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Innovation subsidies versus consumer subsidies: A real options analysis of solar energy ☆

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HIGHLIGHTS

- Stochastic dynamic model of solar PV adoption under two sources of uncertainty.
- Simulation across electricity prices, technical change, subsidies and CO_2 taxes.
- Rate of technical change indicates shift to solar in 25–28 years without incentives.
- Modest impact of consumer subsidies and CO_2 taxes (up to \$150/ton CO_2) in adoption.
- R&D support/further technological change is the main driver of adoption of solar.

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ABSTRACT

Given the interest in the commercialization of affordable, clean energy technologies, we examine the prospects of solar photovoltaics (PV). We consider the question of how to transition to a meaningful percentage of solar energy in a sustainable manner and which policies are most effective in accelerating adoption. This paper develops a stochastic dynamic model of the adoption of solar PV in the residential and commercial sector under two sources of uncertainty – the price of electricity and cost of solar. The analytic results suggest that a high rate of innovation may delay adoption of a new technology if the consumer has rational price expectations. We simulate the model across alternative rates technological change, electricity prices, subsidies and carbon taxes. It is shown that there will be a displacement of incumbent technologies and a widespread shift towards solar PV in under 30 years – and that this can occur without consumer incentives and carbon pricing. We show that these policies have a modest impact in accelerating adoption, and that they may not be an effective part of climate policy. Instead, results demonstrate that further technological change is the crucial determinant and main driver of adoption. Further, results indicate that subsidies and taxes become increasingly ineffective with higher rates of technological change.

1. Introduction

The installed capacity of solar PV systems has increased dramatically over the past five years, i.e. 53% per year in the US and 60% per year globally. While this growth has partly been driven by declining costs, it has primarily been driven by state and federal incentives and policy support. Current adoption of solar PV systems without incentives remains unlikely. Notwithstanding recent declines, the high cost of solar PV renders it unable to compete with incumbent electricity technologies, even when incorporating benefits of the technology which may not have been previously accounted for Goodrich et al. (2012) and Borenstein (2008).

Incentives to the residential and commercial sectors (which historically account for approximately 70% of installed capacity in the US) have ranged from up-front cash rebates to renewable portfolio standards, and federal and state tax benefits. Incentives have covered an estimated 3% to 50% of total system cost, and have amounted up to \$22,000 per installation (Peterson, 2011). Yet in 2012 solar energy amounted to little over 1% of generated electricity in the US and contributed the smallest share amongst all renewable-generated electricity based on Energy Information Administration (EIA) estimates.

If our aim is to speed the commercialization and deployment of affordable, clean energy technologies and transition to market driven industries, then the central question remains – how do we

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get to a meaningful percentage of solar PV generation in a sustainable way? Will there be a widespread shift towards solar PV, and which policies are most effective? The question is pertinent, and Chakravorty et al. (1997) suggest that the transition to backstop technologies may be the only viable solution to global warming.

In this paper, we examine the prospects for future adoption of solar PV in the residential and commercial sector, recognizing that what drives the process on a sustainable basis is the consumer's adoption decision. We examine which policies will have an impact in accelerating adoption and what role solar energy will ultimately play in our future energy mix.

We use a stochastic dynamic framework, and develop a theoretic real options model to evaluate the threshold and timing of the consumer's optimal investment decision, given two sources of uncertainty – the price of electricity and the cost of solar. We derive analytic results regarding the threshold of adoption under alternative regimes of R&D funding and technological change, subsidies and carbon taxes. And we develop an algorithm and simulation technique based on a bivariate kernel density estimation to derive projections of the cumulative likelihood and timing of substitution amongst energy resources and towards solar. We apply the methodology to solar PV as an illustration of the technique given multiple sources of uncertainty, and provide a general framework to evaluate investments in competing renewable energy technologies.

We use a real options approach (*ROA*) which is an application of option valuation techniques originally developed in the finance literature (Black and Scholes, 1973), but which have found important applications in natural resource economics (Arrow and Fisher, 1974; Conrad, 1980; Brennan and Schwartz, 1985), environmental economics (Pindyck, 2000), water economics (Carey and Zilberman, 2002), and most recently in renewable energy economics.

ROA is fundamentally a stochastic dynamic framework analyzing investment decisions in the presence of three factors: uncertainty of the economic environment, irreversibility, and the ability to postpone the investment decision (Dixit and Pindyck, 1994). Traditional static "now or never" net present value (*NPV*) breakeven models of investment have resulted in predictions that have been observed to overestimate investment and adoption. However, a key result of the real options framework is that the investor will require a significant excess return above the expected present value before making the investment in light of these factors.

Recently *ROA* has found applications in evaluating investments in renewable energy technologies, two notable examples being Lemoine (2010) and Schmit et al. (2011). Lemoine (2010) uses option valuation to compute a more complete market valuation of a plug-in hybrid electric vehicle (PHEV) by incorporating the additional benefit derived from the driver's ability to respond to fuel and electricity prices on a daily basis. Schmit et al. (2011) use *ROA* to evaluate combined entry and exit investment decisions in an ethanol plant.

We extend the current literature both methodologically and empirically. Methodologically, based on Dixit and Pindyck (1994), we incorporate two sources of uncertainty as an extension of the traditional single variable model and provide new analytic insights and comparative static results. While both Lemoine (2010) and Schmit et al. (2011) incorporate two stochastic processes in their analysis, they do so in a different framework – Lemoine examines the valuation but not the threshold of adoption, while Schmit et al. use a numerical approximation procedure to solve the optimal switching problem.

Empirically, to our knowledge, this is the first real options paper to examine the question of solar energy. Further, we develop an algorithm and simulation technique based on a bivariate kernel density estimation which is essential to incorporate two stochastic processes, and which can be used to evaluate investments in alternative renewable energy technologies in general.

The results of the model show that if assumptions are maintained, there will be a displacement of incumbent technologies and a widespread shift towards solar PV in the residential and commercial sector in under 30 years, across plausible rates of technological change. Projections consistently indicate that this can occur independent of downstream incentives and carbon pricing policies (up to \$150/ton CO_2) which generally have a modest impact – and may not be an effective part of climate policy in this regard. Further, both consumer subsidies and carbon taxes become more ineffective with higher rates of technological change, making virtually no difference in certain cases. Results demonstrate that further technological change is the crucial determinant and main driver of adoption, outweighing the effect of subsidies and taxes.[1] Suggesting that subsidies and taxes don't make a substantial difference in a technology that's not viable – instead that research does.[2] These results are robust across varying levels of interest rates, technological change, electricity prices, and incentives.

The results suggest several significant policy conclusions: (i) concerns regarding recently decreasing consumer subsidies dampening the consumer economics of solar adoption are overstated. (ii) Carbon taxes of \$21/ton CO_2 and \$65/ton CO_2 have a minor impact in accelerating widespread adoption of solar PV as compared to baseline projections. Carbon pricing at \$21/ton CO_2 accelerates adoption by an average of 0–3 years, and pricing at \$65/ton CO_2 accelerates adoption by an average of 2–5 years, depending on technological change scenario. (iii) A carbon tax of \$150/ton CO_2 will have a modest impact on accelerating adoption by an average of 6–8 years if the recent higher rates of technological change in solar PV are maintained. The impact will be more significant in the scenario with historical lower rates of technological change, accelerating adoption by an average of 10.5–15.5 years. However projections still indicate a widespread shift towards solar within 26–31 years in this scenario.

Results show that R&D support and technological change in solar PV is the crucial determinant in accelerating widespread adoption of solar PV and should play a key role in climate policy. Projections indicate that if recent rates of technological change in solar are maintained, there could be a widespread shift towards solar in 25–28 years without any subsidies or carbon pricing.[3]

2. Methods

We examine the solar PV adoption decision in the residential/

[1] The two main components of technical change are R&D and learning by doing (LBD) – both of which play vital roles (Carraro et al., 2003, Sagar et al., 2006). Deployment policies are justified insofar as capacity driven experience may lead to LBD and cost reductions in technologies. However, in general technological learning/LBD is not an automatic byproduct of cumulative installed capacity, and should not be taken as such. The potential for LBD may fundamentally differ among technologies, and at different stages of a technology (Sagar et al., 2006). For example Nemet (2006) suggests that LBD only weakly explains changes in the most important factors influencing observed cost reductions in solar PV over the past 30 years. Based on this empirical foundation, our study currently does not capture the effect of taxes and subsidies on adoption that may exhibit technological learning/LBD effects, and this omission should be addressed in future research.

[2] Assuming limited LBD potential as suggested by Nemet (2006).

[3] We emphasize R&D and technological change in our model, however e.g. economies of scale may contribute towards declining system prices and the same analysis can apply to these factors, the impact of which we compare to average consumer subsides and CO_2 taxes (up to \$150/ton CO_2) to find that declining system prices will be the crucial determinant and main driver of adoption.