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LEARNING-BY-DOING AND THE OPTIMAL SOLAR POLICY IN CALIFORNIA

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Introduction

Much policy attention has been given to promote fledgling energy technologies that promise to reduce our reliance on fossil fuels. These policies aim to correct market failures, including a dynamic externality due to learning-by-doing (LBD). We integrate this theory in a model of technological advancement in renewable energy markets based on exogenous factors, LBD, and diffusion. The model is used to examine the economics of state subsidies for California's residential solar photovoltaic market. This $3 billion “California Solar Initiative” (CSI) was adopted early 2006 and is one of the largest subsidy programs for solar in the world. CSI provides the assurance of incentives over 11 years, a serious commitment on the part of California to solar energy. The key questions addressed by the model is whether CSI is an economic efficiency-improving policy, and – if not – what would be the optimal solar policy from the point of view of the government.

Two market failures

We identify two market failures that apply to the market for solar energy systems: the well-known environmental externality and an appropriability externality. Spillover benefits from a firm’s research and development (R&D) investment are the most commonly cited form of the appropriability externality, but the production of a good may also have spillover benefits from LBD. In the case of solar, there is evidence for learning in the installation of residential solar systems, whereas evidence for LBD in the PV module cost is very weak. In this paper, we closely examine the LBD dynamic externality, due to its applicability the installation cost component of solar PV. We conjecture that this LBD dynamic externality also holds for other renewable energy sources.

Methodology

The model focuses on the residential PV market, ignoring the effect of the subsidy in the commercial, industrial and government sector, and solar water heating. A constrained optimization model determines the optimal incentives for the period 2006 – 2016, by maximizing the present value of the benefits minus the costs to the state of California. Benefits include environmental benefits and consumer benefits, and costs are incentive costs paid by the taxpayers. Equation (1) is the objective function.

$$(1) \qquad MAX_{I_t} \quad \sum_{t=1}^{T} \frac{\{Xq_t(I_t) + q_t(I_t)NPV_t(I_t, Q_t, e)\} - q_t(I_t)I_t}{(1+r)^t}$$

where X is the environmental externality benefit per installed Watt, $q_t(\cdot)$ the installed capacity (i.e., demand) in year t, Q_t the cumulative installed capacity in year t, I_t the incentive in year t, $NPV(\cdot)$ the net present value to the consumer per installed Watt, e the electricity price growth rate, r the discount rate, and t the time in years.

Constraints are determined by demand (which is a function of the NPV of a solar system to a consumer, and a diffusion term), and supply (based on learning-by-doing in the California residential solar market, and an exogenous growth in global installations). The demand curve is calibrated to historical demand for solar panels in California. The NPV of a solar system for a potential buyer is calculated with an extensive bottom-up spreadsheet model, developed jointly with residential solar installation company Akeena Solar.

After parameterizing the model, we solve for the optimal path of incentives from 2006 – 2016 numerically.

Main Results

We find that, under central-case parameter estimates, maximizing net benefits implies a solar subsidy schedule similar in magnitude to that recently proposed in California under the CSI. This result is quite robust to most key parameters in the model, and is most sensitive to the assumed growth rate in electricity prices. A sensitivity and robustness analysis indicates that the value of a solar policy is sensitive to the parameterization of the model, but the CSI is an efficiency-improving policy under a wide parameter range.

Table 1: Installations in 2018 for CSI, optimal policy and no policy

	Systems in 2018, CSI	MW	Systems in 2018, Optimal Policy	MW	Systems in 2018, No Policy	MW
PV Res Retrofit	145,700	804	141,000	778	28,800	159
PV Res New	69,400	146	80,500	169	3,700	20
Total	215,100	950	221,500	947	32,500	179

Table 1 and the following discussion present the results of the model under central-case parameters. The optimal policy will lead to about 220,000 residential solar systems, or approximately 950 MW. After 2018, growth will continue at an even higher level (Figure 1). The CSI incentives are very close to this optimal policy.

CSI aims at reaching a capacity of 3 GW in 2018. Without any subsidies, only 179 MW would be installed in 2018. Our optimal policy leads to about 1 GW in 2018, at a cost of almost $1,140 million (Table 2). About $2 billion would remain under CSI to subsidize non-residential solar systems and solar water heating, potentially bringing in the final 2 GW. This may be possible, but it is beyond the scope of the current paper to assess this.

Table 2: Financial comparison between CSI, optimal policy, and no policy

($ million)	CSI	Optimal Policy	No Policy
Total Incentive Cost, Res Ret	1,021	937	0
Present Value Res Ret	4,209	4,237	2,919
Total Incentive Cost, Res New	166	203	0
Present Value Res New	965	976	688

The value of the optimal policy – the difference in present value between the policy and no policy case - is approximately $1.3 billion for residential retrofit and $0.3 billion for new construction, adding up to $1.6 billion. Thus, under our central-case estimates, the model suggests there is an economic rationale for solar subsidies in California. Figure 2 shows the costs and benefits to the state relative to the case of no solar policy. The bulk of the benefits accrue after 2020, which illustrates the long-term nature of a solar energy policy. The environmental benefits of the policy are considerably smaller than the consumer benefits in the long run.

Figure 1: Yearly PV residential retrofit installations under the optimal policy

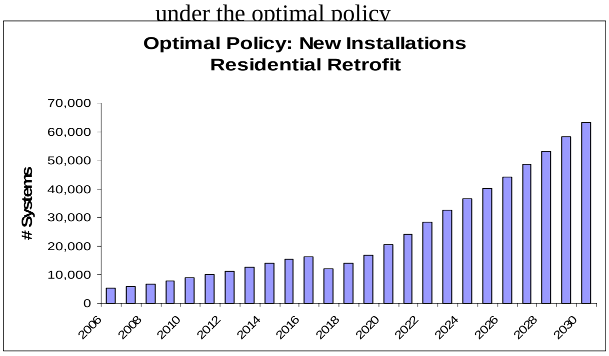
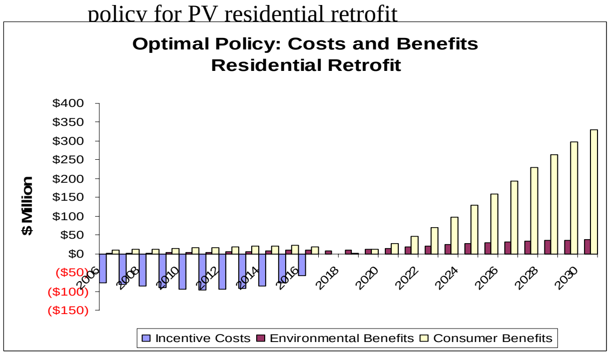


Figure 2: Costs and benefits of the optimal policy for PV residential retrofit



Conclusions

- Under a wide range of most parameter values, a solar policy can correct several market failures in the solar energy market, leading to significant improvements to economic efficiency for society;
- In the case of California, and under central-case parameters, economic efficiency in the residential solar market is increased by $1.6 billion. Subsidies should optimally start above $3/Watt and drop down to $0/Watt in 2017;
- The majority of the benefits can be attributed to consumer benefits,, which relate directly to the learning-by-doing market failure. Environmental benefits are relatively small;
- In 2018, about 220,000 residential systems or 1 GW will be installed. This is much less than the 3 GW envisaged by CSI, but we only examine the PV residential market;
- The specification for technological change is an important driver of the results and should be chosen carefully. A wrong technology specification may lead to misleading estimates of policy effects.

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