"The importance of spillovers for green technology innovation: evidence from wind and solar in China"

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Introduction

- Reducing emissions from greenhouse gases in China while still enabling continued economic growth requires the use of new technologies

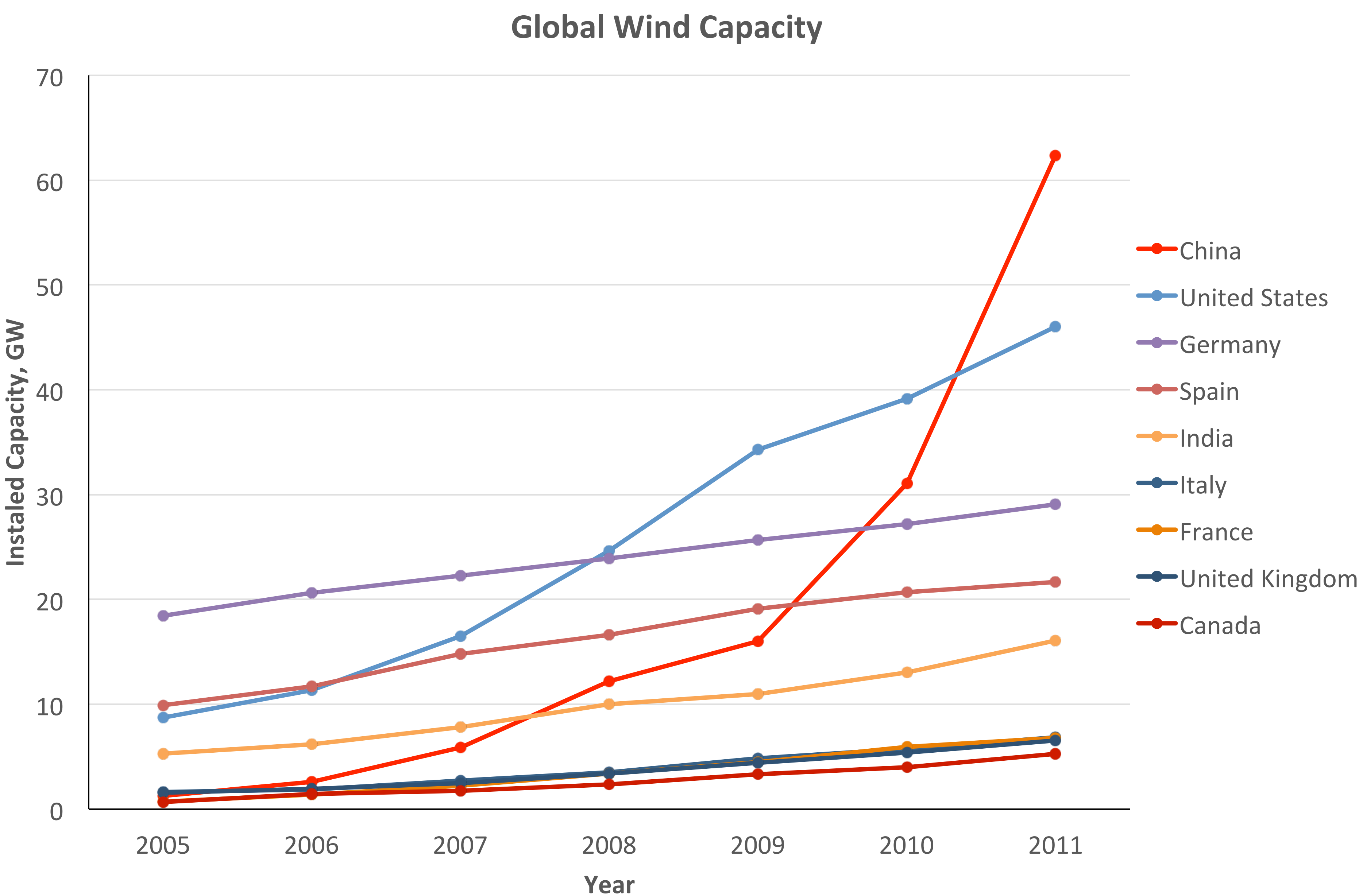
- In most cases, these technologies are first created in high-income countries

- Thus, one challenge for climate policy is to encourage the transfer and continued development of these climate-friendly technologies in China

- I focus on two successful cases, looking at the potential spillover gains from technology transfer

China's growing role in clean energy

- China is beginning to emerge as a key player in both the development and use of clean energy
  - Wind:
    - Annual growth rates of installed capacity over 100% from 2003 to 2009
    - China became the worlds' largest wind power country in terms of cumulative installed capacity in 2010



Source: Energy Information Administration International Energy Statistics

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  - Wind:
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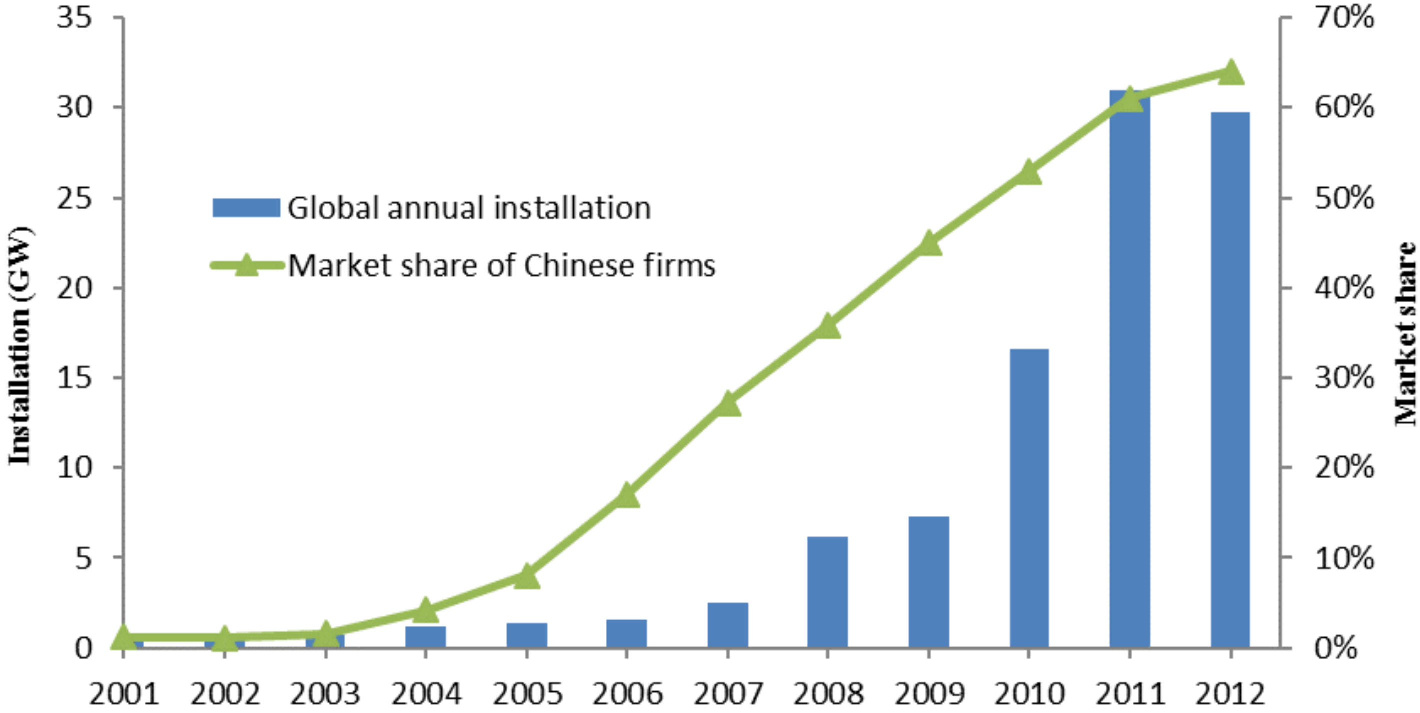
    - China became the worlds' largest wind power country in terms of cumulative installed capacity in 2010
  - Solar:
    - China has become the world's leading producer of solar cells
    - Unlike wind, solar industry focused on exports
      - While exporting more than 95% of its production, China's share of global PV production rose from 1% in 2009 to 59% by 2010

Global Solar Photovoltaic Installation and Chinese Firms' Market Share, 2001-2012



Source: EPIA, 2013

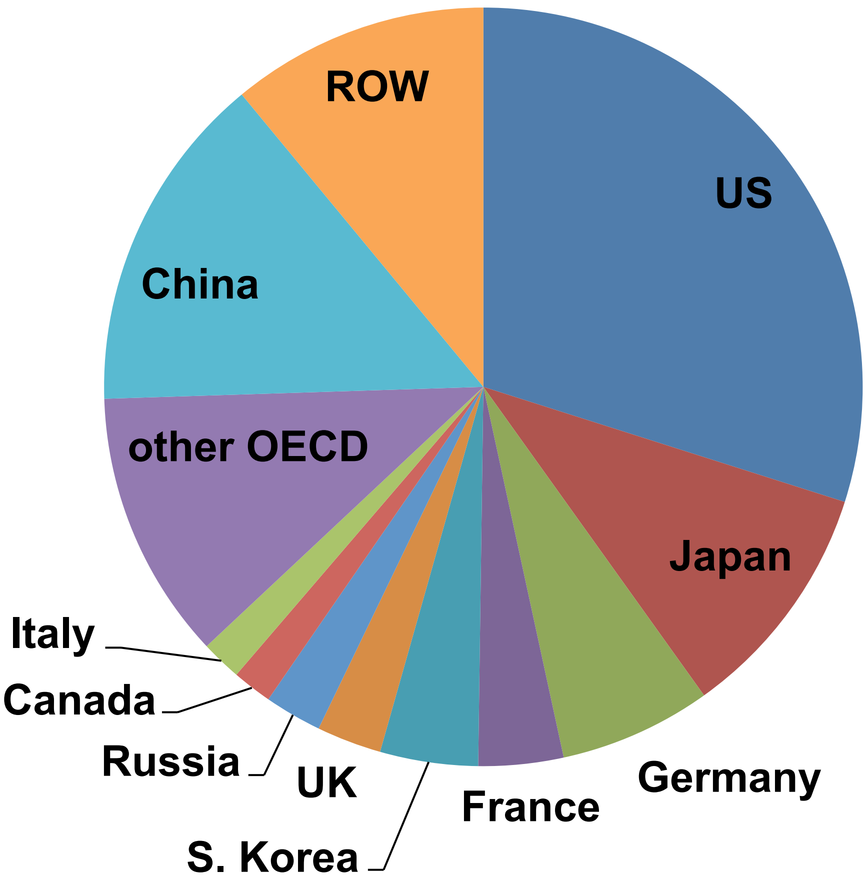
The Role of Technology Transfer

- What is technology transfer?
  - "A broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/ education institutions ."(IPCC 2007)

Why is Technology Transfer Important?

- Nearly all of the world's R&D is performed in the developed OECD economies
  - China is a notable exception

2011 Global R&D Expenditures



Why is Technology Transfer Important?

- Nearly all of the world's R&D is performed in the developed OECD economies

- True for green innovation as well
  - Dechezleprêtre *et al*. (2011) find that 2/3 of climate-friendly innovations from 1978-2003 come from the U.S., Japan, or Germany

  => In many cases, technologies needed to promote green growth will already be available

- Thus, transferring clean technologies to emerging economies is the key issue
  - Can result in both direct use (adoption) and increased capacity to develop and innovate

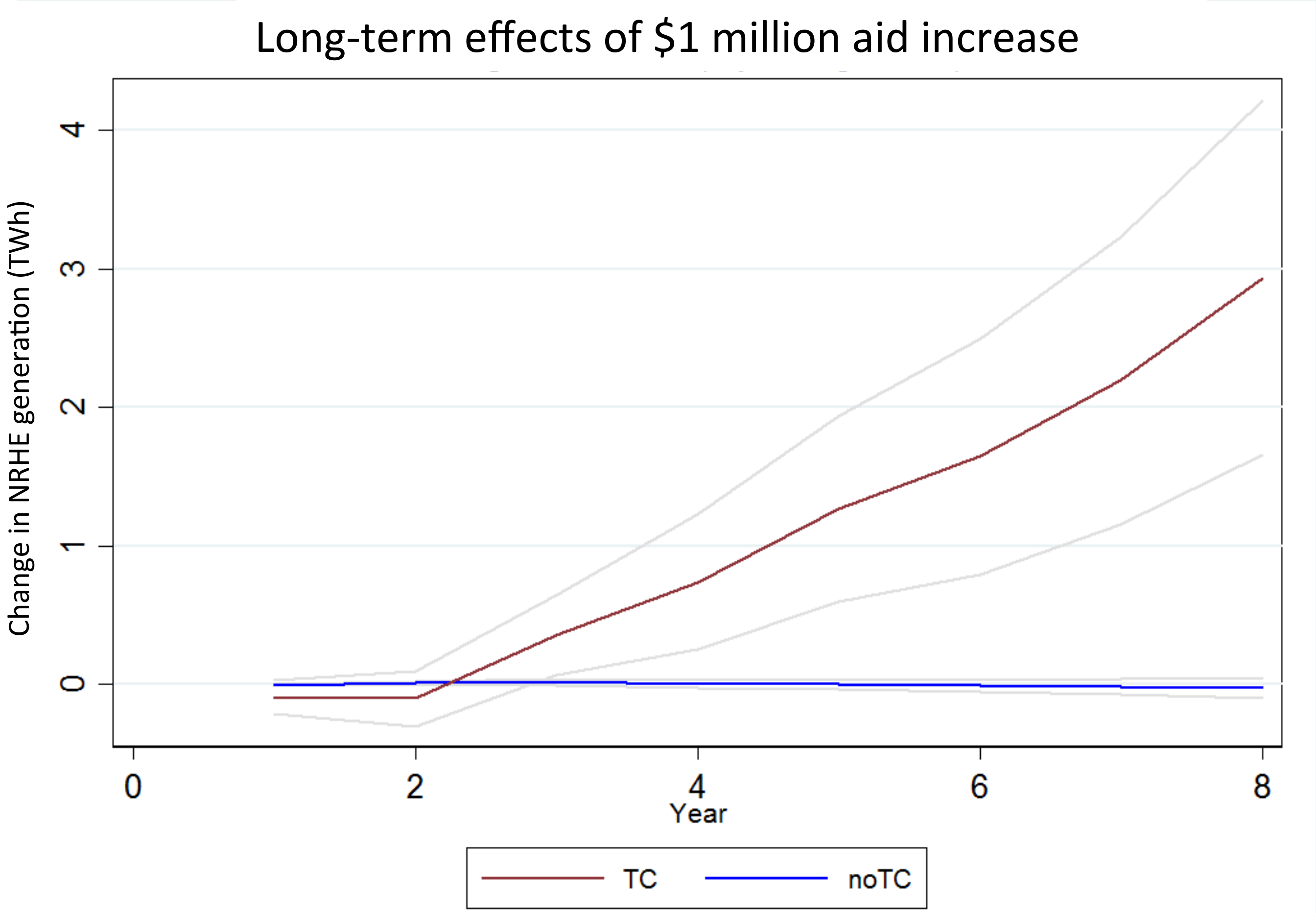
Technology Transfer & Spillovers

- Benefits to the recipient developing country depend on the type of transfer:
  - *Embodied* technology transfer comes through the importation of equipment into a country (e.g., flows of equipment)
    - May make a country more productive, but doesn't give the recipient the ability to replicate
  - *Disembodied* technology transfer involves the flow of know-how or experience
    - Examples include demonstration projects, training local staff, and local firms hiring away staff from multinational firms operating in a developing country
    - May enhance the productivity of future projects in the country
    - A concern to source firms, as lead to *knowledge spillovers*

Technology Transfer & Spillovers

- Knowledge spillovers occur when a new technology enhances the capacity of others to innovate without providing direct compensation to the inventor
  - Enable the recipient to develop skills that can be used in later projects initiated by the recipient country
    - Can increase domestic capacity to produce, use, and innovate

Long run effects of spillovers



Kim (2014)

Two cases

- I present two examples of successful spillovers in clean energy
  1. Learning from Clean Development Mechanism (CDM) wind project partnerships (Tang & Popp, 2014)
  2. PV innovation from intellectual returnees (Luo, Lovely, & Popp 2013)

Case #1:

"The Learning Process and Technological Change in Wind Power: Evidence from China's CDM Wind Projects"

Tian Tang and David Popp, 2014

NBER Working Paper #19921

Motivation: CDM and China's Wind Industry

- **CDM**: **A** ***project-based carbon transaction mechanism*** under the Kyoto Protocol that allows developed countries with emission constraints to **purchase emission credits by financing projects** that reduce carbon emissions in developing countries.

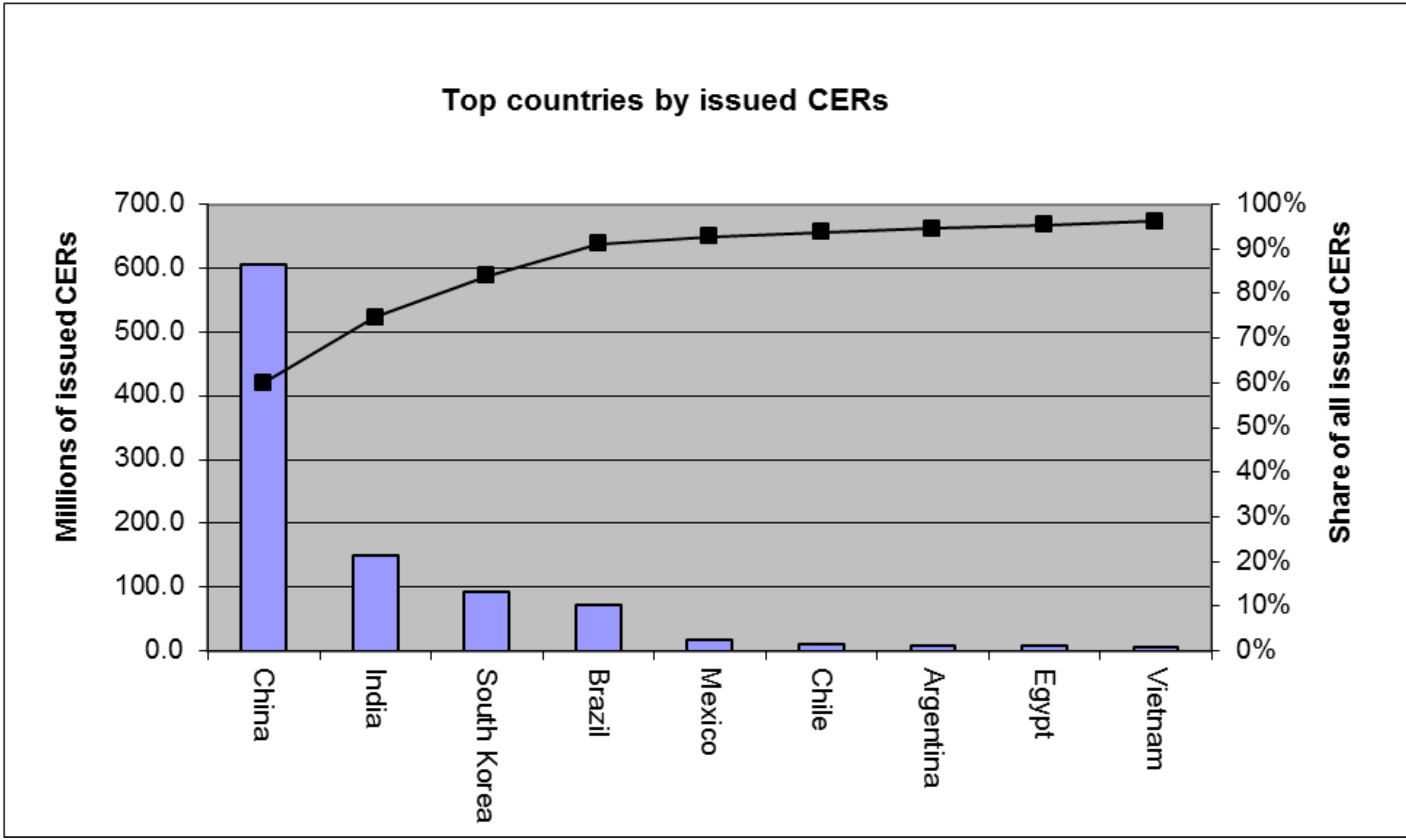
- **Goals of CDM:**

- Help developing countries reduce carbon emissions
- Stimulate sustainable development in developing countries through technology transfer from developed countries

- **The Role of CDM in China's Wind Industry**

- China has actively engaged in CDM since 2002 and used it to provide financial support for over 80% of wind projects

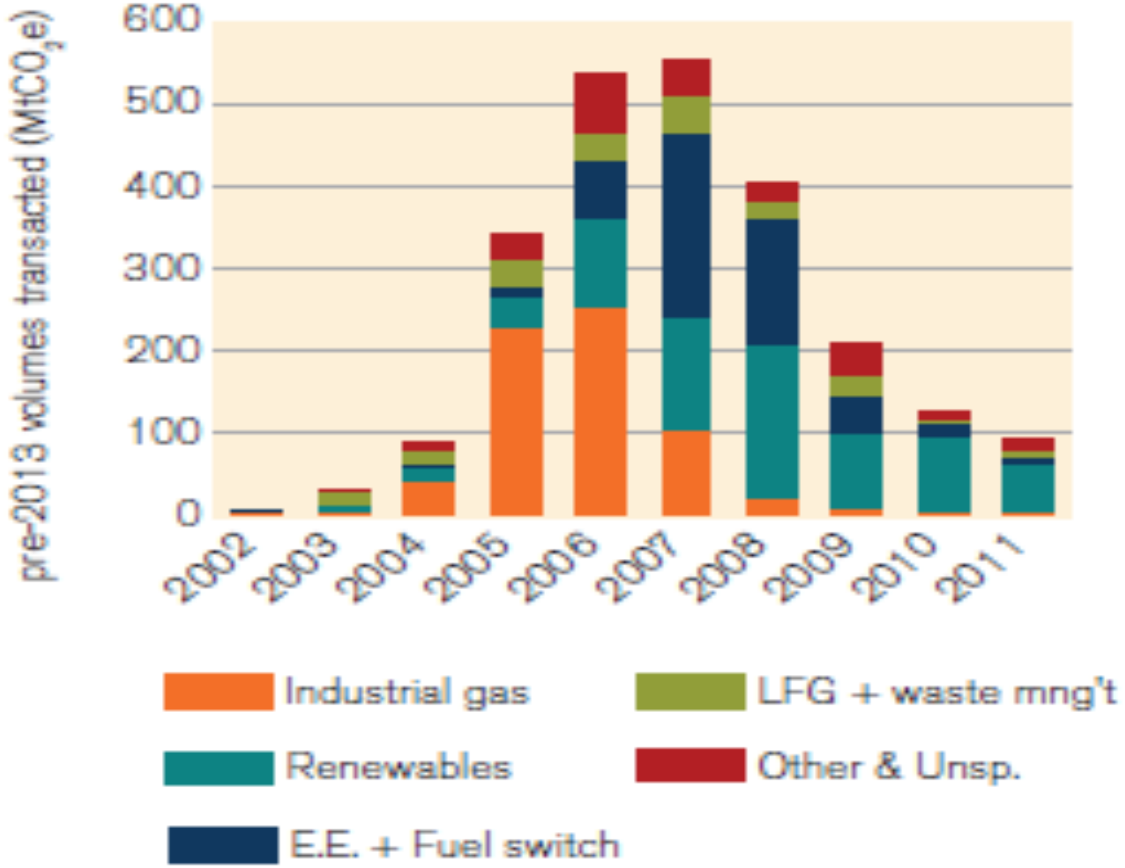
Major sellers in project-based transactions



CDM Pipeline, October 2012

Distribution of technologies in project-based transactions over time

Figure 12: Pre-2013 volumes transacted per sector 2002-2011 ($MtCO_2e$)



Source: World Bank

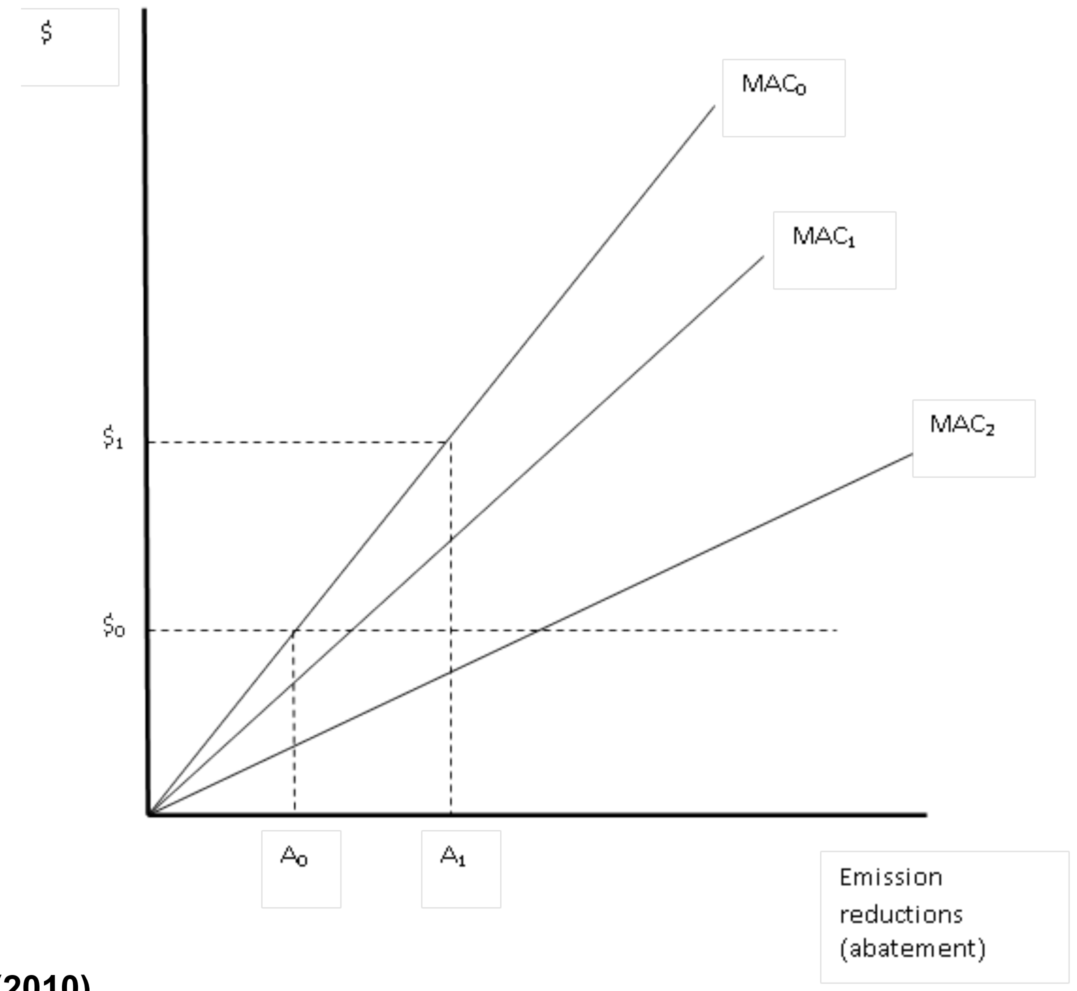
State and Trends of the Carbon Market, 2012

Motivation: CDM and China's Wind Industry

- Can CDM Help Developing Countries Achieve Sustainable Development?

- Depends on whether technology transfers are "embodied" or "disembodied"
  - Disembodied transfers not only reduce emissions now, but lower the costs of future emission reductions
  - In contrast, embodied transfers (e.g. providing equipment) pick "low-hanging fruit" and make it harder for developing countries to do more later
    - *This makes these countries less likely to participate in future treaties!*

Low-Hanging Fruit and Knowledge Spillovers



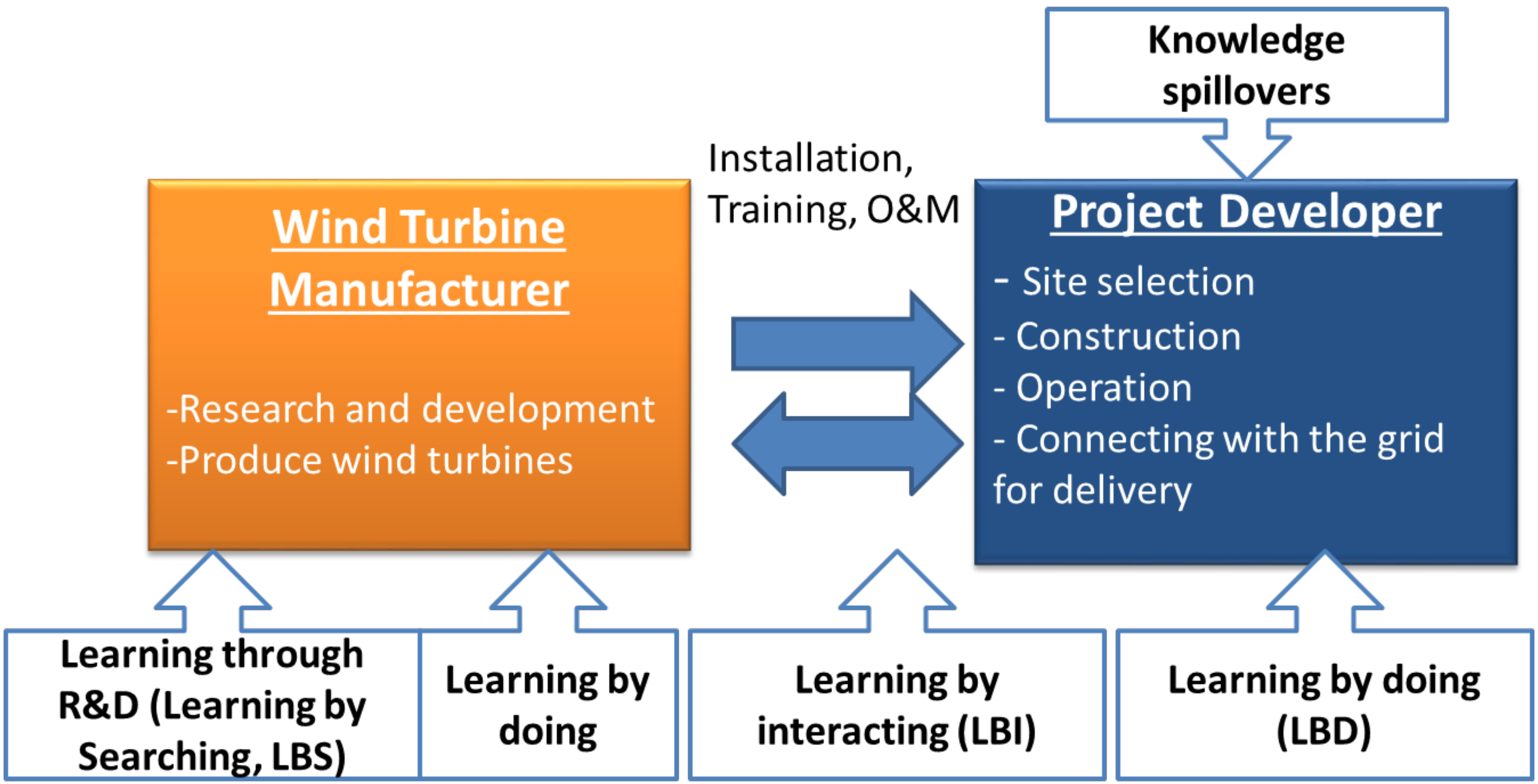
Popp (2010)

Motivation: CDM and China's Wind Industry

- Chinese policy promoted technology transfer
  - Chinese guidelines for CDM project approval state that "CDM project activities should promote the transfer of environmentally sound technology to China."
  - Domestic content requirement: 70% of wind turbine content must be produced domestically

Theory: Learning Process and Technological Change

- Following **technological learning and collaboration theories**, we identify the following ***channels of learning*** that could lead to the reduction of electricity production cost:



Data and Empirical Model

- **Unit of Analysis:** CDM wind power project
- **Data**

- Pooled cross-sectional
- 510 registered CDM wind projects in China that started from 2002 to 2009 (486 obs after excluding missing data)
- Including 87 developers and 23 turbine manufacturers

- **Sources:**

1) Validated CDM project design document and its attached financial analysis spreadsheet for each project
2) Yearbook from Chinese Wind Energy Association
3) Delphion patent database

Data and Empirical Model

- **Dependent Variables:**

1) Projected unit cost of electricity production of project *i* started construction in year *t* *(levelized cost)*

$$(Unit\_cost)_{it} = \sum_{j=1}^{n} \frac{Capital_j + O\&M_j}{(1+r)^j} / \sum_{j=1}^{n} \frac{Electricity_j}{(1+r)^j}$$

2) Projected unit capital cost of project *i* started in year *t*

$$(Unit\_cost)_{it} = \sum_{j=1}^{n} \frac{Capital_j + O\&M_j}{(1+r)^j} / \sum_{j=1}^{n} \frac{Electricity_j}{(1+r)^j}$$

3) Projected capacity factor of project *i* started in year *t*

$$(CF)_{it} = \frac{Annual\ Electiricity}{24hrs/day * 365\ days * Proejct\ Size}$$

Data and Empirical Model

- Explanatory Variables: Learning Effects

LBS	LBS_{mft}	**Manufacturer's knowledge stock**: Cumulative patents related to wind power that the manufacturer has in year t-1
LBD	LBD_{mft}	**Experience from manufacturer:** manufacturer's cumulative installed capacities in year t-1
	LBD_{dev}	**Experience from project developer in CDM projects:** project developer's cumulative installed capacities in CDM projects in year t-1
Spill-over	$Spill_{prov}$	**Experience from wind projects in a province**: Cumulative installed capacities in the province in year t-1
	$Spill_{industry}$	**Experience from the whole industry**: cumulative installed capacities of the whole industry in year t-1
LBI	LBI	**Cooperating experience between project developer and manufacturer**: cumulative capacities installed by this developer and the same manufacturer in previous CDM projects in year t-1.

Results

1. **Learning by searching**

- Wind projects benefit from the knowledge stock of their turbine manufacturers

- The effect is small though

Effects of collaborating experience and technology transfer

Dependent Variables	(1) ln(unit cost)	(2) ln(unit cost)	(3) ln(unit capital cost)	(4) ln(unit capital cost)	(5) ln(capacity factor)
Knowledge stock of manufacturer	-0.00029**	-0.00025*	-0.00031*	-0.00027	0.00032**
	(0.00013)	(0.00013)	(0.00018)	(0.00017)	(0.00013)
Manufacturer's experience alone (GW)	-0.00211	-0.00216	-0.00768	-0.00772	0.00409
	(0.00572)	(0.00571)	(0.00704)	(0.00703)	(0.00561)
Developer's experience in CDM projects alone (GW)	-0.02333***	-0.02230***	-0.03393***	-0.03304***	0.01073*
	(0.00658)	(0.00655)	(0.00800)	(0.00798)	(0.00573)
Cooperating experience in CDM (GW)	-0.04149**	-0.03971**	-0.05406**	-0.05252**	0.00648
	(0.01874)	(0.01876)	(0.02299)	(0.02314)	(0.01987)
Turbine size (MW)	0.01068	0.00929	0.03342*	0.03221*	0.05609***
	(0.01481)	(0.01493)	(0.01817)	(0.01825)	(0.01113)
Project size (GW)	-0.34063***	-0.33709***	-0.34582***	-0.34276**	0.13304**
	(0.12296)	(0.12246)	(0.13293)	(0.13291)	(0.07367)
Wind category 1	-0.14092***	-0.14541***	-0.21581***	-0.21969***	0.13652***
	(0.02805)	(0.02850)	(0.02739)	(0.02766)	(0.03066)
Wind category 2	-0.09387***	-0.09348***	-0.16919***	-0.16885***	0.09923***
	(0.02688)	(0.02706)	(0.02500)	(0.02479)	(0.03028)
Wind category 3	-0.01251	-0.01419	-0.02476	-0.02621	-0.00723
	(0.01974)	(0.01983)	(0.01851)	(0.01852)	(0.01576)
Foreign manufacturer	0.03097*	0.03969**	0.03535*	0.04288**	0.00442
	(0.01607)	(0.01751)	(0.01951)	(0.02138)	(0.01530)
Central SOE developer	-0.01624	-0.01554	-0.00684	-0.00624	0.00514
	(0.01126)	(0.01128)	(0.01453)	(0.01453)	(0.01040)
Local SOE developer	0.03259*	0.03183*	0.05485**	0.05419**	-0.02825
	(0.01885)	(0.01890)	(0.02443)	(0.02451)	(0.01902)
Foreign manufacturer* cooperating experience		-0.13107**		-0.11329	
		(0.06000)		(0.08382)	
Province fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	486	486	486	486	486
R-squared	0.685	0.687	0.607	0.608	0.606

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Results

1. **Learning by searching**
2. **Learning by doing**

- Wind projects benefit from developer's internal experience in both wind farm installation and operation

Effects of collaborating experience and technology transfer

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A typical CDM project by the same developer leads to about a 0.13% decrease in future unit costs

Results

1. **Learning by searching**
2. **Learning by doing**

3. Cost reduction through repeated collaboration

- Repeated partnerships between project developers and manufacturer lead to even lower electricity production costs, particularly for capital costs
- However, cooperating experience does not significantly improve capacity factor

Effects of collaborating experience and technology transfer

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A typical CDM project by the same developer/ manufacturer team leads to around a 0.23% to 0.25% decrease in future unit costs

Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Results

1. **Learning by searching**
2. **Learning by doing**
3. **Cost reduction through repeated collaboration**

4. Technology transfer through CDM

- The Learning-by-interacting effect is largest when a wind project developer repeatedly collaborates with a foreign manufacturer

Effects of collaborating experience and technology transfer

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One more CDM wind project that a developer builds together with the same foreign manufacturer will reduce the unit cost by almost 1%: 4 times of the effects of collaborating with domestic manufacturer

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Maxwell

Case #2:

"Intellectual Returnees as Drivers of Indigenous Innovation: Evidence from the Chinese Photovoltaic Industry"

Siping Luo, Mary Lovely, and David Popp, 2013

NBER Working Paper #19518

Solar PV in China

- As noted earlier, China has become a leading producer of solar PV
- de la Tour *et al.* (2011) identify the importance of international technology transfer as the driver of China's success
  - Particularly in more advanced production segments and for continuing adaptive innovation in downstream segments, they highlight the importance of skills and indigenous adaptation as key the sector's development

Solar PV in China

- During this development process, intellectual returnees played a crucial role
- Pioneers in the industry are the well known “three returnees” of China’s photovoltaic industry: Huaijin Yang, Zhengrong Shi, and Jianhua Zhao
  - All three studied photovoltaic technology in Australia in the 1990s, and then returned to China with advanced technology and foreign capital to start firms using China’s relatively low-wage skilled labor force
- The importance of returnees to the industry is a central finding from field interviews carried out by Luo and Yu (2012) and by de la Tour *et al*. (2011)
  - This paper extends this field work to a broader sample of Chinese PV firms

PV Patenting in China

- While most R&D and patenting occurs in developed countries, China is an exception
- Both overall and in renewable energy, patenting in China has increased rapidly
- Key questions:
  - What about quality?
  - What forces support innovation in the PV sector?

China's share of PV patents is growing

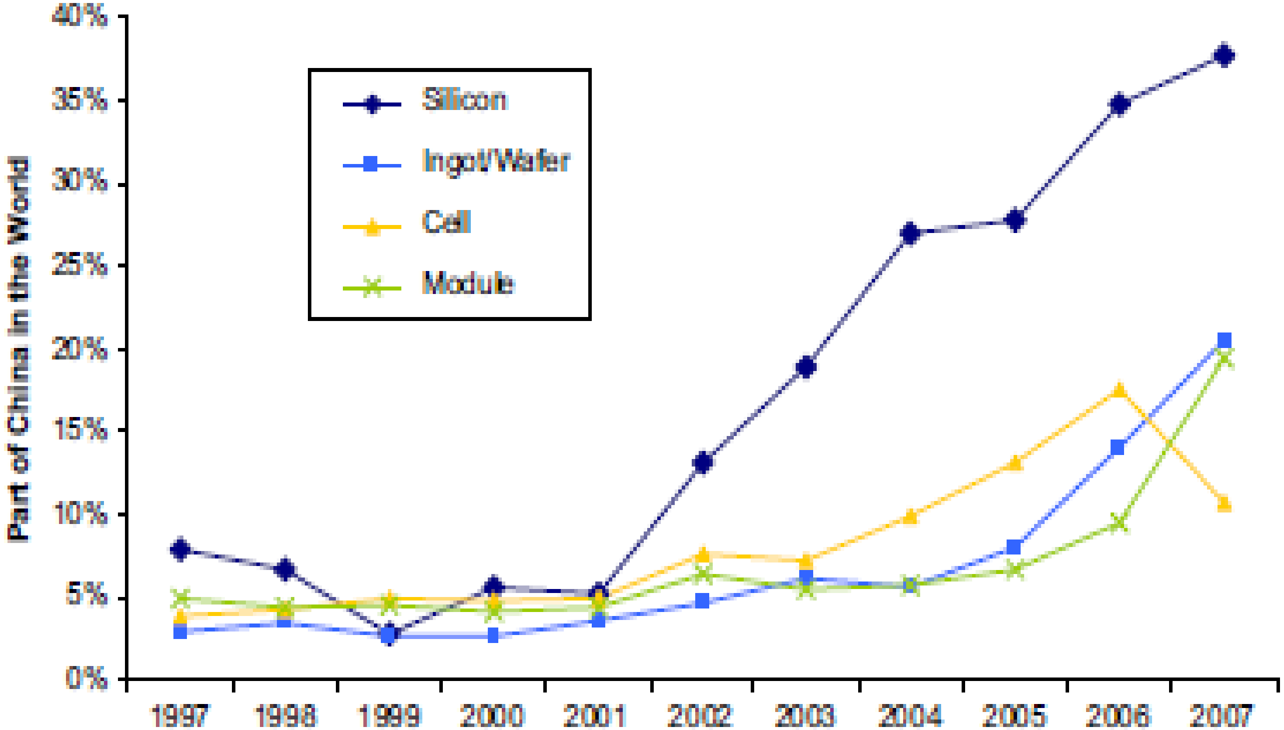

Fig. 6. Share of China in world innovation in each segment of the PV industry. Source: authors' calculation based on the Espacenet database.

de la Tour *et al.*, *Energy Policy* (2011)

Data

- Firm-level operation data of Chinese PV
  - 1998 to 2008, 806 firms in total; 1851 firm-year observation
  - Source: Annual Survey of Industrial Firms of China

- Firm's patents application records
  - 3508 patents in total through 2011, 290 firms have at least one patent
  - Source: Delphion

- Firm leaders' international experience
  - 151 firms' leader(or other executives) have international experience
  - Source: Author's collection from company websites & other Internet sources

Patent Quality

- Detailed scrutiny of the 3508 patent records suggests that much of this innovative activity represents incremental innovation
  - Most are process innovations, rather than new products
  - 2/3 are utility or design innovations
    - Utility patents protect minor improvements to existing technology for only 10 years

- This is consistent with the need for adaptive R&D for technology transfer
  - A key adaptation was using more labor to produce PV cells, to take advantage of lower labor costs in China

Model

$Patent_{i,t} = f(IntlExper\_Leader_{it}, IntlExper\_Exec_{it}, \ln(IntlExper\_Cluster_{it}), \ln(IndustryCluster_{i,t}), \ln(UnivDist_{i,t}), X_{i,t}, year_t)$

- The *Cluster* variables test for spillovers
  - Sums international experience of all other firms, placing more weight on those closest:

$$IntlExper\_Cluster_{it} = \sum_{j \neq i} I_{j,t} / d_{i,j} \quad .$$

Results

- Both the international experience of a firm's leader and its executive board lead to large increases in patenting
  - Increases by a factor of 4 or more!

Dependent Variable	Total Patent Count	
Estimator	[1] Negative Binomial FE	[2] Poisson FE
IntlExper_Leader$_{it}$	1.384***	3.792***
	0.436	0.374
IntlExper_Exec$_{it}$	0.894**	1.649***
	0.407	0.402
Ln(IntlExper_Cluster$_{it}$*)*	0.198	0.876**
	0.236	0.375
Ln(IndustryCluster$_{i,t}$*)*	-0.044	0.289*
	0.11	0.164
Ln(UnivDist$_{i,t}$*)*	-0.016	-
	0.166	-
Ln(MarketPower$_{i,t}$*)*	0.426***	-0.357**
	0.157	0.166
Ln(Export$_{i,t}$*)*	-0.162**	0.079
	0.064	0.087
Ln(Age$_{i,t}$*)*	0.049	0.056
	0.131	0.239
Ln(Size$_{i,t}$*)*	0.058	0.382
	0.153	0.246
Log-Likelihood	-337.48	-503.61
Number of Observations	445	445
Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01		

Results

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Maxwell

Results

- Both the international experience of a firm's leader and its executive board lead to large increases in patenting
  - Increases by a factor of 4 or more!

- There are spillovers from international experience

- Even conditional on R&D, international experience leads to more patents
  - May make R&D more productive
  - May better appreciate need for IP protection

Dependent Variables	Total Patent Count, 2005-2007		
Estimator	[1] Poisson FE	[2] Poisson RE	[3] Poisson RE
Samples	-	Using full sample (2005-2007)	Using the same sample as [1]
$IntlExper\_Leader_{it}$	14.92***	0.528	-0.356
	1.320	0.656	0.415
$IntlExper\_Exec_{it}$	16.46***	2.239***	1.374***
	1.746	0.501	0.375
$Ln(IntlExper\_Cluster_{it})$	-0.720	0.005	-0.030
	0.916	0.209	0.188
$Ln(IndustryCluster_{i,t})$	0.473**	0.380***	0.397***
	0.191	0.090	0.084
$Ln(UnivDist_{i,t})$	-	-0.151	-0.087
	-	0.140	0.116
$Ln(MarketPower_{i,t})$	-0.902***	-0.772***	-0.630***
	0.276	0.125	0.123
$Ln(Export_{i,t})$	-0.058	-0.008	-0.082
	0.147	0.058	0.056
$Ln(Age_{i,t})$	0.397*	0.119	0.082
	0.222	0.112	0.125
$Ln(Size_{i,t})$	0.385	0.444***	0.295**
	0.319	0.149	0.135
$Ln(RD_{i,t})$	0.012	0.057***	0.011
	0.070	0.022	0.020
Log-Likelihood	-155.20	-468.33	-326.05
Number of observations	155	705	155

Maxwell

Summary

- Sources of learning
  - Wind
    - Collaboration important
    - Wind project developers in China learn from partnerships with foreign firms
    - However, little evidence of spillovers in the wind case
  - Solar
    - Bringing foreign experience home leads to more innovation
    - Benefits do spillover to neighboring firms

Key questions

- Moving forward, identifying limits to spillovers is important
  - What is different about the wind and solar cases?
    - Collaborative learning may be tacit knowledge that is difficult to transfer
    - What makes spillovers possible in the solar case?
  - Can other countries follow China's lead?
    - Policies attracting technology transfer must balance encouraging spillovers with discouraging investors
    - Will policies promoting spillovers discourage multinational investment in smaller countries?

Policy Implications

- **For Chinese policymakers:**
  - Provides support for policies encouraging return of those studying abroad
  - Collaboration important. Targeted policies to forge partnerships between foreign and domestic players appear valuable

- **For international climate change policy:**
  - Results shed light on how CDM facilitates technology transfer → by encouraging cooperation between local project developers and foreign turbine manufacturers
  - Success of Chinese solar industry has been controversial
    - To what extent has this success lowered the cost of solar and reduced global emissions?

Thank you!