Evaluating RES support: the case of PV

David Newbery
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http://www.eprg.group.cam.ac.uk

Outline

• Why subsidize low-carbon electricity?
• The need for collective action
  ⇒ Global Apollo Programme 2015
• Factors influencing benefits and subsidy rates
  – learning rate, resource, growth rate, cannibalisation, saturation, fossil and carbon prices
• how much subsidy is justified?
  – For solar PV, on-shore wind and CCS

Why support low-C energy?

• Producing immature technologies creates learning
  • Not captured by producer
• Learning-by-doing depends on cumulative production
  • not output from each unit once installed
• cost reduction per doubling of cum. prod
  • solar PV 20-22% over past 40 yrs, grew 28% last year
  • on-shore wind 12%, CCS: 1-5% (Rubin, 2014)
• Hard to disentangle R&D and production
  • two-factor rates attribute less to LbD, more to R&D
  • solar PV 12%, on-shore wind 9%

But much R&D stimulated by the same factors

Solar PV cost fall 20% as capacity x2
German wholesale prices fall 50% in 5 yrs, 40% of which due to RES
Green is bad, red good

Doubling the irradiance halves the cost

Steady growth of PV capacity

PV learning rates are high econs of scale important

Module learning rate 18-22%
BOS cost excl inverter now 60% of total

The learning model

Let $K_t$ be cumulative installed capacity at $t$, $c_t$ be unit PV cost

$$c_t = aK_t^b, \text{ so } \frac{\Delta c}{c} = (1 + \Delta K/K)^b - 1,$$

The learning rate is

$$\lambda = \frac{-\Delta c}{c} = 1 - 2^b.$$

$c_t = c_m + aK_t^b = c_m + (c_0 - c_m)(K_t/K_0)^b$.

Assume steady growth at rate $g$, then unit costs at date $t$ are

$$c_t = c_m + (c_0 - c_m)e^{gbt},$$

For PV $\lambda = 22$ and current growth rate is 30+%

If $\lambda = 22\%$, $b = 0.36$, $g = 30\%$, then initially costs fall by 11% p.a.

Predicting costs

- 2015 global av. module price $580/kW_p$ for 234 GW_p cum.
- only 55% of installed cost of $1,050/kW_p$
- NREL (2016) total unit cost utility-scale tracking unit in cheapest state $1,190kW_p$
- Adjust for high cost of US labour => $1,050/kW_p$
- ITRPV (2016) 2,000 hrs (23% CF) $44/MWh$
  - some 20yr PPAs signed in Chile for $25/MWh,
  - Mexico $21 (no subsidy)
  - Europe lower 1,000 hrs (11.4% CF) $87/MWh
- Capacity value depends on coincident peak
  - Quite high in CA, zero in Europe

Global Apollo Programme

- Learning spill-overs are global
- PV delivers global climate change mitigation
  => ideally collectively support global programme
- Each member subscribes in proportion to GDP
  – or more progressively? relate to GHG emissions?
- Funds allocated competitively per kW_p
  – e.g. premium subsidy for 20,000 kWh/kW_p
  => invest where subsidy needed is minimized

Project Innovation – 22 countries pledge to double clean energy R&D

Undertaking a social CBA

- Specify program: investment trajectory
- Specify scope – e.g. Global Apollo Programme
- Specify counterfactual absent technology
- Predict penetration allowing for:
  – Cannibalisation given local market area
  – Sequencing of resource exploitation (for PV, wind, …)
  – Ultimate saturation (e.g. solar PV < 20%?)
- Determine social value of output: displaced fuel, CO_2
- Does program have a positive net social benefit?
- If yes, what is the maximum justifiable subsidy?
Specifying the PV project

- Steady growth $g = 25\%$ until saturation at $T = 2028$
  - Thereafter at global demand growth of $m = 1.75\%$
  - Start with highest insolation sites $h_0 = 2,500\text{hrs/yr}$
  - Local cannibalisation/saturation => move to next site
  - Saturation at 15% globally, last site $h_T = 900\text{hrs/yr}$
  - Fossil displaced decreases 1% p.a. from $35\text{$/MWh}$
  - CO$_2$ price $15\text{$/Mwhe}$ rising at 1% p.a.
- No external benefits (C or LbD) after $N$ (2035)
  - Other low-C options could have replaced PV
  - and PV output value falls thereafter at 1% p.a.
- Output site-specific, no degradation until $N$
- Capacity credit $75\text{/kWyr}$ (summer peaking)

Determinants of PV subsidy $B^*_t/c_0$

\[
B^*_t/c_0 = b(1 - \phi)e^{rt}\int_{t}^{T}e^{-(bg+ru)u}du + m^e_{-b(g-m)T}\int_{T}^{N}e^{-(bm+ru)u}du
\]

- $t$: saturation date
- $m$: rate of growth of world electricity
- $g$: social discount rate = 3%
- $r$: rate of growth of cumulative capacity
- $b$: coefficient on cost decline $(K/K_0)^{-b}$
  \[b = -\ln(1-\lambda)/\ln(2)\text{, where }\lambda \text{ is the learning rate}\]

Justified subsidy very sensitive to learning $b$, $\lambda$

Is program worthwhile?

- Is acceleration worthwhile?

Illustration for solar PV
Contributions to global cumulative capacity

\[ \frac{B_t}{c_0} = b(1 - \phi)e^{rt} \left( g \int_t^T e^{-(by+r)}du + me^{-(y-m)} \right) \int_t^N e^{-(by+r)}du \]

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Global cumulative capacity: 188,000 TWh, global power = 24,000 TWh

Spill-over value by country

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80% of total

Wind resource up to 50m depth, hub ht 80m onshore, 120m offshore

Green is good, red poor

Global potential 94 TW @2,000 hrs = 188,000 TWh, global power = 24,000 TWh

Justifies £20/MWh for first 20,000 MWh/MWp

EEA Technical report

http://www.inscc.utah.edu/~krueger/5270/3tier_5km_global_wind_speed.pdf
On-shore wind: taller towers give higher capacity factors

**Figure 8: IRENA Onshore Wind Learning Rate**

Log scale

Learning Rate 12%


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- If $\lambda = 12\%$, $g=12\%$, $T=N=27$ yrs, after 1.75% – saturates at 29% (Ireland plans about 40%)
- 2015 subsidy could be **24% of initial cost of** $1,560/kW = $375/kW
- Over 20,000 hrs = £14/MWh
- If $\lambda = 7\%$, 2015 subsidy could be **15% = £9/MWh**
- Optimal auction is a price/MWh for N hrs – equivalent to a capacity support targeted on LBD

Illustration for (footloose) CCS

Share of initial cost experiencing LbD

For $\lambda = 5\%$, $b=0.074$, $g=10\%$, $T_1=25$ yrs, $m=2\%$, $r=3\%$, subsidy rate = 11%.

At $\lambda = 2\%$, subsidy falls to 7%

**Conclusions**

- Solar PV varies with location, has limited penetration that affects justified subsidy:
  - Benefits maximized by choosing right places
  - Justified subsidy substantial
- On-shore wind – high potential, lower support
- CCS footloose, subsidy rates much lower
- Global benefits need **global support = Apollo**
  - Regional benefits capture only part of cost fall
- Results sensitive to fossil and carbon prices, PV learning and growth rates, discount rate, resource

**Subsidies are technology specific**
References


Estimating spill-over benefits

• Cost of doubling cum prod is low at 10 GW, much higher at 200 GW => early investment valuable
• But cannot instantly raise low base by high amt.
  – constraints on building production capacity
  – limits to rate of dissemination of learning
  – uncertainty whether past LbD is good guide to future
• is program as whole NPV positive compared to fossil?
• Consider modest temporary increase in investment
  => has a current cost but lowers all future costs
• Is it worth it - is NPV positive in terms of costs?
• If so then maximize rate of investment
• If worth it then calculate spill-over benefits