# *The Solar rebound, household income, and subsidization of residential photovoltaic systems*

### Matthew E. Oliver, Georgia Institute of Technology, Phone +1 404 894 0491,

### E-mail: matthew.oliver@econ.gatech.eduJuan Moreno-Cruz, Georgia Institute of Technology, Phone +1 404 894 1890,

### E-mail: juan.moreno-cruz@econ.gatech.edu

#### **Overview**

Subsidization of residential solar photovoltaic (PV) systems is increasingly pervasive, as policy makers around the world seek ways to reduce consumers’ reliance on conventional, carbon-intensive energy technologies. A key policy question is whether the reduction in grid electricity demand resulting from the induced adoption of residential PV systems justifies the cost of providing economic support for this substitute technology. In this spirit, we explore an under-researched topic related to the installation of residential PV systems—namely, that a “rebound effect” occurs.

The rebound effect is a well-known behavioral response through which potential energy savings from efficiency improvements are partially offset by increased consumption of energy services, as the cost per unit of energy services is reduced (Sorrell 2009; Chan and Gillingham 2015). We characterize the rebound effect related to installation of a residential PV system using a simple neoclassical model similar to that of Chan and Gillingham (2015). We distinguish our work from the existing literature, however, in two ways. First, the rebound effect in this case is due not to an improvement in the energy efficiency of a household’s appliances *per se*, but to the supply of a zero-marginal-cost perfect substitute for grid electricity. Second, although we derive the *direct* *rebound effect* (DRE) in a manner consistent with the existing literature, we also introduce a new rebound concept for residential PV, which we refer to as the *solar rebound*. The DRE for PV is the elasticity of total electricity consumption with respect to an increase in PV output. The *solar rebound*, on the other had, is defined as the increase in total electricity consumption as a percentage of the change in PV output. One advantage of this characterization is that, while the DRE characterizes a *marginal* change only (*e.g*., resulting from an exogenous increase in solar irradiation), the *solar rebound* can be defined both for a marginal change and for a *discrete* change (*e.g*., resulting from the decision to adopt a PV system). Moreover, the analytical convenience of our *solar rebound* concept becomes especially apparent when viewed through the lens of a standard indifference map; the solar rebound is essentially equivalent to the effect of an increase in household income.

A key goal of this research is to understand the relationship between household income and the rebound effect, which has implications for subsidies designed to stimulate adoption of residential PV systems. Arguably the two most popular subsidization schemes for residential PV are (i) a partial rebate of the fixed installation cost (or, equivalently, an income tax credit), and (ii) net metering. After establishing the baseline characteristics of our two rebound concepts, in which we assume zero fixed installation cost (equivalent to a full rebate) and no net metering scheme, we extend the model to account for partial rebate and net metering. We then examine how the DRE and *solar rebound* relate to household income, and discuss the implications for the implementation of subsidization schemes targeted toward low-income households.

The final stage of our research (still in progress) is to apply our theoretical results by computing numerically the rebound effect using geospatial data on residential PV installations and household income in California, one of the most heavily-subsidized residential PV markets in the world over the past decade. The California Solar Initiative (CSI) was created in 2007 to manage the state’s $2 billion financial incentive program, and includes significant incentives targeted toward low-income households (Hughes and Podolefsky 2015). We seek to study the relationship between income distribution, solar PV adoption as a result of state-level economic incentives, and the rebound effect.

#### **Methods**

Applied microeconomic theory; numerical computation & quantitative analysis

#### **Results**

We find that, all else equal, the DRE increases as the fraction of fixed installation cost recovered via the rebate decreases. Conversely, the *solar rebound* for a discrete change in PV output (and thus fixed cost) increases as the rebate fraction increases, but is unaffected at the margin because no change in fixed cost is incurred. All else equal, net metering increases both the DRE and the *solar rebound*, the latter for both discrete and marginal changes in PV output. In addition, theory indicates that, all else equal, an increase in household income increases the DRE. The *solar rebound* is constant across income levels under the restriction that households all have structurally identical utility functions; empirically, however, it is straightforward to show that the *solar rebound* is also generally declining as income increases.

This implies that rebate schemes targeted to incentivize adoption by lower-income households are unlikely to yield as much “bang for the buck” in terms of reducing grid electricity consumption as would result from offering the same incentive on the same PV system to a richer household. Preferential treatment of richer households, however, is unlikely to be politically popular. One solution might be to augment the rebate subsidy to low-income households with an additional incentive to reduce total electricity consumption. An obvious way to do this would be to set a joint subsidy policy such that the higher the rebate the household receives upon installation, the lower the compensation level per unit via net-metering. A higher rebate for low-income households implies a higher *solar rebound* (due to both the income and the rebate relationships described above), but this could be partially offset by a lower net metering compensation level.

The results of our quantitative analysis using data on geospatial PV installations and household income will demonstrate the distribution of the *solar rebound* in the California market. If net metering is the same for all households, then the *solar rebound* will depend only on income and rebate levels across adopters. If the rebate-induced installations are concentrated mostly within lower-income areas, then the *solar rebound* would be greater than if installations were concentrated in higher-income areas (and *vice versa*). This will have clear implications for the effectiveness of the CSI in terms of the resulting reduction in grid electricity demand. [Numerical computation and quantitative analysis still in progress.]

#### **Conclusions**

Work still in progress. From a general theoretical viewpoint, the solar rebound is an important contribution that will provide insight into the effects on electricity consumption of greater market penetration of residential PV systems. With our quantitative analysis, we hope to compute in a convincing way the *solar rebound* associated with the CSI program as it relates to income distribution. Our results will be of interest not only to policy makers with jurisdiction in the California markets, but also to those in other states or countries considering following the CSI model to spur adoption of residential PV systems.

#### **References**

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