Innovator's Profit at Risk: Findings from the Photovoltaic Industry, 1954-2015

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Research Topic

Innovator's Profit?

Profits from innovation captured by innovator
Reduced by imitation over time

Why does it matter?

Motivating innovators
Survival of innovative firms
Funding further R&D
-> Faster technological change

Have incentives been sufficient for PV?

Empirical evidence from industry evolution
Understanding in firm-level behavior

PV as Disruptive Technology

Disruptive technology (Christensen, 1997):
Initial poor performance & subsequent improvements
Overtake established technologies
e.g. Cell phones, digital cameras, …

"It is in disruptive innovations, where we know least about the market, that there are such strong **first-mover advantages**." (Christensen, 1997, p.xxi)

Innovator's Incentives for Disruptive Technology

Return Structure

Short term: low if not negative
Long term: depends on when disruption happens

Appropri-ability Regime

Appropriability (Arrow, 1962): capturing returns to innovations
Appropriability regime (Teece, 1986) : external factors that govern appropriability, which may become weak over product life cycle, reducing first-mover advantage (e.g. effectiveness of patents)

Four Focus Areas

Industry Dynamics

Diffusion of innovation & spillover
Market structure
Entry barriers

Market Development

Niche markets
Mainstream markets
Demand-pull policies

Cost Reduction & Tech Change

Product life cycle
Technology-push policies
Major innovators

Major Firms & Industrial Leadership

First-mover advantage
Changes in industrial leadership

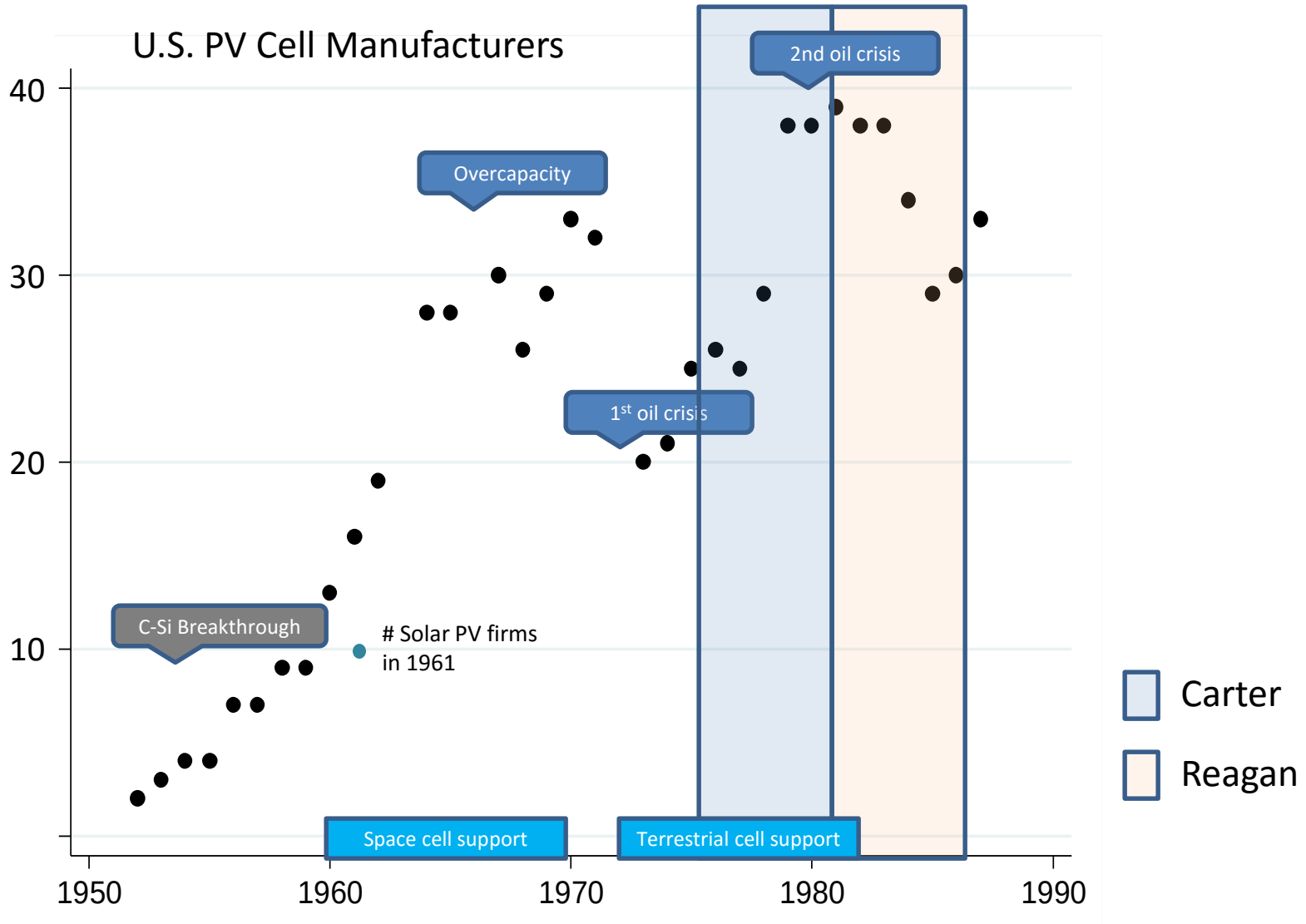
Information Sources

Source	Year	Information/Data
Electronic Buyers' Guide	1952-1987	Firm names, advertisements, firms' technology choice
Tele-Tech	1953-56	Firm names
Electronic Products	1964	Firm names, firms' technology choices, product specifications
IEA Photovoltaic Power Systems Programme	1993, 1995, 1997-2015	Frim names, firms' technology choices, production capacity, installation statistics, number of firms by country, policies
EIA Annual Energy Outlook		Number of U.S. PV firms for 1982-2012, number of U.S. PV cell & module firms for 1995-2013
IEA database	1974-2014	Government R&D spending for OECD member countries
EPO Worldwide Patent Statistical Database		Patents
US National Renewable Energy Laboratory	1976- 2015	Best research-cell efficiency
Expert interviews		

Comparison to Prior Studies

- Most prior literature on the history of the photovoltaic industry is non-academic or outdated
  - Popular books: Perlin (1999), Johnston (2011)
- Patent analysis is interpreted in the context of industry evolution
  - Patent analysis: Popp et al (2011)
- Provides more accurate information on early history
  - Industry history study: Jones and Bouamane (2012, working paper)
  - Entry and tech. Choice study: Kapoor and Furr (2014)
- Adds consideration of appropriability
- More analytic and up-to-date analysis of policy in the context of industry evolution

Industry Dynamics 1952-1987

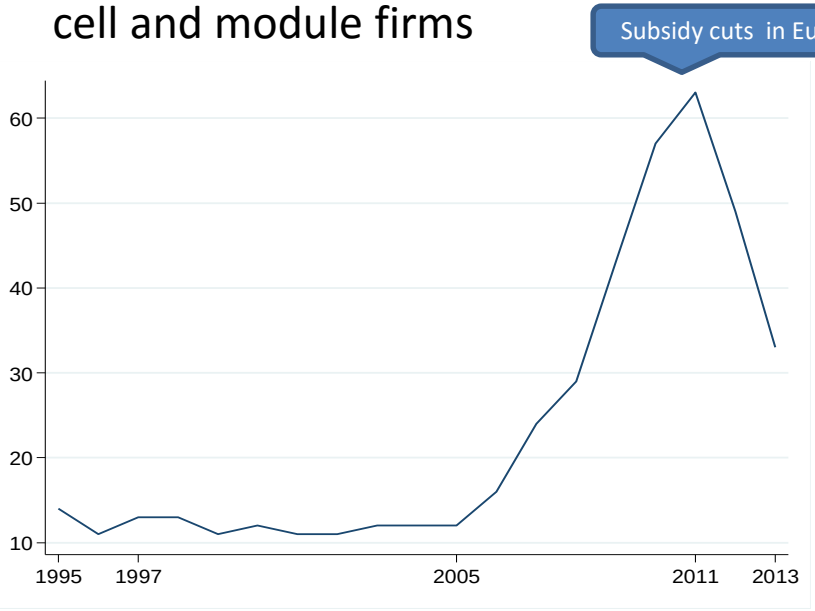


Industry Dynamics 1990-2015

Germany 1993-2003

Year	Number of Cell Firms	Number of Photovoltaic Firms
1993	At least 2 (Siemens and ASE)	At least 5 module manufacturers
1995		At least 6
1997	At least 2 (Siemens and ASE)	At least 15 (5 of them entered in 1996-1997)
1998		19
1999		>20
2000		>30
2001		>30
2002	At least 5 (Shell Solar, RWE, Q-Cells, Ersol, Sunways)	At least 24
2003	At least 6 (Shell Solar, Deutsche Cell, RWE, Q-Cells, Ersol, Sunways)	At least 23

U.S. 1995-2013
cell and module firms



- 2000s: Massive entry from U.S., China, and other East Asian industrialized countries
- China and Taiwan: More than 60 cell firms and more than 330 module firms (Xu, Dou, Wang, & Lv, 2012)

Market Development

Niche markets:

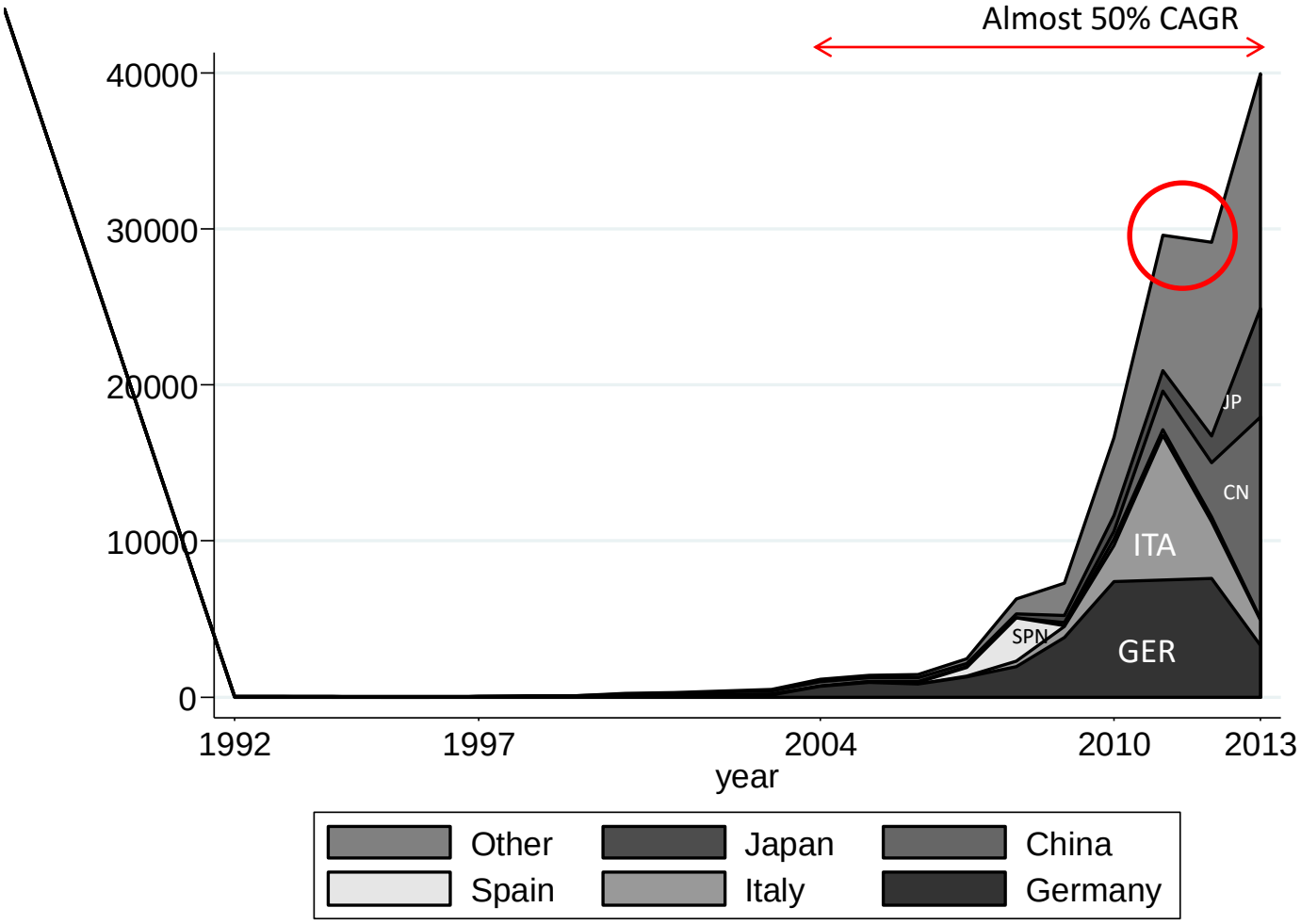
1. Photoelectric detectors (Se): 1952
2. Space cells (c-Si): 1960
3. Off-grid terrestrial power (c-Si): 1973
4. Small electronics cells (a-Si): 1980s

Main market:

5. Grid-connected PV (c-Si & thin-film)
   - Demonstration projects: 1970s
   - German feed-in law: 1990

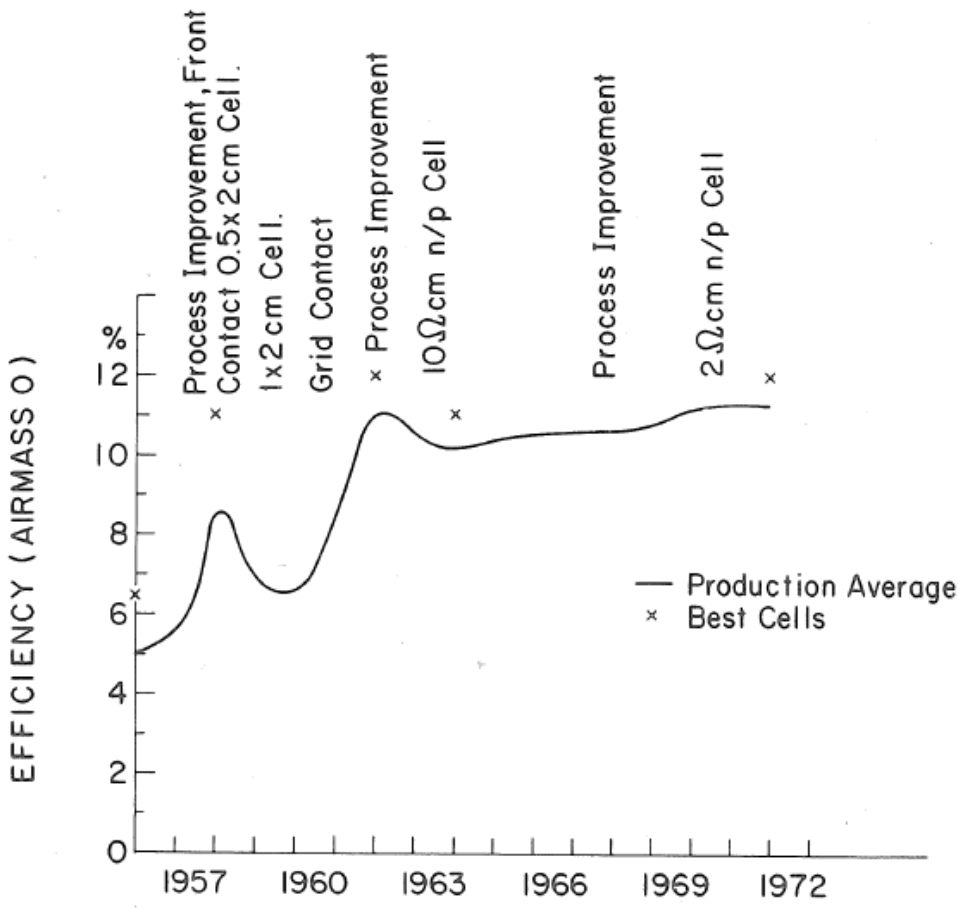
* Dates of take-off shown, some sales earlier

Market Development

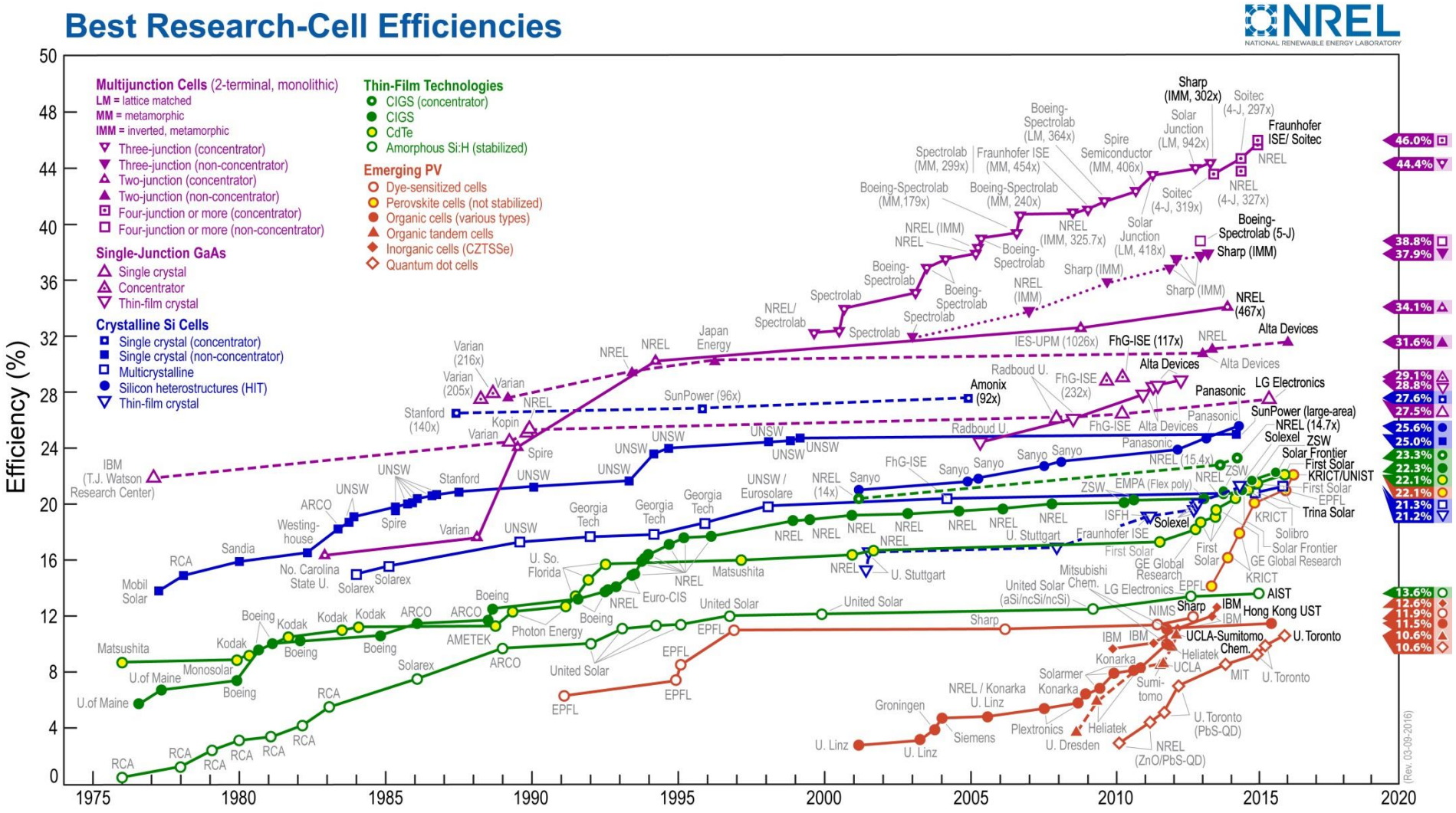


Cost Reduction and Technological Change

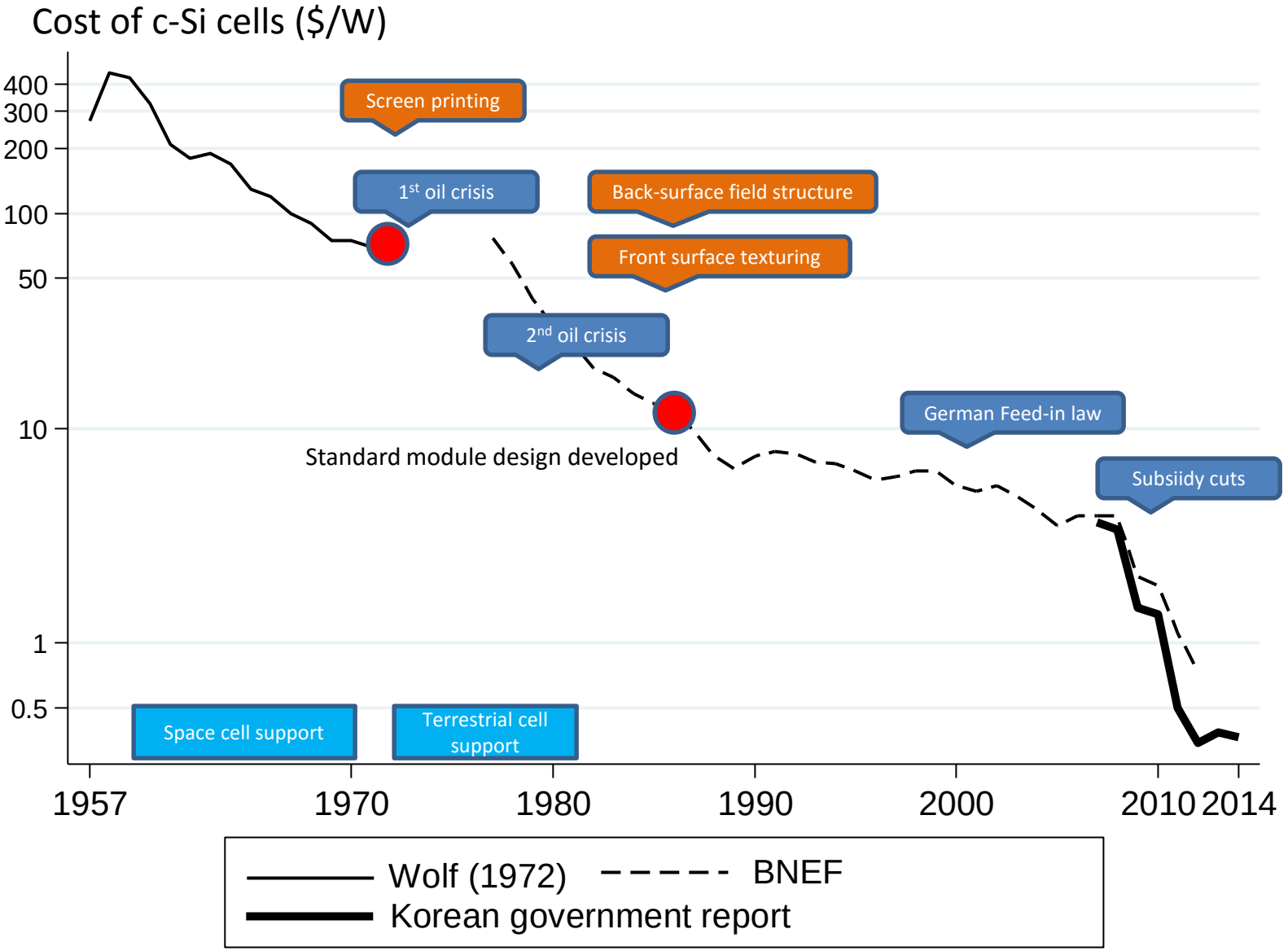
PV Cell Efficiency 1957-1972 (Wolf, 1972)



Cost Reduction and Technological Change

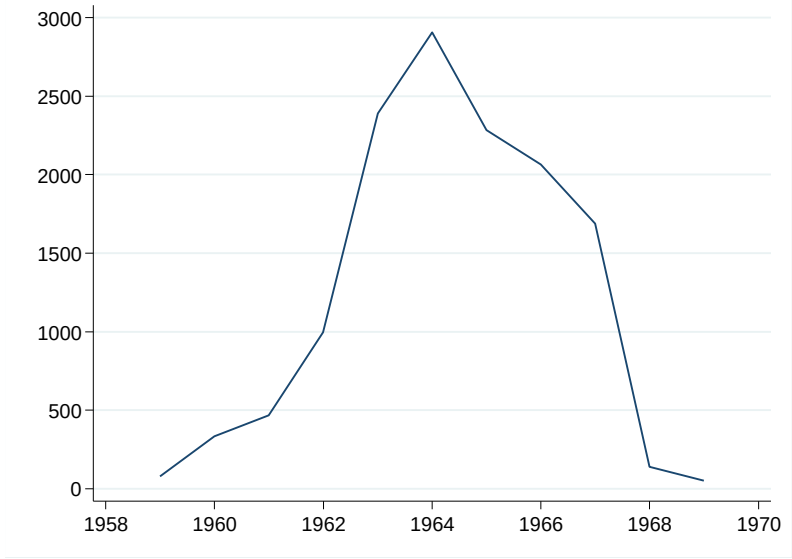


Cost Reduction and Technological Change

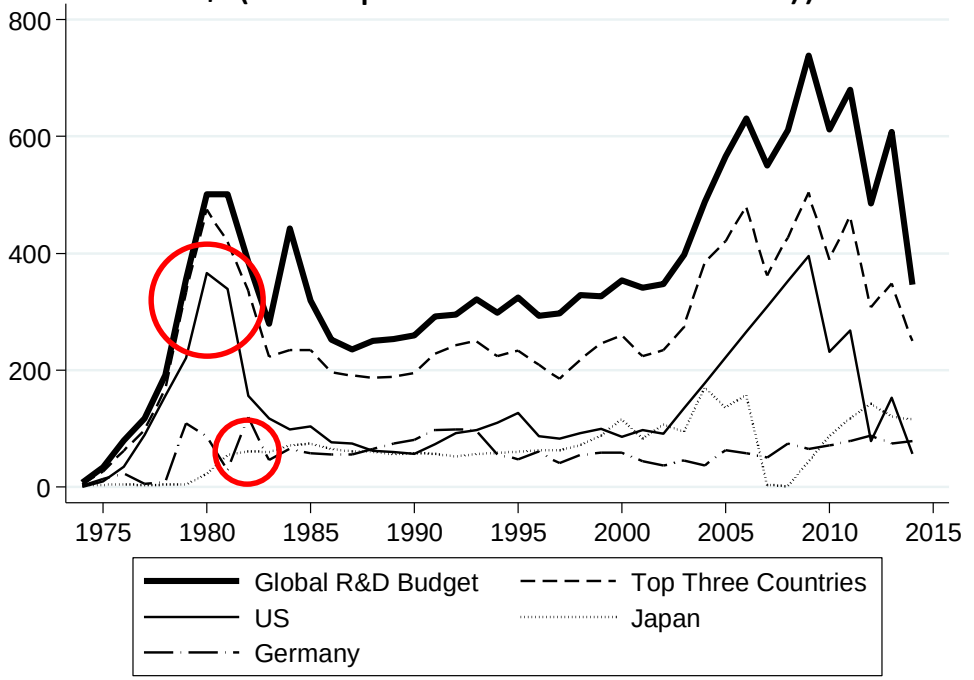


Cost Reduction and Technological Change

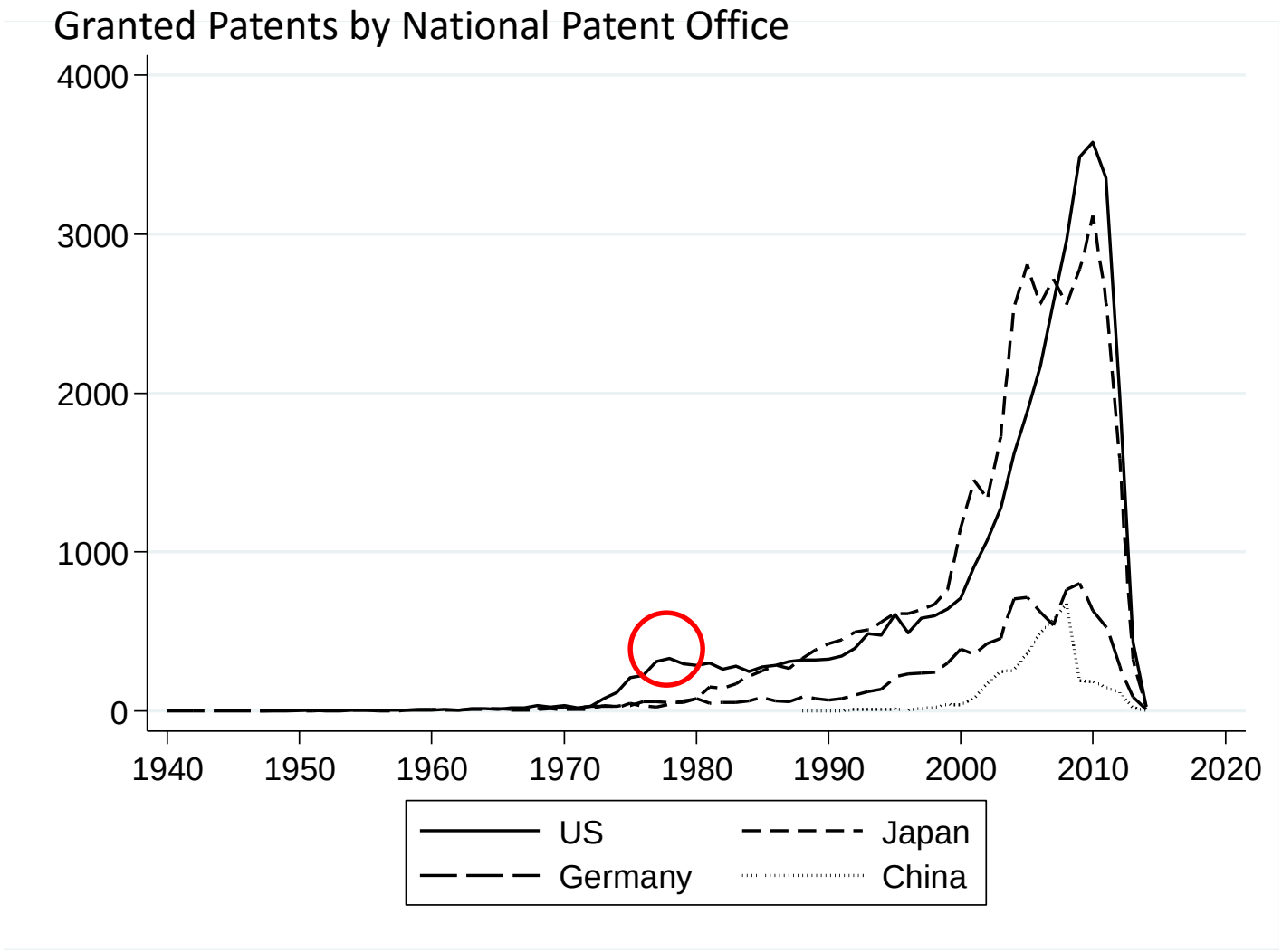
U.S. Government R&D Funding for Space Cells ($1000)



Government R&D Funding for PV (million US $ (2014 prices and exch. Rates))



Cost Reduction and Technological Change



Cost Reduction and Technological Change

Top 15 Innovators by Patent Grants

	Pre-1952	1952-1972	1973-1989	1990~
1	Westinghouse	Philips	Siemens	Matsushita (Panasonic)
2	International Telephone And Telegraph	Siemens	Canon	Canon
3	Siemens	General Electric	Philips	Sharp
4	General Electric	International Telephone And Telegraph	Energy Conversion Devices	Mitsubishi
5	AT&T	Westinghouse	Hitachi	Samsung
6	Philips	RCA	AT & T	Hitachi
7	Sueddeutsche App Fabrik	IBM	IBM	NEC
8	Licentia	Matsushita (Panasonic)	Matsushita (Panasonic)	IBM
9	RCA	AT & T	RCA	Sony
10	AEG	Texas Instruments	Thomson CSF	Fuji
11	Patra Patent Treuhand	BBC Brown Boveri & Cie	Mitsubishi	Micron Technology
12	Erwin Falkenthal	Licentia	Westinghouse	LG
13	Cie Gen De Signalisation	International Rectifier	NEC	Toshiba
14	Mallory & Co	Lucas	US Army	Fujitsu
15	Ruben Rectifier	NASA	Hughs	Seiko Epson

Major Firms and Industrial Leadership

- 1954-1970 space cells
  - Hoffman Electronics, Heliotek, International Rectifier, Texas Instruments, and RCA
- 1971-1990s terrestrial off-grid cells
  - ARCO Solar, Solarex, Solar Power Corp (U.S. oil firm subsidiaries)
- 1980- small electronics cells
  - Sanyo, Sharp, Kyocera (Japanese electronics firms)

Major Firms and Industrial Leadership

- 1990-2015 Grid-connected PV
  - Japanese firms: Sanyo, Sharp, Kyocera
    - 2015: Sharp seeking buyer for solar business
  - German firms: Siemens (acquired ARCO solar), Q-Cells
    - 2006: Siemens sold solar business to SolarWorld
  - Chinese firms: Suntech, Yingly, Trina, Canadian,…

Appropriability and Policy for Potentially Disruptive Technology

- No first mover advantage
- Frequent changes in national industrial leadership
- Low incentives for innovators
  - Small and quickly saturated niche markets
  - Over time, the appropriability regime weakened
  - Innovators rarely made profit (e.g. Sharp, ARCO solar)
  - Decades before potential profits disincentivize innovation
  - After 60 years, most regions not even reached break-even
- Low incentives for public R&D

Policy Implications

- Better policy design for innovator's profit
  - Faster disruption
    - More intensive R&D funding
  - Favorable financing for scaling-up
- Consistent policy
- Internationally coordinated policies to prevent freeriding