Innovation and Entrepreneurship in Renewable Energy

Conference on China, the West, and the Alternative Energy Innovation Challenge

Petersen Institute

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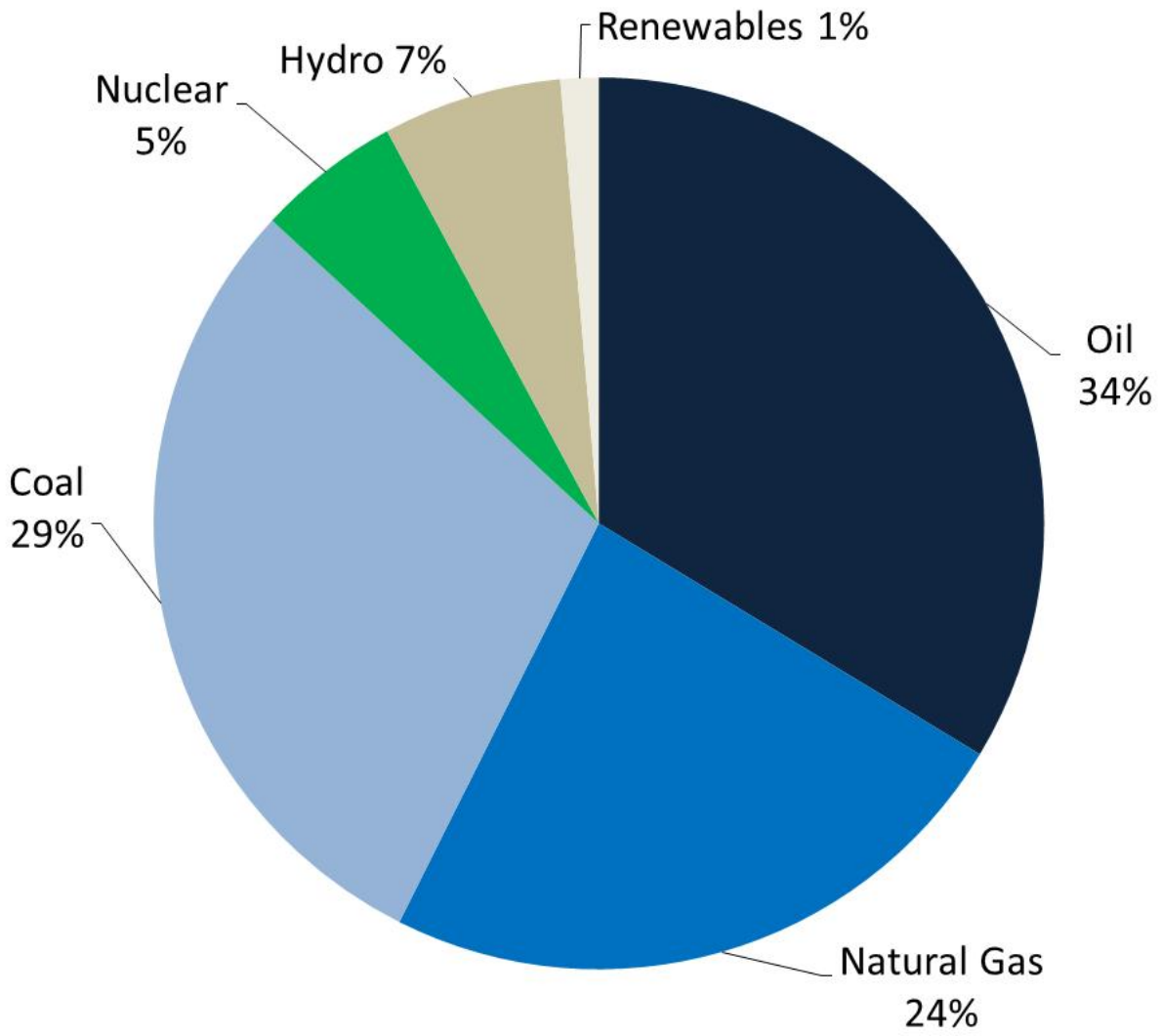
Source of Global Energy Consumed in 2010 (Total = 132,000 TWh)



Need Radical Innovations in Renewable Energy Production

- Global Warming and Pollution
  - Even if energy efficiency increases, population growth and rising incomes across the developing world will drive massive growth in energy consumption
  - Forecast to increase to 350,000 TWh in 2050. This is equivalent to setting up 750 large coal burning power plants **per year** for 40 years
- Energy Security
- National Competitive Advantage

This Talk

1. Characterize innovation in renewable energy by examining patents
   - Patenting in renewable energy highly concentrated among a few large energy firms (20 firms account for over 40% of patents)
   - Incumbents are engaged in more incremental innovation, measured in several ways
   - Sharp rise in patenting by VC-backed startups, coinciding with a funding bubble

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2. Discuss why sustained funding by venture capital investors has been difficult in this sector
   - Potential implications for renewable energy innovation given the dramatic fall in VC finance for renewable energy in recent years

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2. Discuss why sustained funding by venture capital investors has been difficult in this sector
   - Potential implications for renewable energy innovation given the dramatic fall in VC finance for renewable energy in recent years

3. Highlight cases where China is attracting and engaging with US-based startups in ways that can overcome some of these challenges

Outline

I. Renewable Energy Patenting

II. VC Finance of Renewable Energy Startups

III. China's engagement with US-based startups

Focus on renewable energy patents

- Solar / Wind / Biofuels / Hydro / Geothermal
- Leaves out “clean tech” focused on energy efficiency and storage
  - Smart Grid / Energy Efficiency Software, Batteries
- Leaves out cleaner sources of conventional energy that are not renewable
  - Natural Gas (cleaner than coal), Nuclear
- Does not account for innovations that are not patented

Data used to create sample

- IP Checkups
  - Private research firm with expertise in renewable energy patents
  - Focused on USPTO data from 1980-2009
  - 17,090 patents across the 5 sectors

- Validate and extend using LIBLINEAR machine classifier algorithm
  - Identify other patents that look similar based on titles, abstracts
  - Searched over 4.3 million patents in USPTO in sample period and returned a further 31,712 patents

- Manual review of machine classifier patents
  - Contracted with PhD expert at IP Checkups to review machine classifier patents to determine which ones to include
  - Included additional 5,559 patents for total of 22,869.

Categorization of patents

- Unassigned: No assignee associated with patent (typically believed to be individual inventors)
- Academia and Government: Key words such as “university,” “universitaet,” “ecole,” “regents,” etc. followed by manual review
- VC-backed startups: match names to cleantech i3 database of VC-backed startups. Most comprehensive database if VC-backed clean tech startups (more than Venture Economics / Venture Source)
- Residual category: Non VC-backed private firms. Can think of these as incumbents

Patent Sample Breakdown

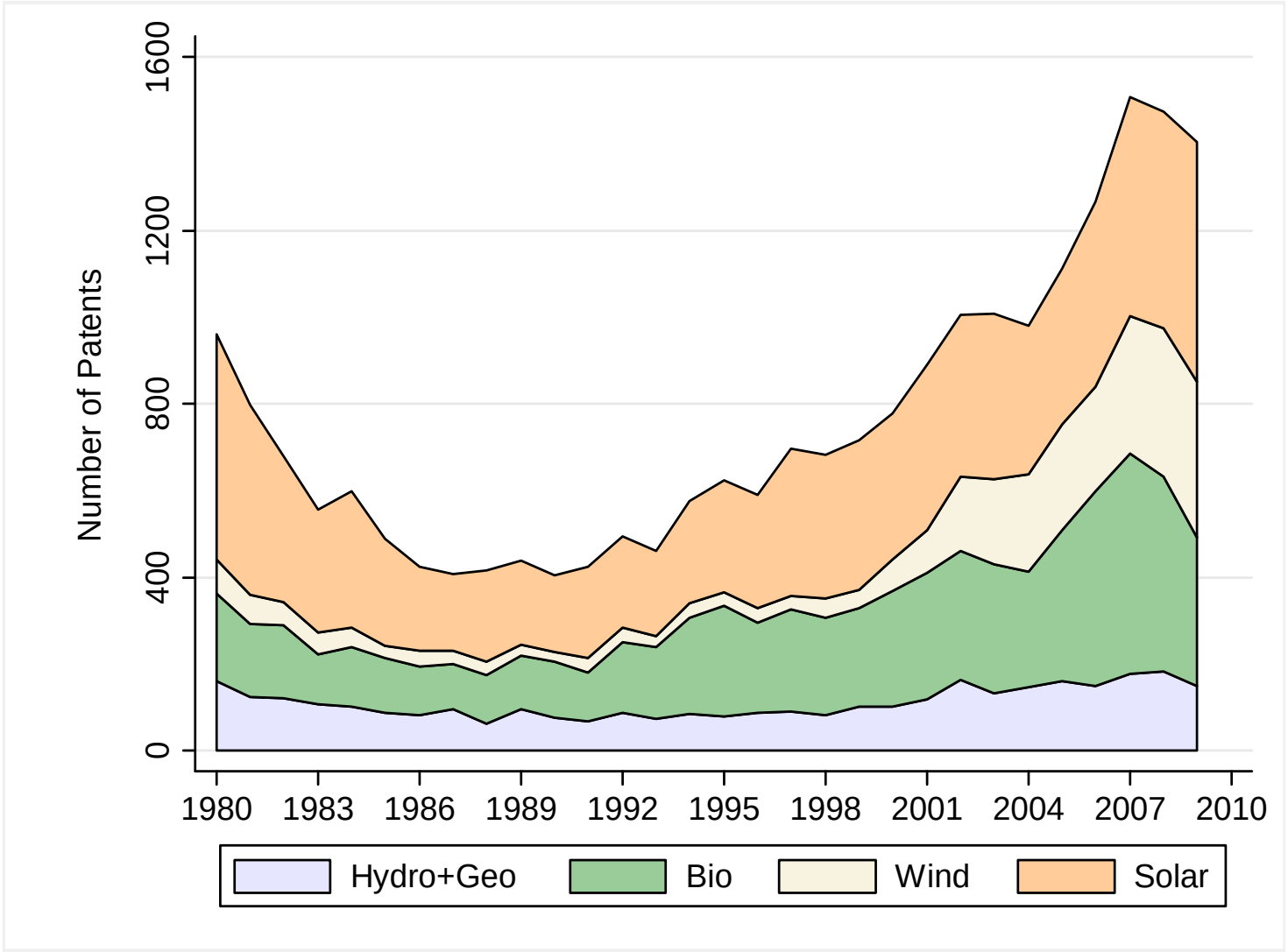
PANEL A: ALL RENEWABLE ENERGY PATENTS AT USPTO (1980-2009)

	Venture-backed Startups	Incumbent Firms	Academia and Government	Un-assigned	Total	Percent
Solar	473	5,937	732	2,502	9,644	42%
Wind	169	1,679	70	1,129	3,047	13%
Biofuels	177	4,995	884	778	6,834	30%
Hydro-electric	78	1,132	107	1,058	2,375	10%
Geothermal	52	597	54	266	969	4%
Total	949	14,340	1,847	5,733	22,869	100%

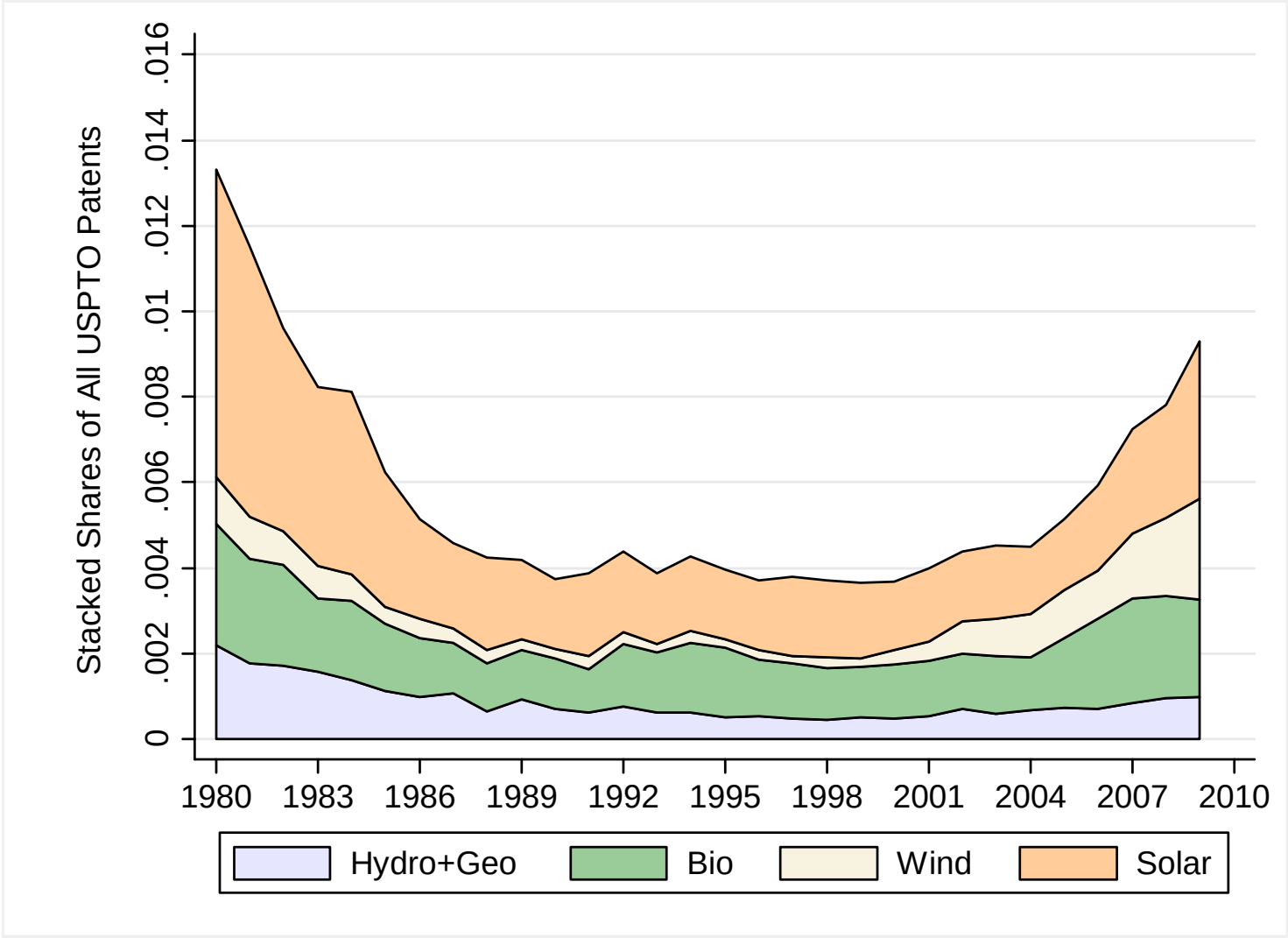
PANEL B: US-BASED INVENTORS ONLY

	Venture-backed Startups	Incumbent Firms	Academia and Government	Un-assigned	Total	Percent
Solar	402	2,797	482	1,884	5,565	41%
Wind	71	689	39	693	1,492	11%
Biofuels	143	2,987	659	513	4,302	32%
Hydro-electric	41	643	68	757	1,509	11%
Geothermal	29	431	42	219	721	5%
Total	686	7,547	1,290	4,066	13,589	100%

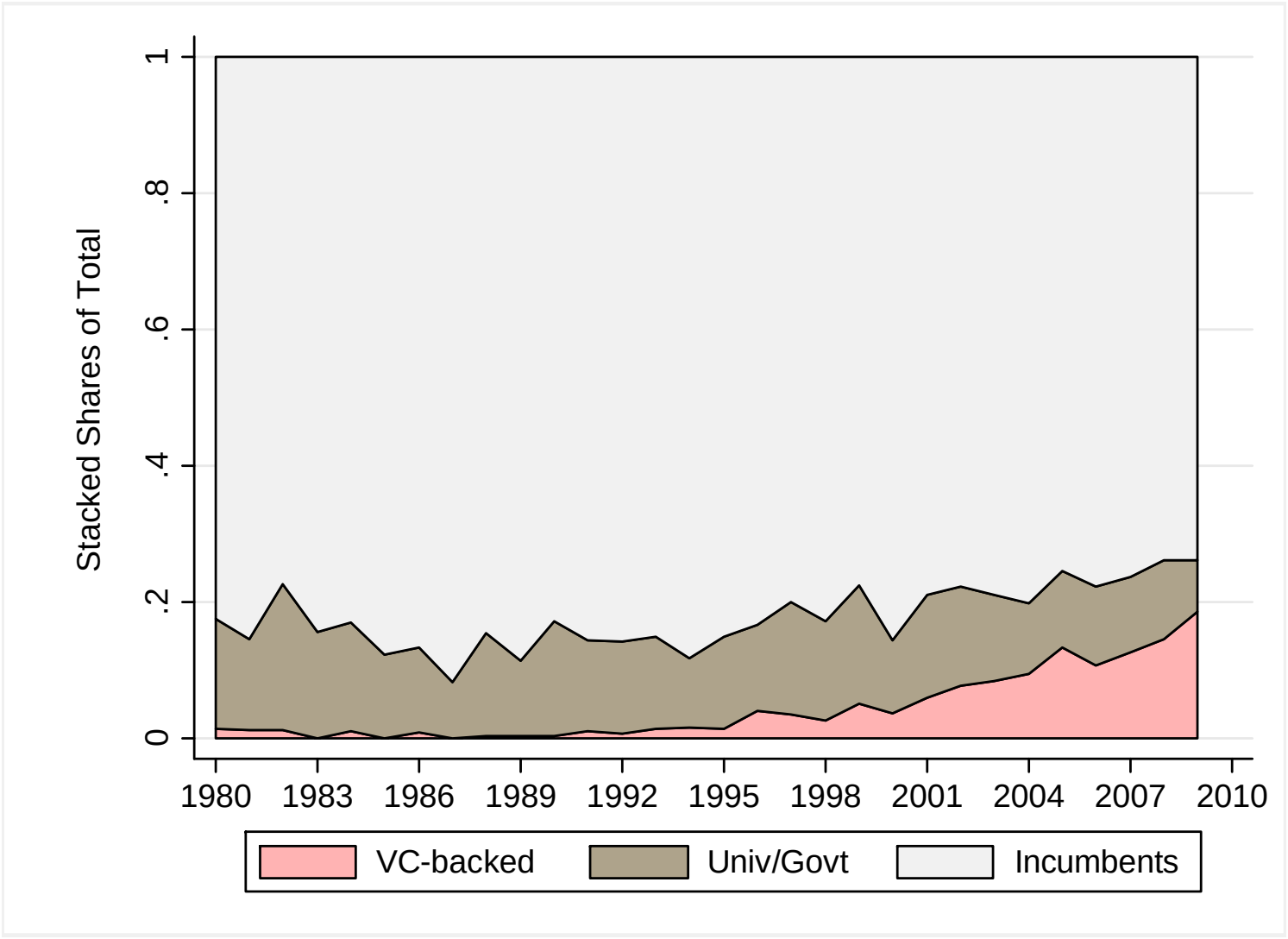
Patent Counts by Year



Share of all USPTO patents



Incumbents still account for vast majority of patents



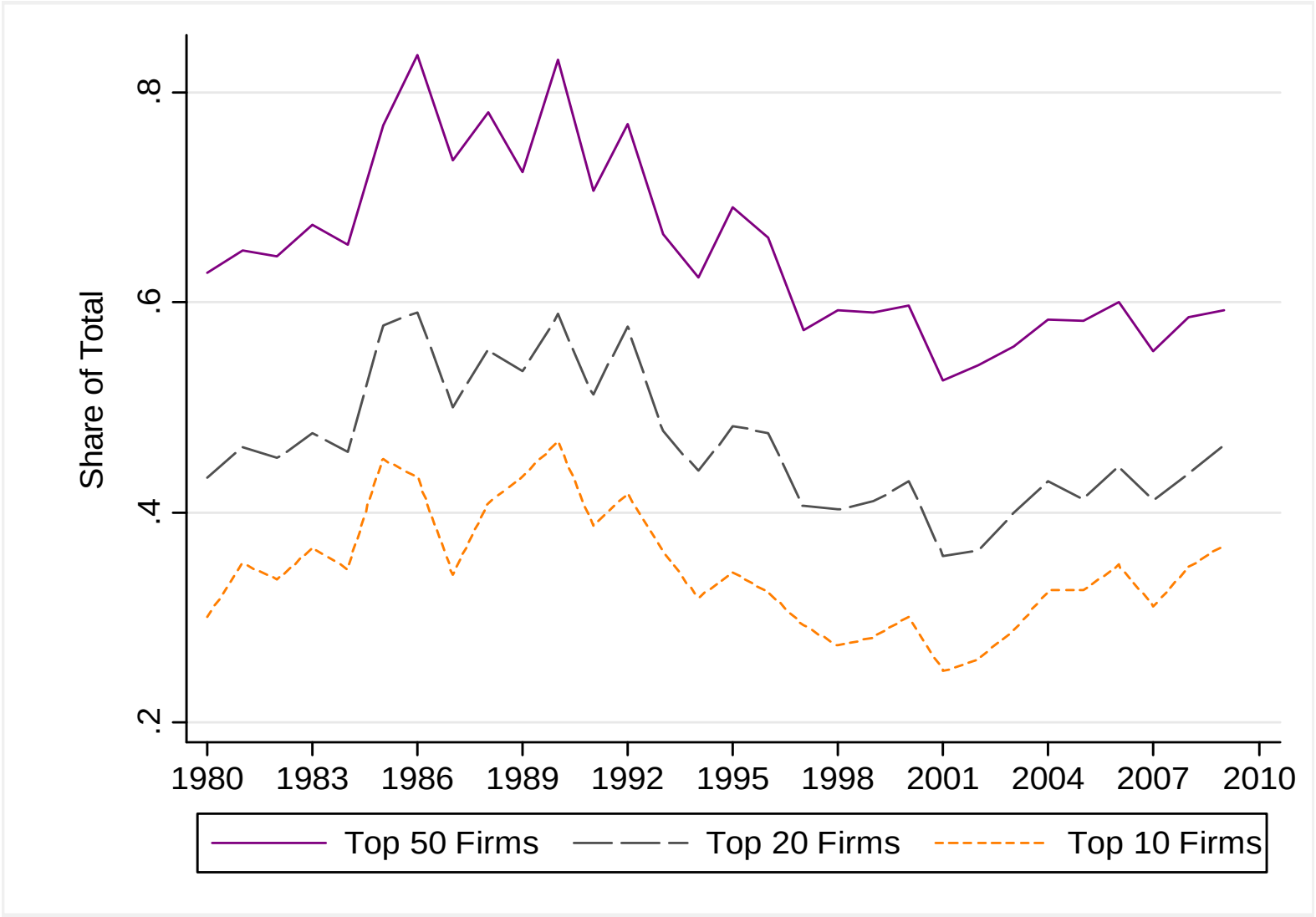
Rank	Solar	Patent Count	Bio	Patent Count
1	Applied Materials, Inc	56	Stine Seed Company	212
2	SunPower Corporation	35	DuPont	78
3	Solopower	33	Merschman Seeds	76
4	GE	31	Novo Group	30
5	Boeing	25	UOP	30
6	Konarka Technologies	24	Chevron	29
7	Stion Corporation	24	Monsanto	29
8	IBM	20	Syngenta AG	25
9	DuPont	18	M.S. Technologies LLC	22
10	Emcore Solar Power, Inc.	17	Dow	21
11	Nanosolar, Inc.	17	Michigan State University	17
12	Guardian Industries Corp.	16	ADM	13
13	Xerox	13	University of Illinios	13
14	Solyndra LLC	12	University of Wisconsin	13
15	TE Connectivity	12	Amyris	12
16	Twin Creeks Technologies	12	Royal DSM	12
17	Lockheed Martin	11	NewMarket Corporation	11
18	Miasole	11	U.S. Department of Agriculture	11
19	Solaria Corporation	9	GE	10
20	UTC	9	University of California	10
21	Energy Innovations, Inc.	8	Battelle Memorial Institute	9
22	GM	8	Ceres, Inc.	8
23	Solexel, Inc.	8	University of Southern Californ	7
24	Solfocus, Inc.	8	BASF	6
25	University of California	8	ConocoPhillips Company	6
26	World Factory, Inc.	8	ExxonMobil	6
27	Foxconn	7	ZeaChem Inc.	6
28	Iostar Corporation	7	Agritope/Aventis	5
29	North Carolina State Univers	7	Battelle	5
30	University of Central Florida	7	Catalytic Distillation Technolo	5

Wind	Patent Count
GE	204
Genedics Clean Energy, LLC	9
Clipper Windpower Technology	8
Northern Power Systems, Inc.	6
FloDesign Wind Turbine Corp.	5
Frontier Wind, LLC	5
RenScience IP Holdings Inc.	5

Hydro	Patent
GE	16
Ocean Power Technologies	12
Alticor Corporate Enterprises	11
Lockheed Martin	6
Verdant Power	6

Geothermal	Patent
Kelix Heat Transfer Systems	7
Earth To Air Systems, LLC	5
GE	5

Concentrated among a few firms



Citations to patents

Negative Binomial Regressions. Dependent Variable is the count of cumulative citations received five years from application

	Full Sample			US-based Inventors only		
	(1)	(2)	(3)	(4)	(5)	(6)
(a) VC-backed startup	0.606***	0.639***	0.672***	0.601***	0.641***	0.670***
	(0.165)	(0.158)	(0.177)	(0.181)	(0.173)	(0.199)
(b) Incumbent firms	0.118	0.113	0.099	0.163*	0.164*	0.143
	(0.073)	(0.075)	(0.108)	(0.087)	(0.089)	(0.132)
(c) Unassigned	-1.365***			-1.472***		
	(0.176)			(0.175)		
P-value on Chi2 test for difference between (a) and (b)	0.002***	<0.001***	<0.001***	0.011**	0.003***	0.002***
Patent application year fi	Y	Y	Y	Y	Y	Y
Technology fixed effects	Y	Y	Y	Y	Y	Y
Observations	22,869	17,136	11,611	13,589	9,523	6,155

Patents with at least one citation

OLS Regressions. Dependent Variable takes a value of 1 if the patent received at least one citation five years from application

	Full Sample			US-based Inventors only		
	(1)	(2)	(3)	(4)	(5)	(6)
(a) VC-backed startup	0.105***	0.130***	0.136***	0.077*	0.114***	0.123***
	(0.034)	(0.027)	(0.029)	(0.040)	(0.030)	(0.032)
(b) Incumbent firms	0.055***	0.053***	0.058***	0.061***	0.063***	0.070***
	(0.016)	(0.014)	(0.017)	(0.019)	(0.018)	(0.022)
(c) Unassigned	-0.353***			-0.381***		
	(0.018)			(0.020)		
P-value on Chi2 test for difference between (a) and (b)	0.126	0.002***	0.003***	0.643	0.059*	0.058*
Patent application year fix	Y	Y	Y	Y	Y	Y
Technology fixed effects	Y	Y	Y	Y	Y	Y
Observations	22,869	17,136	11,611	13,589	9,523	6,155

Highly cited patents

OLS Regressions. Dependent Variable takes a value of 1 if above 90th percentile in terms of citations received five years from application

	Full Sample			US-based Inventors only		
	(1)	(2)	(3)	(4)	(5)	(6)
(a) VC-backed startup	0.075***	0.075***	0.083***	0.086***	0.086***	0.101***
	(0.026)	(0.026)	(0.027)	(0.028)	(0.028)	(0.028)
(b) Incumbent firms	0.018	0.018	0.015	0.037**	0.037**	0.031*
	(0.013)	(0.013)	(0.014)	(0.016)	(0.016)	(0.016)
(c) Unassigned	-0.125***			-0.114***		
	(0.015)			(0.015)		
P-value on Chi2 test for difference between (a) and (b)	0.018**	0.018**	0.008***	0.054*	0.054*	0.009***
Patent application year fixe	Y	Y	Y	Y	Y	Y
Technology fixed effects	Y	Y	Y	Y	Y	Y
Observations	22,869	17,136	11,611	13,589	9,523	6,155

Self citation

Negative Binomial Regressions. Dependent Variable is the count of backward citations that are self citations

	Full Sample			US-based Inventors only		
	(1)	(2)	(3)	(4)	(5)	(6)
(a) VC-backed startup	-0.340	-0.338	-0.213	-0.135	-0.130	-0.146
	(0.266)	(0.266)	(0.281)	(0.296)	(0.296)	(0.308)
(b) Incumbent firms	0.405**	0.405**	0.466**	0.379**	0.380**	0.307
	(0.188)	(0.188)	(0.232)	(0.181)	(0.181)	(0.219)
(c) Unassigned	-5.259***			-5.283***		
	(1.045)			(1.082)		
P-value on Chi2 test for difference between (a) and (b)	0.007***	0.007***	0.013**	0.056*	0.057*	0.087*
Patent application year fix	Y	Y	Y	Y	Y	Y
Technology fixed effects	Y	Y	Y	Y	Y	Y
Observations	22,869	17,136	11,611	13,589	9,523	6,155

Non-citation based measure of novelty

- Textual analysis of patent applications to look at similarity of patent claims
  - Builds a list of all terms used in the sample; list of terms constitutes a high-dimensional positive space wherein each term represents a dimension in that space
  - algorithm positions each patent in the vector space by assigning it a set of coordinates where the magnitude of each dimension is calculated as the "term frequency inverse document frequency" (TF-IDF) of each term in the patent. Intuitively, TF-IDF gives a greater weight to a dimension when a term occurs more frequently in the patent, and gives a lesser weight to a dimension if the word is frequently observed in other patents as well
  - The algorithm then calculates the “similarity” between every possible combination of two patents, by calculating the cosine of the angle formed between their vectors. The measurement of similarity is bounded [0,1], with a measurement of 1 representing a perfect similarity between two patents.

- Particularly useful for science and engineering fields where technical terms are quite unique and likely to signal substantive differences in innovation

Non-citation based measure of novelty

- Calculate novelty by comparing similarity of the patent relative to a comparison set of patents
  - Comparison set is three prior years and same technology as the focal patent
  - To assess the “novelty” of a patent we take the 5th percentile of the rank-ordered distribution of similarities tied to the comparison set.
  - For ease of interpretation, we reverse the novelty measure by subtracting it from 1, arriving at a measurement for Novelty that is bounded [0,1], where 1 represents a patent that is entirely dissimilar from all other patents

Novelty

OLS Regressions. Dependent Variable is the novelty of the patent

	Full Sample			US-based Inventors only		
	(1)	(2)	(3)	(4)	(5)	(6)
(a) Venture Capital Backed Startup	-0.020	-0.017	-0.022*	0.003	0.011	-0.000
	(0.014)	(0.015)	(0.012)	(0.018)	(0.022)	(0.017)
(b) Incumbent firms	-0.039***	-0.039***	-0.052***	-0.050***	-0.049***	-0.068**
	(0.012)	(0.012)	(0.017)	(0.019)	(0.018)	(0.029)
(c) Unassigned	-0.009**			-0.005		
	(0.004)			(0.005)		
P-value on Wald test for difference between (a) and (b)	0.380	0.352	0.222	0.121	0.117	0.10*
Patent application year fixed effects	Y	Y	Y	Y	Y	Y
Technology fixed effects	Y	Y	Y	Y	Y	Y
Observations	22,869	17,136	11,611	13,589	9,523	6,155

Summary of findings so far

- Renewable energy patenting highly concentrated
- Innovation by VC backed firms is more highly cited and seems to be more novel
- Sharp rise in VC-backed patenting in late 2000s
  - Rising from under 5% to over 20% of patents in 2009 (timing coincides with sharp increase in VC for renewable energy startups)
  - Although not showing causal effects, suggests that at the very least VC is associated with more novel and radical innovation

Outline

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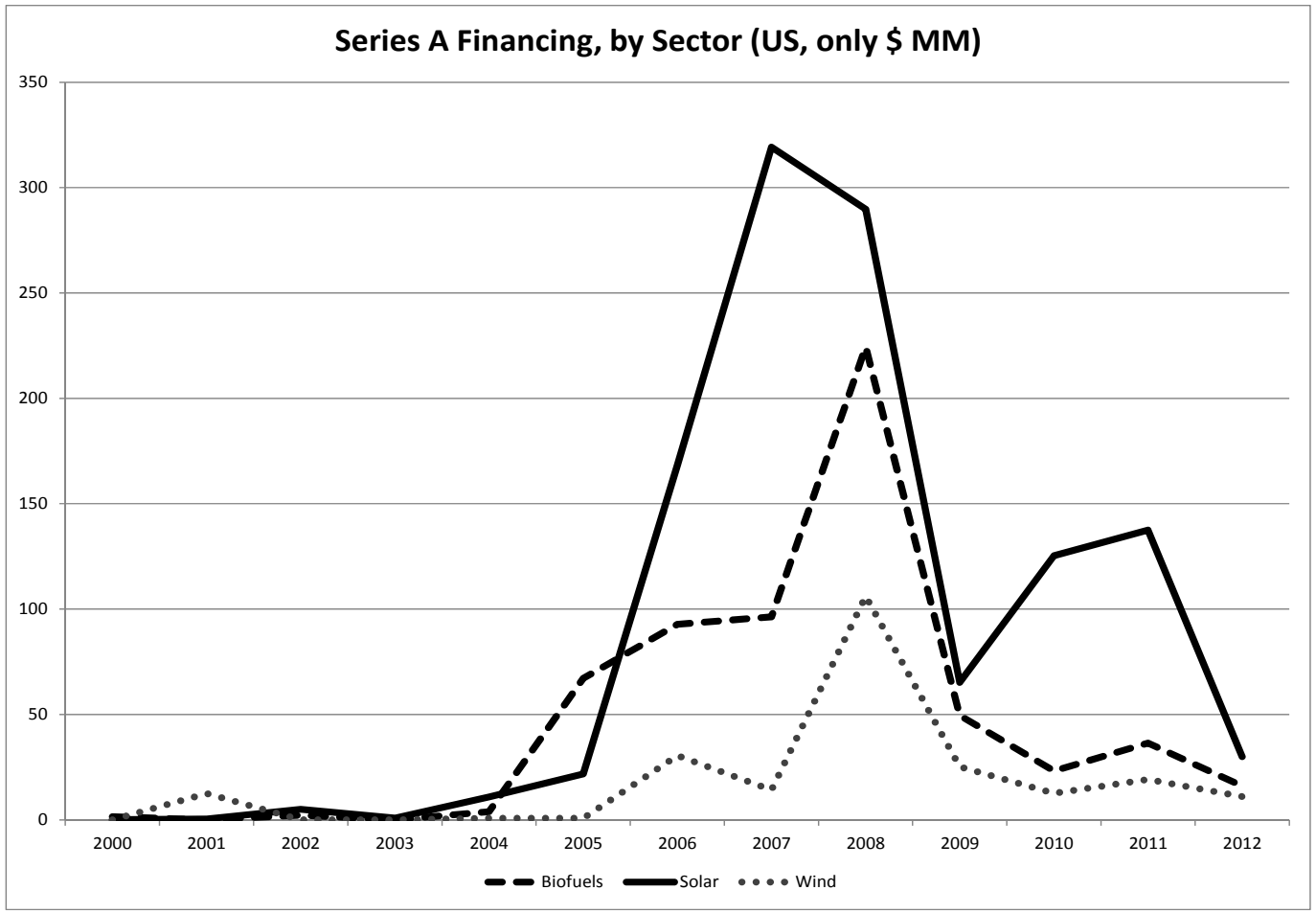
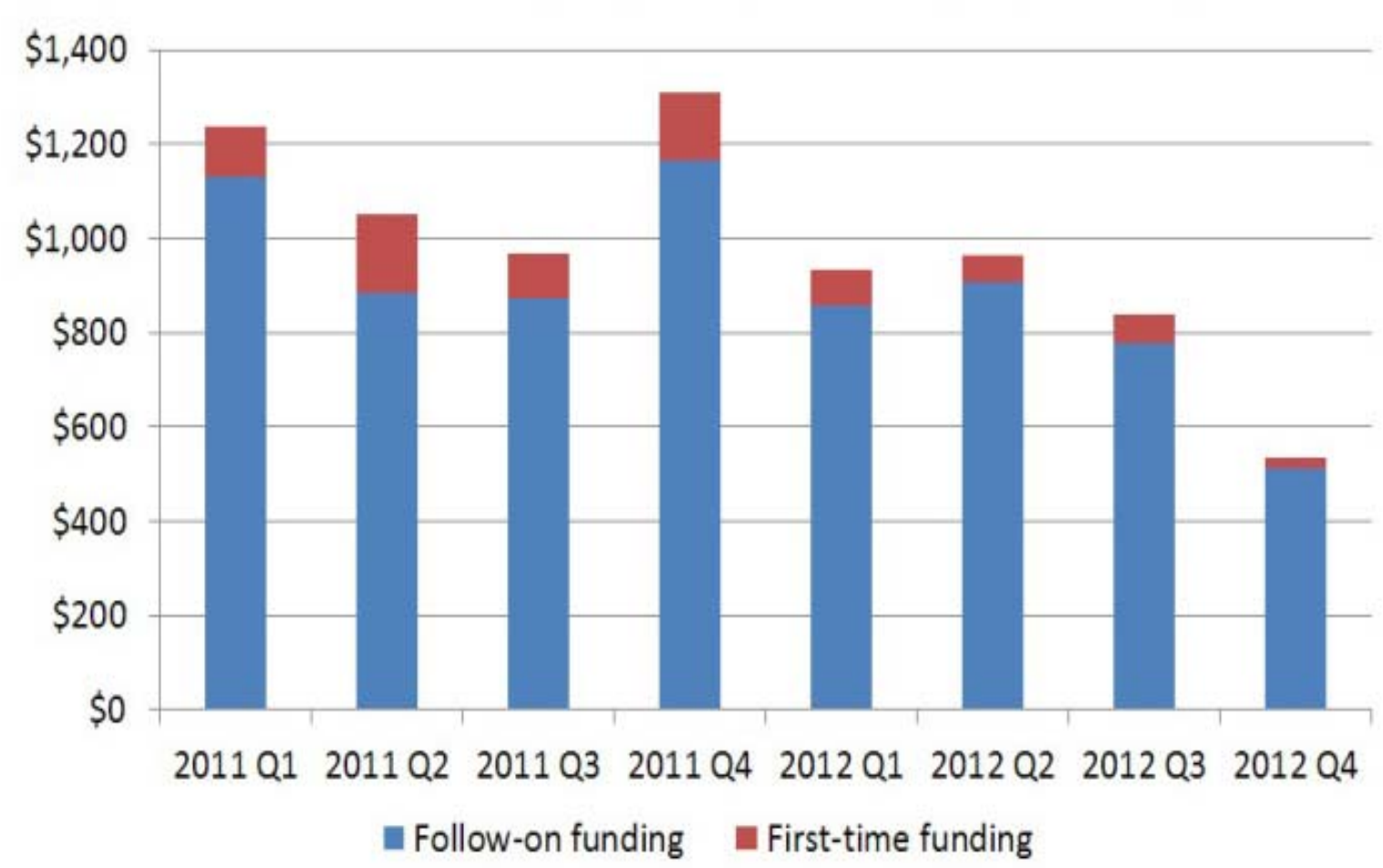
II. VC Finance of Renewable Energy Startups

III. China's engagement with US-based startups

VC Financing of Renewable Energy



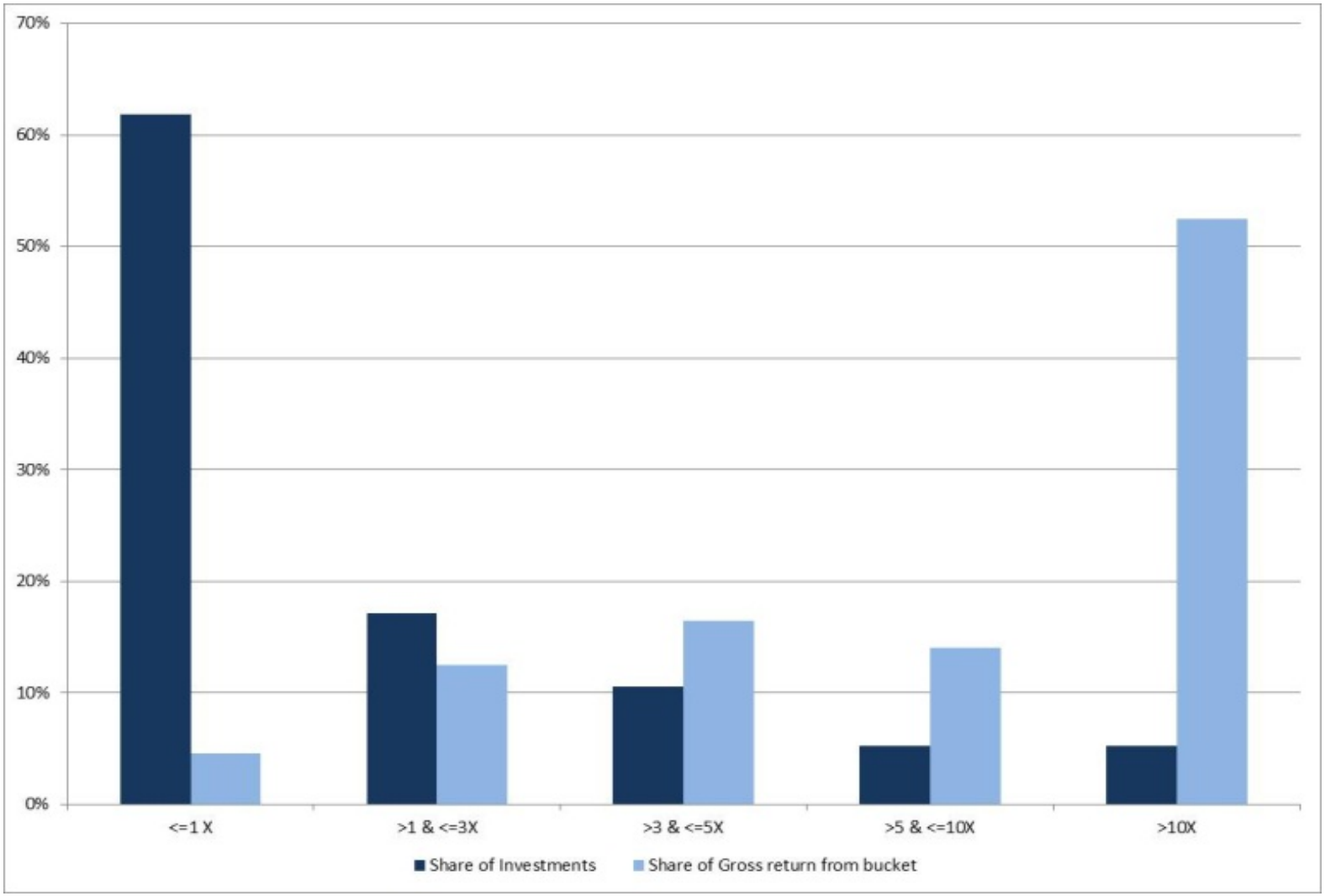
VC Financing of Renewable Energy



VC Investments

- Highly uncertain investments
  - 60% of venture capital investments are terminated below cost
  - All money is made from few big successes
  - Hard to know ex ante which ones these will be

Portfolio composition for a top tier VC



Source: William Kerr, Ramana Nanda and Matthew Rhodes-Kropf (2014), “Entrepreneurship as Experimentation”, forthcoming, Journal of Economic Perspectives

Bessemer Ventures “Anti-portfolio”

BVP had the opportunity to invest in pre-IPO secondary stock in Apple at a $60M valuation. BVP's Neill Brownstein called it "outrageously expensive."

"Stamps? Coins? Comic books? You've GOT to be kidding," thought Cowan. "No-brainer pass."

Incredibly, BVP passed on Federal Express seven times.

Cowan’s college friend rented her garage to Sergey and Larry for their first year. In 1999 and 2000 she tried to introduce Cowan to “these two really smart Stanford students writing a search engine”. Students? A new search engine? In the most important moment ever for Bessemer’s anti-portfolio, Cowan asked her, “How can I get out of this house without going anywhere near your garage?”

Source: http://www.bvp.com/portfolio/antiportfolio

“Anti-Portfolio” (contd)

BVP's Pete Bancroft never quite settled on terms with Bob Noyce, who instead took venture financing from a guy named Arthur Rock.

Along with every venture capitalist on Sand Hill Road, Neill Brownstein turned down Intuit founder Scott Cook. Scott managed to scrape together only $225K from friends, including HBS classmate and Sierra Ventures founder Peter Wendell, who personally invested $25K to get Scott off his back.

Ben Rosen, one of the founders of Sevin Rosen, offered Felda Hardymon the chance to invest in both Lotus and Compaq Computer on the same day. Says Hardymon: "Lotus wasn't proven yet, and I was worried about the situation there. As for Compaq, I told him there was no real future in transportable computers since IBM could do it."

David Cowan passed on the Series A round. Rookie team, regulatory nightmare, and, 4 years later, a $1.5 billion acquisition by eBay.

VC Business Model

- Capital light investment
  - Allows VC to diversify across multiple investments
  - Spend as little money on early experiments to learn about prospects of the venture (“fail fast and cheap”)
- Can scale rapidly after initial experiment
  - Allows VC to still own a significant share in the firms that are successful to generate returns to cover failures
- IPO or acquisition that values growth options
  - Allows VC to exit before the company matures

Example of Pro-Forma shown by VC to their investors

Category of Outcome	Projected Value at Exit	Dollar invested per company	Share owned at Exit	Expected # investments	Total $ invested	Total $ Return
Early Failure	-	$ 5 M	n/a	5	$ 25 M	0
Complete write off	-	$ 8-15 M	n/a	5	$ 55 M	0
Money back	$ 50 M	$ 8-15 M	20%	5	$ 55 M	$ 50 M
Successful exit (low)	$ 200 M	$ 8-15 M	20%	5	$ 55 M	$ 200 M
Successful exit (medium)	$ 350 M	$ 8-15 M	20%	5	$ 55 M	$ 350 M
Successful exit (high)	$ 500 M	$ 8-15 M	20%	5	$ 55 M	$ 500 M
Total					$ 300 M	$ 1,100 M

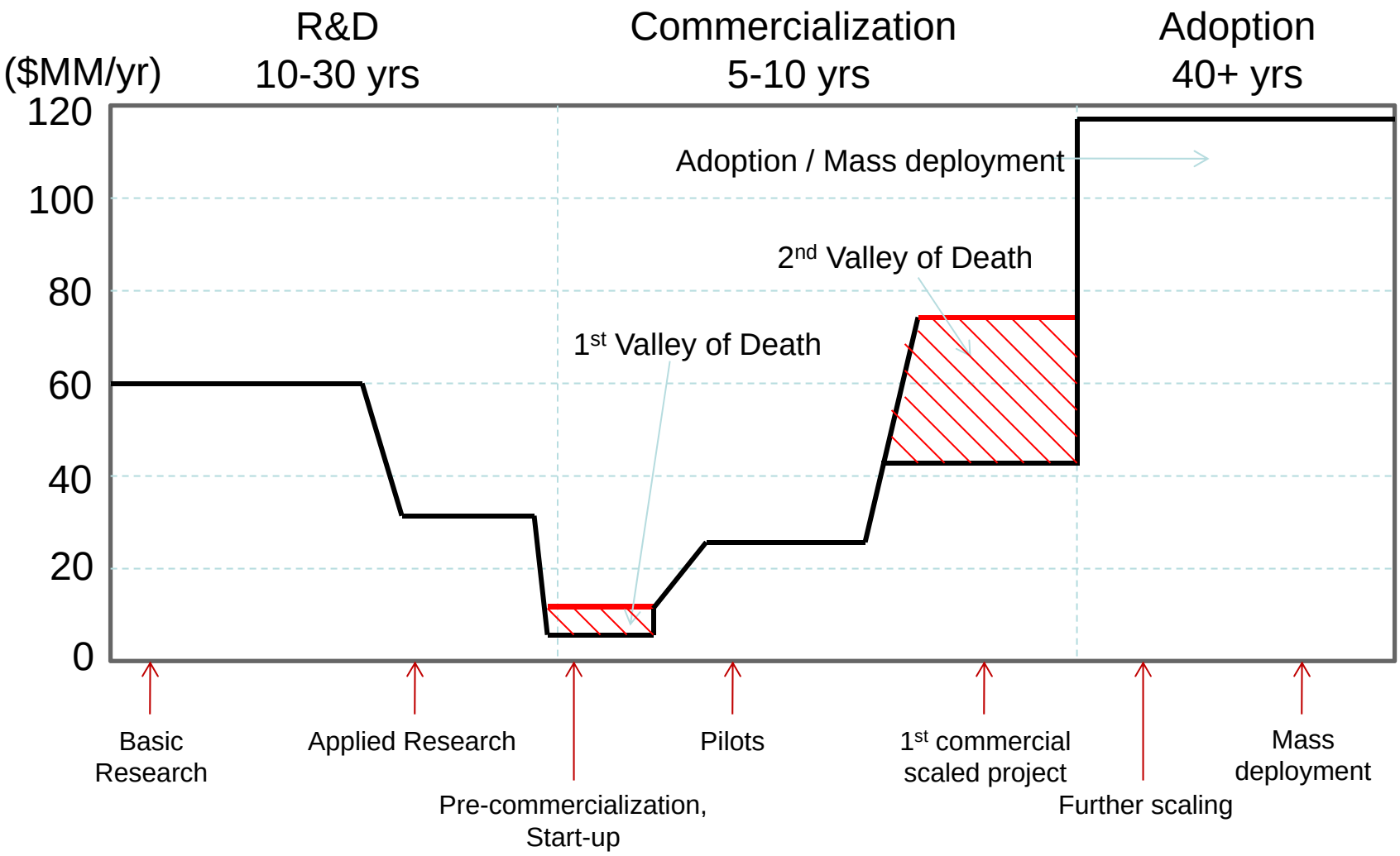
VC Sweet spot: projects where experimentation is particularly valuable

- Huge upside in good state relative to the bad
  - Value from learning
- Can learn about project viability “fast and cheap”
  - Total capital requirement to get to cash flow positive is low if things work out (less dilution)
  - Less money spent on failed projects

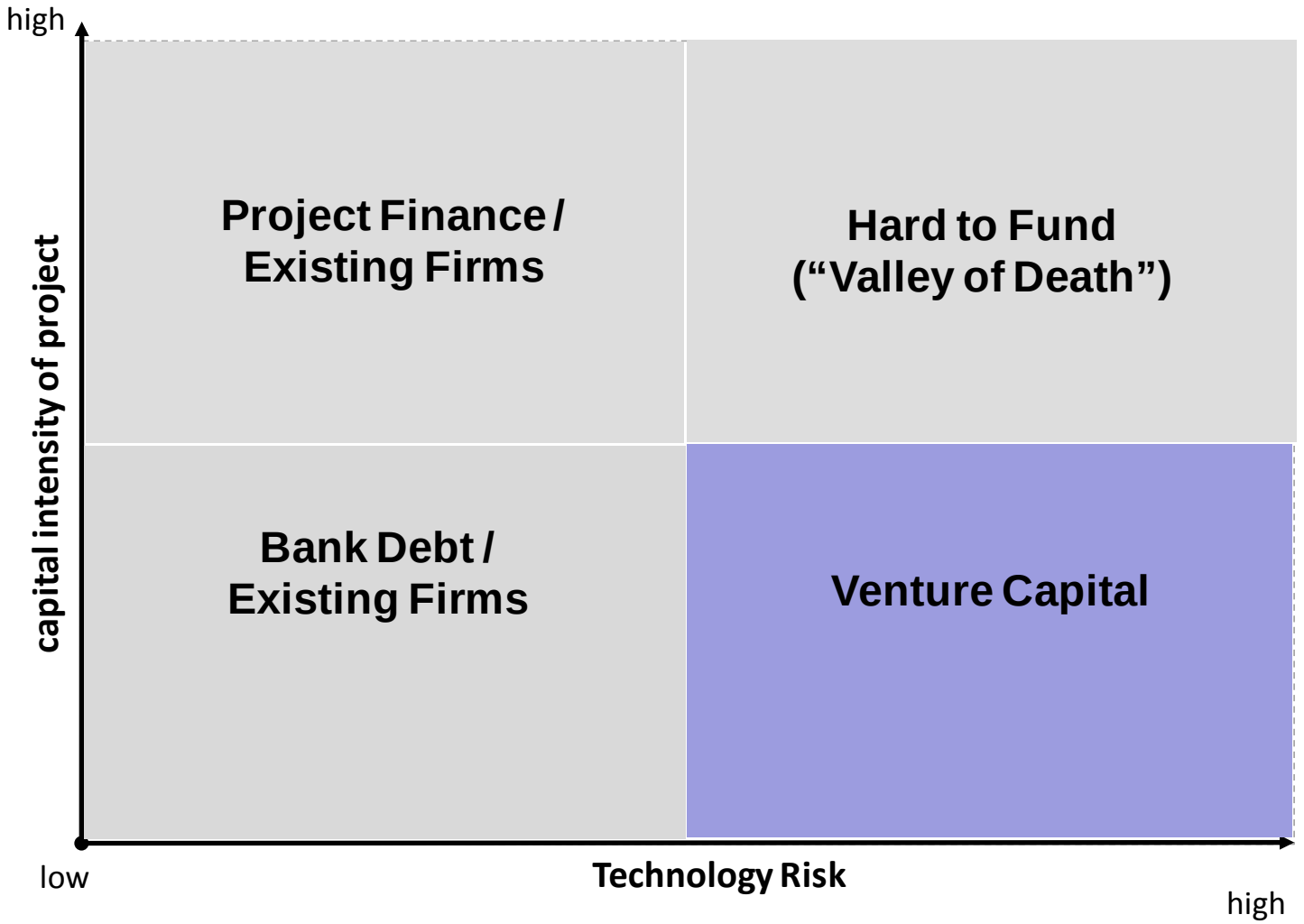
Renewable Energy Startups

- Long development cycles
  - Need to build factories
- Experimentation is costly
  - Economics only work at large scale, but hard to predict economics at smaller scale.. Need to build the factory to find out!
- End product is a commodity
  - Upside may be more limited (different from biotech)
- No well-established exit mechanism (yet)

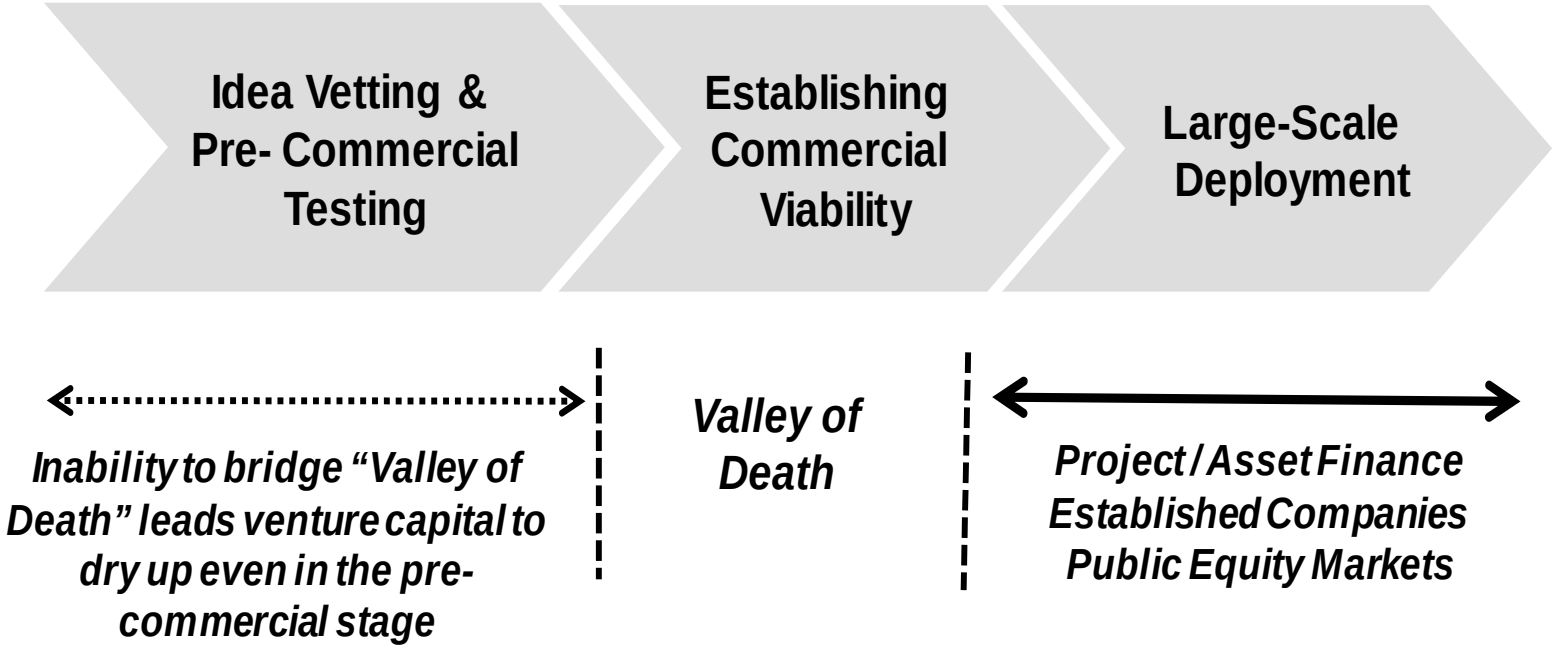
Timelines and Costs in Renewable Energy



VC sweet spot vs. Renewable Energy



Domino effect on financing early experimentation



Possible solutions

- Only focus on capital efficient business models that “fit the VC model”
  - *Demand side startups that are focus of VC investment today*
  - *But is there sufficient financing of experimentation around new energy production and storage technologies?*

- More active engagement by incumbents through strategic alliances and acquisition prior to scale up
  - *Similar to biotech, incumbent balance sheet useful for non-dilutive finance and signaling of quality*
  - *Hand off to those who have resources and capabilities*

- Government intervention through (direct / indirect) subsidies
  - *Finance the scale up or feed in tariffs for selling ‘clean power’*

Acquisition market

- Can you exit the company *prior to scale* up for a sufficiently high price relative to investment?

- Challenge: Hold up and “cram down”
  - “Is Big Pharma Strangling Biotech Startups in Their Cradles?”
  - Same challenge in renewable energy

- Acquisitions will be an attractive exit option if lots of competition for the deal or a credible outside option for the startup
  - For example, government as customer (common in the US through DoD, but not so with DOE)

Outline

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Case studies of renewable energy startups engaging with China

- Terrapower: nuclear energy startup
  - 200 nuclear reactors either proposed, planned or under construction by 2030
  - Government as investor and customer

- 1366 Technologies – solar PV startup
  - Partnering with Chinese manufacturers as part of rapid scale up of solar panel manufacturing equipment

- Oasys Water
  - Equity investment from EPC contractor, Woteer, as part of a move to tap into the massive Chinese market for industrial ZLD and municipal water filtration; helped by regulation