the efficiency improvement was contributing to this planned change). Overall, this small sample provides a preliminary indication that, on average, only limited rebound with industrial process measures can be expected. Further real-world data on these issues would be useful.

Finally, experience at the state level in a state with extensive energy efficiency savings is instructive. For example, in recent years Vermont has had the most aggressive electric and natural gas efficiency programs. As a result absolute electricity use in Vermont peaked in 2005 and has since declined 5% (as of 2010, the last data available). Likewise, absolute natural gas use peaked in 2000 and has declined 11% since then. And there have not been shifts to other energy sources since overall energy use peaked in 2004 and subsequently declined by about 9% (EIA 2012). These changes have not happened at the expense of the state's economy—Gross State Product increased 12% over the 2000-2010 period (in 2005 $) (Bureau of Economic Analysis 2012). The economy of an entire state is very complex and these simple numbers cannot be used to calculate a specific indirect rebound estimate.

---

[8] A quadrillion is 10 to the 15th power. The U.S. now uses about 100 quadrillion Btu of energy annually.

[9] See http://www.eia.gov/oiaf/economy/energy_price.html.

[10] Derived by ACEEE from data in Bollman (2008).

But these numbers do illustrate that efficiency programs and policies do save substantial energy, and while there could be some rebound, backfire is not happening.

In summary, there is substantial uncertainty about the size of indirect rebound effects and more careful studies are needed, such as a detailed macroeconomic study of the U.S. similar to what Barker and Foxon did for the U.K. From the evidence that is available, the most likely estimate is that indirect rebound effects are on the order of 11%, increasing both energy use and the level of economic activity.

Q. What other types of analyses have been done and do they provide useful information about the rebound effect?

A. A variety of other analyses have been done that are purported to support high estimates of rebounds. These include anecdotes, comparisons between engineering estimates of energy efficiency savings and the actual savings achieved, and statistical approaches.

A good example of the use of anecdotes is Owen's article in *The New Yorker* (2010). For example, Owen notes that between 1993 and 2005, new air conditioners in the U.S. increased in efficiency by 28%, but by 2005, homes with air conditioning increased their consumption of energy for their air conditioners by 37%. But as Dr. James Barrett, Chief Economist of the Clean Economy Development Center, responds: "Owen presents this as clear and obvious proof of a [rebound] effect. Case closed. Here is where Owen gets lazy: A few key facts disprove the point." Barrett finds that over this period per-capita real income rose 30%, homes got 16% bigger, the proportion of homes with air conditioning doubled and average efficiency of air conditioners in use (both new and old units) increased only 11% (Barrett 2010). Nadel adds that the cost of air conditioners declined more than 50% over the 1960-2009 period, even after adjusting for inflation (Nadel 2011). Clearly an 11% increase in air conditioner efficiency did not cause all of these other effects. Instead, air conditioning used more energy not because of greater efficiency but despite it.

Among the arguments made by Michaels (2012) is that actual evaluations of savings from utility energy efficiency programs show that savings achieved are typically around 75% of the savings estimated from engineering calculations of the measures installed. He argues that such findings "are consistent with appliance rebound studies." However, there are many reasons that engineering estimates may be off (Nadel and Keating 1991) and thus faulty engineering calculations are not evidence of rebound.

Finally, a variety of statistical analyses have been done that claim to tie increases in energy efficiency to increases in energy use.[11] However, correlation is not the same as causation. As Afsah and Salcito (2012) point out, a careful review of underlying technological change and engineering changes are needed to figure out what is causing the increase in energy use.

In sum, these other lines of evidence are very weak.

---

[11] See, for example, Saunders (2010).

Conclusions

There are both direct and indirect rebound effects, but these tend to be modest. Direct rebound effects are generally 10% or less. Indirect rebound effects are less well understood but the best available estimate is somewhere around 11%. These two types of rebound can be combined to estimate total rebound at about 20%. [12] Claims of "backfire" (100% rebound) do not stand up to scrutiny. Furthermore, direct rebound effects can potentially be reduced through improved approaches to inform consumers about their energy use in ways that might influence their behavior (Ehrhardt-Martinez and Laitner 2010). And indirect rebound effects, which appear to be linked to the share of our economy that goes to energy, may decline as the energy intensity of our economy decreases.

Overall, even if total rebound is about 20%, then 80% of the savings from energy efficiency programs and policies register in terms of reduced energy use. And the 20% rebound contributes to increased consumer amenities and a larger economy. These savings are not "lost" but are put to other generally beneficial uses.

References

Afsah, Shakeb and Kendyl Salcito. 2012. "Energy Efficiency Is for Real, Energy Rebound a Distraction." http://co2scorecard.org/home/researchitem/21. CO2 Scorecard Group.

Barker, Terry and Tim. Foxon. 2008. *The Macroeconomic Rebound Effect and the UK Economy.* http://collapse.xgstatic.fr/energy_sources/pdf/UKERC_The_Macroeconomic_Rebound_Effect_and_the_UK_Economy.pdf . UK Energy Research Center.

Barrett, James. 2010. "Rebounds Gone Wild." http://www.greatenergychallengeblog.com/2010/12/20/rebounds-gone-wild/. Clean Economy Development Center.

Bollman, Andy. 2008. *Characterization and Analysis of Small Business Energy Costs.* Washington, DC: Small Business Administration Office of Advocacy.

Bureau of Economic Analysis. 2012. "Gross Domestic Product by State." http://www.bea.gov/regional/index.htm. Washington, DC: U.S. Department of Commerce.

Dubin, Jeffrey, Allen Miedema, and Ram Chandran. 1986. "Price Effects of Energy-Efficient Technologies: A Study of Residential Demand for Heating and Cooling." *Rand Journal of Economics* 17(3), 310-325.

Ehrhardt-Martinez, Karen and Skip Laitner. 2010. "Rebound, Technology, and People: Mitigating the Rebound Effect with Energy-Resource Management and People-Centered Initiatives." In Ehrhardt-Martinez and Laitner, eds. *People-Centered Initiatives for Increasing Energy Savings.*

[12] 0% direct rebound + (11% indirect rebound * 100% - 10% direct rebound) = 20%.

http://www.aceee.org/people-centered-energy-savings. Washington, DC: American Council for an Energy-Efficient Economy.

EIA. 2012. *State Energy Consumption Estimates, 1960-2010.* DOE/EIA-0214(2012). Washington, DC: U.S. Department of Energy.

Goldstein, David, Sierra Martinez, and Robin Roy. 2011. *Are There Rebound Effects from Energy Efficiency? An Analysis of Empirical Data, Internal Consistency, and Solutions.* http://www.electricitypolicy.com/Rebound-5-4-2011-final2.pdf. Electricity Policy.com.

Greene, David. 2010. "Rebound 2007: Analysis of U.S. Light Duty Vehicle Travel Statistics." *Energy Policy* 41 (2012), 14–28.

Greening, Lorna, David Greene and Carmen Difiglio. 2000. "Energy Efficiency and Consumption—The Rebound Effect—A Survey." *Energy Policy* 28 (2000), 389-401.

Jenkins, Jesse, Ted Nordhaus, and Michael Shellenberger. 2011. *Energy Emergence: Rebound and Backfire as Emergent Phenomena.* http://thebreakthrough.org/blog/Energy_Emergence.pdf. Oakland, CA: The Breakthrough Institute.

Jevons, W. Stanley. 1865. *The Coal Question*. Macmillan.

Khazzoom, J. Daniel. 1980 "Economic Implications of Mandated Efficiency in Standards for Household Appliances." *Energy Journal* 1 (4, 1980), 21–40.

Koomey, Jonathan. 2011. "A Fascinating Encounter with Advocates of Large Rebound Effects." http://www.koomey.com/post/3286897788.

Laitner, John A. "Skip," Steven Nadel, R. Neal Elliott, Harvey Sachs, and A. Siddiq Khan. 2012. *The Long-Term Energy Efficiency Potential: What the Evidence Suggests.* http://www.aceee.org/research-report/e121. Washington, DC: American Council for an Energy-Efficient Economy.

Michaels, Robert. 2012. *Energy Efficiency and Climate Policy: The Rebound Dilemma.* http://www.instituteforenergyresearch.org/efficiency-rebound-dilemma/. Washington, DC: Institute for Energy Research.

Nadel, Steven. 1993. *The Takeback Effect: Fact or Fiction.* http://www.aceee.org/research-report/u933. Washington, DC: American Council for an Energy-Efficient Economy.

Nadel, Steven. 2011. "Our Perspective on the "Rebound Effect" — Is It True That the More Efficient a Product Becomes, the More Its Owner Will Use It?" http://aceee.org/blog/2011/01/our-perspective-rebound-effect-it-true-more-efficient-pro. Washington, DC: American Council for an Energy-Efficient Economy.

Nadel, Steven and Kenneth Keating. 1991. *Engineering Estimates vs. Impact Evaluation Results: How Do They Compare and Why?"* http://www.aceee.org/research-report/u915. Washington, DC: American Council for an Energy-Efficient Economy.

NHTSA and EPA. 2011. *Draft Joint Technical Support Document: Proposed Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards*. EPA-420-D-11-901. Washington, DC: U.S. Environmental Protection Agency.

Owen, David. 2010. "The Efficiency Dilemma." *The New Yorker.* Dec. 20 and 27, 78-85.

Saunders, Harry. 2010. "Historical Evidence for Energy Consumption Rebound in 30 U.S. Sectors and a Toolkit for Rebound Analysts." http://thebreakthrough.org/blog/Historical%20Evidence%20Article%2011-11-10.pdf. Breakthrough Institute.

Sorrell, Steven. 2007. *The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Savings from Improved Energy Efficiency*. http://www.ukerc.ac.uk/Downloads/PDF/07/0710ReboundEffect/0710ReboundEffectReport.pdf. London: UK Economic Research Center.