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Response to Cullenward and Koomey critique of 'historical evidence for energy efficiency rebound in 30 US sectors'

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ABSTRACT

This article responds to a recent critique in these pages by Danny Cullenward and Jonathan Koomey of a prior article reporting measured historical rebound magnitudes on the productive side of the US economy. They argue that the data quality objections they raise are serious enough to warrant outright dismissal of the reported rebound magnitudes. In particular, they cite unaccounted for regional energy price differences as fatal to the credibility of the results.

The present analysis instead shows, via various extreme sensitivities around the energy price trajectory, that historical rebound magnitudes in 30 productive sectors of the US economy are sensitive but robust to energy price differences – both magnitude and variability differences – and remain large and thereby policy-relevant (commonly >50%, with the overall average varying from 15% to over 200% ("backfire") at the extremes). Along the way, the analysis provides further evidence of the reliability of the widely-used Jorgenson et al. econometric data set and methodology, and of the multitude of articles that have followed there from.

1. Introduction

For those readers unfamiliar with the rebound phenomenon: When energy efficiency improvements are introduced into the economy the resulting changes in energy use are complex and subtle. Intuition might say a process that becomes 10% more energy efficient (i.e., uses 10% less energy input to deliver the same level of energy services) will result in a 10% decline in energy use. But such improvements reduce the observed, or "effective," price of energy, incenting economic agents to respond by increasing their energy use as compared to reductions that would be indicated by simple engineering calculations. This offsetting effect has come to be known as "rebound." Rebound analysts seek to determine the magnitude of this effect.

Rebound magnitudes are conventionally stated as percentages: if a new energy-saving technology is introduced that engineering calculations indicate should reduce energy use by 10% but actually results in only a 5% reduction, rebound is said to be 50% (half the projected savings are offset by rebound mechanisms); if the result is no change in energy use, rebound is said to be 100%; if energy use actually increases as a result of the technology, it is said to "backfire" (rebound >100%). If the result is a >10% reduction in energy use, the technology is said to exhibit "super-conservation" (rebound <0%).

Determining the magnitude of rebound effects is important. If they are large (as shown here), such effects significantly change the policy prescriptions available for mitigating climate change impacts. For instance, the International Energy Agency (IEA, 2013) asserts that energy efficiency is the "first fuel" available to member countries for reducing energy-associated emissions heading forward. The Intergovernmental Panel on Climate Change (IPCC, 2014) follows suit, presenting forecasts showing energy efficiency to be the best lever for reducing GHG emissions in the coming decades. But to the extent these organizations' energy demand forecasts understate resulting rebound, energy efficiency policies adopted by governments in their quest to meet commitments agreed to in Paris may be unrealistically optimistic relative to their actual realized effectiveness. This means there is less time available than commonly understood to formulate mitigation remedies and so increases the urgency of developing truly effective climate change mitigation policies.

The original article critiqued by Danny Cullenward and Jonathan Koomey (original: Saunders, 2013a; Cullenward and Koomey, 2016) reports results for rebound magnitudes indicating them to have been historically high across 30 sectors of the US productive economy (62%, weighted average). A main contribution of that article is its focus on rebounds arising on the productive side of the economy. Previous empirical analyses of rebound effects have focused almost exclusively on more readily visualized rebounds arising from deployment of new energy efficiency technologies in households and for personal transportation. Yet production-side energy use dominates these householder

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energy demands. Globally, production-side energy use has been around 66% of the total, and about 60% in the United States (ExxonMobil, 2009; Saunders, 2013b). As new energy efficiency technologies have been extensively deployed in the productive economy, rebound effects there clearly deserve empirical examination.

Cullenward and Koomey (hereafter: CK) raise the objection that the analysis uses national average energy prices that mask potential regional differences, presenting evidence that prices of fuels, especially electricity, historically differed from region to region both in overall magnitude and in variability.

CK use this evidence to argue that the use in the original analysis of the Jorgenson et al. dataset,[1] which relies on national averages for each sector, is fatally flawed – or at least fatally-enough flawed that the reported rebound results warrant outright dismissal by academicians investigating climate change.

Their argument merits attention.

In their critique of the original article, CK state their concern that the (allegedly fatally compromised) rebound magnitudes reported therein could be having inappropriate influence on climate policy: “Important policy and scientific authorities have subsequently cited Saunders (2013a), including the IEA (2014) and the IPCC's Fifth Assessment Report (Blanko et al., 2014).” It is indeed true that this work has been so cited. While they go on to say “If [Saunders'] conclusions are correct, they present severe and sobering implications for energy and climate policy alike,” CK do not believe the conclusions are correct.

The present analysis allows testing of the hypothesis that rebounds in US productive sectors are large irrespective of regional energy price variations, and merit policy consideration. And while CK make no claims as to whether the original reported rebound magnitudes might be overstated or understated, the present analysis allows exploration of that question also.

To examine the merits of the CK critique, the analysis undertakes a series of extreme sensitivity tests aimed directly at the claim that using national average energy prices, rather than regional prices, invalidates the reported rebound results; and also at the claim that using average prices rather than marginal prices further invalidates them.

These sensitivity tests involve testing rebound magnitudes across extreme energy price variations, extreme both in absolute magnitude and variability, well beyond any differences observed among US regions, and well beyond any difference between average and marginal prices. The analysis shows resulting rebound magnitudes are robust to these differences and remain large (most commonly in excess of 50%). By no accounting can they be seen as depicting any kind of “second-order” effect (which would mean magnitudes of 10% or less).

An ancillary benefit arising from the present analysis is that other researchers using the methodology can take comfort in knowing rebound results are not greatly distorted when relying on averaged data in the Jorgenson dataset, or datasets similarly constructed. For context, it should be noted that researchers applying the methodology to countries less geographically dispersed than the US do not have to deal with large regional price variations. The work of Malpede and Verdolini, applying this methodology to five countries in Europe, is a good example of such (Malpede and Verdolini, 2016), but even so the results herein show any regional differences that do occur in larger countries can be dealt with as minor determinants of measured rebound magnitudes.

Finally, there is the Jorgenson et al. dataset itself. CK do an in-depth probe into the limitations of this dataset, and any using this or a similar dataset would be well advised to examine this work, including particularly the Appendix CK provide, to inform their knowledge of dataset limitations. However, the analysis presented herein involves such extreme stress tests of the Jorgenson et al. dataset – yet delivers such remarkably consistent rebound results despite procedural dynamic complexities – that it is difficult to avoid the broader implication of the Jorgenson et al. data set being reliable in a very general sense.

As will be seen, the analysis following reinforces the conclusion that rebound magnitudes in the productive US economy were historically large. Accordingly, thoughtful readers may wish to ask themselves if these new results (combined with the previous ones) might rise to the level of having “severe and sobering implications for energy and climate policy alike,” to re-quote CK above.

2. Methodology

As described in Saunders (2013a), the rebound measurement procedure itself relies on a slightly modified version of the Jorgenson-style Translog function, altered to reflect a factor-augmenting technology gain paradigm.[2] As shown elsewhere,[3] this modification allows the technology terms to be those that would appear in the production function properly dual to the measured Translog cost function as standard factor-augmenting technology parameters. This way, we can treat energy efficiency gains (and efficiency gains of all factor inputs) as being the econometrically-measured values of the production-side technology-augmenting terms. More generally, this duality-based approach allows us to deal with physical quantities as well as prices and costs – rebound as generally defined is stated in physical quantity terms.

Other parameters of the cost function for each sector are likewise measured econometrically. These determine in major part the estimated rebound magnitudes.

The methodology has additional advantages relevant to the proper measurement of energy rebound magnitudes. New physical capital put in place each year (via investment) is vintaged, to reflect the fact that different factor price regimes over time may cause producers to select different ratios of factor inputs for each new vintage. Energy use is tracked for each vintage and aggregated to produce a total. A distinction is made between factor use and the factor use *capacity* of the extant capital stock. Likewise, output production and output production *capacity* are distinguished. This allows for unemployment of factors, and for production not reaching its potential in any one time period. A particular value of this feature is that reported data are for factor use, not capacity, and for actual output, not output capacity.

Another feature of the methodology is that it incorporates restrictions on measured cost functions to honor concavity, a longstanding requirement of neoclassical theory. It employs the method of Ryan and Wales (2000) to force concavity locally, but then tests measured cost functions to evaluate their performance globally.

Further detail of the methodology is given in Saunders (2013a).

2.1. The stress tests

To evaluate the proposition that regional energy price variations do not invalidate an assertion that rebound magnitudes have been historically large in the US productive economy, the analysis employs two “stress tests” of the methodology and the underlying dataset. This, to accommodate two possibilities: regional absolute magnitudes of energy prices may be higher or lower than the national average; or, regional variability of energy prices can differ significantly from the national average price trajectories.

The methodology of each stress test is presented below using these two categories of possibility.

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[1] Throughout this article, the phrase “Jorgenson et al.” is used to designate both the data set (available at Dale Jorgenson's website http://scholar.harvard.edu/jorgenson/data) and the econometric approach developed by Jorgenson and his colleagues. The approach can be found in Jorgenson (2000), Jorgenson et al. (2005).

[2] The Translog function provides a way to treat production-side factor use and output dynamics in a highly general and flexible manner. To treat rebound dynamics, energy efficiency gains must be specified as “factor-augmenting,” meaning that such gains augment energy inputs in such a way that an x% improvement in energy efficiency means x% less energy input can be used to provide each unit of energy services.

[3] Saunders (2005). Supporting Proofs, Theorem 4.