Toward an optimal household solar subsidy: A social-technical approach

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ABSTRACT
An analytical framework is developed for integrating the social science into a socio-technical approach for assessing the optimal solar energy subsidy. Estimating the optimal solar subsidy based on the analytical framework takes into account technical environment, health, employment, and electricity accessibility benefits as well as household’s prosocial behavior. Results indicate that an optimal subsidy is positively affected by the marginal external benefit; however, this effect is mitigated by the rebound effect based on motivational-crowding theory. Calibrating the model using published elasticities yields estimates of the optimal solar energy subsidy equal to approximately $0.02 per kilowatt-hour when prosocial behavior is omitted. The estimated optimal subsidy is in line with many current state feed-in-tariff rates, which may be the upper bound when social science is not considered in policy analysis.

1. Introduction

Despite economic returns from the adoption of many energy-efficient technologies and a wide array of government policies to foster adoption, uptake rates are slow and not aligned with policymakers’ expectations. This “efficiency paradox” indicates an assortment of factors beyond simple cost-benefit economics influences adoption decisions. For the case of residential solar photovoltaic (PV) technologies, Sommerfeld et al. [42] indicate there are a number of motivations and energy use behaviors, including prosocial, associated with adoption. Understanding how consumers view solar technologies and their interaction with policies aimed to foster PV adoption is critical for unlocking the potential of solar PV [41].

As addressed by Bénabou and Tirole [7]; providing government incentives for households taking a certain action can have perverse effects, when considering households’ social reputations. The classic illustration is paying for human blood could actually reduce supply [44], with recent applications by Ackermann et al. [1]; Clot et al. [10]; and Dwenger et al. [13]. Household prosocial behavior is the intrinsic motivation to take actions, which are in the community’s best interest. In accordance with motivational-crowding theory, external motivation in the form of government incentives can result in a loss (crowding out or rebound effect) of intrinsic motivation [23]. A subsidy for PV adoption could mitigate, crowd out, intrinsic prosocial behavior of adoption. Households’ reputation for being pro-environment may not be as strong with a PV subsidy.

Moving beyond simple economic calculations to consider prosocial behaviors has been raised not only for PV policies, but energy policy in general. Cooper [11] offers a diagnosis for why the social sciences have limited impact on energy policymaking and advocates a new socio-technical approach to the study of energy. In terms of PV policy, the idea is to integrate the prosocial behavior

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efforts of Sommerfeld et al. \[42\] into actual PV policy. Economics is the natural bridge for such integration. What is missing in general energy policy, PV policy in particular, is household prosocial behavior. Against this backdrop, the objective of this study is to employ economic theory for integrating prosocial behavior into a socio-technical approach for PV government policy. This will direct the development of empirical efforts within both social and natural sciences toward aligning households’ adoption of renewable energy with policymakers’ expectations.

As a foundation, in the past decade an array of government policies, programs, and financial assistance have supported PV as the fastest rising renewable power technology \[29\]. PV generation expanded from 1.5 GW in 2000 \[29\] to just over 100 GW in 2012 \[39\]. In the United States, a range of government programs drives this expansion of residential-renewable energy systems. At the federal level, taxpayers may claim a 30% personal tax credit for residential PV systems and installation costs \[12\]. State and municipal authorities also employ various supporting policies in the form of cash rebates, net metering, renewable-portfolio standards (RPS), solar set-asides, and solar renewable-energy credits \[5,43\]. Recently, states have enacted Feed-in-Tariff (FIT) systems (California, Hawaii, Oregon, Vermont, and Rhode Island) \[39\]. Goldberg \[25\] estimates when considering cumulative subsidies and electricity generation, from 1947 to 1999, solar energy received subsidies worth $0.51/kWh (in 1999 dollars). Badcock and Lenzen \[6\] estimate that in 2007 the global total subsidy for solar PV was $0.64/kWh (in 2007 dollars). More recent studies by the EIA \[14,18\] estimate that the direct federal financial interventions and subsidies in U.S. solar energy markets grew from $179 million in 2007 to $1134 million in 2010 (2010 dollars). Despite the long history of subsidizing solar energy in the U.S., previous research has not determined the optimal level of a PV subsidy with consideration of possible motivational crowding. In contrast, a research vein is directed toward determining the engineering-economic efficient feed-in-tariff (FIT) \[4\], the design of regulatory incentives \[5,24\], and the influence of a carbon tax or cap-and-trade \[37\] for attracting renewable-energy investments. Similarly, Burr \[9\] and Hughes and Podolefsky \[27\] estimate the effects of policies on residential solar installations. A related effort by Lobel and Perakis \[33\] develops a model which determines the optimal solar subsidies required to achieve a desired adoption target at minimum cost. Supporting this effort is determining the desired adoption target, based on internalizing external environmental effects through a solar subsidy. Various research efforts have integrated the physical science of PV with economics in their development of engineering-economic models. Missing from these efforts is further integration with the prosocial behavior of PV. As developed in the following section, failure to integrate prosocial behavior into the calculus of determining the optimal subsidy can lead to the Sommerfeld et al. \[42\] comment: past policy impacts have missed policymakers’ expected targets.

2. Model

Building upon previous work in the optimal tax/subsidy literature, including gasoline taxes \[36\], ethanol subsidies \[46\], and biodiesel subsidies \[50\], a theoretical model for the optimal residential PV subsidy is developed. In particular, households’ PV prosocial valuations are integrated into this optimal tax/subsidy literature. As addressed by Bénabou and Tirole \[7\], households may receive pro-environmental and social self-esteem benefits from generating solar electricity. Letting $0$ represent the household benefit, a household’s level of PV will influence this benefit, $\theta = \phi(PV)$, where it is assumed $\partial\theta/\partial PV > 0$ and $\partial^2\theta/\partial PV^2 < 0$. The adoption of PV provides a household a positive reputation or mystique of being prosocial in terms of pro-environmental concerns. In contrast, any PV subsidies may decrease these prosocial benefits.

2.1. Agent decision problem

For integrating prosocial valuation into determining the optimal PV subsidy, consider a household PV decision based on utility maximization. The main objective is to provide an intuitive treatment of household PV economics in a universal setting considering prosocial valuation. It is assumed solar energy, $PV$, is determined by peak hours of sunlight per year $z$ (hours) and quantity of solar panels purchased by the household (watts or kW). Let $h$ denote peak hours of sunlight per day, $z = 365h$. In general, a household receives utility from electricity consumption and from generating solar energy (personal satisfaction, independent security from generating energy, and prosocial valuation) \[48\]. A household also receives satisfaction from non-interference of electrical power, $A$. Specifically, access to electricity, $A$, is assumed to depend on a household’s solar energy production

$$A = A(PV) \text{ with } \frac{\partial A}{\partial PV} > 0. \quad (1)$$

Assume a household also receives satisfaction from a conventional utility plant (coal, natural gas, and petroleum), $F$, and a composite consumption good, $X$, with associated numeraire price $p_x = 1$. A utility function may then be represented as

$$u(X,F,PV,A(PV),\theta(PV)), \quad (2)$$

where all the determinants positively influence utility.

Fig. 1 illustrates this household problem where a household’s choice variables directly influence its level of satisfaction. These choice variables are arguments in (2): composite consumption good, $X$, fossil fuel, $F$, solar energy, PV, electricity access, $A$, and prosocial valuation, $\theta$. Electricity access and prosocial valuation are influenced by solar energy. As indicated in Fig. 1, associated with this utility function are external environmental effects along with “green” and high-tech job opportunities and/or rural development effects (externalities).\(^1\)

Let the environmental effect of consuming power-plant electricity, $D$, be decomposed into greenhouse gas emissions, $D_g$, and localized air pollution, $D_a$ (e.g., $SO_2$, $NO_x$, $PM_{2.5}$, and $PM_{10}$) which have a more localized negative impact on the environment, health, and infrastructure. It is assumed greenhouse gas emissions and localized air pollution depend on aggregate conventional electricity, $F$. Specifically,

$$D = D_g(T) + D_a(T) \frac{\partial D_g}{\partial F} > 0. \quad \frac{\partial D_a}{\partial F} > 0. \quad (3)$$

In addition to these environmental effects, there may be “green”

\(^1\) The choice of external effects is subject to empirical investigation determining their individual magnitudes. The objective is to present a set of possible external effects and determine how such effects in general will affect the optimal subsidy. There are other external effects including environmental damage from transportation and extraction of fossil fuels (oil, coal, and natural gas). Including these externalities does not enrich the theoretical model, but will positively affect the optimal subsidy. Also, it is assumed the U.S. economy is closed in terms of no leakages from the United States’ attempts to reduce negative external effects, influencing another country’s efforts \[31\].
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