Let the Sun Shine: Photovoltaic Deployment in Germany

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Motivation

- Technology with a fast market increase
- Policy debate on the various incentive measures (feed-in, ITC, R&D subsidies, tradable green certificates, renewable portfolio standard, net metering) coupled to the European ENR 2020 target
- "Bubbles" in some countries, such as Spain; frequent redefinition of the subsidy policy.
- The question: it is possible to calculate an optimal path of the installed capacity, minimizing the cost of the incentive measures?
  - we establish a theoretical model, using a discrete choice framework, which links profitability of PV investment to annual installed capacity
  - we test the model on German data over the period 1998-2009 and make forecast until 2020.

A brief summary of the related literature

- Learning curve: PV prices decrease as the amount of technology deployed increases (Shaeffer et al. 2004, Nemet, 2005)
  - Limits: sensitivity to data, complexity of the technology and factors of cost reduction others than learning.
- Deployment: diffusion of innovation are often described by logistic functions or "S-curves" (the Bass model-Gerowski, 2000, Guidolin and Mortarino, 2010)
  - Limits: these models do not take into account the incentive policies such as subsidies and feed-in tariffs.
- Profitability of PV investment: values of investments in different countries in Europe, Japan, Germany in presence of incentive schemes (Dusonchet and Telaretti, 2010, Zhang and Hamori, 2011, etc...).
  - Limits: no link with long term targets on terms of installed capacity.

Our model in a nutshell

Two steps: adoption model and cost minimization

- Consumers decide to invest in PV according to a discrete choice model)
  - the choice depends on the NPV (including FIT) and on the overall diffusion of PV (S curve)
    - The discrete choice model combined with diffusion model adequately describes the evolution of German photovoltaic market over the 2000-2009 period.
  - Based on the consumers' choice, we minimize the social cost of attaining an installed capacity target, taking into account the diffusion model.
  - Forecasts using optimal installed capacity trajectories provide insights:
    - on the different phases of PV deployment
    - on the cost of the subsidization scheme

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The model (I)

- Discrete yearly time scale t. If the representative consumer chooses to invest, his utility function is the sum of the observed (V_{1t}) and unobserved utility, i.e. a random variable (X_1):

$$U_{1t} = V_{1t} + X_1. \quad (1)$$

- The probability that a given consumer buys PV panels between t and $t+1$ is as follows:

$$P_t = \frac{\exp(V_{1t})}{1 + \exp(V_{1t})}. \quad (2)$$

- The representative consumer's observed utility is as follows:

$$V_{1t} = NPV_t u_t + I_t, \quad (3)$$

- $NPV_t u_t$ is the net unit present value of an installation and I_t is the diffusion process.

$$NPVu_t = FIT_t.E. \sum_{k=1}^{N} (1+\delta)^{-k} - p_t.(1 - r_t). \quad (4)$$

The model (II)

- *System prices* p_t depend on the learning curve:

$$p_t = p_0 . \left(\frac{x_t}{x_0}\right)^{-b}, \qquad (5)$$

where p_0 and x_0 are respectively the system price and installed capacity at date zero x_0, and x_t the installed capacity at date t.

- The *diffusion process* depends by the installed capacity and the potential market size M_t:

$$I_t = \log\left(\frac{x_t}{M_t}\right). \qquad (6)$$

- PV demand q_t depends on the dynamics of the installed capacity between t and $t+1$:

$$q_t = x_{t+1} - x_t, \qquad (7)$$

- By combining the previous equations (demand, probability, installed capacity), under the hp that M is constant we get:

$$x_{t+1} - x_t = \exp(V_{1t}) M = f(FIT_t, r_t, x_t) \qquad (8)$$

The model (III)

- At a given time t, the subsidy cost for installed PV is as follows

$$c(FIT_t, r_t, x_t) = f(FIT_t, r_t, x_t).(p_t q_t r_t + \sum_{k=1}^{N} (E.FIT_t)/(1+\delta)^{-k}). \quad (9)$$

- The total PV cost until the target is attained $(t = T)$ is:

$$C(T, FIT, r, x) = \sum_{t=1}^{T} c(FIT_t, r_t, x_t), \quad (10)$$

- The objective of the government is to solve the following problem:

$$\min_{FIT, x} C(T, FIT, r, x) \quad (11)$$

under the constraints:

$$\forall t \in [|0; T-1|] \; x_{t+1} - x_t = f(FIT_t, r_t, x_t), \quad (12)$$

$$x_0 = X_0, \quad (13)$$

$$x_T = X_T \quad (14)$$

Model Calibration and Simulations

Case study: Germany (1/2)

- In 2010 more than 50 % of the worldwide PV installations were carried out in Germany.
- Ambitious targets: 18% share of renewable energies in gross domestic energy consumption by 2020
- Feed-in tariff depend on the system size and whether the system is ground mounted or attached to a building.
  - The rates are guaranteed for an operation period of 20 years.
  - On the background of a constantly rising number of installations, a mechanism was introduced to adapt the tariff to the market growth.

Case study: Germany (2/2)

- For 2009 this corridor was defined to be between 1 000 MW and 1 500 MW - but the market reached 3 800 MW.
- Under the current FIT scheme, the reductions are increased or decreased if the marked deviates from the corridor.
- For 2010 to 2012, a new corridor between 2 500 and 3 500 MW was defined.
- In July 2012, Germany's parliament has voted in favor of new photovoltaic cuts.

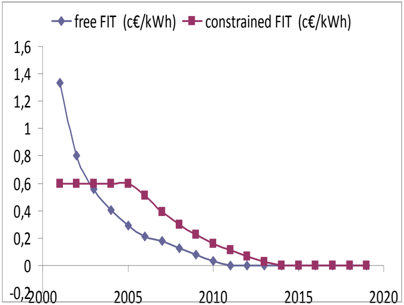
Our question: how can Germany reach a "good balance" between subsidies and market development?

- We simulate the optimal path between 2000 and 2020;
- Initial state : 76MW (2000)
- Final state : 70GW (2020)
- Constrained : FIT 6c€/kWh vs free FIT
- Estimated learning rate: **4%**
- Most data is from IEA, IEA-PVPS et IMF. The long term interest rate in NPV is from OCDE.

Optimal FIT and Installed Capacities.

- **Phase 1 : kick-off and high growth**
  - This first phase is **2001-2006** for the free case and **2001-2010** for the constrained case: very high market growth
- **Phase 2 : shift in business model and stable market**
  - This second phase is the **2007-2012** period for the free path and **2010-2016** for the constrained path. This is a phase where the market remains stable. The NPV becomes very low
- **Phase 3 : return to growth and economic maturity?**
  - This third and final phase is the **2012-2020** period for the unconstrained model and **2017-2020** for the constraint model. It is characterized by a return to growth and the end of FIT

Optimal FIT=0 in 2011 if unconstrained; FIT=0 in 2015 in the case of constrained FIT<6c€/kWh



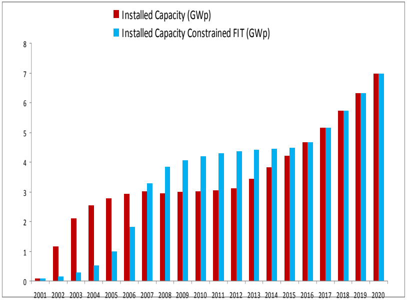


Figure 1 Optimal Trajectories: FIT and installed capacity

Optimal FIT and Installed Capacities: distortions with real parameters 2000-09

- Real parameters until 2009 for prices and subsidies, then simulations according to the optimal path.
- Installed capacity is simulated from 2001 to 2019.
- Investment Tax Credits are equal to zero from 2006.
- Electricity price forecasts are calculated through a linear interpolation based on data from 2000 to 2009.

Shift in the phases: exponential in the first one (until 2009), stable (until 2017), growth (until the end of the period)
Grid Parity 2012 for the residential market and 2013 for the industrial one; optimal FIT=0 in 2017.

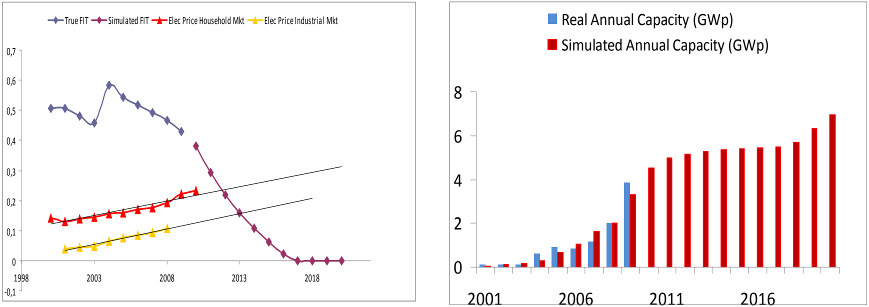


Figure 2 Optimal Trajectories: FIT and installed capacity with real parameters until 2009

Cost of the German Policy to attain 70GW of cumulative PV capacity

- *First scenario*: *optimal trajectory*. Total costs: $67 * 10^9$€, of which $25 * 10^9$€ at the very beginning of the simulated period (2000-2003). $FIT = 0$ in 2012
- *Second scenario: cap on the FIT of* 0.6€/*kWh*. Total costs: $104 * 10^9$€. $FIT = 0$ in 2015
- *Third scenario*: *real costs up to 2009 and then optimal trajectory*. Total costs: $121 * 10^9$€, of which $50 * 10^9$€ until 2009. $FIT = 0$ in 2017.

Conclusions

- Analytical tool that we would like to test for other countries
- Results not shown here: alternative specifications for the utility function: revenue effect (saving over investment) and the electricity price over the price of the electricity produced by the PV installation less satisfactory in explaining the German case.
- Sustainability of the actual schemes?