

30 March 2022

Dear Editors:

My co-authors and I are pleased to submit an original research article to *The Energy Journal*.

TITLE

Advancing the necessary foundations for empirical energy rebound estimates: A partial equilibrium analysis framework

AUTHORS

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STATEMENT

I attest that this manuscript is our original work, that it has not been previously published in a journal, in whole or in part, and that it is not under consideration by any other journal. All authors are aware of, and accept responsibility for, the manuscript. The authors have no conflicts of interest.

NOTE ON ARTICLE LENGTH AND INVITED SUBMISSION

In March 2022, we wrote to Professor Yatchew, Editor-in-Chief of *The Energy Journal*, to ask pre-submission advice, as our draft article is longer than the normal maximum article length for *The Energy Journal*. We recap key elements of our exchange, due to its relevant context for the handling editor:

- Email from Matt Heun to Prof. Yatchew: We noted that the twin novel aspects of the paper (advancing the conceptual framework and operationalizing it via two case studies) made it undesirable to simply trim the paper. We noted that we believe these two highly novel parts deserve their place within the paper, rather than pushing either to an appendix. One option we suggested was to split the paper into Part 1 (conceptual framework) and Part 2 (operationalized case studies). This approach has precedent in the rebound literature, with Thomas and Azevedo's (2013a,b) 2-part paper in *Ecological Economics*. It also has precedent at *The Energy Journal* with at least two 2-part articles: Hendry and Juselius, (2001, 2002) and Burger *et al.* (2019 a,b).

- Prof. Yatchew's response on 22 March 2022: "*I suggest that you submit it to the EJ in its current form. Once it has undergone an initial review, we can make a determination how best to proceed.*"

With Prof. Yatchew's encouragement, we submit the current draft article for review and feedback. We are fully aware of the length of the draft paper, but there are good reasons for the length, namely the foundational advances it makes to the field. That said, we also are open to exploring options after the first-stage reviews are in, following Prof. Yatchew's suggestion.

RATIONALE

Amidst ongoing debates over the size and extent of energy rebound effects, energy efficiency measures are expected to contribute a key part of energy-related CO₂ emissions reductions in support of Paris Agreement targets, even as the world economy grows. Therefore, continued work on energy rebound theory and modelling is required, to support energy efficiency modelling and policy responses.

For this paper, we took inspiration from two earlier papers published in *The Energy Journal*. First, Turner (2013) contends that the empirical estimation of rebound has advanced beyond the conceptual framework frontier. We believe that is still true today. Second, Borenstein (2015) made an important contribution toward a microeconomic rebound framework. However, we think there is more work to do, in particular:

- linking microeconomic and macroeconomic rebound,
- providing accessible and detailed numerical case studies based on a consistent analytical framework, and
- bridging the disciplinary divide between energy analysis and economics.

In response, first, we develop a comprehensive conceptual framework with links between microeconomic and macroeconomic rebound effects, written in a detailed-yet-accessible style, to reach out to both energy and economics fields. Second, we provide two numerical case studies, of a car and an electric lamp upgrade, and produce novel energy, expenditure, and consumption path graphs, which contribute to understanding and communication between energy analysis and economics.

KEY CONTRIBUTIONS

The paper contains four contributions. First, we develop the first comprehensive rebound analysis framework that accommodates embodied energy effects, maintenance and disposal effects, non-marginal energy efficiency increases, and non-marginal energy service price decreases. Second, we provide the first (to our knowledge) visualizations of rebound effects in energy, expenditure, and consumption spaces. Third, we create the first (to our knowledge) operationalized link between rebound effects on microeconomic and macroeconomic scales. Fourth, we provide tools for other researchers to calculate rebound for other EEU's with our framework.

CONNECTION TO THE ENERGY JOURNAL AND ITS AUDIENCE

First, our paper fits well with the Aims and Scope of *The Energy Journal*, with close alignment to the topic area of energy efficiency, but also closely related areas including energy and environmental issues, transportation, energy taxation, and carbon emissions reduction. As such, we believe that our paper will be of interest to the wide readership of *The Energy Journal*. Given the contributions from theoretical framework to replicable empirical examples using real-life data, we believe the paper will be of interest to both academics and practitioners alike.

Secondly, many of the most important and foundational papers on energy rebound have been published in *The Energy Journal*, including Khazzoom (1980, 1987), Lovins (1988), Turner (2013), Borenstein (2015), and Saunders (2015). Our submission to *The Energy Journal* both (i) is a natural choice for the topic of our paper and (ii) helps to maintain *The Energy Journal* as the pre-eminent journal for energy rebound.

REVIEWER SUGGESTIONS

Although author instructions for *The Energy Journal* do not ask for it, we provide the following suggestions, which we trust editors will find helpful.

- **Severin Borenstein**, E.T. Grether Professor of Business Administration and Public Policy in the Economic Analysis and Policy Group of the Haas School of Business at the University of California, Berkeley. Email: severinborenstein@berkeley.edu. His current research interests include the economics of renewable energy and economic policies for reducing greenhouse gases. His 2015 paper provides a foundation for our work:
 - Borenstein S. A Microeconomic Framework for Evaluating Energy Efficiency Rebound and Some Implications. *Energy J.* 2015;36(1):1–21.
- **Ines Azevedo**, Associate Professor, Energy Resources Engineering, Stanford University, USA. Email: iazevedo@stanford.edu. Her research interest are keenly focussed on energy rebound, with some of her papers providing foundations for this current submission.
 - Azevedo IL, Sonnberger M, Thomas B, Morgan G, Renn O. The Rebound Effect: Implications of Consumer Behaviour for Robust Energy Policies. 2013.
 - Thomas BA, Azevedo IL. Estimating direct and indirect rebound effects for U.S. households with input–output analysis Part 1: Theoretical framework. *Ecol Econ.* 2013;86:199–210.
 - Azevedo IML. Consumer End-Use Energy Efficiency and Rebound Effects. *Annu Rev of Environment Resour.* 2014;39:393–418.
- **Reinhard Madlener**, Director of the Institute for Future Energy Consumer Needs and Behavior (FCN), Aachen, Germany. Email: RMadlener@eonerc.rwth-aachen.de. His research interests include energy

economics, energy management, energy policy-making. He has a wealth of experience in energy rebound, which makes him a very suitable reviewer:

- Madlener R, Alcott B. Energy rebound and economic growth: A review of the main issues and research needs. *Energy*. 2009 Mar;34(3):370–6.
- Madlener R, Turner K. After 35 Years of Economic Energy Rebound Research: Where do we stand? *Rethinking Climate and Energy Policies*. 2016. 1–26 p.
- Colmenares G, Löschel A, Madlener R. The rebound effect representation in climate and energy models. *Environ Res Lett*. 2020;15(123010):1–35. 20-1.
- **Harry Saunders**, Carnegie Institution for Science, Global Ecology Group, Stanford, California 94305, USA; email: hsaunders@earthlink.net. His experience in the topic of energy rebound spans over 30 years, and is one of the foremost researchers in this topic:
 - Saunders, H.D., Roy, J., Azevedo, I.M., Chakravarty, D., Dasgupta, S., de la Rue du Can, S., Druckman, A., Fouquet, R., Grubb, M., Lin, B. and Lowe, R., 2021. Energy Efficiency: what has research delivered in the last 40 years?. *Annual review of environment and resources*, 46, pp.135-165.
 - Saunders, H.D., 2015. Recent evidence for large rebound: Elucidating the drivers and their implications for climate change models. *The Energy Journal*, 36(1).

ARTICLE KEYWORDS

- Energy efficiency
- Energy rebound
- Energy services
- Microeconomic rebound
- Substitution and income effects
- Macroeconomic rebound

REPLICABILITY

A key obligation for research today is replicability. We have taken four important measures to ensure replicability for this paper. First, we provide the R-code in open-source packages via links for readers. The R package has a permanent doi link. Second, we will make available our excel-based example sheets in a University of Leeds data repository, also with a permanent doi link. Third, all data used in our examples have been obtained from freely available, public domain sources. Last, we have secured open access funds for the paper, if it is successful in its submission, which will expand readership and aid replicability.

Finally, we have worked hard to provide an article that makes a key foundational advance in this important field that we believe will be of significant interest to your readership. We hope you agree.

Yours sincerely,



Matthew Kuperus Heun

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- Burger, S.P., Jenkins, J.D., Batlle, C. and Perez-Arriaga, I.J., 2019b. Restructuring revisited part 2: coordination in electricity distribution systems. *The Energy Journal*, 40(3).
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- Saunders, H.D., 2015. Recent evidence for large rebound: elucidating the drivers and their implications for climate change models. *The Energy Journal*, 36(1).
- Saunders, H.D., Roy, J., Azevedo, I.M., Chakravarty, D., Dasgupta, S., de la Rue du Can, S., Druckman, A., Fouquet, R., Grubb, M., Lin, B. and Lowe, R., 2021. Energy Efficiency: what has research delivered in the last 40 years? *Annual Review of Environment and Resources*, 46, pp.135-165.
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- Thomas, B.A. and Azevedo, I.L., 2013. Estimating direct and indirect rebound effects for US households with input–output analysis. Part 2: Simulation. *Ecological Economics*, 86, pp.188-198.
- Turner, K., 2013. "Rebound" effects from increased energy efficiency: a time to pause and reflect. *The Energy Journal*, 34(4).