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Adoption of residential solar power under uncertainty: Implications for renewable energy incentives

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HIGHLIGHTS

- We examine household adoption of solar PV using the option value framework.
- Uncertainty in benefits and costs leads to delay in investment timing.
- Discounted benefits from solar PV have to exceed investment cost by 60% to trigger investment.
- Policy incentives that reduce uncertainty in returns from solar PV are most effective.

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ABSTRACT

Many incentives at the state and federal level exist for household adoption of renewable energy like solar photovoltaic (PV) panels. Despite generous financial incentives the adoption rate is low. We use the option value framework, which takes into account the benefit of delaying investment in response to uncertainty, to examine the decision by households to invest in solar PV. Using a simulation model, we determine optimal adoption times, critical values of discounted benefits, and adoption rates over time for solar PV investments using data from Massachusetts. We find that the option value multiplier is 1.6, which implies that the discounted value of benefits from solar PV needs to exceed installation cost by 60% for investment to occur. Without any policies, median adoption time is eight years longer under the option value decision rule compared to the net present value decision rule where households equate discounted benefits to installation cost. Rebates and other financial incentives decrease adoption time, but their effect is attenuated if households apply the option value decision rule to solar PV investments. Results suggest that policies that reduce the uncertainty in returns from solar PV investments would be most effective at incentivizing adoption.

1. Introduction

Solar energy has received growing support from the United States (US) government in the past several years. State governments, in particular have introduced various incentive programs in the form of rebates, tax incentives, and mandates (DSIRE, 2013). Many of these policies are targeted specifically to small residential installations, which is projected to be the fastest growing segment in solar installations in the US (GTM Research and Solar Energy Industries Association, 2014). In the state of Massachusetts, the combination of federal and state incentives has lowered the cost of a typical 6-kW residential system by over 50%, from about $33,000 to $16,000.[1] Despite generous incentives, adoption rates have been low. In 2012, less than 0.5% of households in Massachusetts that own their homes have solar panels.[2]

One possible reason for the low uptake of solar PV is the presence of uncertainty in the pay-off over the lifetime of the PV

[1] The average installed cost of PV systems under the Massachusetts Solarize II program that ran from 2010–2014 was $33,000 for a 6-kW system. The average rebate received for each installation was $4000. Adding the federal and state tax credits of $12,000 to the rebate amount gives the total incentive amount of $16,000 which is 48% of installation costs. Including payments for solar renewable energy credits (SRECs) which could vary from roughly $1000 to $2500 per year depending on the SREC price, increases the incentive amount to over 50% of installation cost (MassCEC, 2013).

[2] In 2012, an estimated 7256 homes have solar PV installed, out of about 1.6 million owner occupied housing units in Massachusetts (National Renewable Energy Laboratory, 2013; U.S. Census Bureau, 2012).

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system. Adopting solar PV involves large upfront costs with uncertain future benefits. Furthermore, the investment is irreversible or very costly to reverse. Thus, households may see a benefit or 'option value' to waiting to see how energy prices, government incentives, and solar PV technology will evolve before deciding to invest. The option value model for investment under uncertainty suggests that in the context of irreversible (or costly reversible) investments and uncertain future benefits, agents see a value to postponing the investment decision until uncertainty is resolved (Dixit and Pindyck , 1994). This implies that compared to investments whose returns are subject to less uncertainty, households may require a higher rate of return on their investment in solar PV. Thus, one would observe less adoption relative to the case where net benefits from solar PV adoption could be obtained with certainty. Since significant public funds are being expended on solar incentive programs, it is important to examine the effect of uncertainty on households' decisions to investment in solar power, and what this effect implies for policies that incentivize adoption of solar PV.

We find that uncertainty has a significant impact on the timing of investment in residential PV. When we assume that households take into account the option value of their investment dollars, the present value of benefits from solar PV needs to be 60% greater than installation costs for investment to occur. Compared to the net present value (NPV) decision rule that equates discounted benefits to initial investment cost, the median adoption time under the option value (OV) decision rule is 6–21 years longer depending on assumptions about what policies are in place. We find that financial incentives like rebates and tax credits decrease adoption times under both the NPV and OV decision rules, although the effect is weaker under the OV decision rule. Revenues from solar renewable energy credit markets have a modest effect on adoption times under the NPV decision rule, and may even increase adoption time under the OV decision rule. These results suggest that policies that reduce uncertainty of returns from solar PV investments would be most effective at encouraging adoption and diffusion of solar PV technology.

This paper is related to a number of previous studies that have examined the effect of uncertainty on technology adoption and energy investments. Hassett and Metcalf (1993) provide the first formal application of the option value framework to investments in energy efficiency. Using data on electricity prices and capital costs in the U.S. from 1955–1981, they conclude that the threshold rate of return on investment for energy efficiency investments is over four times that of the conventional rate of return. Isik (2004) uses the option value framework to examine the impact of policy uncertainty on the adoption of site-specific technologies by farmers in the state of Illinois. He considers the impact of policy changes, specifically the probability that an existing subsidy will be removed and the probability that a subsidy policy will be implemented when none currently exists. He finds that the expectation of a subsidy removal encourages investment, while the probability that a subsidy will be provided in the future delays investment. Ansar and Sparks (2009) also use the option value framework to examine the effect of uncertainty on the decision to invest in solar PV. They extend the model developed by Hassett and Metcalf (1993) by incorporating the effect of experience-curves on the drift and variance of benefits from solar PV adoption. They also consider the possibility of a downward jump in future benefits that would cause benefits to fall to zero. They conclude that the effect of experience-curves on threshold rates of return dominates the effects of the trend in energy prices and other possible shocks to future benefits.

In the last several years, many states have put in place policy incentives for residential solar PV. Many of these incentives change over time and are subject to uncertainty. For example, the average rebate in Massachusetts was $1.34 per watt in 2010, while in 2014 the average amount has been reduced to $0.36 per watt (MassCEC, 2014). States have also implemented solar-specific mandates. These mandates have led to the creation of markets for solar renewable energy credits (SRECs) that are priced in the marketplace.[3] While these policies increase the financial benefit available to PV adopters, they also add additional uncertainly to the level of net benefits. In 2012, SREC prices in Massachusetts were over $500 per 1000 kWh, which would yield a household owning a 5-kW system $2750/yr in benefits.[4] In early 2014, with an SREC price of about $200, projected SREC revenues were $1100. Existing studies have not accounted for the effect of policy uncertainty on the adoption of solar PV. This paper fills this gap in the literature.

We develop a dynamic stochastic model of household adoption of solar PV systems using the option value framework to examine the impact of uncertainty on households' decisions to invest in solar PV. Using data from Massachusetts on electricity prices, installation costs, rebates (including tax credits), SREC prices, and energy production of solar PV systems, we estimate drift and volatility parameters for benefits and costs over time, and derive the optimal investment rule for solar PV adoption. We then derive the threshold value of discounted benefits that trigger adoption and the length of time for investment to occur under the net present value (NPV) and option value (OV) decision rules. We also simulate adoption rates over time and examine the impact of different incentive mechanisms on adoption decision and timing. Finally, we discuss the implications of the option value decision rule on the effect of various policy incentives for solar PV.

We extend the analysis by Ansar and Sparks (2009) in a number of ways. First, we account for the effect of government policies on net benefits. As discussed earlier, these policies significantly alter the benefits and costs of solar power, as well as the uncertainty in net benefits. Second, we consider trends in both benefits and costs of solar PV adoption. Ansar and Sparks (2009) do not consider changes in installation costs over time. A significant portion of uncertainty in net benefits may come from uncertainty in future installation costs, which include not only the price of materials but also labor and managerial costs that are related to the level of expertise of installers and economies of scale. Finally, we examine the effect of applying the option value decision rule on the impact of policy incentives for solar power. If households take into account option values when making investment decisions, the level of uncertainty associated with policy incentives will affect the way households respond to these policies. Since policy incentives play a crucial role in a household's decision to invest, it is important to examine how uncertainty affects the effectiveness of different incentives.

The remainder of this section provides a brief background on the solar PV market in the US and in the state of Massachusetts. Section 2 presents the model we use to derive the optimal investment decision rule. Section 3 discusses data sources and presents results and Section 4 concludes.

[3] SRECs are commodities that are traded on SREC markets. In principle, SREC sales can be transacted directly by buyers and sellers, provided that the seller is certified by the state. However, residential PV owners typically contract with SREC aggregators and brokers who then sell SRECs on spot markets, through forward contracts, or at auction. SREC prices are determined by supply and demand, and the level of the Alternative Compliance Payment, the fee that electricity suppliers have to pay if they do not meet state-mandated requirements for solar-generated electricity.

[4] Assuming energy production of 1100 kWh per 1-kW capacity.