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Tailoring deployment policies to support innovation in specific energy technologies

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Joern Huenteler
Pre-doctoral fellow, Belfer Center for Science and International Affairs
PhD candidate, ETH Zurich, Switzerland

(co-author Tobias Schmidt, ETH Zurich)
Tailoring deployment policies to support innovation in specific energy technologies

Overview

– Large-scale deployment of technologies is increasingly used to stimulate innovation

– But the way we currently think about deployment policy design is strongly influenced by models that have been developed for consumer goods and that do not apply to all energy technologies

– Deployment policies could stimulate innovation more effectively if they account for differences between technologies

Work in progress!

– Do ask clarification questions during presentation
– All forms of feedback very welcome
Agenda

- Why analyze deployment policies?
- Innovation life-cycles and deployment policy
- An empirical study of innovation life-cycles in wind and solar PV
- How to reflect technology characteristics in deployment policies
Why analyze deployment policies?

Spending on deployment policies: ~ $4.8 trn until 2035

Definition:
- Deployment policies are public policy measures to increase the demand for innovations or to improve conditions for their adoption
- Examples: Feed-in tariffs, production tax credits, renewables portfolio standards, bidding schemes, investment subsidies, environmental standards

Estimated global deployment policy spending for renewable energy

Source: BNEF 2013, IEA 2012
Why analyze deployment policies?

Deployment increasingly used to stimulate innovation

Innovation as explicit policy objective (some examples):

- German **feed-in tariff for PV**: "market entry assistance to allow for cost reductions, which will then facilitate the diffusion of photovoltaic through the market" (German Federal Diet, 2000, p. 11,064); ~$5-10bn annually

- The **U.S. production tax credit** for electricity production from wind power and other technologies was enacted to enable “further advances of renewable energy technologies”, and “exports of United States renewable energy technologies and services” (102nd Congress, 1992) ~$5-10bn annually

- The **U.S. ‘Recovery Act’ in 2009** (tax credits) “to create tens of thousands of jobs in construction and manufacturing, … [and] to help renewable energy technologies achieve economies of scale and bring down costs” (The White House, 2009) provided 7.5 bn$ in tax credits
Why analyze deployment policies?

Motivations for government involvement in deployment

Cumulative production

Learning curves ....  

... and industrial success of early movers

Source: McNerney et al 2011
Why analyze deployment policies?

But technology differences not very well understood yet

Learning curves differ significantly between technologies ....
Why analyze deployment policies?

But technology differences not very well understood yet

... and so does the relationship between domestic markets and globally successful domestic industries

RCA: revealed competitive advantage, measured by trade data

Source: M Huberty & G Zachmann (2011)
Why analyze deployment policies?

How to account for technology differences?

Research questions:

- How do innovation processes in the deployment phase differ between energy technologies?
- How can deployment policy be designed to address these differences and stimulate innovation in different energy technologies effectively?
  - How to keep up pressure to be innovative?
  - Support regional/national or global markets?
  - Support manufacturers or support users?
  - Emphasis on demonstration effects or market scale?

Research case:

- Comparison of wind power and solar PV
- Two most significant beneficiaries of deployment policies – in the past and most likely in the future as well
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Technology characteristics in deployment policies

Deployment policies support ‘late’ stages of innovation

Source: IRENA (2013); *LCOE: levelized cost of electricity
Innovation life-cycles and innovation policy

The Utterback/Abernathy or 'technology life-cycle' model

Much of the thinking on how to design policies across the innovation cycle is influenced by the Utterback/Abernathy model from the 1970s/80s.

Source: Abernathy & Utterback (1988)
Innovation life-cycles and innovation policy

Example of a dominant design – wind power

1970s

2000s

Source: windsofchange.dk; vestas.com
## Innovation life-cycles and innovation policy

### Deployment policy in the Utterback/Abernathy model

<table>
<thead>
<tr>
<th></th>
<th>Fluidic phase</th>
<th>Transitional phase</th>
<th>Specific phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Competitive emphasis on</strong></td>
<td>Functional product performance</td>
<td>Product variation</td>
<td>Cost reduction</td>
</tr>
<tr>
<td><strong>Innovation stimulated by</strong></td>
<td>User needs / users' technical inputs</td>
<td>Opportunities from internal technical capabilities</td>
<td>Pressure to reduce cost and improve quality</td>
</tr>
<tr>
<td><strong>Predominant type of innovation</strong></td>
<td>Frequent major changes in products</td>
<td>Major process changes</td>
<td>Incremental product and process changes</td>
</tr>
<tr>
<td><strong>Production process</strong></td>
<td>Diverse, often custom designs</td>
<td>Significant production volume for dominant design</td>
<td>Mostly undifferentiated standard products</td>
</tr>
<tr>
<td><strong>Plant</strong></td>
<td>Small scale</td>
<td>General-purpose with specialized sections</td>
<td>Large-scale, highly-specific to particular products</td>
</tr>
<tr>
<td><strong>Production equipment</strong></td>
<td>General purpose, requiring highly skilled labor</td>
<td>Some subprocesses automated</td>
<td>Special-purpose, mostly automatic with labor tasks mainly monitoring</td>
</tr>
</tbody>
</table>

-> Deployment policy support should emphasize scale & competitive markets to stimulate innovation (mainly through learning by doing!)

-> Little need to focus on e.g., product standards or user-producer interaction

Source: Abernathy/Utterback (1988)
Innovation life-cycles and innovation policy

Many technologies do not seem to follow U/A model

- The empirical evidence for the innovation life-cycle model mostly comes from mass-produced consumer goods.
- One of the shortcomings has been the neglect of high cost, engineering-intensive and capital-intensive products, systems or constructs.
- Since the 1990s, research on innovation in such ‘complex product systems‘ has shown that many technologies do not follow the Utterback/Abernathy model.

- Complex product systems are characterized by product complexity: a high degree of customization in the final product and its component parts, and a larger number of components and multiple interactions among the different levels.
- They are often characterized by government-driven markets, bilateral oligopolies (few customers + few suppliers), and small-batch production.
- Examples include cellular phone systems, bridges, trains, airplanes and coal power plants.
Innovation life-cycles and innovation policy

An innovation life-cycle model for complex products

Emergence of a ‘dominant design’

Innovation in components

Innovations in product architecture

Source: Davies (1997)
**Innovation life-cycles and innovation policy**

**Deployment policy in complex product systems**

| Multipurpose emphasis on ... | Competitive emphasis on ... |
|-----------------------------|--|-----------------------------|
| Innovation stimulated by ... | Innovation stimulated by ... |
| Predominant type of innovation | Predominant type of innovation |
| Production process | Production process |
| Plant | Plant |
| Production equipment | Production equipment |

<table>
<thead>
<tr>
<th>Architectural phase</th>
<th>New product generation phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional product performance</td>
<td>Component innovations, sequences of new product generations</td>
</tr>
<tr>
<td>User needs / users' technical inputs</td>
<td>Evolving user needs as well as internal and external technical opportunities</td>
</tr>
<tr>
<td>Frequent major changes in products</td>
<td>Sequences of systemic and incremental component changes</td>
</tr>
<tr>
<td>Diverse, often custom designs</td>
<td>Maximum: small-batch</td>
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-> Deployment policy support should emphasize user-producer interaction and continuous demonstration of new technology to stimulate innovation (pure learning by doing not very important)
Innovation life-cycles and innovation policy

Deployment policy in energy technologies

- Most novel energy technologies are neither consumer goods nor customized infrastructure systems

- Many technologies, such as wind turbines, PV modules, biomass plants, gas turbines, fall in between the two extremes

- Which life-cycle model do energy technologies follow?

- Can we observe significant differences?
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Innovation life-cycles in wind and solar PV
Method to study life-cycles: Patent citation networks

- **Patents** as measures of innovation in wind and PV
- Database of 110,000 global wind power and solar PV patents

- **Patent citations** are references to prior art that indicate if technological principles are shared between patents
- Calculation of *significance of individual patents* in the network using network analysis methods

- Manual coding of abstract content of top 500-1,000 patents per technology
- Classification into product / process innovation and different technology components (e.g., rotor blades or generators in wind turbines)
Innovation life-cycles in wind and solar PV

Full patent network of wind power as starting point
Innovation life-cycles in wind and solar PV

Top 158 patents that form network core
Innovation life-cycles in wind and solar PV

Top patents sorted by application date
Innovation life-cycles in wind and solar PV

Top patents sorted by date & focus of invention

**Rotor**
- Variable-pitch rotors

**Power train**
- Variable-speed drive trains

**Mounting**

**Grid connection**
- Low-voltage & fault ride-through
Innovation life-cycles in wind and solar PV

Evolution of dominant design is visible in patents

Dominant design has emerged, but not one single process-related invention among top patents!
Innovation life-cycles in wind and solar PV

The life-cycle of solar PV resembles classical model

Cell designs

Cell production processes

Module circuitry & encapsulation

Crystalline silicon

Thin-film and other emerging PV technologies
Innovation life-cycles in wind and solar PV

Differing life-cycle patterns between solar PV and wind

Solar PV shows characteristics of a mass-produced good, wind power follows life-cycle of complex product system
Innovation life-cycles in wind and solar PV

Which firms in value chain interact in innovation projects?
Innovation life-cycles in wind and solar PV

Interviews indicate differences in innovation processes

Primary supply chain activities

- Production equipment suppliers
- Logistics and installation services
- Materials suppliers
- OEMs
- Power producers O&M
- Component suppliers
- EPC, project development
- University research and education
- R&D institutes, certification, test & inspection services
- Consulting, legal advice, financial services
- Regulators

Supportive activities

- Products and services

Primary channels of interaction in innovation projects:

1. PV: Cell and module design, module installation
2. WIND: Wind turbine design
3. PV and WIND: Power electronics and grid integration, system control and monitoring
4. PV and WIND: Project financing & contracts

Innovation life-cycles in wind and solar PV

Interviews indicate differences in innovation processes
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How to account for technology characteristics?

- Wind power and solar PV have **different innovation cycles and innovation processes**

- The differences that exist between wind and solar PV are possibly even more extreme when considering technologies such as nuclear or LEDs

- During the scale-up and deployment phase, innovation in mass-produced goods such as PV cells is **primarily focused on process innovations and driven by the pressure to reduce costs**

- For complex products such as wind turbines, the scale-up and deployment phase still involves **significant product modifications**, often over decades, and is driven more by evolving user requirements and technology standards
<table>
<thead>
<tr>
<th></th>
<th>Mass-produced goods</th>
<th>Complex product systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary objective</td>
<td>Enabling economies of scale &amp; learning by doing</td>
<td>Demonstrate product innovations, enable user-producer interaction</td>
</tr>
<tr>
<td>Geographical scope</td>
<td>Large (ideally global)</td>
<td>Regional / national</td>
</tr>
<tr>
<td>Primary target links</td>
<td>Manufacturers &amp; their suppliers</td>
<td>Users &amp; producers</td>
</tr>
<tr>
<td>Pressure to innovate</td>
<td>Through cost competition -&gt; continuously adapt remuneration, minimize entry barriers and standardize regulation across jurisdictions</td>
<td>Through evolving requirements -&gt; monitor and continuously adapt performance standards</td>
</tr>
</tbody>
</table>
Thank you for your attention!

Joern Huenteler

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PhD candidate, ETH Zurich, Switzerland