

The Learning Process and Technological Change through International Collaboration: Evidence from China's CDM Wind Projects

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Research Question

- **Research Question:** How does the learning process lead to technological change in wind power?

- **Technological Change:** Reduction in unit cost of wind power

- **Learning Process:** How the knowledge related to wind power is acquired and diffused among project participants

- **Case:** China’s wind power projects supported by the Clean Developed Mechanisms (CDM)

Background: 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
- On average, 20% of project revenue comes from CDM

Background: Partnership in CDM Wind Projects

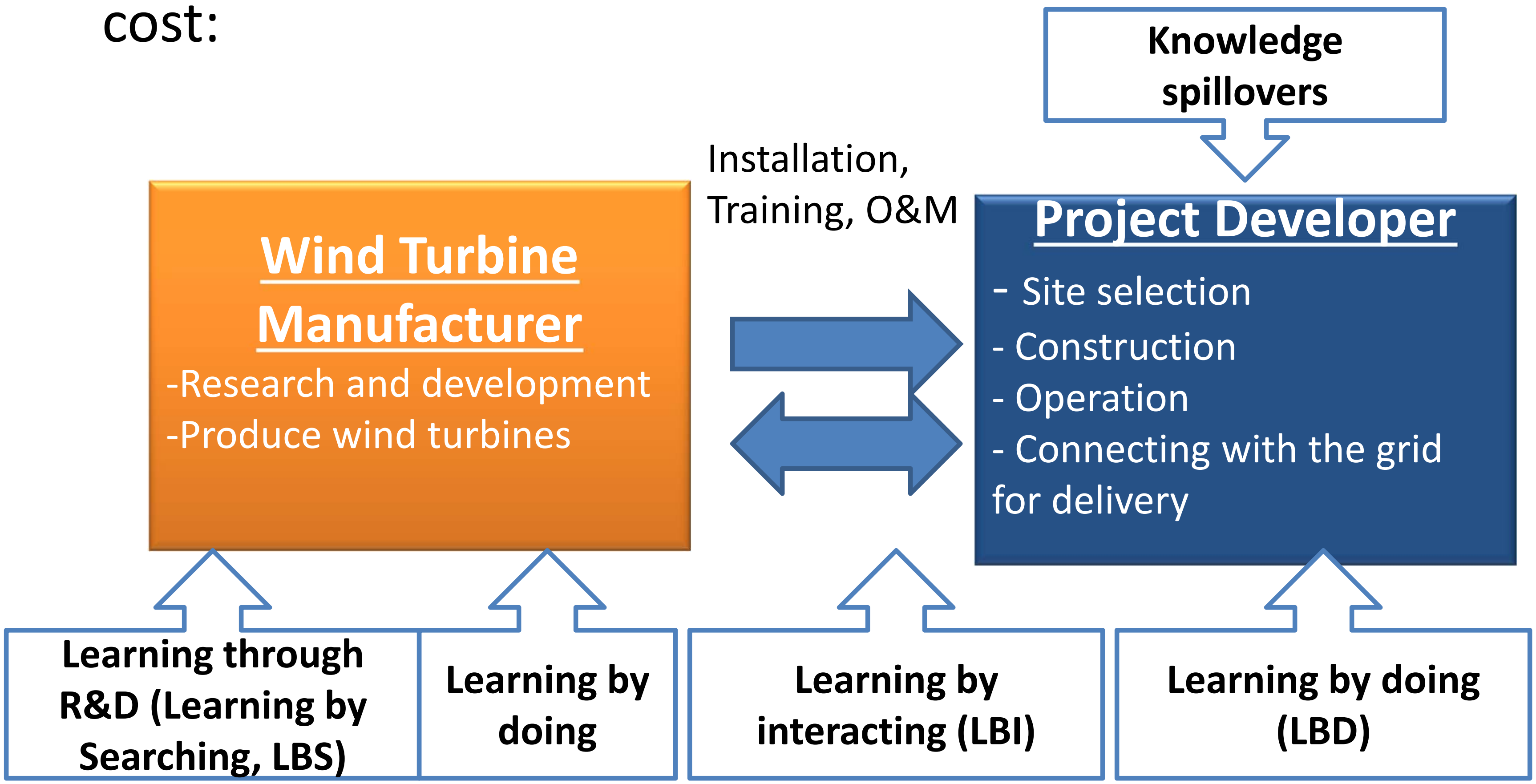
- **Highly standardized and transparent project process:**
- Project design and financial analysis are validated by 3rd party agencies.
- Project operation is monitored by 3rd party agencies.

- **Engage both the public and private sectors of the carbon trading countries, and international organizations**

CDM Project hosting country	Central and local government, wind power companies, carbon trade consultants
Emission credits buying country	Central government, investment banks or carbon trading firms
International organizations administering and monitoring CDM process	Executive Board of CDM, 3rd party validating and monitoring agencies

Theory: Learning Process and Technological Change

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



Data and Empirical Model

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

- Cross-sectional
- 410 registered CDM wind projects in China that started from 2002 to 2009
- Including 59 developers and 28 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

Data and Empirical Model

- **Dependent Variable:**
  Projected unit cost of electricity production of project i started construction in year t, UC_{it}

- **Calculation**: Life cost/Life electricity production

$$(UC_{it}) = \sum_{t=1}^{n} \frac{Capital_t + O\&M_t}{(1+r)^t} \Big/ \sum_{t=1}^{n} \frac{E_t}{(1+r)^t}$$

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.

Data and Empirical Model

- **Full Model:**

Manufacturer's knowledge stock

Manufacturer's experience and developer's experience

$$\ln(UC_{it}) = \beta_0 + \beta_1 LBS_{mft} + \beta_2(LBD_{mft} - LBI) + \beta_3(LBD_{dev} - LBI) +$$

$$\beta_4\,(Spill_{industry} - LBD_{dev} - LBD_{mft} + LBI) + \beta_5 LBI \;+ \beta_6 Turbine\_size_i$$

Spillover from the industry

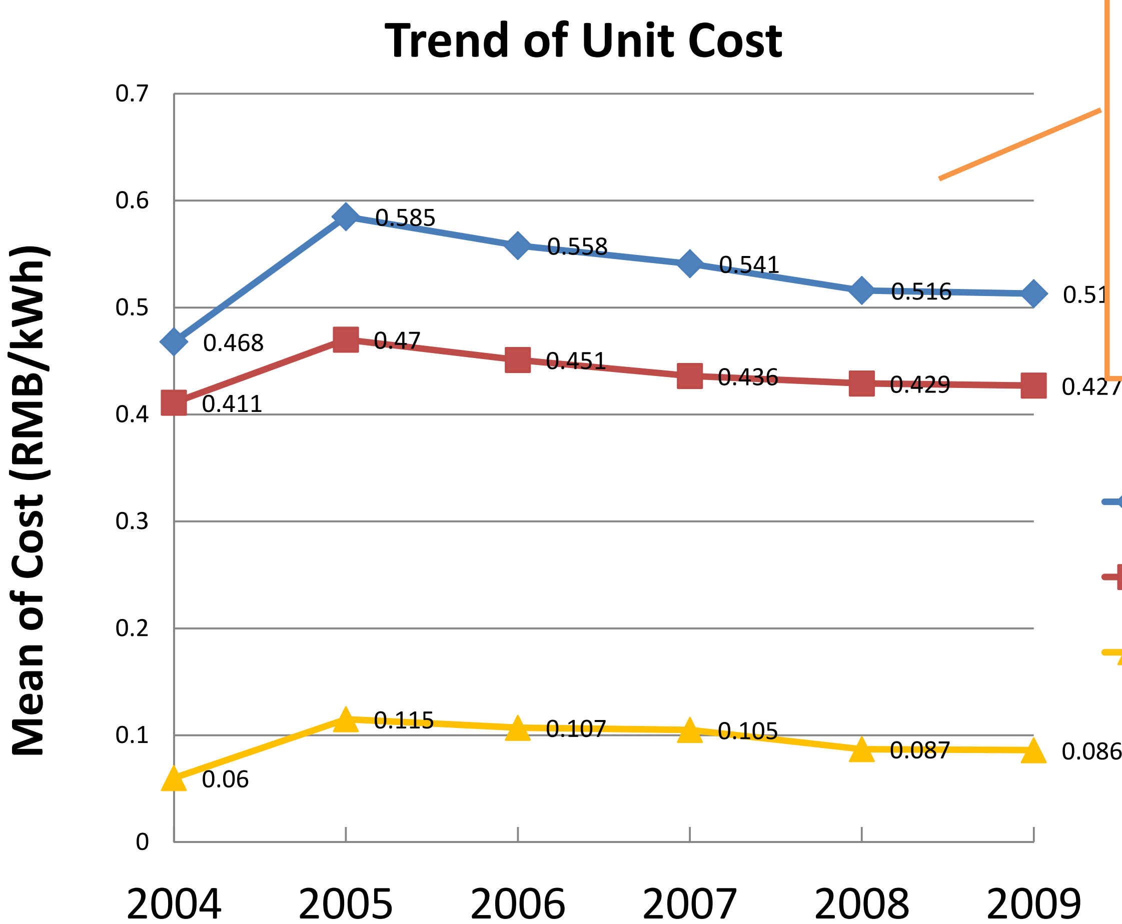
Interacting experience

$$+\beta_7\, Project_{size_i} \;+ \beta_8 W_{1i} + \beta_9 W_{2i} + \beta_{10} W_{3i} + \beta_{11} Domestic_{mft} + \beta_{12} SOE_{dev}$$

Wind resource

$$+Province\_Dummies + Year\_Dummies + u_i$$

Descriptive Statistics:
Projected Unit Cost of Electricity Production



Decreases from 2005-2009

Unit cost: 12.3%
Unit capital cost: 9.1%
Unit O&M cost: 25%

Empirical Results

- Effect of aggregate level experience
- Effect of developer's internal experience v. spillover effects
- Effects of interacting experience and other channels of learning

Empirical Results 1: Aggregate Level Experience

VARIABLES	(1)	(2)	(3)
knowledge stock of manufacturer	-0.0024	-0.00035	-0.00029
	(0.0064)	(0.00030)	(0.00031)
Province level experience	-0.0027	0.00106	-0.00255*
	(0.0144)	(0.01405)	(0.00156)
Industrial level experience	-0.0270**	0.00003**	0.00003***
	(0.0125)	(0.00001)	(0.00001)
Turbine size (MW)	0.0625**	0.03179	0.02932
	(0.0294)	(0.02830)	(0.02874)
Project size (MW)	-0.0772***	-0.54539**	-0.65148***
	(0.0220)	(0.23034)	
Wind category 1	-0.2054***		
	(0.0239)		
Wind category 2	-0.1486**	0.03598**	
	(0.0556)	(0.01344)	
Wind category 3		0.10483***	
		(0.03394)	
Wind category 4	0.0690**	0.10762***	
	(0.0304)	(0.03219)	
Year fixed effects	No	Yes	No
Province fixed effects	No	Yes	Yes
Observations	387	387	387
R-squared	0.523	0.659	0.590

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

All learning variables at the aggregated level are not statistically or economically significant when adding year fixed effects.

Empirical Results 2: LBD and Spillover Effects

VARIABLES	(1)	(2)	(3)
knowledge stock of manufacturer	-0.00149	-0.00241	-0.00342
	(0.00249)	(0.00435)	(0.00362)
Developer's experience in CDM projects within one province	-0.09364**	-0.09840**	-0.14136***
	(0.04345)	(0.04634)	(0.04626)
Spillover from other projects in the province	0.01487	0.00532	0.01422
	(0.04050)	(0.01439)	(0.01603)
Developer's experience in CDM projects in other provinces	-0.01595	-0.02935	-0.03255
	(0.02049)	(0.02703)	(0.02495)
Spillover from the industry	0.00025	0.00032	-0.00001
	(0.00033)	[illegible]	[illegible]
Turbine size (MW)	0.03239	[illegible]	[illegible]
	(0.02582)	[illegible]	[illegible]
Project size (MW)	-0.50761**	[illegible]	[illegible]
	(0.21823)	[illegible]	[illegible]
Wind category 2	0.05452**	[illegible]	[illegible]
	(0.02365)	[illegible]	[illegible]
Wind category 3	0.21528***	[illegible]	[illegible]
	(0.03506)	[illegible]	[illegible]
Wind category 4	0.15095***	[illegible]	[illegible]
	(0.05033)	(0.029302)	(0.02305)
Year fixed effects	Yes	Yes	No
Province fixed effects	Yes	No	No
Observations	387	387	387
R-squared	0.663	0.504	0.480

The unit cost is expected to decrease by nearly 1% when the project developer develops one more project in the same province.

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

Empirical Results 3: Different Channels of Learning

VARIABLES	(1)	(2)	(3)
knowledge stock of manufacture	-0.00035	-0.00044	-0.00040
	(0.00022)	(0.00031)	(0.00032)
Experience of manufacturer alone	-0.02408	-0.02503	-0.02538
	(0.01549)	(0.01355)	(0.01436)
Experience of developer alone in CDM	-0.02705	-0.02775	-0.02690
	(0.02684)	(0.02032)	(0.02134)
Cooperating experience in CDM	-0.10539**	-0.10805**	-0.10890**
	(0.04693)	(0.05035)	(0.05035)
Spillover from the industry	-0.00003***	-0.00003***	-0.00004***
	(0.00001)	(0.00001)	(0.00001)
Turbine size (MW)	0.02356	0.02368	0.02484
	(0.02876)	(0.02975)	(0.02823)
Projectl size (MW)	-0.45060**	-0.48395**	-0.43059**
	(0.21309)		
Wind category 2	0.05259**		
	(0.02439)		
Wind category 3	0.10594***		
	(0.03338)		
Wind category 4	0.11363***		
	(0.03270)		
Domestic manufacturer (dummy)			
State-owned developer (dummy)			
Domestic* Knowledge_stock			
			(0.00638)
Year fixed effects	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes
Obs	387	387	387
R-squared	0.698	0.696	0.696

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

The unit cost of electricity is estimated to decrease around 1% when the project developer cooperates with the same manufacturer in one more project.

Key Findings

1. **Learning by doing:**

Wind project experience is location specific. Project developers mainly learn from their own experience of project developing and operating within province.

2. **Learning by interacting:**

The interaction between project developer and manufacturer matters, which leads to lower cost of electricity production.

Key Findings

3. **Learning by searching:**

- The effects of manufacturer's knowledge stock, measured as cumulative patent counts, on cost reduction is both economically and statistically insignificant.

4. Knowledge diffusion:

- Existing literature has suggested that wind power firms can learn from the experience of other firms.

- The results indicate that wind power firms in China mainly learn from their own experience and the knowledge spillovers may mostly occur within certain partnerships.

Policy Implications

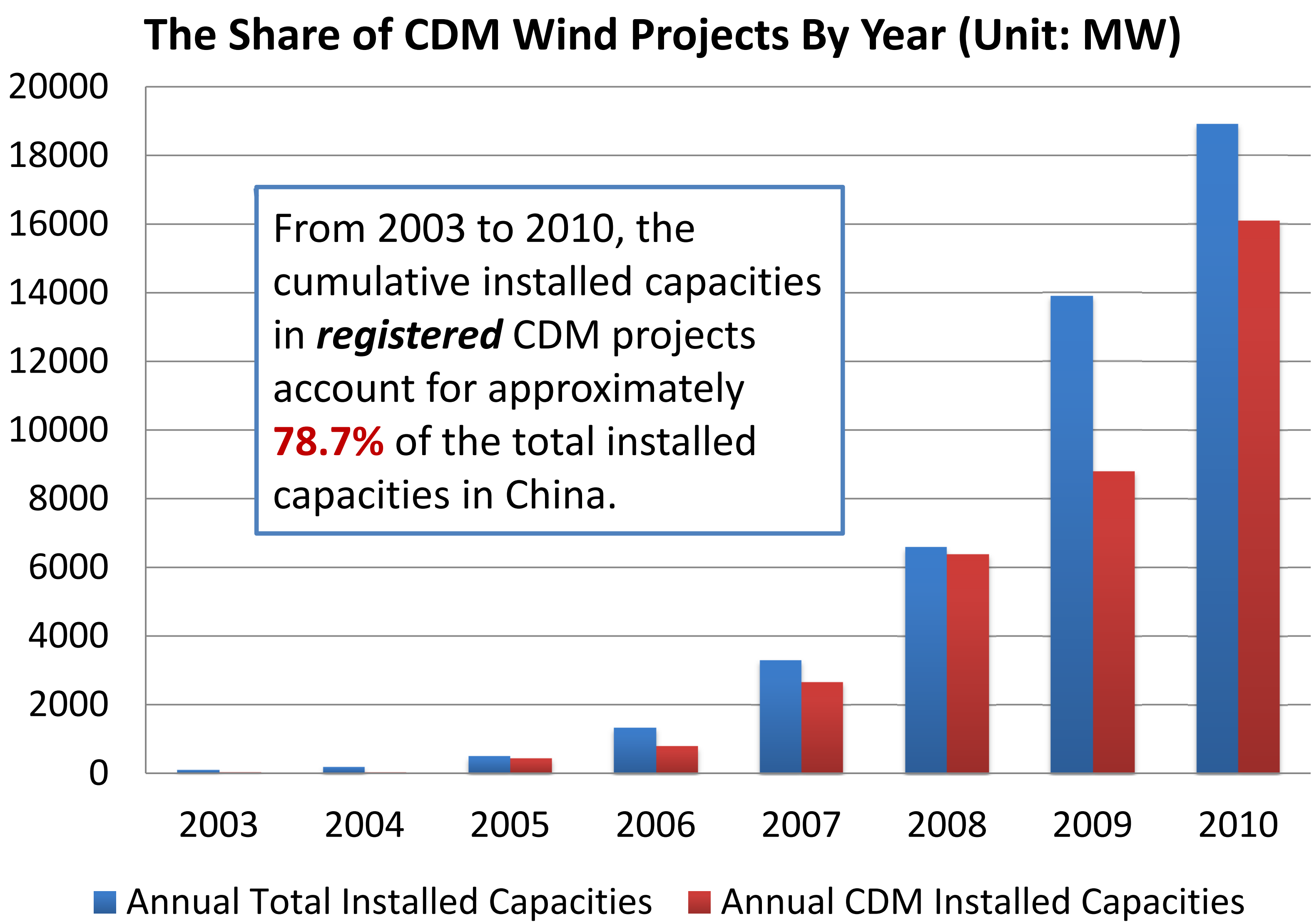
- **For Chinese policymakers:**
- Increase understanding of the learning process in China's wind industry
- Help to make more targeted policies to facilitate different channels of learning , especially policies to forge the partnership between project developers and turbine manufacturers

- **For international climate change policy making:**
- Shed light on how the international carbon trade mechanism (e.g. CDM) leads to technological progress in wind power

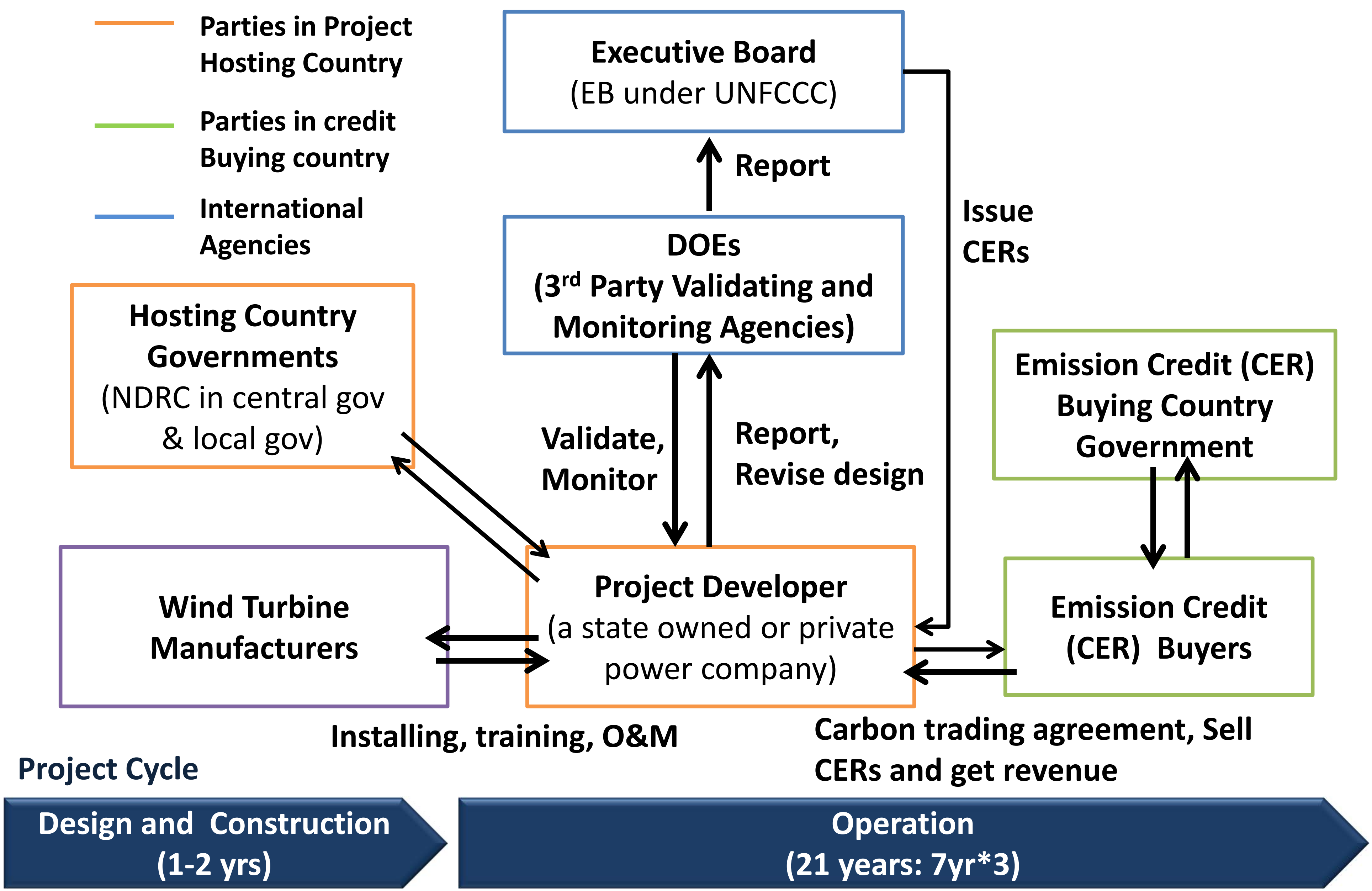
THANKS!

Questions and comments are appreciated.

Background: CDM and China's Wind Industry



Background: Partnership in a CDM Wind Project



Background: CDM as a Demand-Side Policy for Wind Technology

	Domestic	International
Supply Side	-National basic research program (973 Program, 1997) -National high-tech R&D program (863 Program, 1986) - National key technology R&D program (TKPs, 1982)	
Demand Side	- National wind concession program (2003-2008) -Mandatory renewable market share (1997) -Power surcharge for wind power (2006) -Relief of VAT and import tax for wind turbines (2008)	Clean Development Mechanisms (CDM)

Contributions to the Literature

	Existing Literature	This Research
Learning process in wind power	Focus on: -Learning through R&D - Learning by doing (Goulder, 2004; Junginger, et al, 2005; Nemet, 2012; Qiu et al, 2012)	-Provide empirical evidence on the learning by interacting effect. - Highlight the importance of partnership and collaboration in technological change
Technological change in China's wind industry	- Qualitative study - Concentrated on domestic policies	-First empirical research on CDM projects - Data improvement on electricity production cost
Collaboration	Concentrated on public service delivery such as welfare program, health, education etc.	Extends empirical study on collaboration to international collaboration on carbon reduction and renewable energy technology diffusion.

Descriptive Statistics:
Projected Unit Cost of Electricity Production