19 June 2021

Dear Editors:

My co-authors and I are pleased to submit an original Research Article to *Energy Economics*.

*TITLE*

**Analytical support estimating micro and macro rebound effects for particular energy efficiency upgrades**

*AUTHORS*

Matthew K. Heun a\*, Gregor Semieniuk b, Paul E. Brockway c;

a Engineering Department, Calvin University, 3201 Burton St. SE, Grand Rapids, MI, USA, 49546

b Political Economy Research Institute & Department of Economics, University of Massachusetts at Amherst, 412 North Pleasant St., Amherst, MA, 01002, USA

c Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, United Kingdom

\* Main author for correspondence: mkh2@calvin.edu; Tel.: +1 (616) 526-6663

*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.

*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 while the world economy grows. Therefore, continued work on energy rebound theory and modelling is required to support energy efficiency modelling and policy responses.

The research gap we identified is that while work on rebound is now routinely cast in terms of microeconomic categories, microeconomic rebound theory is scattered across papers and lacks unification. In response, we develop a comprehensive, consumer-based rebound analysis framework, which includes emplacement, substitution, income, and macro effects. Further, we develop two empirical case studies, of a car and an electric lamp, and obtain estimates of total rebound of 45–84%.

We make several novel contributions. First, the framework developed is the most comprehensive yet developed, and is consistently based on microeconomic theory. Second, we utilise a general model of consumer preference, based on a Constant Elasticity of Substitution (CES) function. Third, our framework is applicable for both marginal and non-marginal energy service price changes from the adoption of an energy efficiency upgrade (EEU). Fourth, we develop a novel approach to utilize a macroeconomic factor (*k*) to link micro-to-macro rebound effects, taking inspiration from recent comparisons with empirical studies of the Marginal Propensity to consume (MPC) for windfall income gains. Fifth, we make the framework operational by using real-world empirical data and providing case study examples to show magnitudes of the different rebound effects and sensitivity to rebound parameters. Sixth, we provide novel rebound visualization in energy, expenditure, and consumpti0n spaces.

From the development and application of the framework, we can draw three important conclusions. First, the car and lamp examples show that the framework enables quantification of magnitudes of all microeconomic rebound mechanisms, including direct and indirect locations for emplacement, substitution, and income effects. Second, the examples show that magnitudes of rebound effects vary with the type of energy efficiency upgrade performed. Third, the sensitivity studies enable evaluation of rebound sensitives to important parameters, including for the first time the full emplacement effect and macro effect. For the examples in this paper, total rebound is more sensitive to the price of energy, the elasticity of energy service demand, and the macro factor (k) than either energy efficiency or capital costs.

*REVIEWER SUGGESTIONS*

* **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](mailto: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](mailto:iazevedo@stanford.edu). Her research interests are keenly focussed on energy rebound, with some of her papers providing foundations for this current paper.
  + Azevedo IL, Sonnberger M, Thomas B, Morgan G, Renn O. The Rebound Effect: Implications of Consumer Behaviour for Robust Energy Policies. International Risk Governance Council. 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](mailto: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 ? In: Santar. 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.
* **Christopher Blackburn**, Research Economist in the National Economic Accounts Research Group at the Bureau of Economic Analysis, United States.

Email: [cblackburn8@gatech.edu](mailto:cblackburn8@gatech.edu). We draw on his recent co-authored paper, which provides critical insights to consumer theory of rebound:

* + Blackburn CJ, Moreno-cruz J. Energy Efficiency in General Equilibrium with Input-Output Linkages. BEA Working Paper Series, WP2020-1. 2020;(October).

*KEYWORDS*

* Energy efficiency,
* Energy rebound,
* Energy services,
* Microeconomic rebound,
* Substitution and income effects,
* Macroeconomic rebound

*REPLICABILITY*

A key requirement for Energy Economics is that the paper should be replicable. In our case, we have made sure our work is replicable. First, we provide the R-code packages and links for the reader. Second, we will make available our excel-based example sheets in a University of Leeds data repository, which has a permanent doi link. Third, all data used in our examples are freely available in the public domain. Last, we have secured open access funds for the paper. If this submission moves to publication open access will encourage its use and aid replicability.

Finally, we have worked hard to provide a concise, novel article that we believe will be of significant interest to your readership. It is keenly aligned to both the Aims and Subject Areas of *Energy Economics*, especially conversion and use of energy, regulation and taxation, and environment and climate*.*

Yours sincerely,

Matthew K. Heun