Building Dynamic Capabilities:

Innovation Driven by Individual, Firm, and Network Level Effects
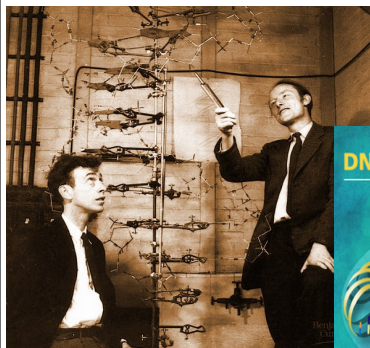
Paper forthcoming in Organization Science

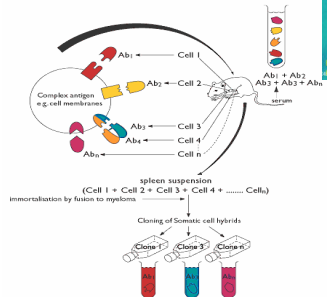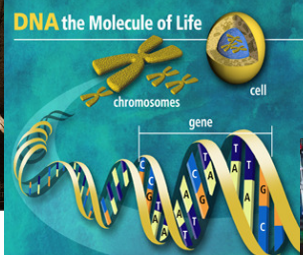Frank T. Rothaermel
Andrew M. Hess
Georgia Institute of Technology

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The Biotechnology Revolution(s)

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Global Pharmaceutical Industry
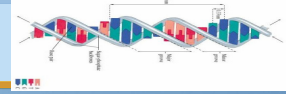
- R&D expenditures have grown from $6.8 billion in 1990 to $21.3 billion in 2000 (17% of sales)

- Development cost for new drugs have increased from $231 million to $802 million over the same period

- Average sales per patented product have fallen from $457 million in 1990 to $337 million in 2001

^ Constant 1999 dollars.

R&D Investments and New Drug Approvals
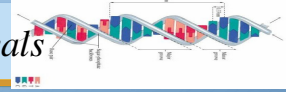
"Despite its outward strength, the [pharmaceutical] industry is ailing. The pipelines of forthcoming drugs on which its future health depends have been drying up for some time."

− The Economist, March 13, 2004

*Includes biologics. SOURCE: Datamonitor, PhRMA
Acumen Journal of Sciences, Vol. I, Issue II

Value of Expiring Pharmaceutical Patents
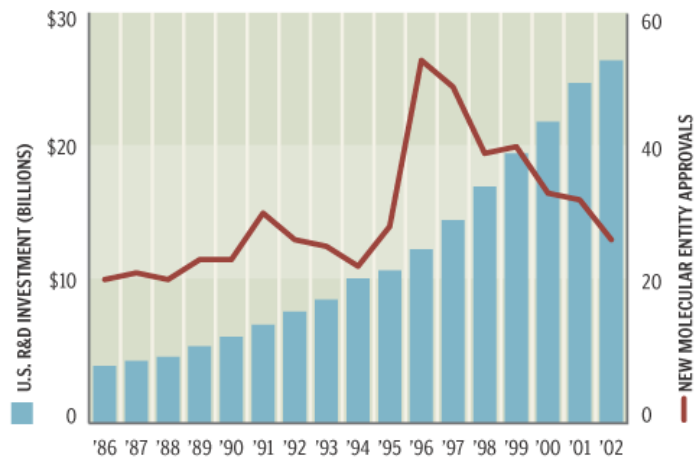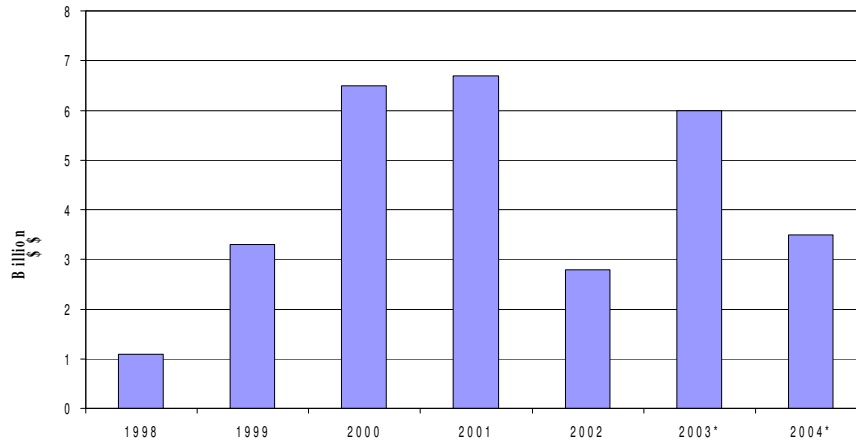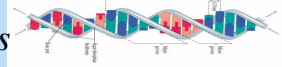
Source: Warburg Dillon and Read

Research Questions
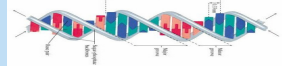
- Where is the locus of innovation capabilities?

  – Is it within the individual, firm, or network level of analysis

  – Is this a multilevel story of capability development involving interactions across levels of analysis?

- If so, are the different innovation mechanisms complements or substitutes?

Most research has focused on one level of analysis:

– Network Level: Powell, Koput, Smith-Doerr (1996), Rothaermel (2001), Higgins and Rodriguez (2006)

– Firm Level: Cohen and Levinthal (1989, 1990)
  Tushman and Anderson (1986)

– Individual Level: Zucker and Darby studies

Such a focus makes two implicit assumptions:

– Homogeneity *within* non-focal levels of analysis
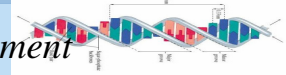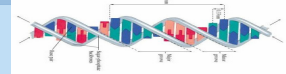– Independence *between* focal and non-focal levels of analysis

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- **Complements vs. Substitutes**
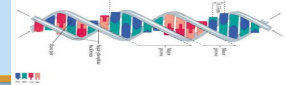 - Competing hypotheses are advanced to test the interdependence *across* levels

- Two activities are complements (substitutes) if the marginal benefit of each activity increases (decreases) in the presence of the other activity:
  - *Complements:* the interactions across levels are *positive*
  - *Substitutes:* the interactions across levels are *negative*

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Individual-Level:
Intellectual Human Capital (H1a)
Star Scientists (H1b)

Firm-Level:
R&D Capability (H2)

Network-Level:
Biotech Alliances (H3a)
Biotech Acquisitions (H3b)

H4: Complements

H5: Substitutes
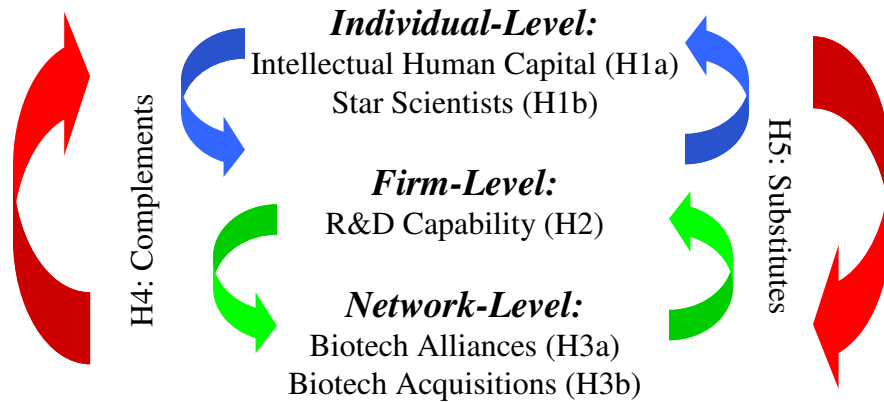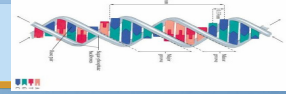
Methodology: Overview

- Developed a detailed & comprehensive panel dataset (1980-2004) documenting:
  - 900 biotech acquisitions
  - 4,000 biotech alliances
  - 13,200 biotech patents
  - 110,000 non-biotech patents
  - 135,000 research scientists
  - 480,000 journal publications of biotechnology research
  - 9.2 million journal citations
  - *Last but not least:*
    - *These data are complemented by qualitative fieldwork through interviews and direct observation before, during, and after completion of the study.*
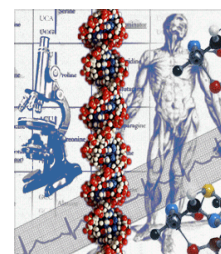
Dependent Variable
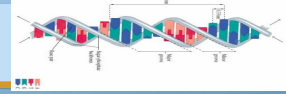
- ***Innovation Output***

  Biotechnology patent applications granted:

  - Externally validated measure of technological novelty

  - Critical to success in pharmaceutical industry and correlated with key performance measures
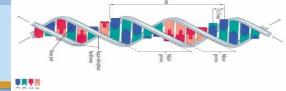
    – Citation-weighted patents

    – New product development

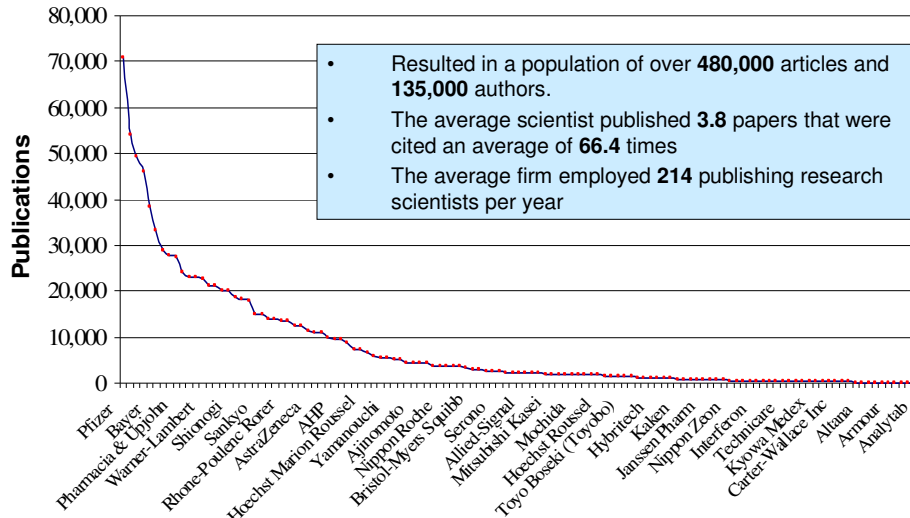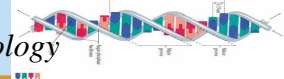## Independent Variables

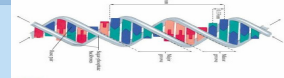- ***Intellectual Human Capital (IHC):***

  – Searched ISI Scientific Citation Index for journal articles published between 1980 and 2004:

    - An organization's name corresponding to a pharmaceutical firm

    - A keyword related to scientific research

    - Longer time period than study period

      – To address "rising star" effect

      – To address right truncation

Pharmaceutical Firm Publications in Biotechnology

- Resulted in a population of over **480,000** articles and **135,000** authors.
- The average scientist published **3.8** papers that were cited an average of **66.4** times
- The average firm employed **214** publishing research scientists per year

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Independent Variables

Star Scientists:

- Number of publications & times cited
- Defined stars based on 3 standard deviations above the mean in publications *and* citations
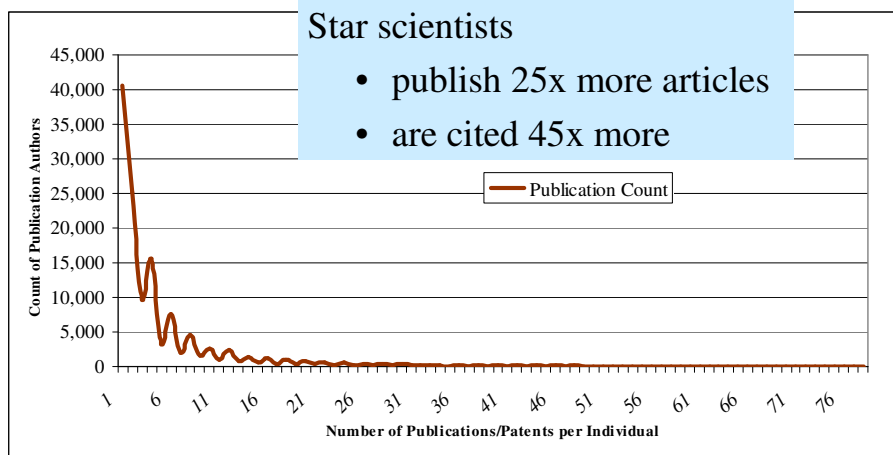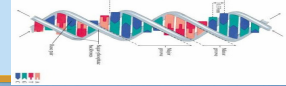- <u>Sample Statistics:</u>
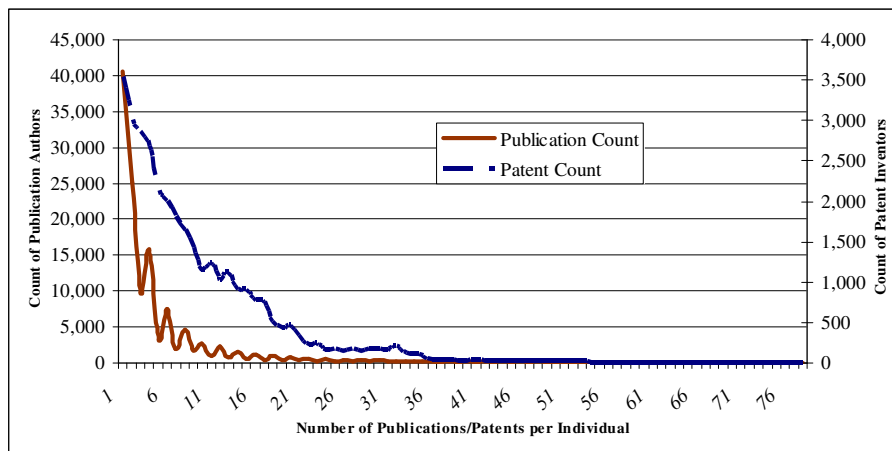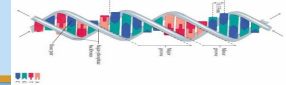 - Number of Stars @ st. dev > 3:
    - By publication: 2,392 stars
    - By citation: 1,570 stars
    - Both: 851 stars

< 0.65% of total pop. is responsible for **15.2%** of total pubs & **27.3%** of total cites

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Distribution of Innovative Output

Star scientists
- publish 25x more articles
- are cited 45x more

Distribution of Innovative Output
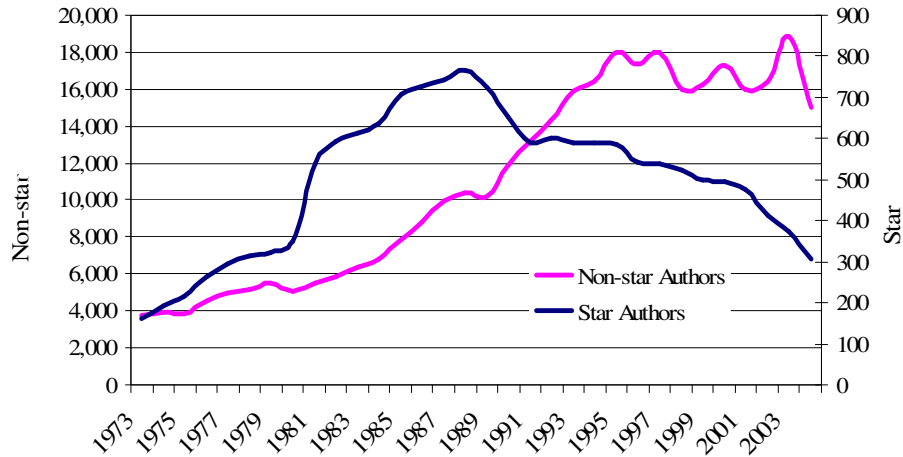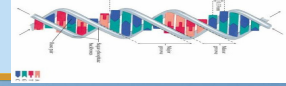
Independent Variables and Controls
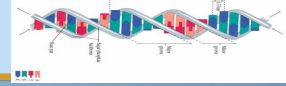
Other IV's:
- R&D Capability
  - R&D expenditures
- Biotech alliances and acquisitions

Controls:
- Lagged biotech patents
- Non-biotech patents
- Time to Cohen-Boyer patent citation
- Diversified pharmaceutical firm
- Horizontal merger
- Firm size (total assets)*
- Firm performance (net income & revenues)
- Country Effects: U.S., European, Asian (Japanese) Firm
- Year Effects

* All financial data are in constant U.S. dollars

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Results

Model 1: Controls Only

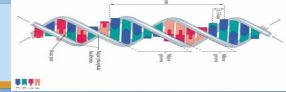|	BPA	IRR	Factor Change
Firm Merged	$p < 0.001$	1.20	20%
Total Assets	$p < 0.001$	0.62	- 38%
Total Revenues	$p < 0.001$	1.22	22%
Time to Cohen-Boyer Patent Citation	$p < 0.001$	0.55	- 45%
Non-Biotech Patents	$p < 0.001$	1.14	14%
Lagged Biotech Patents	$p < 0.001$	1.18	18%

Results – Direct Effect Hypotheses

	BPA	IRR	Factor Change
Intellectual Human Capital	$p < .001$	1.15	15%

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Results – Direct Effect Hypotheses
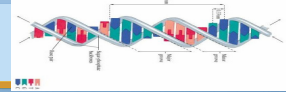
	BPA	*IRR*	*Factor Change*
Intellectual Human Capital	*p < .001*	1.15	15%
R&D Expenditures	*p < .05*	1.32	32%
R&D Expenditures Squared	*p < .001*	0.92	-8%

Results – Direct Effect Hypotheses
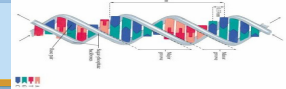
	BPA	*IRR*	*Factor Change*
Intellectual Human Capital	*p < .001*	1.15	15%
R&D Expenditures	*p < .05*	1.32	32%
R&D Expenditures Squared	*p < .001*	0.92	-8%
Biotech Alliances	NS	-	-

Results – Direct Effect Hypotheses
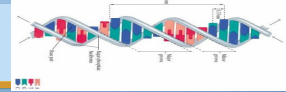
	BPA	*IRR*	*Factor Change*
Intellectual Human Capital	*p < .001*	**1.15**	**15%**
R&D Expenditures	*p < .05*	**1.32**	**32%**
R&D Expenditures Squared	*p < .001*	**0.92**	**-8%**
Biotech Alliances	NS	-	-
Biotech Acquisitions	*p < .05*	**1.04**	**4%**

Results – Direct Effect Hypotheses
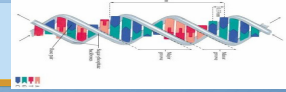
- The effect of stars

	BPA	*IRR*	*Factor Change*
Star Scientists	*p < .01*	**1.08**	**8%**
R&D Expenditures	*p < .05*	**1.32**	**32%**
R&D Expenditures Squared	*p < .001*	**0.92**	**-8%**
Biotech Alliances	NS	-	-
Biotech Acquisitions	*p < .01*	**1.06**	**6%**

Results – Direct Effect Hypotheses
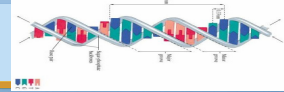
- The effect of stars disappears while controlling for non-stars
- Unobserved heterogeneity
- Non-stars fully mediate any star effect

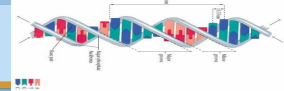|	*BPA*	*IRR*	*Factor Change*
Star Scientists	NS	-	-
Non-Star Scientists	$p < .05$	1.10	10%
R&D Expenditures	$p < .05$	1.32	32%
R&D Expenditures Squared	$p < .001$	0.92	-8%
Biotech Alliances	NS	-	-
Biotech Acquisitions	$p < .05$	1.05	5%

Results – Interaction Effect Hypotheses*

Individual x Firm Level	*BPA*	*IRR*	*Factor Change*
IHC x R&D Expenditures	$p < .05$	0.91	- 9%
Star Scientists x R&D Exp.	$p < .05$	0.92	- 8%

* only significant interactions are shown

Results – Interaction Effect Hypotheses*

Individual x Firm Level	BPA	IRR	Factor Change
IHC x R&D Expenditures	$p < .05$	0.91	- 9%
Star Scientists x R&D Exp.	$p < .05$	0.92	- 8%

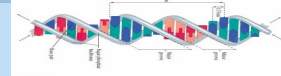| Individual x Network Level	BPA	IRR	Factor Change
IHC x Bio Alliances	$p < .001$	0.94	- 6%
Non-Stars x Bio Alliances	$p < .001$	0.91	- 9%

* only significant interactions are shown

## Results – Interaction Effect Hypotheses*

Individual x Firm Level	BPA	IRR	Factor Change
IHC x R&D Expenditures	$p < .05$	0.91	- 9%
Star Scientists x R&D Exp.	$p < .05$	0.92	- 8%

Individual x Network Level	BPA	IRR	Factor Change
IHC x Bio Alliances	$p < .001$	0.94	- 6%
Non-Stars x Bio Alliances	$p < .001$	0.91	- 9%

| Firm x Network Level	BPA	IRR	Factor Change
R&D Exp. x Alliances	$p < .01$	1.08	8%

* only significant interactions are shown

Conclusions – Direct Effects
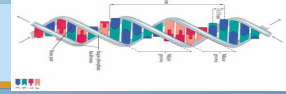
- Locus of innovation capabilities resides across different levels
  - In the intersection between individual, firm, and network-level effects
- Significant amount of the variance in biotech patenting is explained by *individual-level* factors
  - Mediation of star effect on innovation by non-stars
    - Stars close cognitive gap, while non-stars close operational gap (Lavie, 2006)

Conclusions – Direct Effects
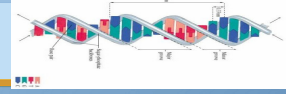
- Firms are able to build, buy and access innovation capabilities through
  - Recruitment of IHC and star scientists,
  - R&D spending,
  - Acquisitions of new technology firms,
- But: Firms must already possess necessary R&D capabilities to be a means by which firms can leverage different innovation mechanisms

Conclusions – Interaction Effects
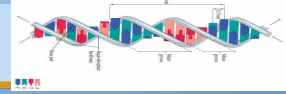
When attempting to innovate:

- Individual-level effects appear to be *substitutes* to firm or network-level antecedents

- In contrast, firm and network-level effects appear to be *complements*