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The Global Diffusion of Clean Energy Technologies:

Lessons from China

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Motivations

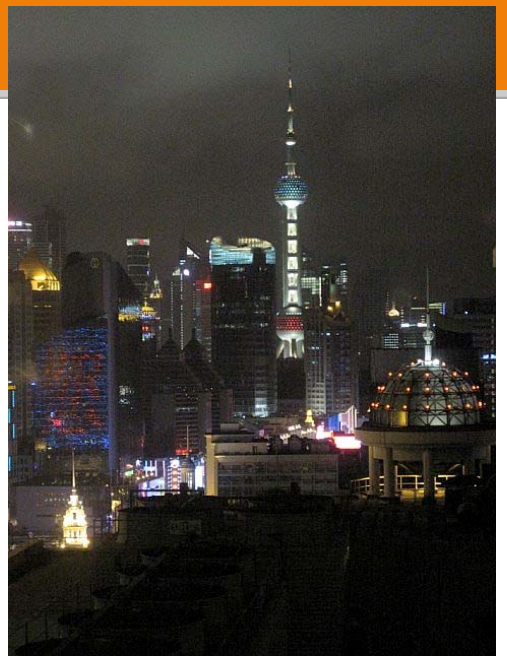
Why clean energy	Why global diffusion
Global climate change	Emissions shifting to non-OECD
Jobs	Human development
Resource efficiency	Finite global resources
Energy insecurity	Global peace and stability
Air pollution (conventional)	Cleaner air and water at local and regional levels
Economic competitiveness	Sustainable prosperity

Research Questions

What are the main barriers and incentives to the cross-border movement of cleaner energy technologies based on empirical evidence?

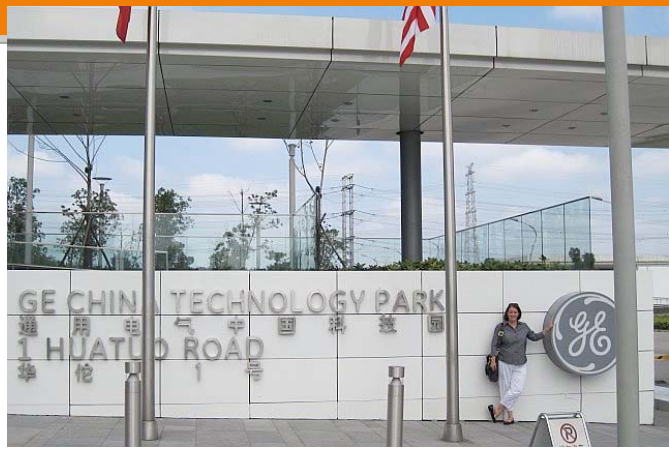
- Does the diffusion of clean energy technologies differ from other technologies?
- Does the theory about international technology transfer hold up to the evidence for cleaner technologies?
- What do the conclusions imply for business practice and government policy?

Into the Dragon's Den

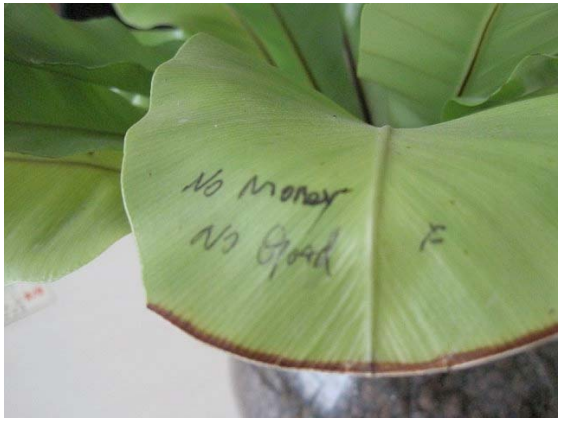


- China has a large quantity of energy firms that have used every conceivable strategy for developing and/or acquiring technology
- Chinese policy for clean energy evolving rapidly
- China is fastest-growing large economy, 2nd in world
- China is fastest-growing major energy consumer, now 1st in world, projected by the IEA to be the largest energy market for the next two decades
- Fair or not, China is the country currently that industrialized countries are most scared of in terms of IP infringement. China has previously argued it lacks access to key energy technologies

Four Telling Tales: Case Studies
四个生动的故事：案例分析



- Solar PV/太阳能光伏
- Coal gasification/煤气化
- Natural gas turbines/天燃气燃气轮机
- Batteries for advanced vehicles (EV, HEV) /电动汽车电池



Mechanisms for diffusion

Mechanism	Variation	Used by Chinese firms to acquire from foreigners	Used by foreign firms to acquire from China
Exports or imports of final goods	Equipment for manufacturing	✓	✓
Licenses		✓	✓
Purchase of foreign firm (M&A)	To acquire technology; merger	✓	✓
Strategic alliance or joint venture	Partial or 100%-owned	✓	✓
Migration of people for work or education	As entrepreneur, consultant, or employee recruited overseas	✓	✓
Contract with research entity	IP is negotiated with foreign university lab, research institute, firm	✓	✓
Collaborative RD&D		✓	✓
Open sources	Textbooks, conferences, journal articles, exhibitions	✓	✓
Bi-lateral or multi-lateral technology agreement	Research, development, demonstration	✓	✓

Sources: author, Lanjouw and Mody 1996, Mowrey and Oxley 1997, Gallagher 2006, Barton 2007, Lewis 2007, Odigiri et al. 2010, Lema and Lema 2010

Barriers to the Transfer of Cleaner Energy Techs to and from China

		Gas Turbines	Advanced Batteries	Solar PV	Coal Gasification
Policy factors	Export controls				
	Import tariffs				
	Restriction of access to domestic market				
	Weak innovation policy				
	Weak industrial policy				
	Weak market-formation policy		*	*	
	Weak export promotion policy				
Cost and finance factors	Access to finance/ability to invest				
	Lack of "natural" market				
	High cost of foreign technology				

Source: Author analysis, based on case study research. Yellow is the Chinese point of view. Blue is foreign point of view. Green denotes agreement between foreign and Chinese perspectives. A question mark (?) denotes a lack of data, where as lack of an entry means that the barrier does not clearly apply in this case.
*Before new policies announced in the 12th Five Year Plan

(continued)

Barriers to the Transfer of Cleaner Energy Techs to and from China (cont.)

		Gas Turbines	Advanced Batteries	Solar PV	Coal Gasification
Intellectual property factors	Export prohibitions in license agreements				
	Defensive, anti-competitive patenting				
	Fear of IP infringement				
	Refusal by foreign firms to license				
Business practice factors	Lack of experience in foreign markets				
	Weak IP management				
	High risk aversion				
	Poor after-sales service				

Source: Author analysis, based on case study research. Yellow is the Chinese point of view. Blue is foreign point of view. Green denotes agreement between foreign and Chinese perspectives. A question mark (?) denotes a lack of data, where as lack of an entry means that the barrier does not clearly apply in this case.

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Incentives for the Transfer of Cleaner Energy Techs to and from China

		Gas Turbines	Advanced Batteries	Solar PV	Coal Gasification
Policy factors	Clear long term policy		*	*	
	Lack of trade barriers				
	Strong innovation policy				
	Strategic industrial policy		*	*	
	Stable market-formation policy		*	*	
	Strong export promotion policy				
	Alignment of policy				
Cost and finance factors	Good access to finance				?
	"Natural" market exists				
	Ability to buy tech if needed				
	Costs of foreign or Chinese technology reasonable				

Source: Author analysis, based on case study research. Yellow is the Chinese point of view. Blue is foreign point of view. Green denotes agreement between foreign and Chinese perspectives. A question mark (?) denotes a lack of data, where as lack of an entry means that the barrier does not clearly apply in this case.
*Before new policies announced in the 12th Five Year Plan

Incentives for the Transfer of Cleaner Energy Techs to and from China (cont.)

		Gas Turbines	Advanced Batteries	Solar PV	Coal Gasification
Intellectual property factors	Strong or improving patent regime domestically				
	Confidence in domestic courts	some	some	some	some
	Willingness of foreign firms to license or cooperate in joint development				
	Strong domestic technological capabilities				
	Knowledge of technology needed/absorptive capacity				
Business practice factors	Experience in foreign markets				
	Flexibility, nimbleness of firms	some			
	Co-location with supply chain				
	Global perspective on markets				
	Good IP management				?
	Tolerance for risk-taking	some	some		
	Good after-sales service				

Source: Author analysis, based on case study research. Yellow is the Chinese point of view. Blue is foreign point of view. Green denotes agreement between foreign and Chinese perspectives. A question mark (?) denotes a lack of data, where as lack of an entry means that the barrier does not clearly apply in this case.
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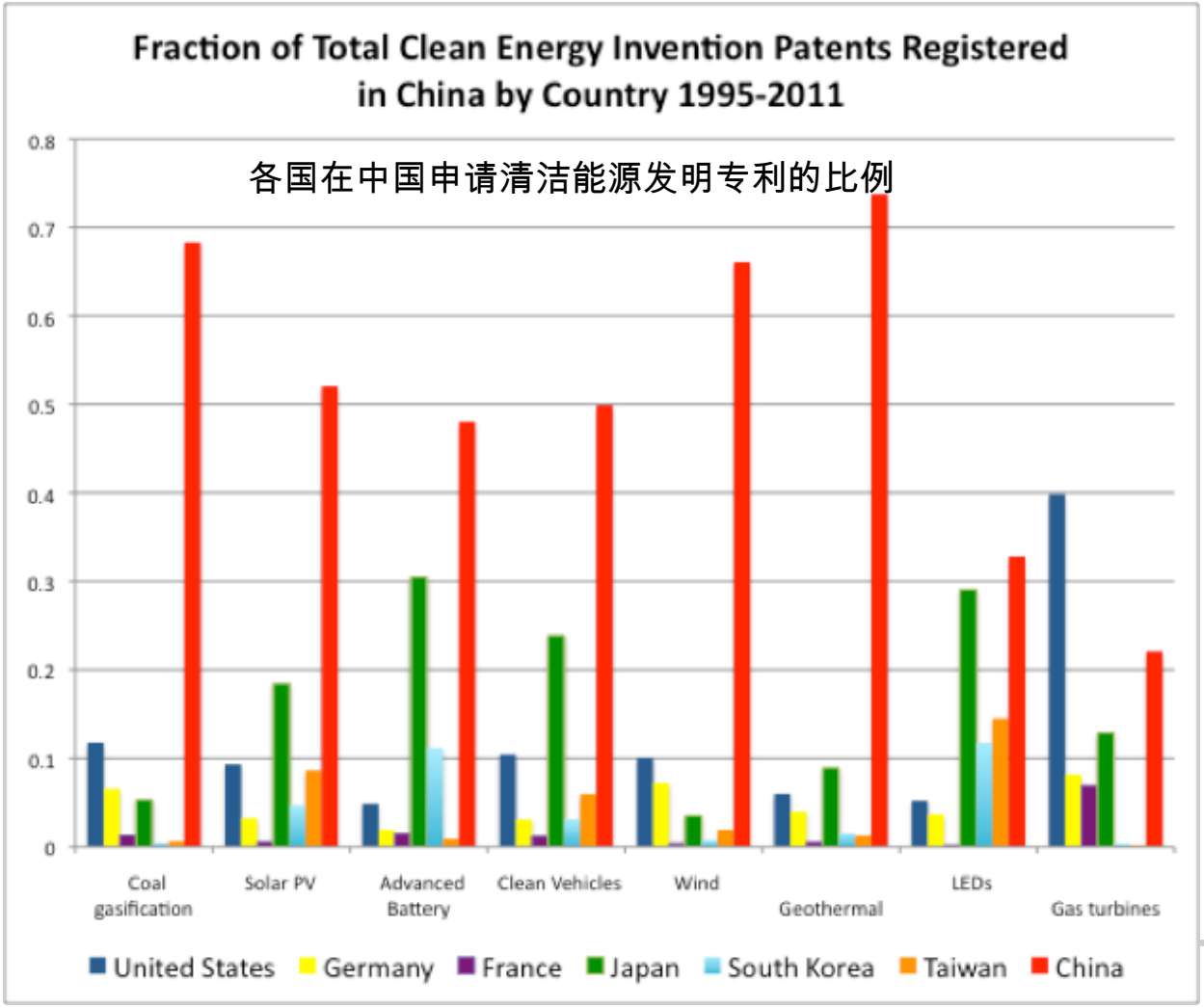
Intellectual Property: 3 Research Methods
知识产权：3种方法

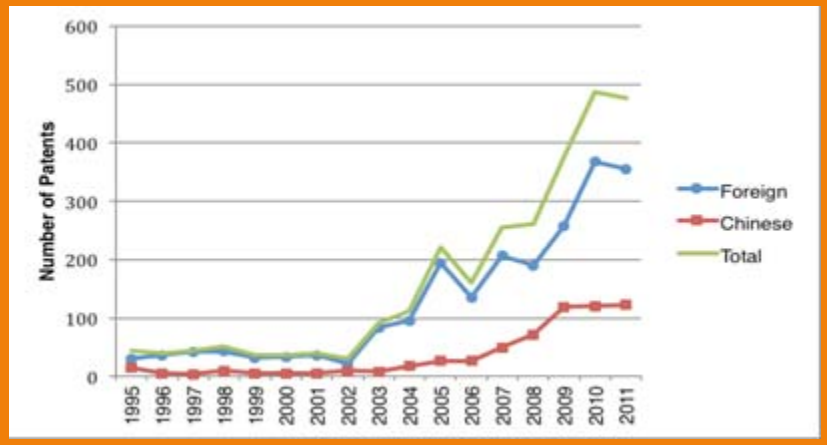
- Case studies
  - Evidence of infringement from interviews
    - One notorious case (Sinovel vs. AMSC)
    - Several minor incidences, none life threatening to firmEvidence of withholding from interviews
  - Evidence of withholding
    - Gas turbines
    - Hybrid electric vehicles
- Analysis of invention patents granted
- Analysis of court cases
  - No Chinese vs. foreign IP infringement court cases in case studies (except for Sinovel, not in the case selection

Annual Share of Foreign Patents: My Case Studies
外国在中国申请专利的比例：案例研究

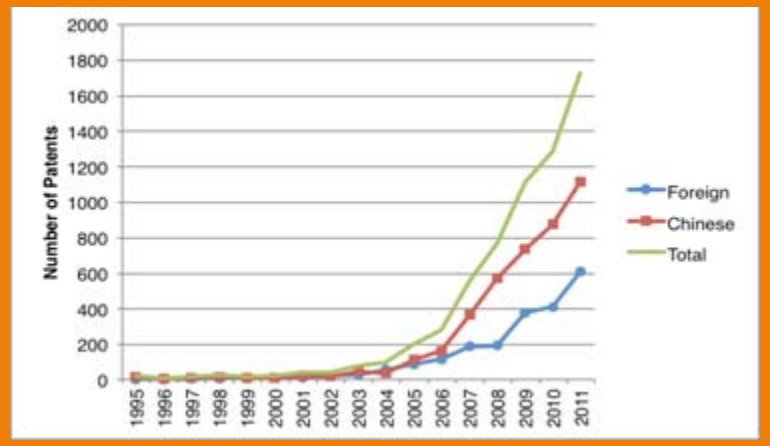


Gallagher, K.S. and A. Irwin, The Fletcher School. Raw data from the State Intellectual Property Organization, China – accessed 2012.

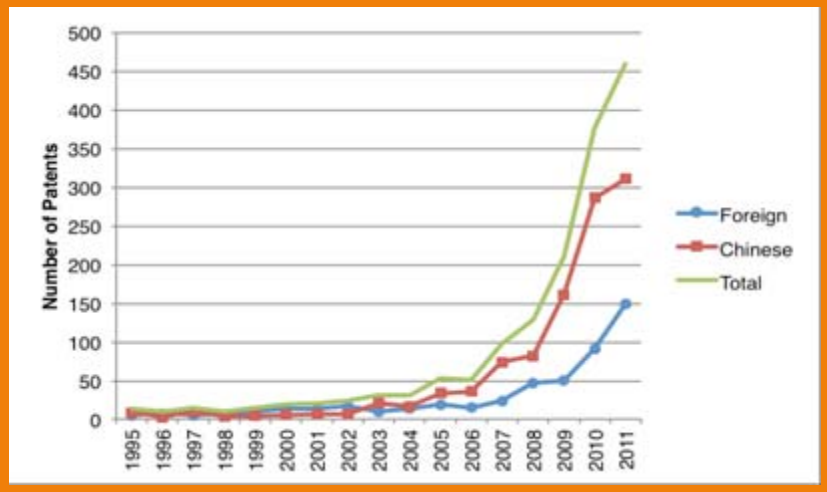
Gas Turbine Invention Patents
燃气轮机发明专利



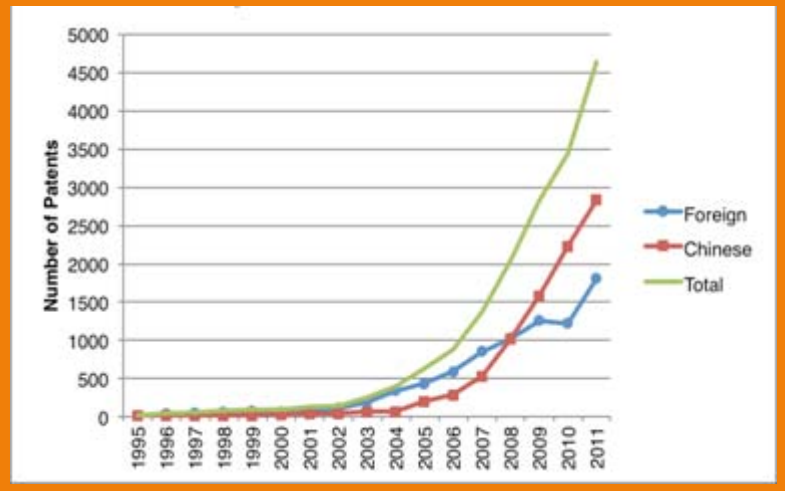
Wind Power Invention Patents
风电发明专利



Coal Gasification Invention Patents
煤气化发明专利



Solar PV Invention Patents
光伏发明专利



Charts by K.S. Gallagher (2013), data accessed from State Intellectual Property Organization (China) in 2012.

Clean Energy Invention Patents Granted by China's State Intellectual Property Office (1995-2011)

中国知识产权局授权的清洁能源发明专利（1995-2011）

Cleaner Energy Technology	Foreign Percentage of Total	Chinese annual growth rate since 2005	Foreign annual growth rate since 2005	Year that number of new Chinese patents surpassed number of foreign patents
Gas turbines	78%	37%	28%	Not yet
LEDs	67%	72%	28%	Likely in 2012
Wind	34%	68%	44%	2005
Clean vehicles	50%	49%	39%	2009
Coal gasification	32%	58%	46%	2003
Advanced batteries for vehicles	52%	n/a[1]	n/a[1]	n/a[1]
Geothermal	26%	53%	23%	2002
Solar PV	48%	85%	28%	2008

Notes: All data from SIPO, calculations by author.
[1]The data series is too short

The IP Puzzle: some hypotheses

Hypothesis 1: Foreign firms are reluctant to pursue court cases because (1) they don't think they would win in a Chinese court, or (2) don't think it is worth the trouble

Hypothesis 2: Clean energy techs are not sufficiently mature to warrant significant litigation yet

Hypothesis 3: Many cases don't go to court because they are mediated or arbitrated instead.

Hypothesis 4: E techs are complex systems, requiring great deal of tacit knowledge. Hard to copy.

Hypothesis 5: Chinese capabilities are strong, so no need to infringe, plus they want to protect their own IP.

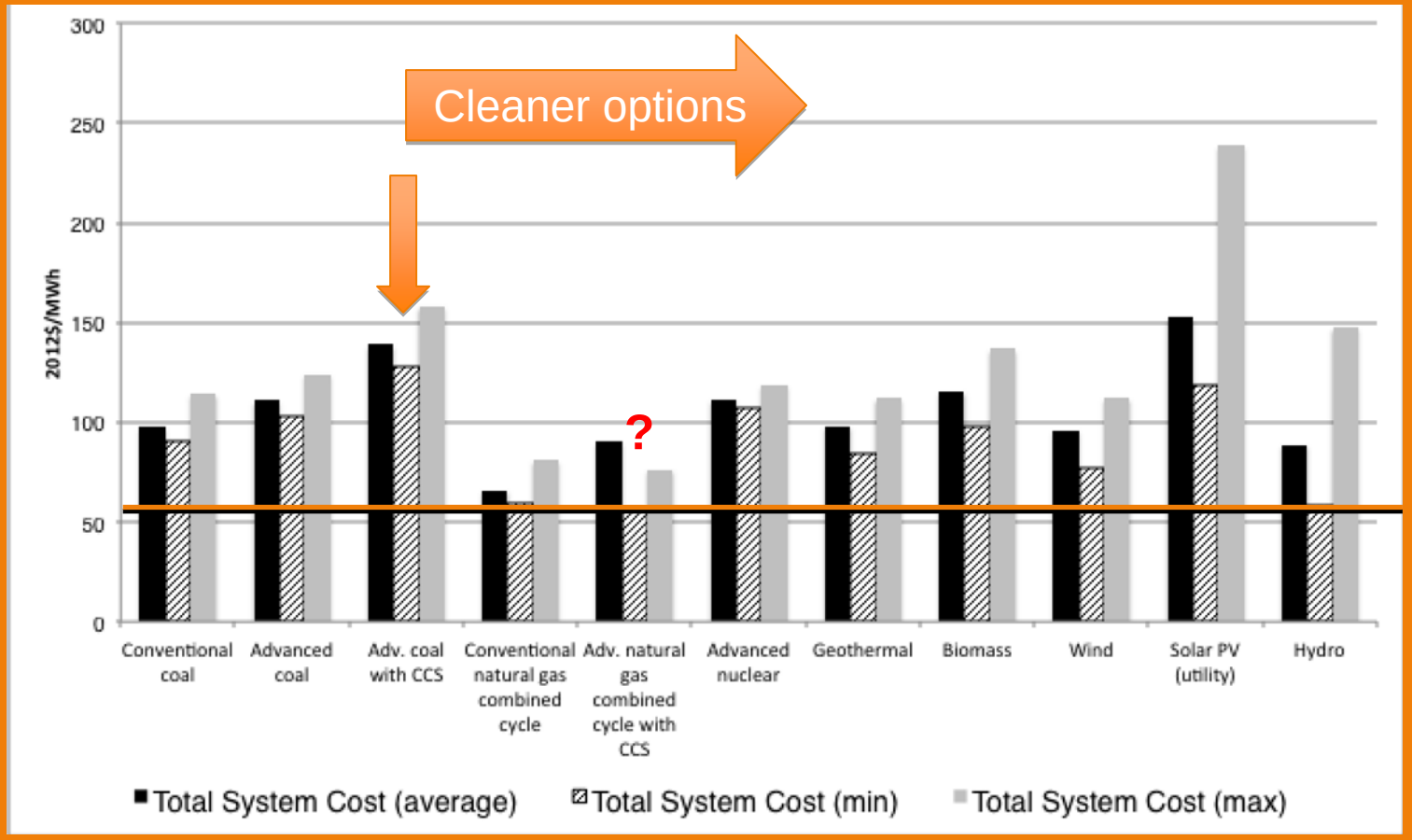
Market failures pervasive

- Energy markets are far from “perfect”
  - Asymmetric information (e.g. OPEC vs. consumers)
  - Highly subsidized in some countries
  - Highly regulated in some countries
- Externalities are pervasive and not valued by market
  - Energy security costs
  - Costs of conventional air pollution in terms of public health, premature death, damage to infrastructure
  - Costs of climate change (benefits of avoiding it, costs of adaptation)

Cost and Finance/成本和金融

- "The number one barrier is policy. Well, it is cost, and therefore you need to have policy to create the market." – *Shi Zhengrong, CEO, Suntech*
  - The 2 main barriers cited in case studies
- Access to finance is not a barrier for the Chinese. It is a major competitive advantage.
- For foreign firms, especially smaller ones from the USA, access to finance is their biggest problem (e.g. Evergreen Solar, A123).
- The incremental costs of cleaner technologies clearly matter, but in many cases are being overcome with market-formation policies around the world.

Levelized Cost of New Generation Resources in the United States for Power Plants Entering Service in 2017



Data from U.S. Energy Information Administration 2012, Annual Energy Outlook

Universal agreement about importance of policy

"Government policy is extremely important to drive long-term sustainable development." – Ed Lowe, GE

"Without government regulation, you won't have a market for clean energy." Hans-Peter Bohm, Siemens

"The policy environment is important – principally the stability and the predictability." Dick Wilder, Microsoft

Four types of policy 政策的核心作用

- Domestic manufacturing or industrial policy
  国内制造或工业政策
- Technology or innovation policy
  技术或者创新政策
- Export promotion policy
  出口推动政策
- Market-formation policy
  市场形成政策

Of course, policies can also inhibit diffusion as well

Domestic manufacturing or industrial policy

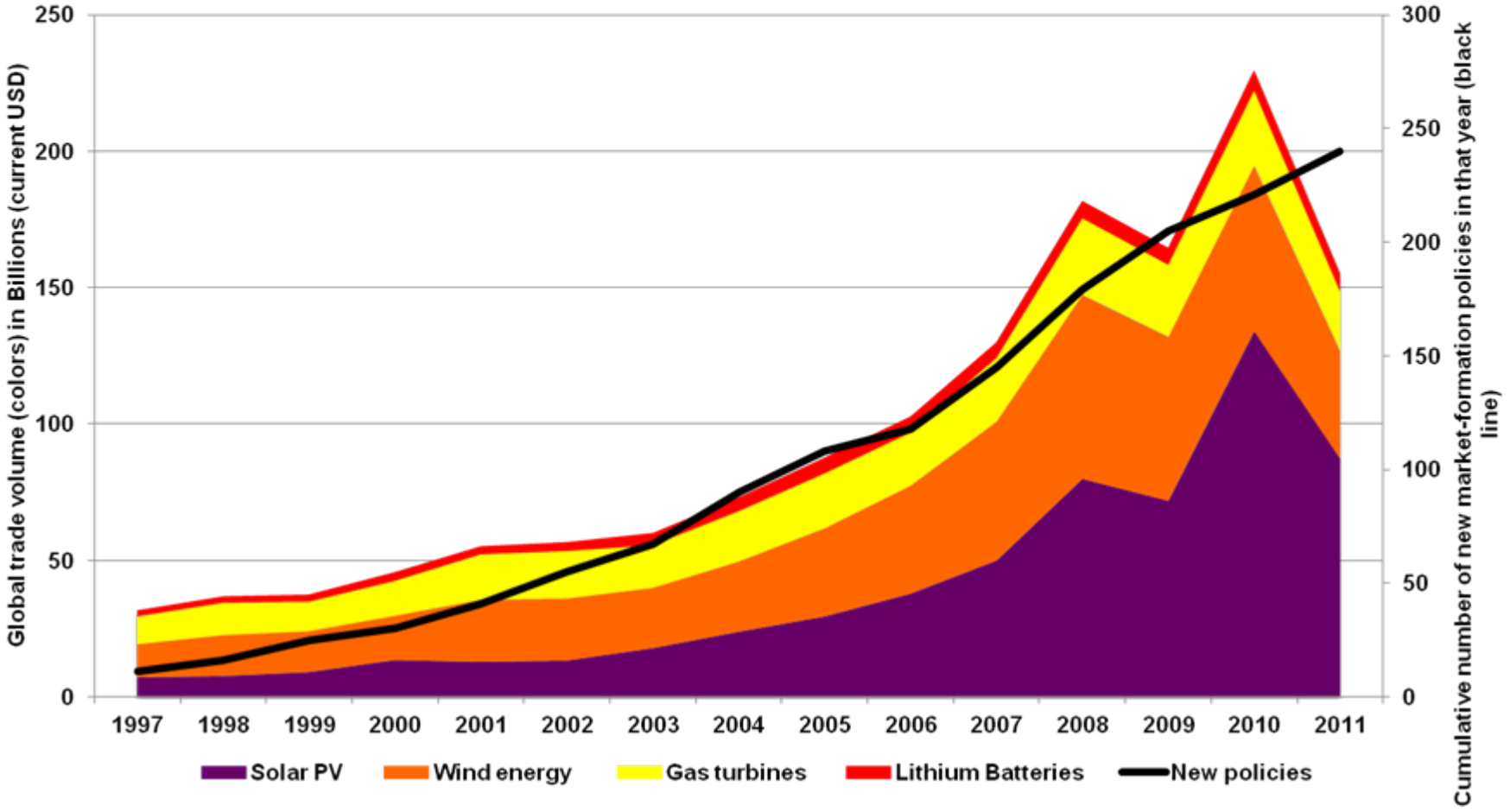
- Essential to exports. "You cannot export what you don't manufacture"
  - Need to have domestic market for scaling up, commercial demonstration, national branding. Need forgiving market.
- Availability of capital is key
  - "Like snowballs rolling down a hill"
- Standardization, agglomeration through technical and regulatory standards
- Innovation and technology policy
  - Technology push and pull – emphasis on a systemic approach
- Export promotion

What is market-formation policy?

- It is not niche market formation
- More structural and broader in intent: correcting for market failures, not trying to overcome “valley of death”
- It is policy that creates demand for certain types of technologies, e.g. carbon tax, cap-and-trade system, or:
  - 92 states, provinces or countries have established feed-in policies
  - 71 states, provinces or countries have either a RPS or a quota policy
- Evidence from the cases – solar PV (large global market induced by policy) vs. natural gas in China (weak natural market, no market formation)

National and Sub-National Market-Formation Policies and International Trade in Clean Energy Technologies

国家和次国家单元的市场形成政策与全球清洁能源技术贸易的关系



Trade data from COMTRADE (UN Statistics Division). Policy data compiled from various sources by Gallagher, K.S. 2013

The clean energy industry globalized around 2000: why and how?

- Internationalization of university education
- International collaboration
- Ease and increased normalcy of migration
- Globalization of energy RD&D
- Aggregated national market formation policies = global markets
- Trade liberalization and new int'l institutions
- Chinese willingness to finance the transition

Conclusions

1. Clean energy innovation is no longer a national process: it has globalized
2. Most important barriers are cost (due to market failures & distortions), lack of policy, insufficient access to finance
3. Best incentives are market-formation policies, provision of affordable finance

Updating an integrated theory

1. Diffusion is part of a *global* ETIS – a systemic approach required
   - Harmonization?
2. Most diffusion occurs through private markets
3. Diffusion caused by national and sub-national market formation
4. Market formation is wider than niche markets – structural change is needed(big is beautiful in market scale)
5. Anti-competitive behavior and monopolistic structures hinder diffusion
6. Core to periphery pattern true but international networks matter
7. Appropriateness, absorptive capacity indeed important
8. Technological leapfrogging is possible but not automatic

Acknowledgements

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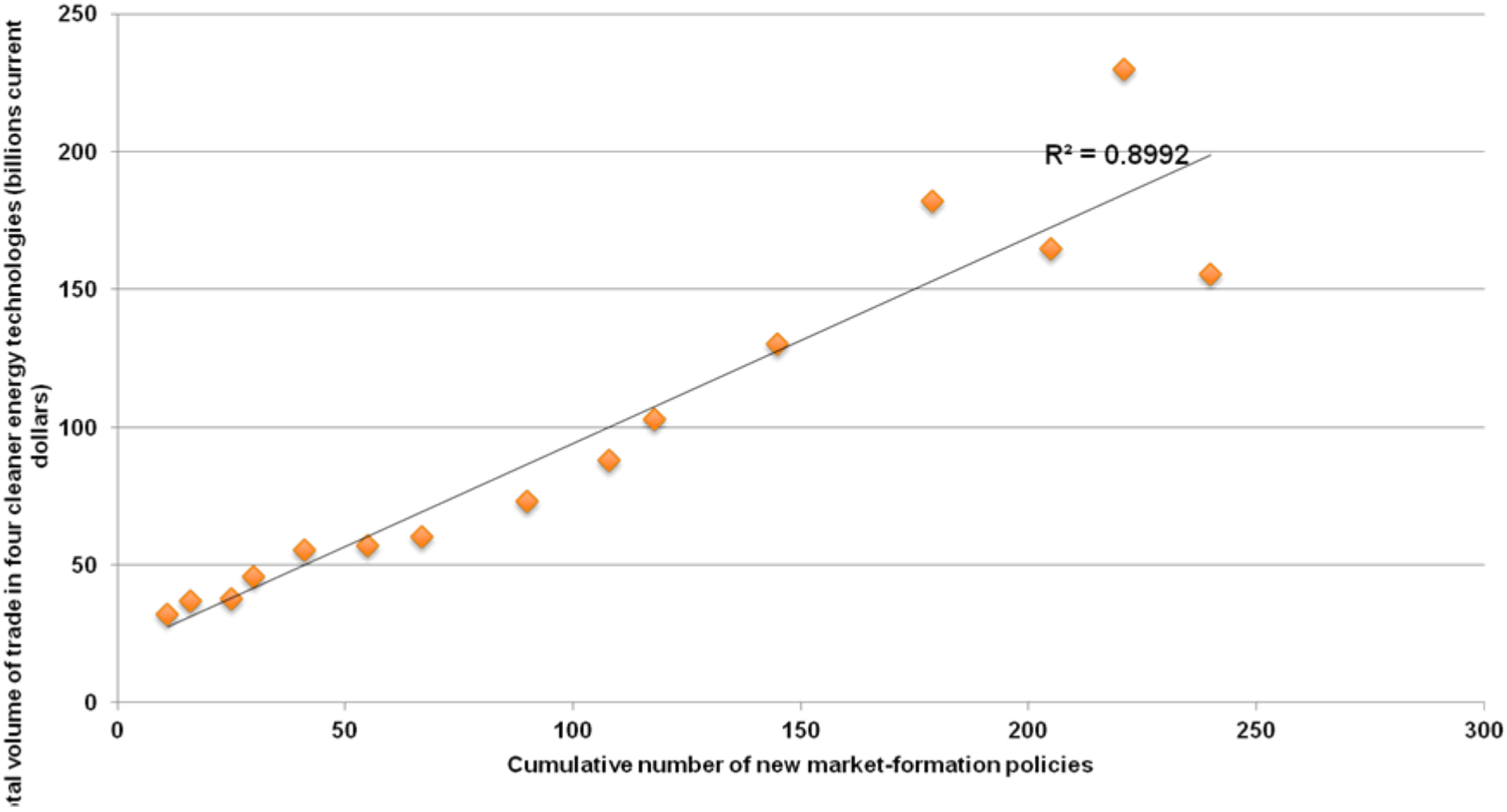
Back-Up

Relationship Between Cumulative Market-Formation Policies and the International Trade in Cleaner Energy Technologies

累计市场形成政策数目与国际清洁能源技术贸易的关系



Estimated Levelized Cost of New Generation Resources for Plants Entering Service in the United States in 2017 (2012$/MWh)
2017 年美国投入使用的发电厂的平准化发电成本成本估计

Plant Type	Capacity Factor (%)	Fixed O&M	Variable O&M (includ-ing fuel)	Trans-mission Investment	Total System Cost (average)	Total System Cost (min-imum)	Total System Cost (max-imum)
Conventional coal	85	4.0	27.5	1.2	97.7	90.5	114.3
Advanced coal	85	6.6	29.1	1.2	110.9	102.5	124.0
Adv. coal with CCS	85	9.3	36.4	1.2	138.8	127.7	158.2
Conventional natural gas combined cycle	87	1.9	45.8	1.2	66.1	59.5	81.0
Adv. natural gas combined cycle with CCS	87	4.0	50.6	1.2	90.1	56.8	76.4
Advanced nuclear	90	11.3	11.6	1.1	111.4	107.2	118.7
Geothermal	91	11.9	9.6	1.5	98.2	84.0	112.0
Biomass	83	13.8	44.3	1.3	115.4	97.8	136.7
Wind	33	9.8	0	3.8	96.0	77.0	112.2
Solar PV (utility)	25	7.7	0	3.8	152.7	119.0	238.8
Solar thermal	20	40.1	0	6.3	242.0	176.1	386.2
Hydro	53	4	6	2.1	88.9	57.8	147.6

Notes:
Source: Adapted from U.S. Energy Information Administration, *Annual Energy Outlook 2012*, June 2012, DOE/EIA-0383 (2012).