HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

June 3, 2015

The future of energy technologies and the role of policy (and policy research)

34th International Energy Workshop
Abu Dhabi

Laura Diaz Anadon

Assistant Professor of Public Policy
Co-Faculty Chair– Energy Technology Innovation Policy research group
Associate Director – Science, Technology and Public Policy program

Outline

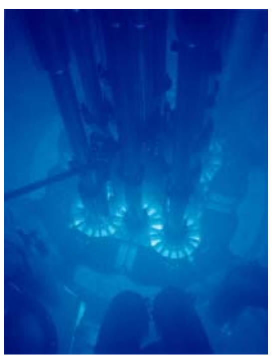
1. The role of government policy in energy innovation
2. **Public energy R&D investments**
3. **Multiple policies: balancing deployment and R&D**
4. **Effectiveness of government R&D organizations**
5. **Looking beyond energy**
6. **Looking beyond the OECD**
7. **Inclusion of other trends**
8. Takeaways

1. The role of government policy in energy innovation

Innovation in energy technologies is essential

- Energy is one of the top global challenges
  - Environmental impact (local and global)
  - Economic vulnerabilities (interlinkages, competitiveness)
  - National security (nuclear technology, infrastructure, networks)
  - Access to energy

- Most studies (e.g., IPCC) conclude that meeting these challenges will require new and improved technologies

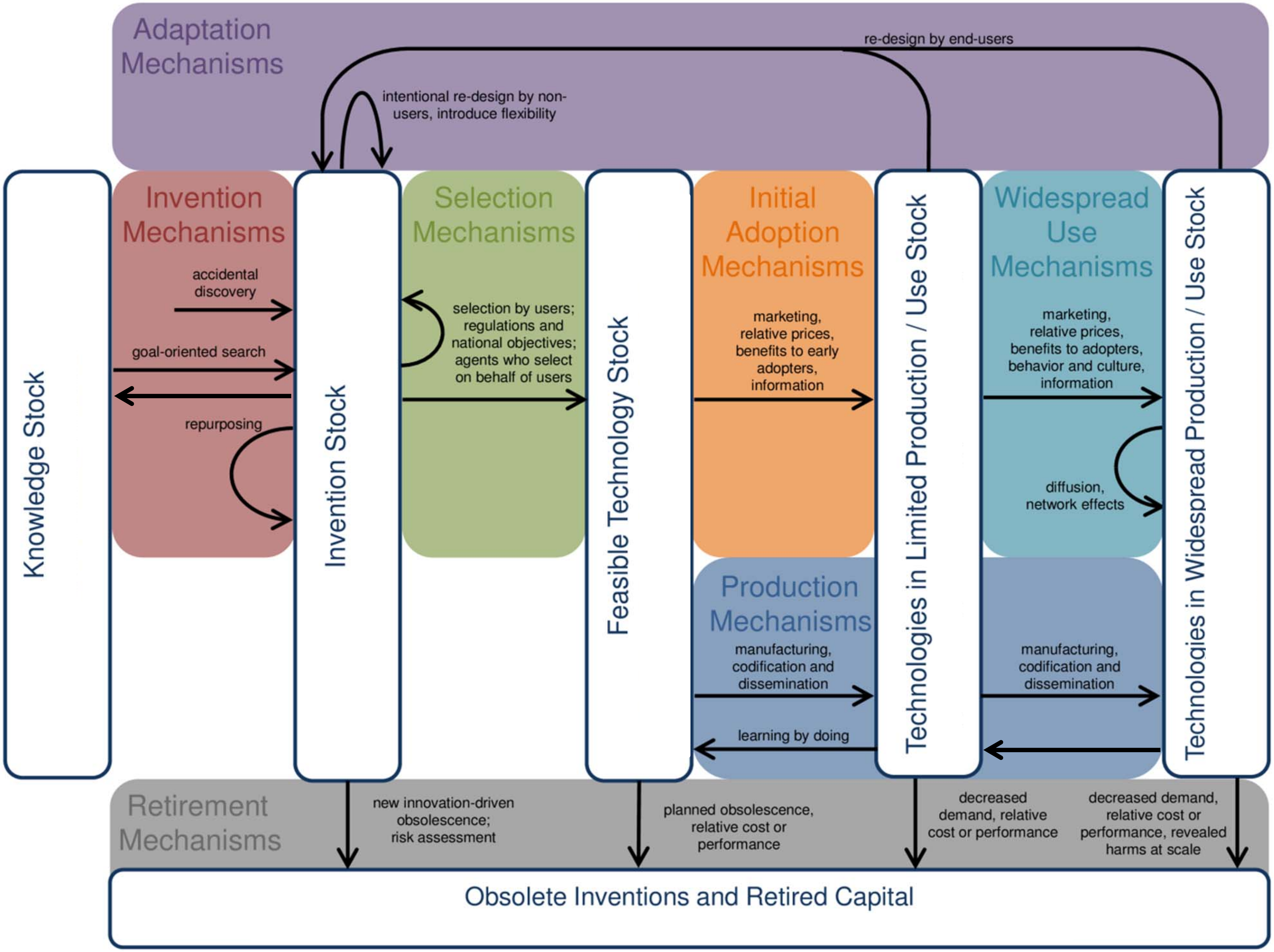





The key question is what governments can and should do

- Question is complicated (and thus a rich area for policy-relevant research!) because of four key dimensions:
  - Complexity of innovation process
  - Multiple policies
  - Multiple policy goals
  - Heterogeneous technologies

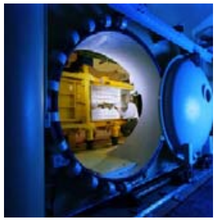
Innovation goes beyond R&D



Anadon, Matus, Moon et al. (2014)

Many interlinked factors can contribute to innovation

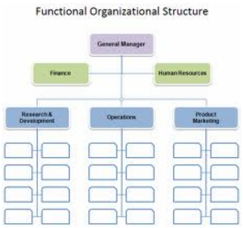
- Learning-by-doing or by using



- R&D (goal-oriented)

- Knowledge spillovers from other sectors

- Economies of scale

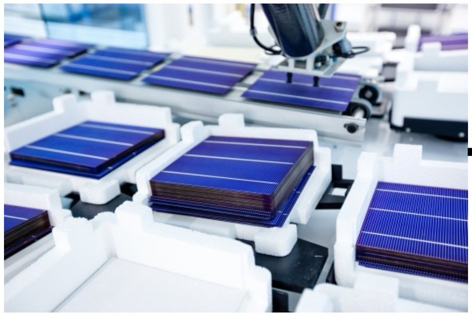


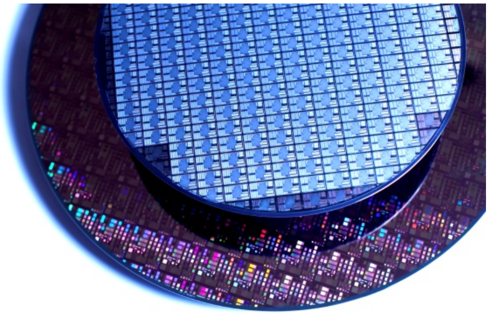
- Economies of scope

- Materials and labor costs

Properties of innovation and energy require a role for governments

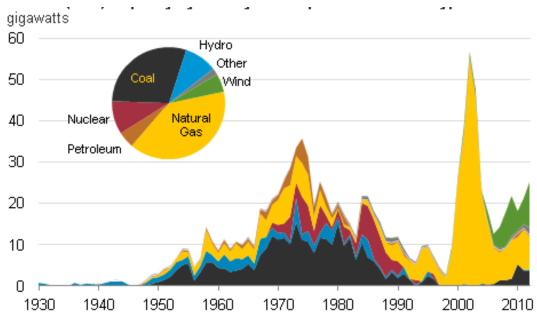
- Knowledge spillovers

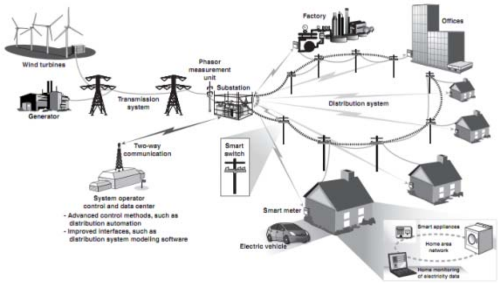




- Environmental externalities

- Institutional lock-in
- Capital intensity, long lifetimes, and network effects





Many policies can shape the pace and direction of innovation

Reducing cost of innovating:
Increasing the supply of knowledge

Technology-Push Policies

- RD&D policy:
  - Federal/state RD&D funding
  - Public-Private partnerships for demonstration projects
  - R&D tax credits
  - International cooperation in RD&D, etc.

- Education policy to improve and expand the labor force

Technology Innovation

Increasing payoff to innovators:
Increasing the demand for innovation

Market-Pull Policies

- Price incentives
  - Direct spending (rebates)
  - Government procurement
  - Tax-related subsidies
  - Loan guarantees
  - Intellectual property, etc.

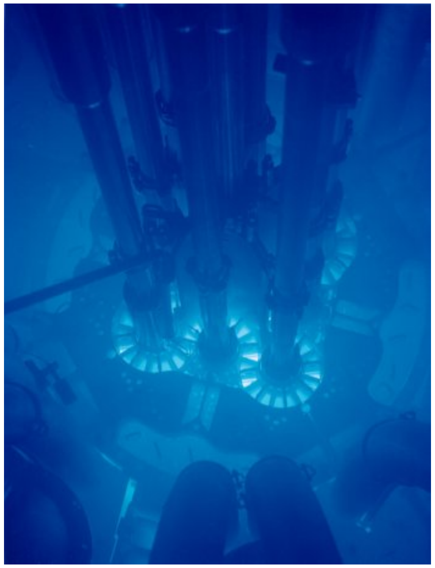
- Standard-based policies
  - Performance standards
  - Interconnection standards
  - Portfolio standards, etc.
  -

- Market-based policies
  - Cap and trade
  - Charge systems, etc.

Adapted from Mowery and Rosenberg (1979) and Anadon and Holdren (2009)

Government policy plays a unique role

- Government R&D and its combination with other policies has played and continues to play a key role in energy





Investments are significant, effectiveness matters

2013 global deployment subsidies:

- $121 billion for renewables
- $548 billion for fossil fuels

R&D funds for all energy technologies about $20 billion
(<1/6 renewables subsidies)

Emerging economies and developing countries are playing major roles

- In energy R&D, in 2008 BRIMCS governments spent $13.7 bn PPP, more than IEA governments combined combined

IEA (2015); Kempener, Condor & Anadon (2011)

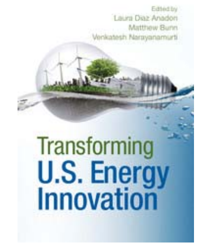
HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

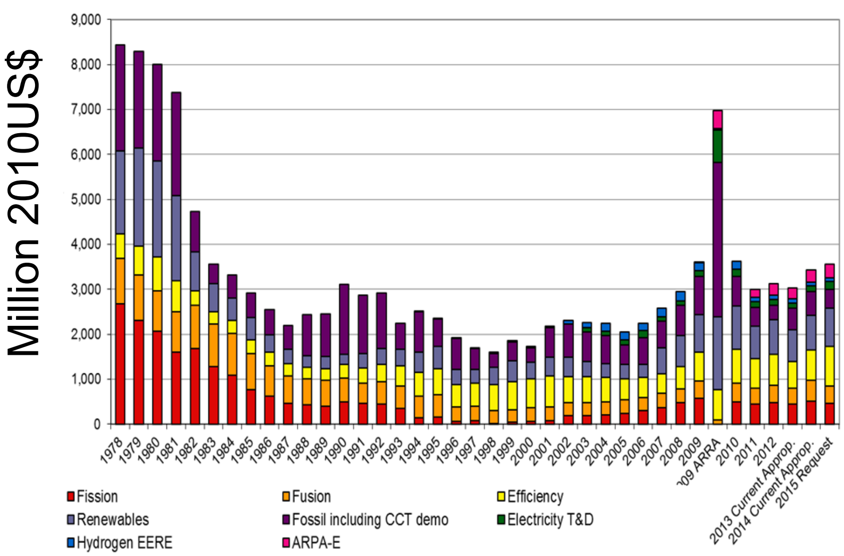
2. Public energy R&D investments

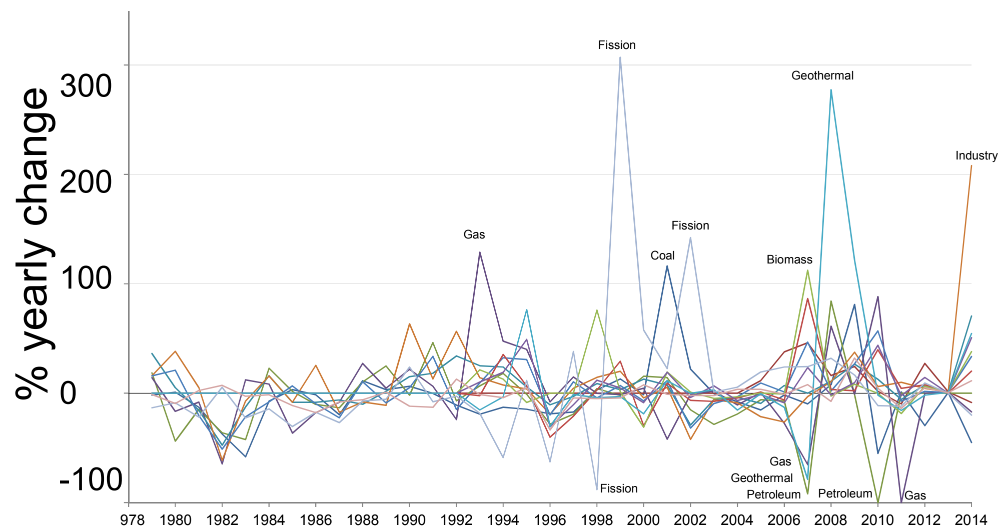
Current decision methods could be improved

U.S. example



- US:$3bn, ~5% of non-defense R&D goes to Dept. of Energy
  - DOE proposes a budget and allocation, based on technical inputs from labs
  - OMB scrutinizes requests based on Presidential objectives
  - Congress allocates funds
- Analysis and R&D allocation outcome do not consider market interactions, are volatile and lack legitimacy



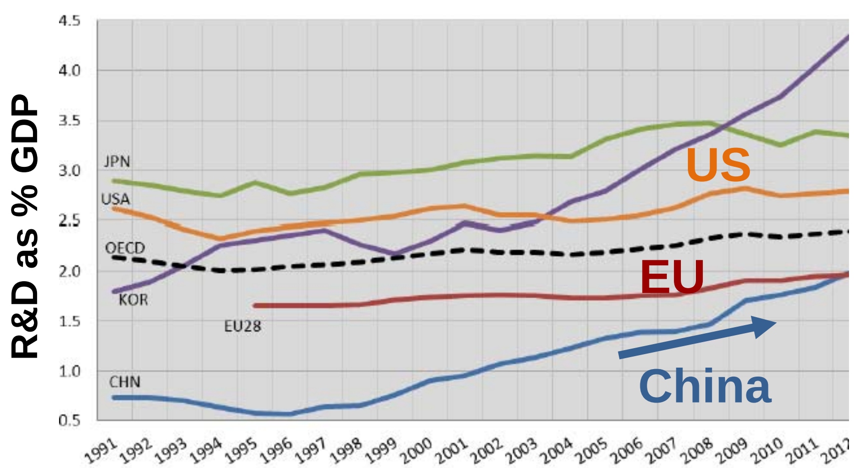


Anadon, Chan & Lee (2014); Chan & Anadon (2015)

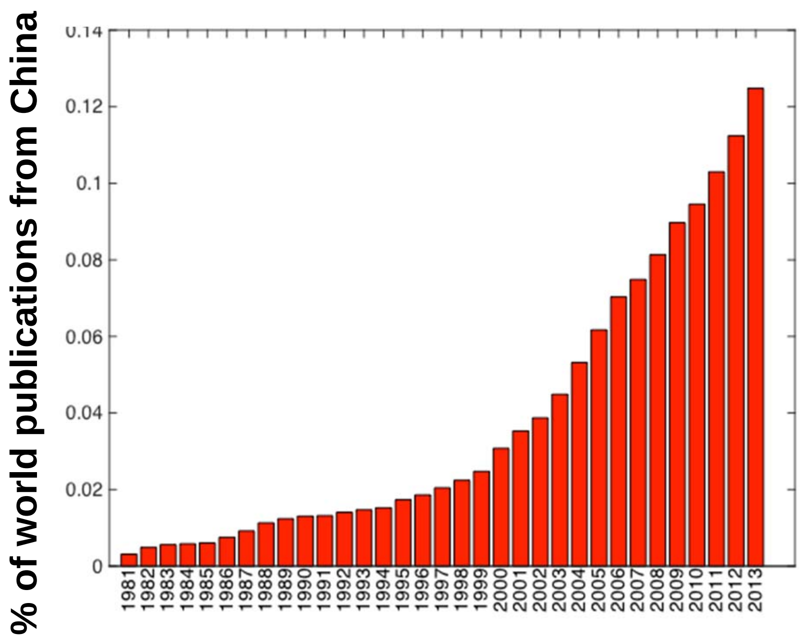
Current decision methods could be improved

China example

- Energy spread across ministries
- A large fraction of public R&D centers on energy
- Changes in program management, role of scientists
- But no coordinated process used to support effort (no info on technology allocation)



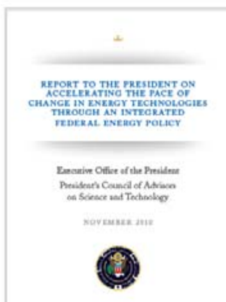
OECD (2014)



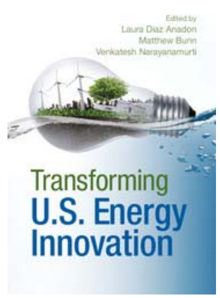
Zhi et al. (2012); Siddiqi et al. (2015); Binz et al. (2015)

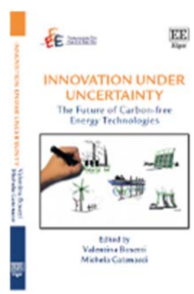
Growing area of focus for practitioners and researchers

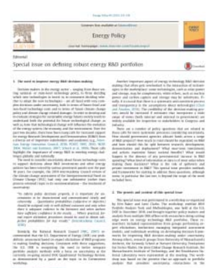
- Policy makers and other high-level leaders called for improvements
  - NRC (2007), PCAST (1997, 2010), American Energy Innovation Council (2010), Ru et al (2013) report, DOE Quadrennial Technology Review (2011, 2015)



- New research emphasis
  - E.g., *Energy Policy* 2015 special issue on 'Defining robust energy R&D portfolios (Baker, Bosetti & Anadon, 2015)







Principles for designing decision-support tools

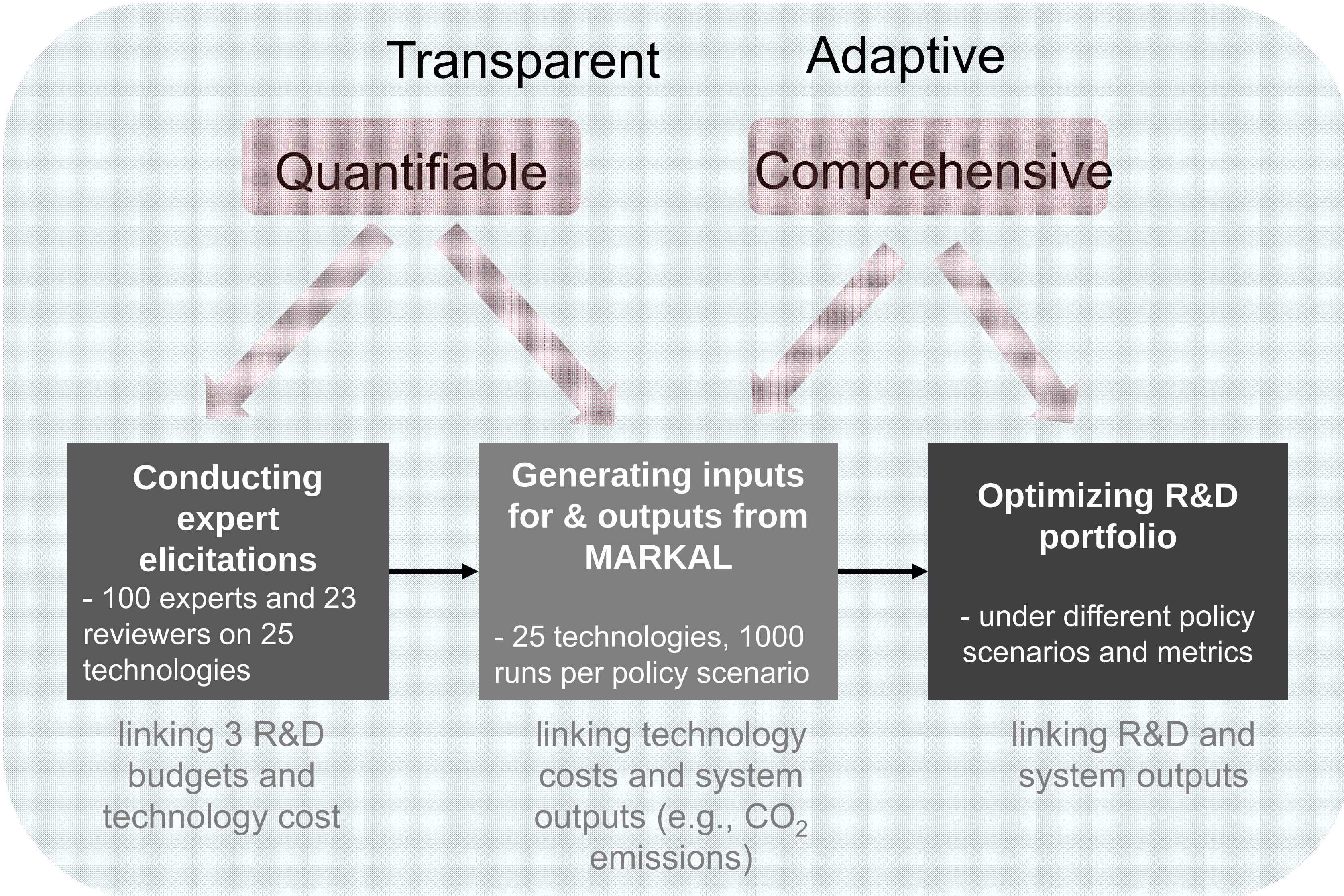
Need to merge technical rigor and political economy

- Analytical requirements
  - **Quantifiable:** accounting for uncertainty and benefits
  - **Comprehensive:** evaluating interactions

- Institutional feasibility
  - **Adaptive:** enabling improvements & interaction w/ stakeholders
  - **Transparent:** increasing credibility

Chan & Anadon (2015)

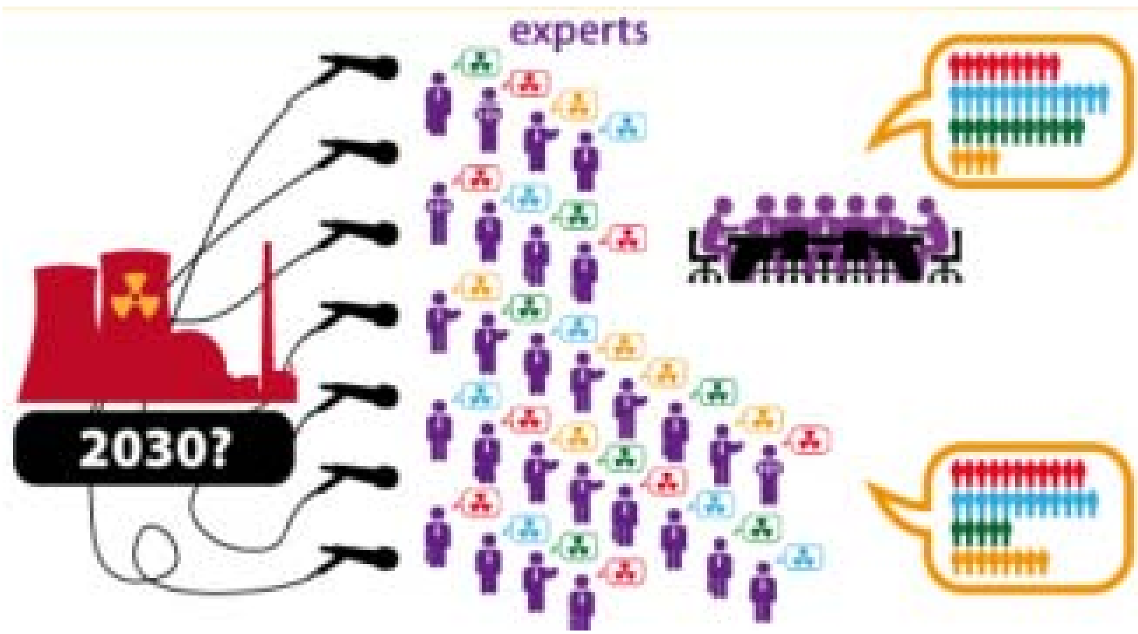
Application of principles to decision tool



Anadon, Chan & Lee (2014); Chan & Anadon (2015)

Technology costs are key, and expert elicitations are increasingly used to parameterize uncertainty

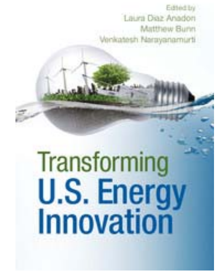
- Expert elicitations increasingly used in various policy areas
- New insights and methods on combination of expert elicitations and group workshop, on impact of expert diversity, etc.
- Summary in forthcoming, OECD report

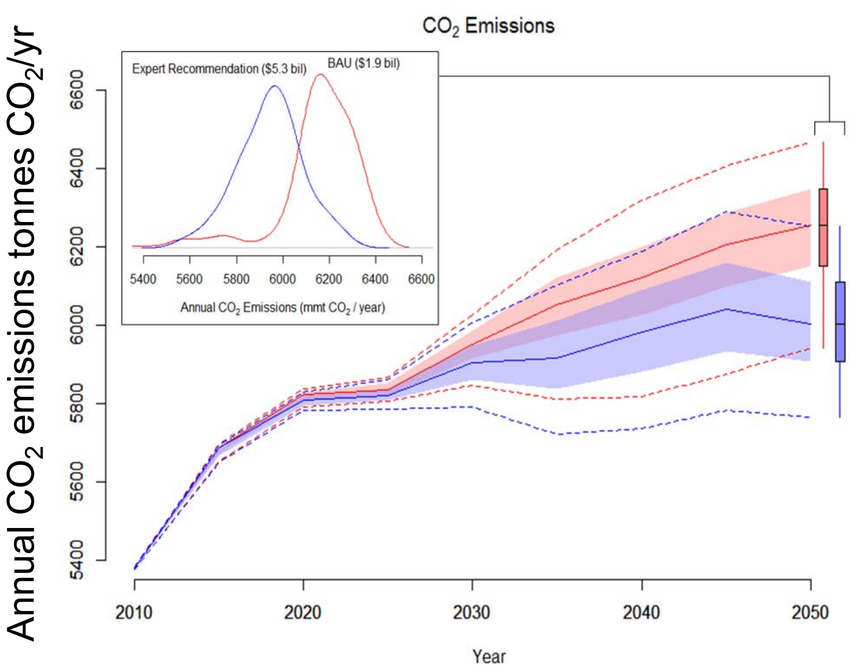


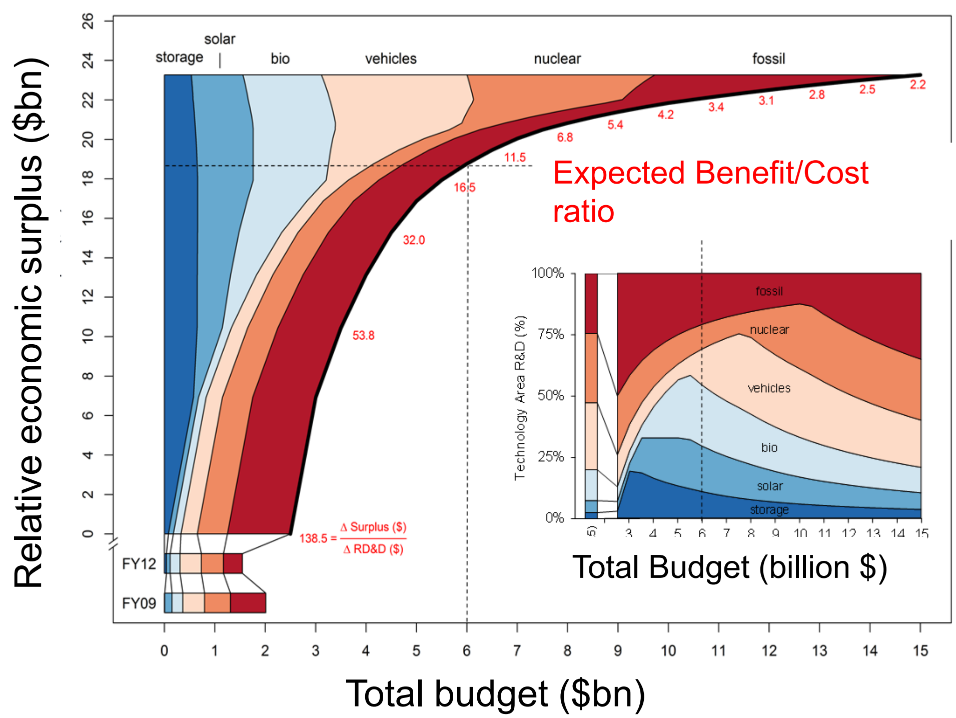
Anadon, Bosetti, et al. (2012); Bosetti, Anadon, Baker, Reis, Verdolini (2015)

New methods can provide new insights (& increase legitimacy)

- R&D is not enough
- Expected returns justify greater investments
- Current allocation not optimal (storage and solar underfunded)







Chan & Anadon (2015); Anadon, Chan & Lee (2014)

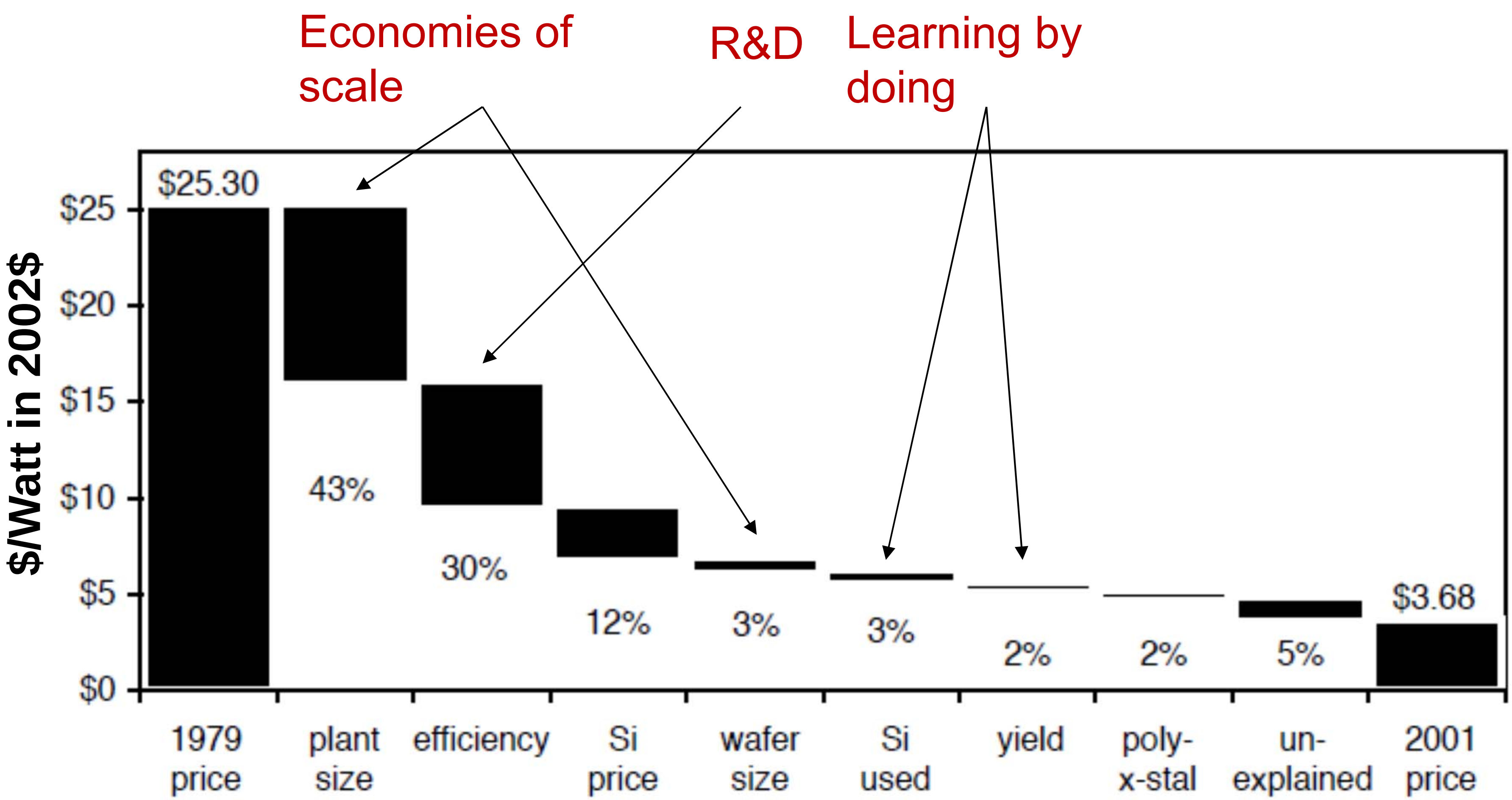
HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

3. Multiple policies: balancing deployment and R&D

Insights from energy innovation research
Historical data from solar PV

- Nemet (2007) on PV showed factors beyond learning curves

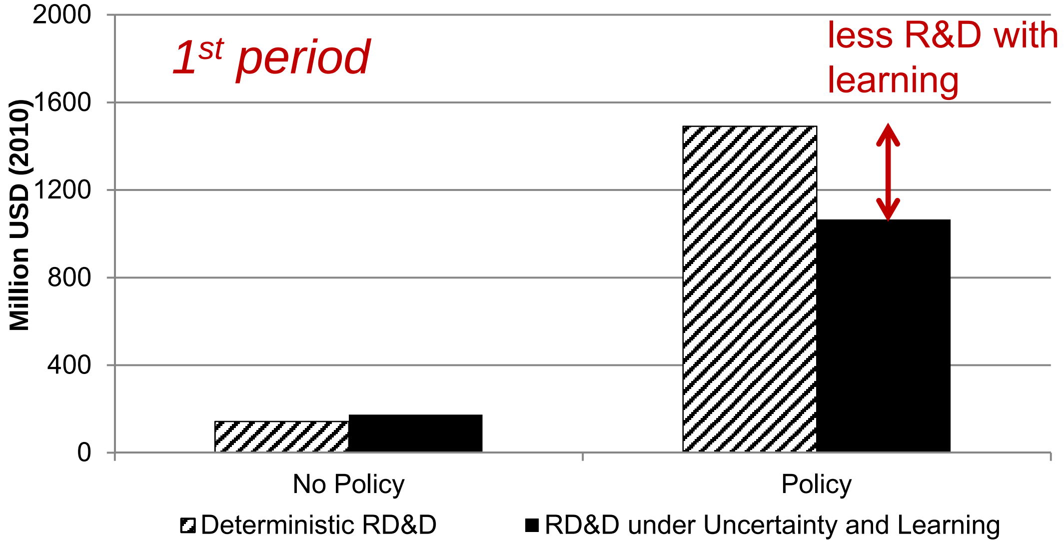


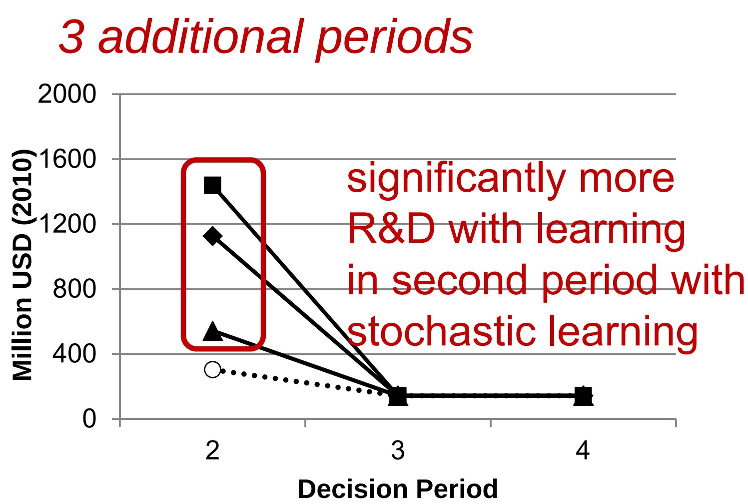
Balancing policies to induce innovation
Historical data from wind in China

- ‘Joint learning rate’ for wind lower than previous estimates (Qiu and Anadon, 2012)
  - Need to include wind quality, local manufacturing, and others
- Policy needs to consider interaction of manufacturers and developers (Tian and Popp, 2014)
- Quantifying factors explaining low generation of turbines in China (Huenteler, Chan, Tang, Anadon, 2015)
  - Policy tradeoffs and systemic issues

Balancing policies to induce innovation
Modelling and forecasting

- Cost-effectiveness of California PV subsidy depends on learning assumptions (Van Benthem et al., 2008)
- R&D important to increase PV competitiveness (Nemet & Baker, 2009)
- Considering learning in decision-making in more realistic electricity capacity expansion models reduces short term R&D investments (Santen & Anadon, 2015)





HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

4. Effectiveness of government R&D organizations

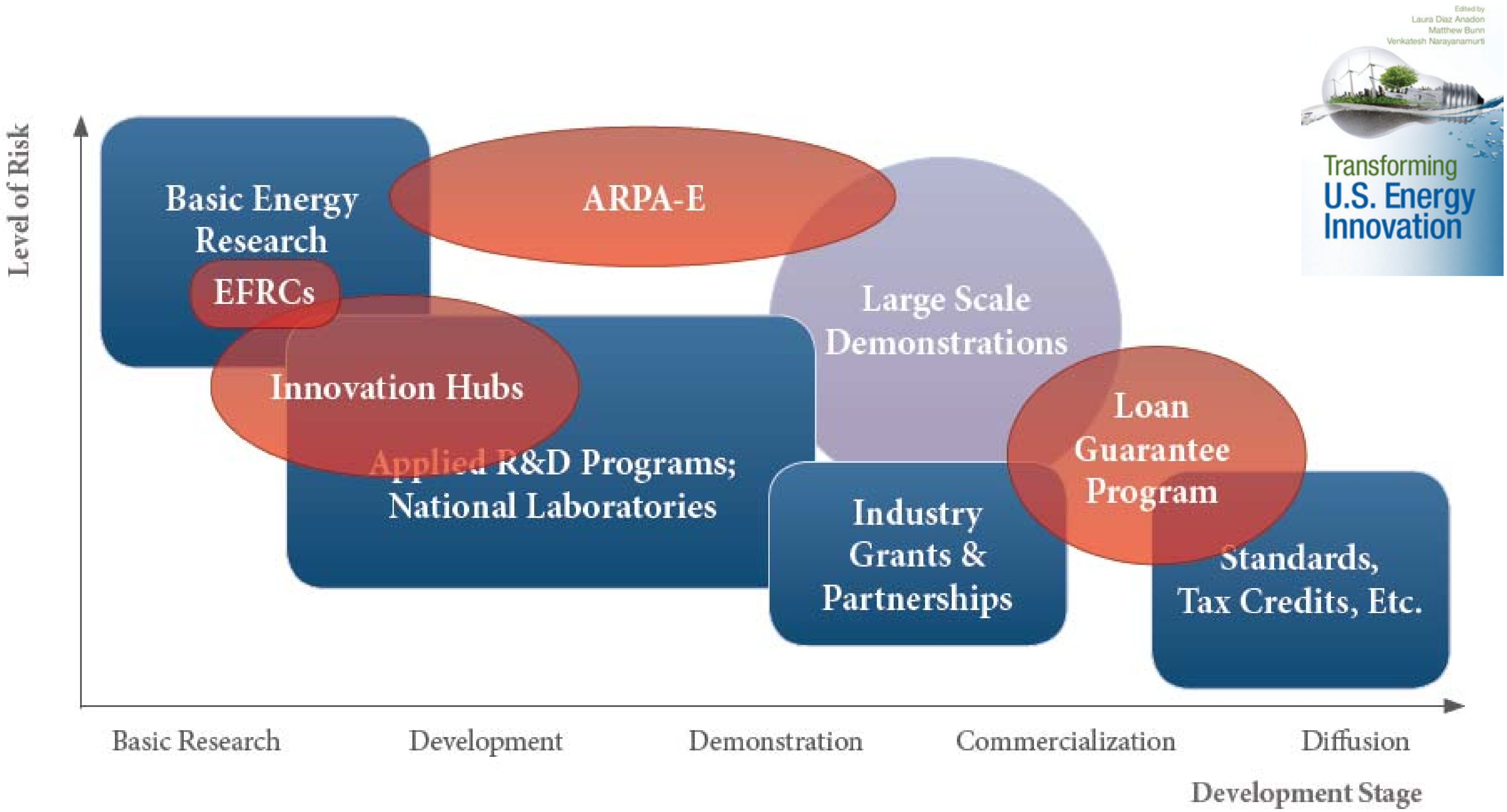
Governments are not just energy R&D funders, they are also performers

- 68 of the largest economies, conduct at least 30% of their R&D in government-owned facilities

- U.S. example:
  - over $125 billion/yr in R&D conducted by the government (12% of R&D)
  - 40 Federally Funded R&D Centers use nearly 40%
  - U.S. energy National Labs have been the subject of many reviews
  - Key issues
    - funding volatility
    - Congressional mistrust
    - lower productivity
    - growing bureaucracy

Logar, Anadon, Narayanamurti (2014); Anadon, Chan, Nun, Narayanamurti (2015)

US has tried to improve through 'osmosis' creating new institutions, but more reform is needed



'Old institutions' in blue, newer institutions in red, and non-existing institution in purple

- China may face a similar challenge and is considering changes

Anadon (2012); Anadon, Bunn, Narayanamurti (2014)

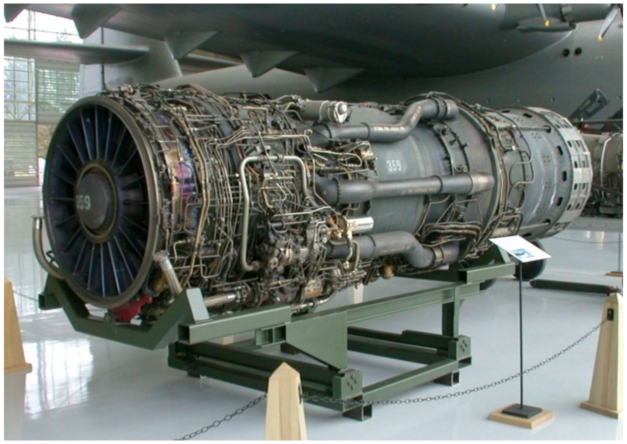
HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

5. Looking beyond energy

Example: technology spillovers in wind

Ship making

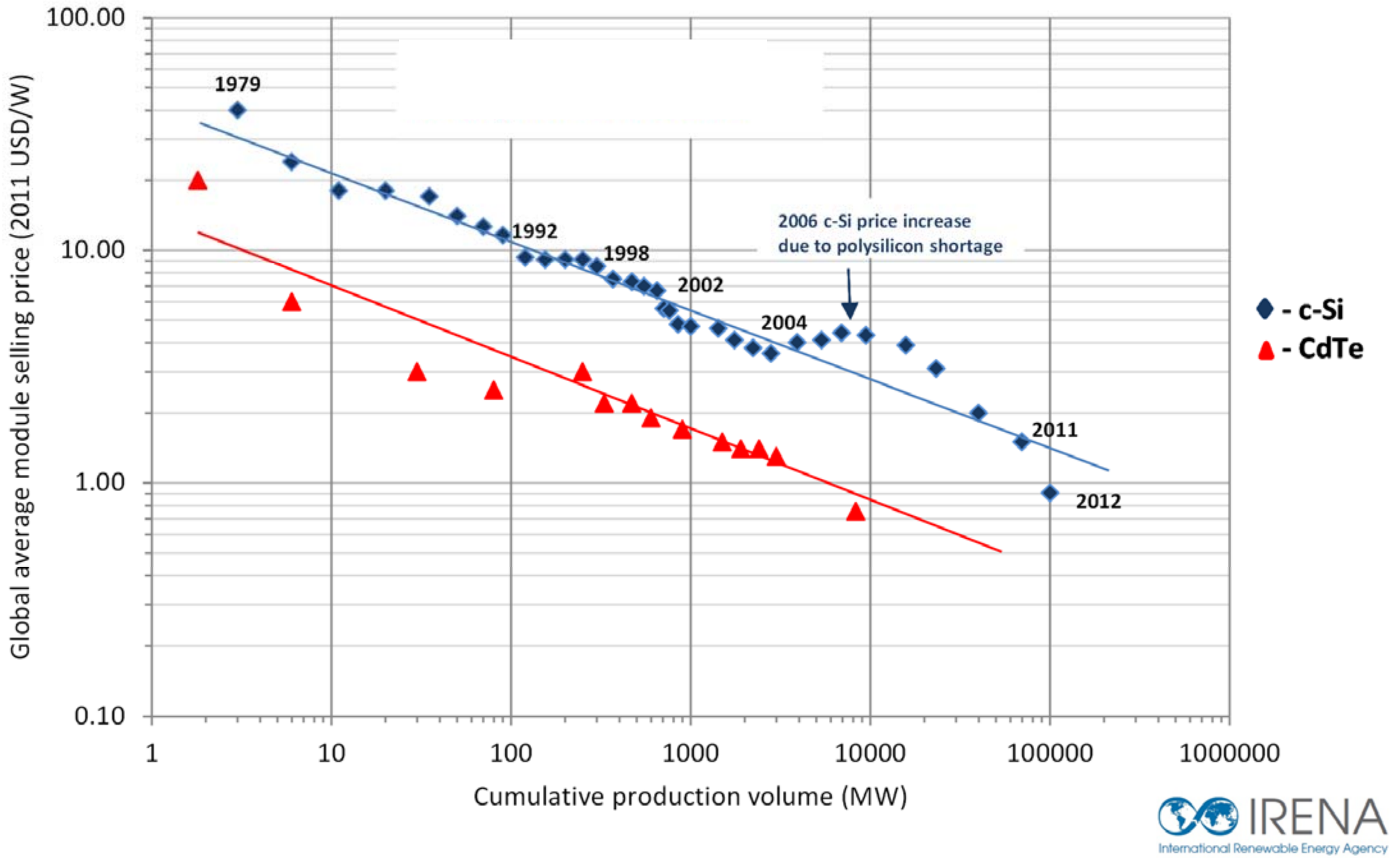


Jet engine design & manufacturing

Wind turbine manufacturing & design

Case study on silicon solar Si PV panels

- Significant progress over more than 3 decades
- Key technology in the energy sector with government engagement



Key takeaways from micro-history of spillovers
Interviews and archival research

- Governments have been major enablers of solar PV spillovers
- Now there are **reverse spillovers** to semiconductors
- Spillover (translation) happened in the wake of oil crisis
- Time between development and commercialization 2-30 years…

Anadon & Wüstemeyer (2014, 2015)

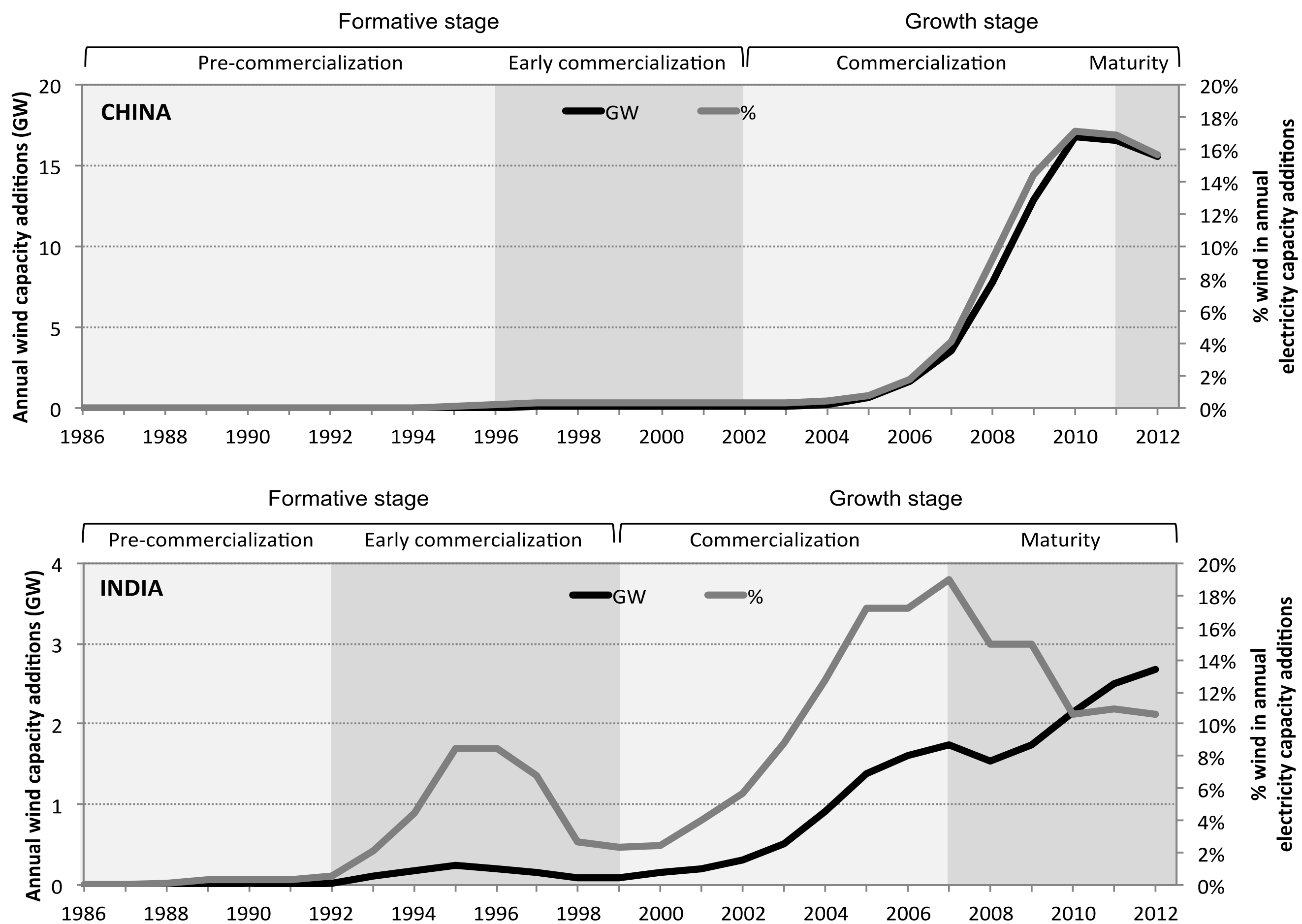
HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

6. Looking beyond the OECD

Broader technology diffusion experience is emerging
Example of wind in China and India

- Important to understand dynamics of emerging economies
- Almost 3 decades of wind policies
  - Still issues
- Growth accelerated after policies addressing various risks were put in place
- Different outcomes



Surana & Anadon (2015)

Distinct outcomes in both countries

- India
  - Smaller farm sizes (less turbines per owner <100)
  - Concentration ratio (market share of top 5 investors) around 25%
  - Much greater role of private sector in project development
  - Over 80% domestic manufacturing
- China
  - Larger farms sizes (>800 average turbines per owner)
  - Small role of private sector in project development (<10%)
  - Concentration ratio of market around 55%
  - Under 60% domestic manufacturing

Surana & Anadon (2015)

HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

7. Inclusion of other trends

Increasingly multi-dimensional multi-goal problem

E.g., integration of LCA and spatial analysis

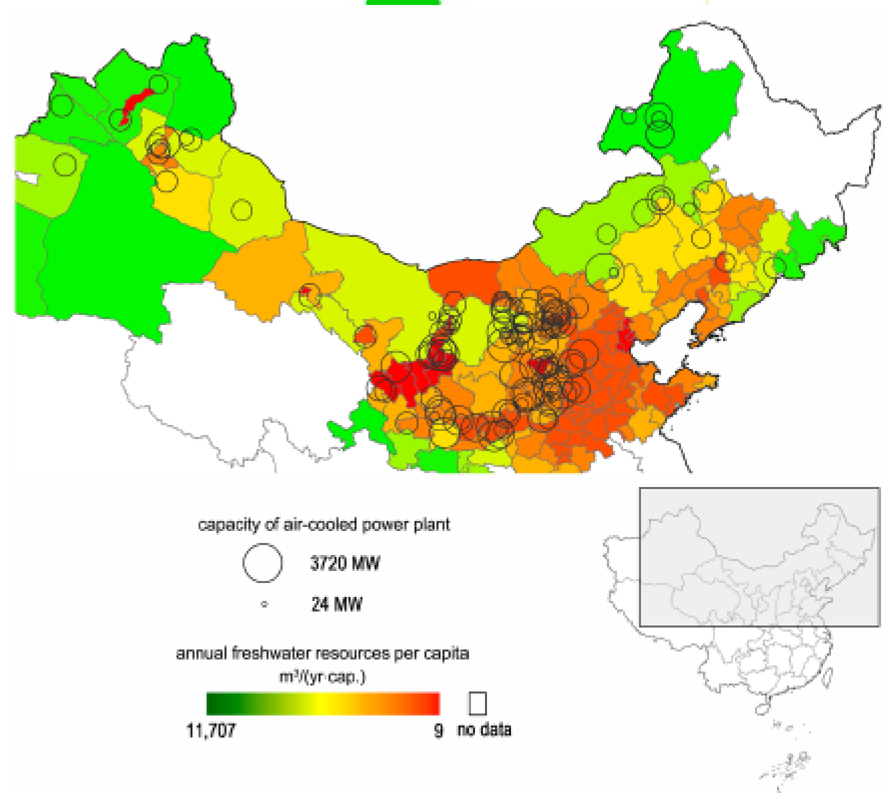
In 2012 air-cooled coal plants contributed ~1.0% of total Chinese electricity emissions

- saved 832−942 million m^3 water use (60% of Beijing annual water)

CO2 emissions largely offset CO_2 emissions reduction benefits from retirement of small and outdated coal plants.

Air-cooled units expected to account for 22% of China's coal-fired capacity in 2020

Need to account for other trends



Zhang, Anadon et al. (2015)

HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

8. Key takeaways

Key takeaways

- Energy technology innovation complex because of
  - Innovation process, multiple policies and goals, technology heterogeneity
- Research is increasingly used and requested by policy makers
  - E.g. R&D investments, deployment subsidies
- China could be game changing
- Understanding multiple methods is important
  - E.g., econometrics, expert elicitation, optimization, stochastic programming, interviews, archival research, LCA
- Areas where more focus is needed
  1. Consideration of implementation and political economy
  2. Integration of research from transitions, economic geography, and technology innovation systems, & broader science policy
  3. When and how to extrapolate findings across technologies

     ➔ e.g., consumer adopters
  4. Development and use of insights from emerging economies

HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

laura_diaz_anadon@harvard.edu

Acknowledgements
All members STPP and ETIP groups, in addition to funding from Doris Duke Charitable Foundation, STPP, KFAS, Italian Ministry for the Environment, Land and Sea, BP, Shell, Harvard Chemistry Dept, among others