Are There Rebound Effects from Energy Efficiency? – An Analysis of Empirical Data, Internal Consistency, and Solutions

Of the rigorously-framed hypotheses claiming that large negative rebounds exist, we measure them against the data, which refute the hypotheses. Rebounds at the end-use level are small and decrease over time. Rebounds at the economy-wide level are trivially small, and might well be a net positive.

by David B. Goldstein, Sierra Martinez, and Robin Roy

Every few years, a new report emerges that tries to resurrect an old hypothesis: that energy efficiency policy paradoxically increases the amount of energy we consume. This paper attempts to develop a rigorous and scientifically sound hypothesis for rebound theory. It shows that many of the hypotheses on which the recent papers promoting rebound effects are based are neither scientific nor testable. Further, the formulations of previous rebound hypotheses are biased toward only discovering negative second order effects of efficiency policies. We provide an unbiased formulation of rebound theory and call for balanced research into both positive and negative second order effects.

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We then assess the rebound theorists' solutions to climate change. We find some of the solutions inconsistent with rebound theory itself. We also find that regardless of the extent to which rebound theory may be true, once an emissions cap is instituted, efficiency policies only enhance that solution.

Last, we analyze the qualitative nature of rebounds and find that they are largely providing basic energy services to low income communities and those in developing countries. Rebound theorists have yet to explain how recommendations of less reliance on energy efficiency does not require maintenance of lower standards of living for many poor and developing populations around the world.

I. Introduction

Reducing our greenhouse gas emissions is essential if we are to combat climate change.[1] Efficiency has played and will play an essential role in achieving those goals.[2] However, rebound theorists argue that efficiency cannot make much of a difference in solving our climate change problems. Given the importance of climate change, we find it imperative that any theory that would challenge what is increasingly recognized as our most effective tool to combat climate change—energy efficiency—be subject to careful standards of scientific scrutiny.

In this paper we analyze the structure of the various hypotheses concerning rebound effects, and find that many are so loosely stated that they are incapable of being tested, or of yielding unambiguous and meaningful predictions. In some cases, hypotheses that rebounds can occur for some end uses in some countries are conflated with hypotheses that rebounds occur universally. For more rigorous statements of rebound hypotheses, we compare these hypotheses to the facts, and find that the data and logic do not support the claims of significant economy-wide losses due to rebound. We find that rebound is at most small and gets smaller as efficiency increases. Finally, we note that rebound, to the limited extent that it occurs, represents a net increase, not a loss, in consumer welfare. These findings reinforce the urgency with which we must deploy efficiency measures to address the threats of climate change.

After a hiatus of several years in academic and policy-related discussions of possible second-order effects of efficiency policies, several recent news articles have emerged arguing that efficiency programs cannot possibly save as much as one would think.[3] These articles present a particular version of possible second order effects by looking at "rebound" effects,[4] which assumes that

[1] Lenny Bernstein, et al., *Climate Change 2007: Synthesis Report: An Assessment of the Intergovernmental Panel on Climate Change* (2007) http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

[2] *See, e.g.*, International Energy Agency, World Energy Outlook 2009, which shows efficiency as the dominant component of a program to stabilize CO2 emissions at 450 ppm.

[3] David Owen, *The Efficiency Dilemma*, New Yorker, 78 (Dec. 27, 2010) [hereinafter "Owen"]; John Tierney, *When Energy Efficiency Sullies the Environment*, New York Times, (Mar. 7, 2011) [hereinafter "Tierney"]; *Not Such A Bright Idea*, The Economist, (Aug. 26, 2010); Jesse Jenkins, Ted Nordhaus, and Michael Shellenberger, *Energy Emergence: Rebound & Backfire as Emergent Phenomena* (Breakthrough Inst., Feb. 2011) [hereinafter "BTI"]; Steve Sorrell, *The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Saving From Improved Energy Efficiency* (UK Energy Research Centre, Oct.. 2007) [hereinafter "Sorrell"].

[4] There are many terms in addition to "rebound" to describe these theories, including "snap back," "take back," "backfire," and "bounceback," among others.

the sign of the effect is negative, (i.e., that the second order effects all cause savings to be reduced instead of increased).[5] They also leave the impression that rebound effects are consistent and universal across uses and levels of efficiency.

Several of these articles note that the original idea was introduced in the 19th century under the name of "Jevons's Paradox." Jevons asserted that increases in efficiency of coal processes would cause coal consumption to increase, to a level that would exceed previous consumption levels.[6] What Jevons failed to address was that future consumption levels could also exceed previous consumption levels absent any improvements in efficiency, due to technological innovation and its consequent economic growth, which were emergent and poorly understood processes at the time. Further, Jevons lived during a time in which energy costs composed a much larger share of GDP than presently.[7] Additionally, Jevons limited his scope to the industrial sector, in which the share of energy costs were, and are, larger than many other sectors. These conditions would give the impression of high sensitivities to energy costs. As energy costs decrease as a share of total costs, sensitivity to energy prices decreases, as does the rebound effect.[8] However, we now live

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For purposes of this paper, "rebound" will be used to describe all these effects, with the term "backfire" reserved for rebounds of greater than 100 percent of the savings. See Sec. III, at 4, below, for further description.

[5] There is variation in terminology of "positive" versus "negative" rebound (or second order) effects. In this paper, we use "positive" second order effects to mean that savings were greater than expected, and "negative" to mean that savings were less than expected.

[6] "It is very commonly urged, that the failing supply of coal will be met by new modes of using it efficiently and economically. . . . [However, it] is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth. As a rule, new modes of economy will lead to an increase in consumption." William Stanley Jevons, *The Coal Question*, 2nd ed., 122-123 (1866). Available at: http://wesurroundthemmelbourne.com/Downloads/ClimateChange/TheCoalQuestion.pdf. In fact, rebound was not the major thesis of his book, which addressed a wide variety of issues concerning coal, nor was rebound demonstrated with anything more analytical than a few individual coal uses and technologies. These were all cases where the uses that Jevons found to be rebounding were new technologies that had not consumed much or any coal in the past. In contrast, current theories of rebound address only efficiency measures aimed at processes or end uses that already use substantial amounts of energy.

[7] Jevons observed the British economy at an anomalous point in time, when its energy intensity was at or near its peak over the last 500 years. In 1865, energy intensity was over four times as high as it was in 2000. In 1865, energy intensity was >9 kWh (of final energy consumption)/£2,000 GDP and was about 2 kWh/£2,000 in 2000. Roger Fouquet and Peter Pearson, *Five Centuries of Energy Prices*, World Econ., vol. 4, no. 3, 2003) [hereinafter "Fouquet"]. *See also,* Imperial College London, *Energy History, Development, and Sustainability*, ESS Conference, Fig. 4, UK Energy Intensity, Final Use Energy Consumption Per Unit Real GDP, 1500-2000 (Dec. 2003), available at: http://www.scj.go.jp/ja/int/kaisai/ess2003/pdf_pre/s33_pearson.pdf.

[8] International Energy Agency, *The Experience with Energy Efficiency Policies and Programmes in IEA Countries: Learning from the Critics"* 6 (Aug. 2005) [hereinafter "IEA/Geller"]. Envtl. Protection Agency, Natl. Hwy. Traffic Safety Admin., *Final Rulemaking To Establish Light Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards*, Joint

in a world in which energy costs are a much smaller portion of total costs and we apply efficiency to all sectors, not just the industrial sector. Many experts have since found that Jevons erred.[9]

The theory resurfaced in a 1980 article by Khazzoom, who claimed that energy savings from appliance efficiency regulations might be much lower than engineering calculations would estimate.[10] This article, along with most of those that have followed, relied heavily on conjecture, rather than on empirical data.[11] It also relied heavily on a faulty assumption: that consumers would respond to reductions in the operating cost of appliances but would fail to respond to increases in the purchase price. Efficiency standards would cause both price changes, but Khazzoom did not analyze those effects.[12] We know that consumers do respond strongly to purchase price, because unexploited short paybacks do exist with consumers often exhibiting hurdle rates in excess of 30 percent[13]; and mainstream analyses of the effect of standards do show reductions in product sales in response to product price increases[14]. Failure to consider all capital costs and exclusive reliance on operating costs renders the Khazzoom analysis incomplete, biased and unproven.[15]

In section II, we present the various versions of rebound and backfire theory that we have collected from the literature. We find that some theories fail to meet scientific standards because they cannot be tested. While demonstrating this

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Technical Supporting Document, 4-19 (Apr. 2010) [hereinafter "EPA/NHTSA"].

[9] "Jevons wasn't wrong about nineteenth-century British iron smelting, [Schipper] said; but the young and rapidly growing industrial world that Jevons lived in no longer exists." Owens, 79 (quoting personal conversation with Schipper). "[V]arious studies suggest that this effect [rebound] is minimal – a loss of no more than 1 or 2 percent of the direct energy savings." IEA/Geller, 8. More generally, "This provocative claim [backfire] would have serious implications for energy and climate policy if it were correct. However, the theoretical arguments in favour of the postulate rely upon stylized models that have a number of limitations, such as the assumption that economic resources are allocated efficiently. . . .Since a number of flaws have been found with both the theoretical and empirical evidence, [backfire] cannot be considered to have been verified." Sorrell, vii.

[10] J. Daniel Khazzoom. *Economic Implications of Mandated Efficiency Standards for Appliances*, Energy J., vol. 1, no. 4, 21-39 (Oct. 1980).

[11] In fact, some rebound theorists have resisted the application of data and facts to their theories: "[N]o single, widely accepted methodology exists to quantify rebound effects at the scale of aggregation most relevant to climate and energy resource depletion concerns . . . [E]fforts to study and quantify rebound effects face inherent epistemological challenges, particularly at all but the simplest of microeconomic scales. . . . [T]he study of rebound at macroeconomic scales, . . . may be properly considered the domain of theoretical inquiry." Jenkins, 25;."

[12] Khazzoom refused to consider the capital cost increase: "I do not deal with the capital cost of appliances with higher efficiency. This should not affect the result." Khazzoom, s*upra* note 10.

[13] Energy Info. Admin., *Assumptions to the Annual Energy Outlook 2010* (DOE/EIA-0554, Apr. 2010), available at http://www.eia.doe.gov/oiaf/aeo/assumption/residential.html.; EPA/NHTSA, 4-19.

[14] *See, e.g.*, DOE analysis, *infra* note 32.

[15] "Since a number of flaws have been found with both the theoretical and empirical evidence, the K-B [Khazzoom-Brookes] postulate cannot be considered to have been verified." Sorrell, vii.

failure, we try to take a more scientific approach by selecting and shaping rigorous hypotheses concerning second-order effects of efficiency policies. We also attempt to improve them by including a more comprehensive analysis about the sign[16] and the mechanisms of the second order effects. We caution against the overreliance on economic theory because many of the critical assumptions of economic theory for conditions necessary to make markets work are conspicuously absent in the energy efficiency arena.[17] Thus, we rely only sparingly on economic theory or model-based results.

In Section III, this paper discusses the evidence that informs the most rigorous, testable, and internally-consistent forms of the rebound hypotheses. We find that the evidence consistently disproves the hypotheses that large rebound effects are likely at the end-use level and on an economy-wide basis. Some modest forms of rebound hypotheses are consistent with evidence in a limited number of cases. Such hypotheses of negative rebound have been analyzed in detail by IEA[18] and EPA.[19] These data show that rebound is generally small to trivial. This paper does not disagree with these findings. In addition to rebound hypotheses, others have hypothesized that second-order effects can be positive.[20] However, these hypotheses have not been tested, or were tested in limited fashion, like the Prius effect.[21] We conclude that further studies are warranted to

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16 Sorrell acknowledges: "in some cases individual component of the rebound effect may be negative [i.e. savings are greater than expected]. It is theoretically possible for the economy-wide rebound effect to be negative ('super conservation'), . . ." Sorrell, UKERC Review of Evidence for the Rebound Effect, Supplementary Note: Graphical Illustrations of Rebound Effects, 2 (Oct. 2007). However, Sorrell does not investigate data supporting this conclusion.

17 "[A] number of standard neoclassical assumptions . . . are poorly supported by empirical evidence." Sorrell, 53. "Challenges to the existence of market barriers have, for the most part, failed to provide a testable alternative explanation for the evidence, which suggests that there is a substantial 'efficiency gap' between a consumer's actual investments in energy efficiency and those that appear to be in the consumer's own interest." William H. Golove and Joseph H. Eto, *Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies To Promote Energy Efficiency* xi (LBL-38059, Mar. 1996) (finding numerous market barriers in the energy service markets, including misplaced incentives, lack of access to capital, flaws in the market structure, and imperfect information) available at: http://eetd.lbl.gov/ea/emp/reports/38059.pdf. Energy Modeling Forum, *Markets for Energy Efficiency*, EMF Rept. 13, vol. 1 (Sept. 1996) (finding common ground among various stakeholders that market barriers are widespread and exist in energy markets, preventing energy markets from allocating available resources efficiently) available at: http://emf.stanford.edu/research/emf13/.

18 IEA/Geller, *supra* note 8.

19 EPA/NHTSA, *supra* note 8. Note that the estimates of rebound were estimated without attempting to control for the effect of decreasing location efficiency on the amount households drive; location efficiency decreased throughout the period that fuel economy was increasing.

20 "[I]n some cases individual component of the rebound effect may be negative [i.e. savings are greater than expected]. It is theoretically possible for the economy-wide rebound effect to be negative ('super conservation'), . . ." Sorrell, 3.

21 Edmund Fantino, *Choice, Conditioned Reinforcement, and the Prius Effect*, The Behavior Analyst, vol. 31, no. 2, (Fall 2008); Jack N. Barkenbus, *Eco-driving: An Overlooked Climate Change Initiative*, Energy Pol., . 767-76, vol. 38, issue 2, (Feb. 2010) (showing that eco-driving can result in 10 percent to 25 percent savings).

explore initial evidence that positive second-order effects exist in some cases.

Section IV analyzes three energy and climate policy solutions that rebound theorists have proposed. First, some rebound theorists propose that reversing our efficiency progress, making energy use *less* efficient, is the solution. This paper finds that increasing *in*efficiency would not in fact decrease energy consumption, based on all available data. Second, some rebound theorists propose that increasing the supply of cleaner generation sources is the solution. We agree that increasing renewable or other low-emissions generation is a valuable strategy to combat climate change; however, we find that within rebound theory, supply-side solutions might also induce increases in energy consumption. Third, some rebound theorists propose that some combination of instituting a cap on absolute consumption or emissions, in conjunction with energy pricing policy, is the solution. We agree with this policy in part, and discuss why the issue of potential rebounds from efficiency may have less policy relevance than meets the eye.

Section V addresses the qualitative nature of rebounds. Rebounds mean that consumers are increasing their energy consumption. However, rebounds also mean that consumers are receiving increased energy services at lower cost. These services contribute to higher standards of living, such as being able to maintain thermal comfort in a home. Rebounds are a benefit to consumer welfare. Thus, an attempt to use rebound theory to disparage efficiency policy would necessarily reduce economic welfare by reducing the value of energy services, and largely affect low-income communities disproportionately. A carbon emissions strategy that ultimately requires much of the population to live a sub-standard lifestyle, with decreased energy services, is an untenable strategy. On the other hand, energy efficiency offers a strategy that allows people to live at a higher standard of living, with increased energy services, while decreasing consumption and carbon emissions. Instead of discrediting energy efficiency, rebound theorists concerned about emissions and economic welfare should promote accelerating energy efficiency policies.

II. Framing Hypotheses of Rebound and Other Second-Order Effects

There are numerous versions of the rebound hypothesis in the literature. Many of them are difficult to define, as acknowledged by rebound theorists themselves.[22] Thus, we attempt to clarify and strengthen the various versions of rebound theory in the literature.

A. Magnitude and Scope

We provide two factors to help organize the various hypotheses: magnitude and scope. The magnitude of the hypotheses refers to how much of the energy is consumed due to the efficiency improvement. If the amount of energy is less than 100 percent of the savings, the hypothesis is considered just "rebound."[23] If the amount is greater than 100 percent, it is considered

[22] Regarding macroeconomic rebound theory: "there is no single accepted framework to rigorously define these dynamics . . . ." BTI, 23.

[23] "'If you increase the productivity of anything, . . . demand goes up.' Nowadays, this effect is usually referred to as 'rebound'" Owen, 79; Sorrell, vii.

"backfire."[24] Jevons's Paradox was a backfire theory because he claimed that energy efficiency actually increased consumption, the result of rebounding over 100 percent.

The scope of the hypothesis refers to the level at which the analysis is being conducted: the micro or macro level. A micro-level hypothesis would be at the level of the individual consumer increasing their energy demand due to the cheaper price of operating the efficient appliance. A macro-level hypothesis would be consumers reinvesting their bill savings into other sectors of the economy. We find that these two factors help keep the various hypotheses organized.

B. Rebound Hypotheses

At the outset, we note that a simple reading of economic theory would assert that large cost effective energy efficiency resources—that is, efficiency measures whose present value of benefits greatly exceeds their present value of costs—are not supposed to exist.[25] The limits of classical economic theory in allowing cost-effective energy efficiency require that we use it only cautiously and self-consistently in analyzing that efficiency. Thus, the analyses of policies must be performed in a context that recognizes the array of market failures that allow the large efficiency resource to exist in the first place.

1. Hypothesis A

The first hypothesis is the strong version of the rebound hypothesis, backfire, with rebound exceeding 100 percent of savings, as noted by Owen and others.[26] We will call this Hypothesis A: "With fixed real energy price, energy efficiency gains will increase energy consumption above where it would be without these gains."[27]

Let us analyze the scientific rigor of this hypothesis. First, the concept of "energy efficiency gains" is insufficiently defined in order to test or refute. "Energy efficiency gains" could include those efficiency gains that occur from normal business decisions in the economy or they could be limited to improvements caused by policy. We will start with "energy efficiency gains" that are not attributed to any policy driver,

24 "[W]here increased consumption more than cancels out any energy savings, as 'backfire.'" Owen, 79; "In some cases, the overall result can be what's called 'backfire': more energy use than would have occurred without the improved efficiency." Tierney, .2. "Behavioural responses such as these have come to be known as the energy efficiency "rebound effect". While rebound effects vary widely in size, in some cases they may be sufficiently large to lead to an overall increase in energy consumption – an outcome that has been termed 'backfire'." Sorrell, v.

25 Simple economics argue against the existence of energy efficiency: if there were $20 bills lying on the ground, people would already be picking them up. But note: "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." Sorrell, 53. The presence of market barriers and market failures prevent the use of all cost-effective energy efficiency, in the absence of market intervention. Golove finds that neoclassical economic theory, on which many rebound theorists base their beliefs, (see BTI's reliance on neoclassical economic theory at 6, 9, 10, 11, 23, 25, 32, 41-46), fall short of identifying the full list of market barriers and failures, and finds additional barriers under transaction cost economics. Golove, 24.

26 Owen, 79 (citing H. Saunders, *The Khazzoom-Brookes Postulate and Neoclassical Growth*, Energy J. 113-148, vol 13(4), (1992)).

27 Saunders, *Id.*.

such as the improvement in the fuel economy of commercial aircraft. Thus, we have Hypothesis A1: "With fixed real energy price, energy efficiency gains, from any cause, will increase energy consumption above where it would be without these gains." This hypothesis in not refutable, since:

- "[W]here it would be without these gains" is not calculable, even approximately. Energy efficiency has increased in the American economy 57 percent over the last 60 years.[28] It would be extremely difficult to estimate, in a repeatable way,[29] what energy consumption *would have been* if efficiencies had remained constant for the last 60 years. A robust hypothesis, given Jevons's observations dating back to 1865, would need to provide a method to estimate what energy consumption would have been if efficiencies had remained constant for the last century and a half. The complexity of an economic model of all the energy uses and predictions for each where energy use would be if efficiency were held constant creates an insurmountable requirement. The fact that demand for energy services is always shifting would further complicate the process. Fundamental choices would have to be made that create irresolvable ambiguities. For example, we would have to estimate how far people would travel if a jet plane had the speed and efficiency of a horse-drawn cart.[30] For all intents and purposes, this requirement is unattainable, so the theory is not refutable.

Energy efficiency offers a strategy that allows people to enjoy a higher standard of living, with increased energy services, while decreasing consumption and carbon emissions.

- The condition of fixed real energy price has never been met for very long in practice, so this condition to Hypothesis A1 prevents us from analyzing such a theory with much data. At best, we could try to predict what would have happened in both the "would be" scenario and the real world scenario based on price elasticities, which leads to immense indeterminacy because estimates of price elasticity may vary by factors of 12 and more.[31] These estimates are further hampered by the fact that efficiency effects energy price.

[28] In 1949, the U.S. economy required 19.6 TBtu to produce $1 billion (in 2000$); whereas in 2008, it only required 8.4 TBtu to produce $1 billion. For data through 2004: US Department of Energy, Energy Intensity Indicators in the U.S., Economy-wide Total Energy Consumption (May 2008). Available at: http://www1.eere.energy.gov/ba/pba/intensityindicators/trend_data.html. For data from 2005-2008: US Department of Energy, State Energy Database System Consumption, British Thermal Units, 1960–2008, (June 2010). Growth in post-2004 years normalized to May 2008 data in order to maintain consistency across data sources. Both sources combined hereinafter referred to as "DOE Intensity."

[29] Here "repeatable" means in a way where two different analysts would derive the same result.

[30] Sorrell acknowledges this difficulty: "[A]s the time horizon extends, the effect of [fundamental] changes on the demand for the energy service becomes increasingly difficult to separate from the effect of income growth and other factors." Sorrell 2009, 1357.

[31] Sorrell cites to studies showing long-run elasticities of demand ranging from -0.05 to -0.6. Sorrell, 45 (citing Sweeney (1984) and Kauffman (1992)).

In conclusion, we cannot measure or calculate where it would be without these gains.

2. Hypotheses A2 & A3

Let us frame a narrower version—Hypothesis A2: "With fixed real energy price, energy efficiency gains *due to policy interventions* will increase energy consumption above where it would be without these gains." This hypothesis rectifies the problem of determining the cause of the efficiency gains, but fails to be testable for two reasons. First, as was the case with previous hypotheses, the condition of fixed real energy price makes it impossible to use long time periods for data. Second, there is considerable disagreement about what energy consumption would have been without any individual policy, both at the microeconomic level and at the macro level. For example, analysts do not agree on what automobile fuel economy would have been without the 1975 CAFÉ standards, or how many compact fluorescent lamps would be in use today without utility-based incentive programs.

At the macroeconomic level, many analysts assume that without any policy, energy use would grow proportionally to GDP. While this assumption may be correct in limited cases, theory does not necessitate that energy use be a fixed fraction of GDP. This is not true for other broad resource categories, such as food, metals, transportation, etc. Nevertheless, we can frame a hypothesis that assumes these problems away: Hypothesis A3 asserts that: "energy efficiency gains *due to policy interventions* will increase energy consumption above where it would be if energy use were proportional to GDP." This hypothesis is capable of being tested. As we show in Section III, it is refuted by the data.

3. Hypothesis B

Let us try a weaker form of the hypothesis—Hypothesis B: "With fixed real energy price, energy efficiency gains will decrease energy use by less than would be predicted."

This is also fatally ambiguous, because it begs the question of what would be predicted. In fact, most predictive models *already incorporate elasticities of demand that model several rebound effects*. Thus, if heating equipment becomes more efficient, somewhat higher thermostats are predicted. Models like the National Energy Modeling System (NEMS)[32] balance supply and demand at a lower price due to efficiency policies and cause predicted energy consumption for other end uses to increase through price elasticity. Whether these modeled effects are correctly done is another question, but some level of rebound is already predicted. Thus, Hypothesis B might be claiming that current energy models incorporate rebound, and that there is nothing new to add. Or it might be claiming that some other effect beyond current models is in play. Or it might be critiquing models other than NEMS. Without answering these questions, we cannot adequately define or test Hypothesis B.

4. Hypothesis C

[32] As documented below, rebound effects are already incorporated in to energy forecasting models in use at the Departments of Energy, both in the NEMS model and in models used by individual programs. Available at: www.eia.doe.gov/oiaf/aeo/overview/residential.html#consumption.

A modified version of the previous hypothesis would say that: "energy efficiency gains from policy will increase energy consumption above where it would be, assuming the difference between proposed efficiency versus constant efficiency."[33] Hypothesis C is a well-framed and testable hypothesis. We discuss testing it in Section III and show that the data disprove it.

However, Hypothesis C's formation contains a weakness: it assumes a sign of the effect without any reason. As we will show, there are reasons based on non-economic motivators of human behavior to expect positive rebound effects as well as negative ones.

5. Hypothesis D: Other second order effects

Every previous hypothesis assumes that the second order effects will be negative, i.e., decrease what the savings were expected to be. We think this assumption should be questioned. Let us introduce Hypothesis D: "energy efficiency gains from policy will result in energy consumption being *different* from where it would be assuming the difference between proposed efficiency versus constant efficiency." This formulation does not presume the sign of the effect. Such an absence of presumption is important, because if the hypothesis suggests *a priori* a sign of the second-order effects of efficiency policies, data analysis may be restricted to searching for the expected sign and may ignore data with the unexpected sign,[34] a point acknowledged by rebound theorists.[35]

Evaluating Hypothesis D would require considerable disaggregation, since the effects will be different for each end use and since there are a number of economy-wide or industry-wide effects that are possible. Simple price elasticity adjustments to account for reductions in the price of energy services would probably be insufficient to account for actual behaviors, since customers are so heterogeneous.[36]

Here are some examples of possible second-order effects about which we do not know *a priori* the sign of the effect:

- Assume energy policy makes homes use less energy. Will home size increase or decrease?

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[33] Variants of Hypothesis C might allow the predicted savings from efficiency policy to be modified slightly by including, as NEMS does, some small end-use rebounds and some overall price elasticities due to energy price reductions caused by efficiency policy.

[34] E.g., if we hypothesize that a beam of alpha particles shot at a gold foil will cause them to deviate slightly from their path without the foil, we will fail to set up instruments to measure the existence of alpha particles that are scattered backward, and fail to discover, as Ernest Rutherford did around 1910, that atoms are made up of small nuclei at the center of clouds of electrons, rather than that they are a "plum pudding" of electrons and positively charged particles, and that therefore can scatter incident particles back toward their source.

[35] "Most estimates of the direct rebound effect assume that the change in demand following a change in energy prices is equal to that following a change in energy efficiency, but opposite in sign. . . . In practice . . . these assumptions may be incorrect." Sorrell, et al., Empirical Estimates of the Direct Rebound Effect: A Review, Energy Policy, Vol. 37, 1356-1371, 1362 (Jan. 2009) [hereinafter "Sorrell 2009"]. , 1362.

[36] *E.g.*, the behaviors of a household after a home retrofit performed on an uninsulated home heated to 18C would likely be far different than those of a household in an already modestly efficient home that could afford to heat to 23C before the retrofit.

- Alternate A: it gets bigger because the present value of energy is enough lower to allow the buyer to pay for more home.
- Alternative B: it gets smaller because the energy efficient investment increases the cost of construction and consumers bid up the price of the efficient home due to anticipated energy savings and non-energy benefits of the efficiency investments. Buyers can no longer qualify for a loan at the higher cost and have to buy an equally-priced, smaller home.

- Building codes increase insulation levels and reduce summer solar heat gain:
  - Occupants can afford more thermal comfort.
  - Occupants can maintain reasonable comfort levels without running the AC or furnace.
- More efficient lighting is installed in an office with an improvement in lighting quality:
  - Occupants leave lights on because the costs are lower.
  - Occupants turn the lights off aggressively because the improved appearance of the lights reminds them of the energy use, its costs, and its consequences.
  - Alternative C: occupants' rent does not depend on the energy management and there is no change in operations.
- More drivers purchase hybrid cars:
  - Travel is less expensive so people travel more, increasing energy consumption.
  - Drivers are so fascinated by the performance (and dashboard) of their cars that they practice eco-driving and increase fuel economy compared to their previous habits, consuming less energy than anticipated.

Rebound theory argues that when efficiency improvements cause the price of energy to fall, consumers will demand more of it. However, this is not necessarily the case.

- Consumers have more money in their pockets because of savings from energy efficiency:
  - They re-spend the money on a market basket of goods and services with the same energy intensity as the economy as a whole.
  - They re-spend the savings on air travel and an SUV and other energy-intensive choices.
  - They reduce debt and increase savings, a service less energy-intensive than the general economy.
  - They discover how beneficial efficiency works and spend their saved money on additional savings or on other clean energy choices.

These are only a few examples where either from individual experiences or logic one could infer reasons for positive rebound and other reasons for negative, with no data yet that determine which effects are greater.

Further, the very assumptions behind rebound theory suggest that these positive rebound effects might very well occur. Rebound theory argues that when efficiency improvements cause the price of energy to fall, consumers will demand more of it. However, this is not necessarily the case, given the complexity of energy markets.

Instead, when the price of energy falls, the supply might fall. This is documented as the "de-investment" effect, and acknowledged by rebound theorists.[37]

While these suggestions are speculative, the speculation is similar to those supporting rebounds: either may happen and at varying frequencies but we cannot know without measurement. While this paper does not call for unending research into every second order effect, it does call for a balanced approach in researching second order effects.

III. Data Do Not Support Large Rebound Hypotheses

First, there is a paucity of data that support large rebound hypotheses.[38] Rebound theorists acknowledge the lack of reliable data supporting the theory.[39] Where there are data, they reveal that rebound effects are small and decreasing. Additionally, none of these data include the positive second order effects discussed in Section II, so represent the highest end of rebound estimates.[40]

A. Micro Level Data Do Not Support Large Rebounds

The data show that rebounds are small, diminishing over time, and difficult to measure. "[E]mpirical evidence suggests that the size of the rebound effect is very small to moderate."[41] Further, "most of the direct energy savings from technical improvements in energy efficiency in OECD countries remain even after the direct rebound effect is accounted for."[42] These findings from a U.S. Department of Energy and International Energy Agency combined study provide the most comprehensive data and analysis on rebounds. The study found rebound effect of 0 percent for residential appliances, 0-2 percent for commercial lighting, and 5-12 percent for residential lighting.[43] Given that utility energy efficiency programs, research and development, and codes and standards have focused heavily in

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37 "[I]f demand is not sufficiently elastic, final market prices may remain lower following efficiency improvements, driving a 'disinvestment effect', which may actually decrease long-term energy demand." BTI, 22.

38 "[D]espite growing research activity, the evidence remains sparse, inconsistent and largely confined to a limited number of consumer energy services in the United States . . . "The methodological quality of many quasi-experimental studies is poor, [and] the estimates from many econometric studies appear vulnerable to bias." Sorrell 2009, 1364. "In summary, the accurate estimation of direct rebound effects is far from straightforward." Sorrell 2009, 1363.

39 "Evidence for the scale of macroeconomic composition effects is very limited." BTI, 23. "The available evidence for all types of rebound effect is far from comprehensive." Sorrell, 7. "There are very few studies of rebound effects from energy efficiency improvements in developing countries." Sorrell, 8. "[T]he empirical evidence for both [direct rebound effects in developing countries and from producers] is weak." Sorrell, 9.

40 *I.e.,* the bias of searching for negative data leads to an overestimate of the rebound effect. "[There are] a number of potential sources of bias with econometric estimates that may lead to the direct rebound effect to be overestimated." Sorrell 2009, 1357. "Both theoretical considerations and the limited empirical evidence suggest that direct rebound effects are significantly smaller for [certain] household energy services." Sorrell 2009, 1362.

41 IEA/Geller, 6.

42 *Id.*

43 *Id.*

these sectors and end uses, these results carry great explanatory weight. Additionally, the data showed a rebound effect of 0-20 percent for industrial processes, 10-30 percent for residential space heating, <10 percent-40 percent for residential water heating, and 0-50 percent for residential space cooling.[44] In transportation, EPA and DOT conducted a thorough and comprehensive survey of rebound estimates and found that in 2000-2004 the rebound effect in transportation was 6 percent[45], and ultimately proposed to use a 10 percent rebound estimate.[46] These data demonstrate that to the extent rebounds occur, they are small.

The empirical evidence reveals that in addition to being small, rebounds are diminishing with time. As efficiency increases, the rebound effect decreases because: (1) energy costs as a share of total costs decreases, decreasing sensitivity to energy prices;[47] (2) incomes increase, decreasing sensitivity to energy prices;[48] and (3) there are limits to end-use-specific energy services demanded, against which rebounds are measured.[49] As measured in transportation, rebound was estimated at 22 percent for 1966-2001, but decreased to 11 percent looking only at the later years 1996-2001, and decreased further to 6 percent looking at 2000-2004.[50] The empirical evidence shows that the magnitude of the rebound effect is declining over time.[51]

B. Macro Level

1. Survey of the Data Does Not Support Rebound Theory

44 *Id.*

45 Actually, the rebound in travel is likely to be even smaller, because none of the studies controlled for the fact that as cars became more fuel-efficient, land use patterns in America and throughout most of the world became less location efficient. The consequent increase in travel demand over time would be hard to distinguish from a rebound statistically without explicitly including it in the regressions.

46 Envtl. Protection Agency, National Highway Traffic Safety Administration, Final Rulemaking To Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, Joint Technical Support Document, EPA-420-R-10-901, 4-19 (Apr. 2010).

47 "[T]he sensitivity of travel demand to fuel cost per mile has fallen over time as fuel cost as a fraction of the total cost of owning and operating a vehicle has declined . . . ." IEA/Geller, 6 (citing Green 1992).

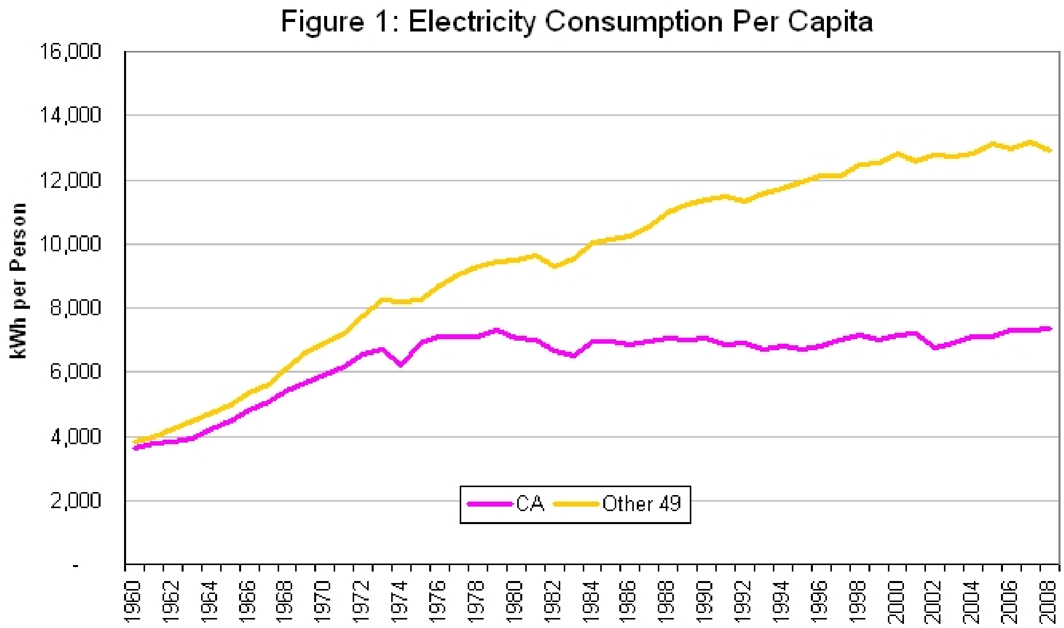
48 [The] sensitivity of travel demand to fuel cost per mile has fallen over time . . . as incomes have risen . . . ." IEA/Geller (citing Green).

49 Rebound, measured as a percentage of expected savings, decreases because there are finite and maximum levels of energy services demanded per end use. *E.g.,* there are a finite number of hours to drive during the day, and an absolute level of heat desired in a home, beyond which consumer would not or cannot increase consumption. Thus, the percentage of energy demand caused by rebound can only continue to decrease. "[A]s the consumption of a particular energy service increases, saturation effects should reduce the direct rebound effect. For example, direct rebound effects . . . should decline rapidly once whole-house indoor temperatures approach the maximum level for thermal comfort." Sorrell 2009, 1357.

50 EPA/NHTSA, 4-19 (citing Greene).

51 "[T]he magnitude of rebound effect is declining over time." EPA/NHTS, 4-19 (citing Greene).

The data at the macro level show that rebound is trivially small, at rebound theory's best, and some data suggest the second order effects could be positive, at rebound theory's worst. The dearth of data at the macroeconomic or economy-wide level is greater than micro-level data.[52] The most comprehensive survey of the literature shows that the economy-wide rebound effect is about 0.5 percent.[53] In other words, "more than 99 percent of the direct energy savings from energy efficiency improvements remain after the economy-wide effects are taken into account."[54]



Source: Energy Info. Admin., *State Energy Database System, Consumption, Physical Units 1960-2008*, (June 2010), available at: http://www.eia.doe.gov/states/_seds.html.

2. State Comparison Data Does Not Support the Rebound Theory

Given the rebound Hypothesis C: "energy efficiency gains from policy will increase energy consumption above where it would be assuming the difference between proposed efficiency versus constant efficiency," we can test it on an economy-wide level. The results refute it.

California embarked on a broad set of policy reforms to encourage efficiency and promote renewable energy in 1974, and has continued since. The California Energy Commission has estimated the cumulative electricity savings produced by these policies, using conservative assumptions, at about 15 percent of load.[55] Figure 1 shows the results of both these policies and all second order effects. The reduction in electricity use compared to the rest of the US is not smaller than what the policies were estimated to produce, it is greater. It is approximately four times as great.[56] In addition to being 400 percent of

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52 "[N]o single, widely accepted methodology exists to quantify rebound effects at the . . . total economy-wide rebound [level] at a global scale." BTI, 25.

53 IEA/Geller, 7 (citing Lietner 2000).

54 IEA/Geller, 7.

55 Calif. Energy Commn., *Energy Action Plan II, Implementation Roadmap for Energy Policies*, 5 (Oct. 2005) (stating 15 percent of demand in 2003 saved by efficiency policies).

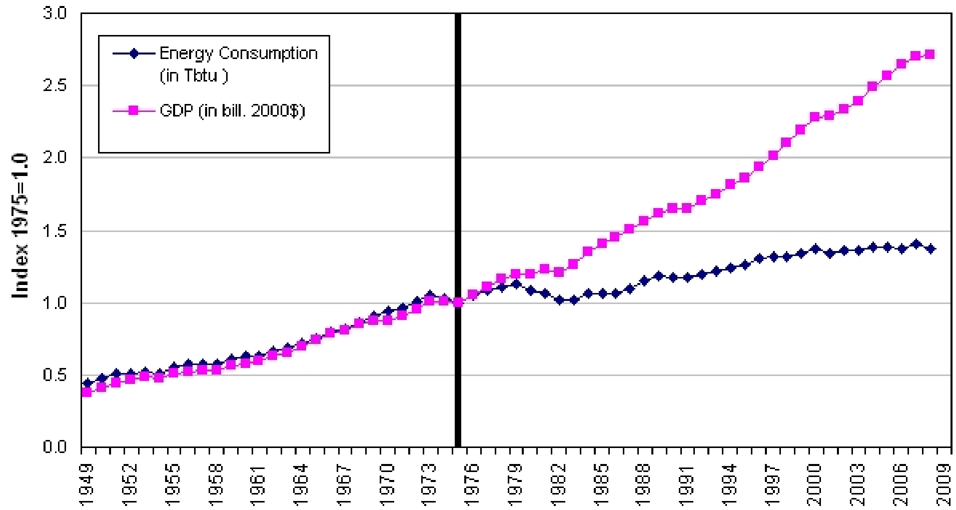
56 CEC estimated 40,000 GWh saved in 2003 due to efficiency policies. Given a population of 35.251MM in 2003 for California, that represents 1,134 kWh per capita due to efficiency policies. US Census Bureau. Since 1975, the rest of the US has increased its

expected results, realized savings are not compared here to a base case of roughly constant efficiency but compared to a base case of other states, some of which are also pursuing efficiency policies and all of which save energy due to spillover effects of California policies on efficiency.

Similar, but about 50 percent smaller, results are documented for New York State.[57] Several other states and regions demonstrate that stronger energy efficiency policies result in energy consumption that is indeed lower than in states without such policies.[58] So, if anything is rebounding, it is the influence of energy efficiency policies: They are causing a whole economy to save much more than one would expect.

Further, two detailed statistical studies of California found that the majority of this difference could be explained by other factors[59]

Figure 2: Energy Intensity of US Economy 1949-2008



Black line delineates year of index, where both values equal 1, and approximately, the beginning of some efficiency policies in the US. Source: DOE Intensity, *supra* note 28.

that are not related directly to energy efficiency but causing decreases in consumption. This analysis refutes Hypothesis C, which predicts that other factors must be causing additional increases in consumption, not decreases[60].

Last, it is hard to find a case showing the opposite: a jurisdiction that has implemented energy efficiency policies that are shown by careful analysis to be saving enough energy to be visible at the first order level, but which has no reductions in intensity or other macro indicators in the long run.

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consumption 4,695 kWh per capita, while California has remained flat. Energy Info. Admin., *State Energy Database System, Consumption in Physical Units* (2010), available at: http://www.eia.doe.gov/states/_seds.html. Thus, the increase in the rest of the US is 4.14 times the savings in California.

57 National Academy of Sciences, *Real Prospects for Energy Efficiency in the United States* (2010).

58 See differences between Vermont or Massachusetts versus Kentucky or Wyoming. Energy Info. Admin., *supra* note 56.

59 *See* Anant Sudarshan, *Deconstructing the 'Rosenfeld Curve': Why is Per Capita Residential Energy Consumption in California so Low?* (US Assn. Energy Econ., USAEE-IAEE WP 10-063, Dec. 2010). Anant Sudarshan, *Deconstructing the 'Rosenfeld Curve': The Problem with Energy Intensities?*, (US Assn. Energy Econ., USAEE-IAEE WP 10-057, Nov. 2010).

60 Proponents of Hypothesis C might argue that the other factors that clearly are not consequences of energy efficiency policy should be controlled for, rather than considered part of the results. If such an argument were correct, it would undermine the ability to test Hypothesis C: different analysts could have different interpretations of which parameters might be second-order effects.

3. The Macro "GDP-Dependence" Theory Is Not Supported by Data

Hypothesis A3 is based on the assumption that energy tends to increase in proportion to GDP. This assumption is derived from the correlation that historically, societies' GDPs increased as did energy consumption.[61] The data show that economies can, and do, decrease their energy intensity beyond the status quo.[62] In the U.S., energy intensity dropped twice as much in the 13 years after energy efficiency became a policy priority than it did in the previous 25 years.[63] In China, energy intensity increased twice as fast as GDP before implementing energy efficiency policies; then dropped precipitously afterwards.[64] Energy intensity in the major OECD countries all decreased from 1973 to 1998.[65] And in last 500 years of the British economy, energy intensity has varied incredibly, more than doubling from 1700 to 1850, then dropping to its lowest levels ever by 2000, about one-fifth the level of its peak.[66] Even Jevons observed, and Owen recognized,[67] that economic productivity of energy consumption can increase, which decreases the energy intensity of an economy. By decreasing our energy intensity, we can in fact move towards unhinging our economy from energy that we currently depend upon.

In conclusion, energy consumption and GDP were previously believed to have an unchangeable causal relationship based on observed positive correlations of absolute levels. However, the data show that many advanced

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61 We note that such a simple correlation ignores the proportion in which GDP and energy increase. The energy intensity of the US economy in post-World War II was actually decreasing, despite both GDP and energy consumption increasing. From 1949 through 1973, energy intensity (measured by the E/GDP ratio) declined by 11 percent." DOE Intensity, *supra* note 28.

62 "Believers in an unbreakable link between energy use and GDP assigned the immutability of a physical law to this historical relationship, but found their belief shattered by events. From 1973 to 1986, U.S. primary energy consumption stayed flat, but GDP rose 35 percent in real (inflation-adjusted) terms. These believers had forgotten that people and institutions can adapt to new realities, and historically-derived relationships (like the apparent link between energy use and GDP that held up for more than two decades in the post-World War II period) can become invalid . . . ." Jonathan Koomey, *Avoiding 'the Big Mistake' in Forecasting Technology Adoption*, 2 (LBNL-45383, Apr. 2000), available at: http://enduse.lbl.gov/Info/LBNL-45383.pdf.

63 From 1949-1973, US energy intensity declined by 11 percent. Between 1973 and 1985, the E/GDP ratio decreased by 28 percent. DOE Intensity*, supra* note 28.

64 From 1952 to 1980, energy demand grew twice as fast as GDP. From 1980 to 2002, after efficiency policies took effect, GDP grew much faster. Levine et al., *The Greening of the Middle Kingdom: The Story of Energy Efficiency in China*, LBNL-2413E, Figures 3a, 3b, (May 2009). Available at: http://china.lbl.gov/sites/china.lbl.gov/files/LBNL-2413E.Story_of_EE_in_China.pdf.

65 *Annually*, between 1973 and 1998, US and Norway decreased their energy intensity over 2 percent; UK, Japan, Germany, Denmark, and Sweden all decreased over 1.5 percent; Australia, France, and Italy decreased over 1 percent; and Finland decreased over 0.5 percent. On average, these OECD countries decreased their energy intensity 1.6 percent per year. IEA/Geller, 3.

66 Fouquet, 101.

67 "[W]e can extract vastly more economic benefit from a ton of coal than nineteenth-century Britons did, ..." Owen, 82 (citing conversation with, though not endorsing, Schipper).

economies and also China have been able reduce their energy intensities over sustained periods, while increasing overall GDPs. The hypothesis (A3) that we cannot decrease our energy intensity without decreasing absolute GDP is disproven by the facts. It is indeed possible to decrease our dependence on energy consumption through energy efficiency.

IV. Rebound Solutions

In addition to needing a scientifically rigorous hypothesis, rebound theorists must be able to provide the equivalent in a solution if we are to decrease our energy consumption or associated emissions. Most rebound theorists agree that reducing energy consumption and GHG emissions is a worthy objective.[68] However, they believe that energy efficiency will either: a) help us to reduce our absolute energy consumption or GHG emissions less than we expect, but will still help somewhat, or b) will not help us. For those that agree that efficiency helps, the data above suggests we should not only continue pursuing efficiency as the primary strategy to reduce energy consumption, but accelerate it. For those that do not, they propose the following alternate solutions.

A. The Model T Solution

Backfire theorists believe that efficiency causes increased consumption of absolute energy; consequently, backfire theorists must necessarily believe that *in*efficiency causes decreased consumption of absolute energy. Regarding this conundrum, Amory Lovins joked, "[W]e should mandate inefficient equipment to save energy."[69] However, this is the logical conclusion of believing that efficiency causes increased consumption. There are presently mandates in place that increase efficiency. If these efficiency requirements are the problem, there must be a mandate to remove the efficiency requirements. Such a mandate increases inefficiency relative to the status quo. This is one proposed solution by backfire theorists and rebound theorists.

Owen proposes this solution, in the form of a Model T example[70]: "If the only motor vehicle available today were a 1920 Model T, how many miles do you think you'd drive each year . . . ?"[71] The explanation of the Model T solution, or switching to inefficient products, is that the Model T was (a) more costly to drive per mile, given inferior fuel efficiency compared to present fleet-wide averages and (b) delivered many fewer energy services (such as acceleration and air conditioning); therefore, the consumer would choose to drive less. First, this solution has yet to show results that would support it—e.g., we have not seen data that show Hummer drivers drive less than Prius drivers. Additionally, the Model T solution faces an extra hurdle: due to the new *in*efficiency, driving less would not necessarily decrease total energy consumption—drivers would first need to drive some amount less just to offset the new

68 "Decreasing reliance on fossil fuels is a pressing global need." Owens, 85. Tierney, 3. *See* Sorrell, 1; BTI, 4-5.

69 Robert Bryce, *Energy Tribune Speaks with Amory Lovins*, Energy Tribune, (Nov. 9, 2007). Available at: http://www.energytribune.com/articles.cfm?aid=672.

70 While he later recognizes the political inability to enact such a solution, he never disavows it on substantive grounds. Owen, 85.

71 Owen, 85.

inefficiencies, then, they would need to drive an additional amount less than that to actually decrease absolute consumption. In the Hummer example, the data would need to show that Hummer owners not only drive less, but that they consume less energy overall than Prius drivers—a tall order. These empirical and theoretical hurdles render this solution ineffective to reduce our climate emissions and energy consumption.

B. The Energy Price Solution

Owens foregoes the Model T solution in favor of the energy price solution,[72] as does Tierney.[73] The energy price solution states that increasing the cost of energy consumption will decrease demand.[74] Efficiency advocates believe a cap on greenhouse gas emissions is the appropriate mechanism to internalize some environmental costs into the price of energy. The cap might cause the price of energy to increase, as emissions permits are limited. Rebound enthusiasts believe that this price will be high, since one of the most effective means of lowering it—energy efficiency—is believed not to work, or to work less effectively than modeled. Environmentalists believe any price increase will be modest. But the important observation is that this solution—pricing the externality of emissions by placing a cap on them, makes as much policy sense if one rejects rebounds as it does if one accepts them. We should all be satisfied to let that experiment work its way through the economy, since we will be better off economically with strong efficiency policies[75] and a cap that meets environmental needs.[76]

C. The Supply-Side Solution

Rebound theorists have also proposed a supply side solution, which does not intend to decrease consumption, but rather to decrease GHG emissions through the supply of clean energy.[77] On this solution, we fully agree. Pursuing renewable energy is a priority strategy in reducing our GHG emissions

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72 "No one's going to 'mandate inefficient equipment,' but, unless we're willing to do the equivalent—say, by mandating costlier energy—increased efficiency, . . . , can only make our predicament worse." Owens, 85.

73 "it makes more sense [compared to efficiency] . . . to impose a direct penalty for emissions, like a tax on energy generation from fossil fuels. . . . [consumers] respond to a gasoline tax simply by driving less." Tierney, 3.

74 "Carbon/energy pricing needs to increase over time, . . . simply to prevent carbon emissions from increasing. It needs to increase more rapidly if emissions are to be reduced." Sorrell, 9.

75 As acknowledged by rebound theorists: "[S]uch efforts [cost-effective EE] make for excellent economic policy, as they are well suited to accelerate economic growth and modernization and expanding welfare." BTI, 11.

76 Which agrees with some in the rebound field: "Carbon/energy pricing may be insufficient on its own, ... A policy mix [including efficiency] is required." Sorrell, 9.

77 "Efforts to reliably reduce greenhouse gas emissions or dependence on depleting fossil fuels would be prudent to avoid the risk of overreliance on energy efficiency measures. Such efforts should therefore focus primarily on shifting the means of energy production (rather than end use), relying on zero-carbon and renewable energy sources to diversify and decarbonize the global energy supply system." BTI, p.52. "[I]f your immediate goal is to reduce greenhouse emissions, then . . . it makes more sense to look for new carbon-free sources of energy." Tierney, 3.

regardless of what one expects concerning efficiency gains.

However, suggesting cost-effective[78] clean energy supply[79] expansions as a solution to the problem of rebounds is not entirely self-consistent. According to rebound theory, increases in low-cost supply[80] would be expected to increase demand, and some cases such increases have been observed. A good example is in the transportation sector, where studies demonstrate supply-side rebounds or "induced demand" —the idea that as road supply increases, the cost per use will decrease, and demand will increase. In these studies the cost was indirect in the form of cost of traffic congestion. They show that increasing capacity of roads results in less-than-expected reductions in congestion. As lane-miles increase, some amount of vehicle- miles-traveled increases also. The estimates of induced demand vary widely, from 0.2-0.8 in some studies, depending on how wide the boundaries are in the particular study.[81] However, induced demand in the transportation sector must be higher than energy rebound effects because there is no cost to the consumer directly when increasing lane-miles, whereas there is cost to the consumer directly when investing in new energy supply. Additionally, the estimate of induced demand has increased over time, whereas rebounds have decreased. In sum, the effects of induced demand reveal inconsistencies[82] in the rebound theorists' proposed supply-side solutions.

78 Here, "cost-effective" is defined as being less than the marginal cost of new energy resources, and we assume that prices properly reflect those marginal costs.

79 *E.g.*, in many places of California, wind is a cost-effective source of clean energy supply because it costs less than the benchmark for marginal resources. The Renewable Energy Transmission Initiative estimates wind to cost between 6 and 11.6 cents/kWh whereas the CPUC estimates the market price referent to be between 8.5 and 14.4 cents/kWh. RETI, Phase 2B, Final Report, Figure 1-1 Typical Cost of Generation Ranges (May 2010). Available at: http://www.energy.ca.gov/2010publications/RETI-1000-2010-002/RETI-1000-2010-002-F.PDF. CPUC, Resolution E-4298, Table 1: Adopted 2009 Market Price Referents, (Dec. 2009). Available at: http://docs.cpuc.ca.gov/word_pdf/FINAL_RESOLUTION/111386.pdf.

80 As the price of renewables decreases, we expect this inconsistency to be a larger problem for rebound theory.

81 Robert Cervero, *Road Expansion, Urban Growth, and Induced Travel: A Path Analysis*, J. Am. Plan. Assn. 69, no. 2, 145 (2003); Robert Cervero and M Hansen, Induced Travel Demand and Induced Road Investment: A Simultaneous Equation Analysis, J. Transpt. Econ. Pol. 36, no. 3, 469-490 (2002) [hereinafter "Cervero 2002"]; Lewis Fulton et al., "A statistical analysis of induced travel effects in the US Mid-Atlantic region," J. Transp. and Statistics 3, no. 1, 1-14 (2000); Kent M. Hymel, Kenneth A. Small, and Kurt Van Dender, *Induced demand and rebound effects in road transport*, Transp. Research Part B: Methodological 44, no. 10, 1220-1241 (2010). In general, and not surprisingly, the wider the boundaries of the study (the greater the geographic extent of travel that was measured), the higher the induced traffic.

82 In addition, we note an inconsistency regarding GHG emissions between supply- and demand-side solutions. Rebound theorists would hold that rebounds from low-cost clean energy supply do not create additional GHG emissions because the rebounds are being demanded from the new supply of

V. The Meaning of Rebounds

The main concern of rebound theory is that consumers might increase their energy consumption, relative to the level that could possibly be reached by an energy efficiency improvement—i.e., consumers might, through income or substitution effects, demand more energy services than previously demanded. Let us analyze the people to whom rebounds apply, the nature of these newly-demanded energy services, and the full set of consequences that results from opposing them.

Through income or substitution effects, the consumers that are demanding new energy services are those who either could not previously afford them or viewed the benefits as less than the cost. However, due to greater unsatisfied demand among low income communities, the consumer groups that account for the greatest rebounds are low-income communities.[83] Within this group, the now lower price of energy services allows the consumer to purchase an increased level of energy services. Through the income effect, the low-income consumer can demand new energy services, as her budget is expanded. Both mechanisms allow consumers, largely those who were unable to pay for it, to demand new energy services.

Theory suggests that rebounds apply largely to those who need energy services the most, those in the developing world.[84] Rebounds require consumers to have unsatisfied demand. The place where there is the greatest unsatisfied demand is in the developing world. Thus, large rebound should occur largely in the developing world. In fact, according to what empirical data exists,[85] the consumers that are demanding new energy services are largely located in the developing world.

Let us analyze the nature of these services. The end uses with high rebounds were: residential water heating, space heating, and space cooling. In other words, people were demanding basic energy services, like being able to heat their home, pump water, and have hot water.[86] These are energy services that improve consumers' quality of life and raise their standard of living. These services are mostly the basic energy services that those in the developed world already enjoy, a fact acknowledged by rebound theorists.[87]

If rebound theory were correct, energy efficiency would be a most effective policy for economic

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clean energy. If so, the same must hold for efficiency: rebounds from low-cost energy efficiency are being demanded from the new supply of energy efficiency; thus, also resulting in no increase of GHG emissions.

[83] "One important implication is that direct rebound effects will be higher among low-income groups, since these are further from satiation in their consumption of many energy services. Sorrell 2009, 1357 (citing Milne and Boardman, 2000).

[84] "Rebound effects may be expected to be larger in developing countries." Sorrell, 7. "The abundance of such 'marginal consumers' in developing countries points to the possibility of large rebounds in these contexts, ..." Sorrell 2009, 1357. While demand for energy services is typically inelastic in developed countries (Greening et al., 2000; Sorrell, 2007), (Laitner, 2000), demand for even basic energy services is largely unfulfilled across much of the developing world." BTI, 22

[85] Sorrell, 36 (citing Zein-Elabdin 1997).

[86] IEA/Geller, 6.

[87] BTI, 22.

development and improvement of the quality of life for the poorest of people in the poorest countries. Rebounds, if real, would provide basic energy services to those who vitally need them.

Projections of global energy demand assume that poor nations continue to strive for maximizing economic development, and thus are based on projections of rapidly growing energy service demands. But these demands should not be construed as rebound effects without evidence, and there is almost no evidence that supports a hypothesized link to efficiency policy.

Any energy reduction strategy that ultimately requires much of the population to maintain a lower standard of living is an untenable strategy. Advocates of policies based on rebound theory have yet to explain how recommendations of less reliance on energy efficiency policy avoid such a consequence.[88] Energy efficiency is a strategy that allows people to live a higher standard of living, with increased energy services, while decreasing their energy consumption. If these advocates agree that populations need not maintain lower standards of living, and are still concerned about reducing energy consumption, they should not disparage efficiency, but rather work to accelerate it.

VI. Conclusions

We have shown theories that predict large rebounds are difficult to specify in terms that are scientific and testable. We frame the most scientifically rigorous versions possible. We also propose unbiased formulations that would measure both positive and negative rebounds. We call for a balanced approach to research on second order effects.

Of the testable hypotheses, we analyze the available data. Those data show that end-use level rebounds are small, that economy-wide rebounds are trivial, and may be positive. They also show that negative rebounds are decreasing over time, as efficiency increases.

Assessing rebound theorists' proposed solutions to climate change, we find that even if one believed that economy-wide rebounds not accounted for in energy models were significant, it would not change the policy prescriptions compared to what the energy efficiency advocacy community has been promoting: a combination of a greenhouse gas emissions cap and energy efficiency policies.

We analyze the qualitative nature of rebounds and find that efficiency policies are largely providing basic energy services to low-income communities and those in developing countries, and that rebounds would amplify this effect. We find that energy efficiency provides a solution that allows us to reduce energy consumption without stifling the standard of living for many poor and developing populations around the world. ■

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[88] Jevons himself indicated that the ultimate solution requires a lower standard of living: "It is thence simply inferred that *we cannot long continue our present rate of progress*. [A]fter a time we must either sink down into poverty, adopting wholly new habits, ..." Jevons, 18.