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When do households invest in solar photovoltaics? An application of prospect theory

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ABSTRACT

While investments in renewable energy sources (RES) are incentivized around the world, the policy tools that do so are still poorly understood, leading to costly misadjustments in many cases. As a case study, the deployment dynamics of residential solar photovoltaics (PV) invoked by the German feed-in tariff legislation are investigated. Here we report a model showing that the question of when people invest in residential PV systems is found to be not only determined by profitability, but also by profitability's change compared to the status quo. This finding is interpreted in the light of loss aversion, a concept developed in Kahneman and Tversky's prospect theory. The model is able to reproduce most of the dynamics of the uptake with only a few financial and behavioral assumptions.

1. Introduction

The majority of countries has RES targets and support policies in place (REN21, 2016). Such deployment policies, i.e. the desired diffusion of RES into the market via remunerations like feed-in tariffs, tenders or market premiums, can be effective tools in creating a market pull which fosters the uptake of renewables and can, if well designed, invoke technological evolution and innovation (Hoppmann et al., 2013). There is little insight, however, on how to set adequate remuneration levels and when to adjust them, mainly because the drivers and dynamics of investment are poorly quantified. The policy instruments that try to incentivize RES deployment therefore often fail to reach desired quantities. Costly misadjustments could be avoided with a better understanding of deployment and diffusion dynamics.

The modeling of market diffusion of RES and in particular photovoltaics (PV) has attracted a considerable amount of research interest in recent years. While there is a fairly large body of literature on how to set optimal levels of remunerations via real option analysis (for an overview see e.g. Zhang et al., 2016), or how firms would ideally time and size investments under regulatory uncertainty (see e.g. Chronopoulos et al., 2016), a growing body of research shows that the residential sector behaves rather differently. For instance, the intention formation of home-owners to adopt PV does not solely depend on optimality principles and financial factors (see e.g. Korcaj et al., 2015). Energy policy can benefit from a more detailed consideration of behavior (Allcott and Mullainathan, 2010). However, methods that take into account more realistic or boundedly rational decision rules have had little impact on the evaluation of residential deployment dynamics – modeling of small scale investments in RES is challenging since many heterogeneous actors and motives are involved.

So far, scholars have focused on the socio-demographics of home-owners and the evaluation of local peer effects (see e.g. Bollinger and Gillingham, 2012; Kwan, 2012; Rode and Weber, 2016). They find that localized peer-to-peer communications reduce barriers to PV adoption (Rai and Robinson, 2013). Most recently, elaborate agent-based modeling approaches have been presented by Palmer et al. (2015) and Rai and Robinson (2015), which combine both socio-economic characteristics and peer effects. While all of these approaches provide a detailed view of the drivers and boundaries of RES uptake, these evaluations are relatively hard to trace back and generalize, as they require granular spatial socio-economic data in the former and relatively specific agent specification in the latter case. They are therefore hard to apply to other cases and not reducible to analytic demand formulas and hence of limited use if to be applied in a whole systems energy modeling context.

Curve fitting approaches try to fill this gap and relate the economic profitability of a representative PV project with observed aggregated deployment rates. Grau (2014) mapped the profitability of PV onto the deployment observed in Germany via a logarithmic fit function. A dynamic time lag between investment decision and installation is proposed, which is reduced in situations when remuneration reductions are announced. Similar exponential curve fitting contributions

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have been made by van Benthem et al. (2008) and Wand and Leuthold (2011), additionally with technology diffusion terms. Similarly, Lobel and Perakis (2011) are applying a logit demand function, where the utility of adoption mainly depends on profitability and the logarithm of cumulative installations. All of these approaches, however, provide only limited insight into the dynamics of observed deployment rates, as they either only focus on yearly installation values (van Benthem et al., 2008; Lobel and Perakis, 2011; Wand and Leuthold, 2011) or must be recalibrated over time to make up for unknown dynamic changes in the adoption behavior (Grau, 2014). Finally, Leepa and Unfried (2013) present a time-series analysis of the effect of remuneration cuts on the investment behavior of PV in Germany and find that step-wise adjustments temporarily accelerate installments. However, a limit of their study is that they cannot establish causal relationships.

To summarize, a need for dynamic, fundamental, parsimonious models which are able to depict the magnitude of PV deployment over time is identified. The aim of this study is to address this research gap.

The remainder is structured as follows: Section 2 introduces the research case – residential PV deployment in Germany over the years of 2006–2014 - and explains why this is a useful example to study deployment dynamics and the interaction with the policy regime. Section 3 is concerned with the methodology, i.e. the techno-economic modeling of PV systems. A way to calculate mean internal rates of return via a Monte Carlo simulation method is presented. The deployment modeling via utilities, and most notably, our proposed extension with the value function of prospect theory, is presented. Section 4 presents a deployment analysis on absolute level of PV profitability, and most notably, shows how this approach fails to capture the subyearly investment dynamics. The evaluation then presents how prospect theory can be used to explain the stylized features of the subyearly deployment dynamics substantially better. Section 5 discusses the findings, and points out to possible short-comings and extensions of the study. Section 6 concludes with policy recommendations.

2. Research case – residential photovoltaics in Germany

To study the market diffusion of RES, the case of residential PV deployment in Germany over the years of 2006–2014 is investigated. As one of the earliest examples of a RES incentive program, the German government introduced the Renewable Energy Sources Act (EEG) in 2000. Among others things, the act regulates the remuneration of RES, which are granted a technology-specific compensation for each kWh of electricity fed into the grid. For photovoltaics, the instrument has been effective in creating a dynamic demand and a competitive supplier and installation industry (Seel et al., 2014).

This feed-in tariff remuneration scheme is a remarkable possibility to study the impacts of incentives on the observed deployment dynamics: the basic logic of the incentive program – a fixed compensation for 20 years starting with the date of initial operation – did not change for residential PV; the level of remuneration and system costs, however, have changed. This allows to examine the effect of this particular policy instrument by assessing the relationship between profitability of PV systems and the aggregated deployment.

Remuneration adjustments were necessary because the economics of PV have been shifting rapidly (Candelise et al., 2013): PV module cost decreased by approximately 80% in the last 10 years alone (Farmer and Lafond, 2016). Fig. 1 depicts the relative development of PV module cost and feed-in tariffs for solar photovoltaic systems. These developments were not in alignment at all times, especially in the year 2009–2012. As module prices fell, remunerations were decreased, often hastily, between 2006 and 2010 stepwise in a yearly way, between 2010 and 2012 in higher iterations as the rapid price decline made more amendments necessary, and since April 2012 on a monthly basis in dependence of the actual deployment over the past year.

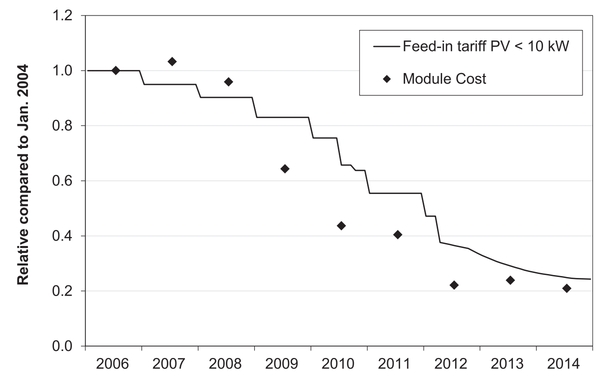

Fig. 1. *Relative development of feed-in tariff and PV module costs.* The feed-in tariff for residential PV systems with a capacity of $<10\ \mathrm{kW_p}$ is shown by the solid line. The markers indicate the PV module costs in the same period of time. Both feed-in tariff and module cost developments are given relative to their values in January 2006. The sharp decrease in PV module cost made tariff adjustments necessary, and the developments were not in alignment at all times. Data source: (Bundesnetzagentur, 2016; Farmer and Lafond, 2016).

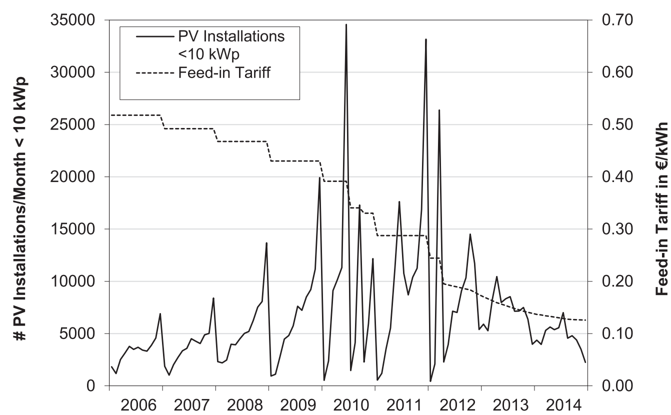

Fig. 2. *Monthly PV installations and feed-in tariff.* For the years 2006–2014, the installations of PV systems $<10\ \mathrm{kW_p}$ per month are depicted by the solid line, corresponding numbers are given on the left axis. The dashed line shows values of the feed-in tariff given in Euro/kW h, scale on the right axis. The installation peaks correspond with anticipated feed-in tariff cuts.
Data source: (Bundesnetzagentur, 2016; Open Power System Data, 2017).

Fig. 2 illustrates the monthly PV installations $<10\ \mathrm{kW_p}$[1] between 2006 and 2014, in total about 700,000 installations. The development is characterized by pronounced spikes, which correspond with anticipated step-wise feed-in tariff cuts (Leepa and Unfried, 2013).

3. Methodology

In order to reduce complexity, the study abstains from looking on individual level decision making and focuses on the aggregate of investment dynamics. To establish a link between the profitability and deployment, home-owners are regarded to consider the installation of a PV system as an investment. As such, PV systems have to compete with other investment possibilities. With decreasing economy wide average rates of return, a lower internal rate of return (IRR) on PV installations becomes more acceptable for profit-oriented installers, as comparative investments on other markets get less attractive. The modeling steps are outlined below and substantiated in the following subsections:

[1] $\mathrm{kW_p}$ is an often employed unit to depict the nominal power of PV systems. It measures the output of a system under peak (hence the “p”) conditions, i.e. standard testing conditions with a horizontal irradiance of $1\mathrm{kW/m^2}$ at 25°C ambient temperature.