14.461: Technological Change, Lecture 10
Creativity and Leadership

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October 8, 2013.

Creative Innovations

- More than half a million patents per year granted by the USPTO but only a handful of those are truly transformative.
- E.g., in drugs and medical inventions, 223,452 patents between the years 1975 and 2001, but the median number of citations to these patents within the next five years was **four** (and with limited impact on the technology of the field).
- But the patent for "systems and methods for selective electrosurgical treatment of body structures" by the ArthroCare Corporation receive many more citations and has been transformative for surgical procedures.
- Similarly, Amazon's patent for "method and system for placing a purchase order via a communications network" (263 citations within the next five years) was a game changer for online business.

Modeling Creativity

- What determines the creativity and productivity of innovations?
- Related question, what determines technological leadership?
- This lecture: some ideas and clues about this.

Social Attitudes and Creativity

- Schumpeter (1934): a key determinant of creating innovations is a society's or an organization's **openness to disruption**—openness to new new ideas, innovations and practices and tolerance to disruptive or even rebellious behavior.
- Captured by Facebook's inscription on its headquarter walls:

  "move fast and break things."

- Such openness is a function of a company's "corporate culture," also influenced by society-wide institutions and policies and perhaps social norms ("national culture").
- Acemoglu, Akcigit and Celik (2013): modeling the choice between incremental and radical innovations and the effect of social attitudes and institutions on this.

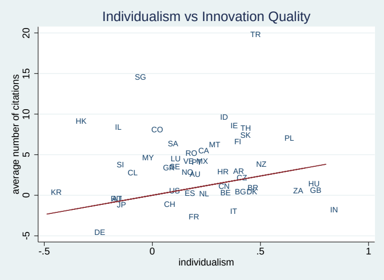
Related Ideas

- Gorodnichenko and Roland (2012): innovation and individualism and provide evidence using Hofstede's individualism data. But no focus on creative innovations, just reporting cross-country relationships with TFP and growth.
- There is also interesting empirical literature on age and creativity: Galenson and Weinberg (1999, 2001), Weinberg and Galenson (2005), Jones and Weinberg (2011), Jones (2010). The main finding is that scientists or artists have different styles, more reliant on creative genius, early in their careers, and more reliant on experience later in their careers.
  - Also, "early" Nobel prize winners have a different style of work than those who have received the Nobel prize for work done later in their careers.
- We will also discuss briefly issues related to technological leadership and creativity, building on Acemoglu, Robinson and Verdier (2012) and issues of "burden of knowledge" based on Jones (2009).

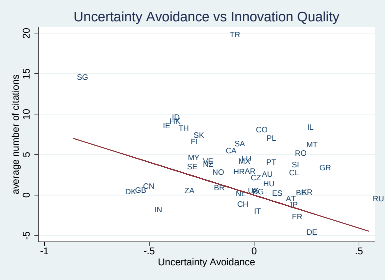
Cross-Country Motivation

- In cross-country data, we can look at various different measures to capture these ideas.
  1. Individualism:
     - Edmund Burke: individualism as the cause for the community to "crumble away, be disconnected into the dust and powder of individuality".
     - Alexis de Tocqueville: individualism in America resulting from the recognition of individual rights and freedoms and restrained government.
     - Hofstede's index of individualism: "preference for a loosely-knit social framework in which individuals are expected to take care of themselves and their immediate family only".
  2. Hofstede's index of uncertainty avoidance.
  3. Our own measure of average age of top managers—as a proxy for an open corporate culture.
  4. Institutional variables, such as rule of law.

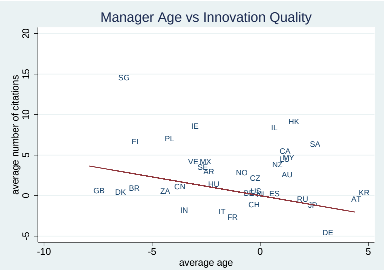
Cross-Country Patterns

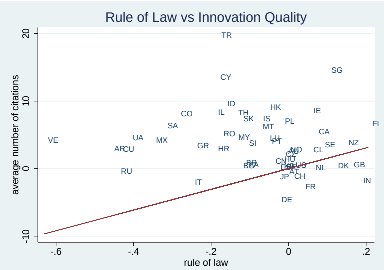


(a) Individualism vs Innovation Quality



(b) Uncertainty Avoidance vs Innovation Quality





Outline of Theory

- A model of endogenous innovations with a choice between incremental and radical innovations.
- Incremental innovations run into diminishing returns within a *technology cluster*.
- Radical innovations start new technology clusters by recombining ideas.
    - Also more original, building on broader knowledge, and will receive more citations in the future.
- Young managers for the comparative advantage and radical innovations (more recent knowledge base, less wedded to existing technologies and practices).
    - Assignment of managers to firms by age.
- But also key is firm type ("corporate culture"): only some type of firms can undertake radical innovations.
- Also institutional factors are important.

Theory: Additional Predictions

- Replacement effect and technology effect:
    - Radical innovation more likely when current technology is less profitable because of Arrow's replacement effect.
    - Radical innovation more likely when more innovations in the past because this implies more likely to have run into diminishing returns to incremental innovations.

Firm-Level Evidence

- Focus on average manager age of a company (from the Compustat).
- Several different measures of creative innovations (described below).
- Confirm cross-country patterns with better data and perhaps cleaner variation,
  - Though still only correlations, since manager age related to company characteristics.
- Fairly robust correlations.
- Also broadly consistent with replacement and technology effects.

Setup

- Economy consists of continuum of product lines along the circle $\mathcal{C}$.
- Each product line has a quality q_j.
- Profits for a monopolist with a leading-edge product quality q_j:

$$\pi(q_j) = \beta q_j.$$

- Managers will be hired by monopolists to manage production and innovation in their leading-edge products.
- When a manager is born, she acquires knowledge of the average technology in the period that she is born, giving her a knowledge base of

$$\bar{q}_b \equiv \int_{\mathcal{C}} q_{jb} dj.$$

- In addition, managers of age a generate cost reductions of $f(a)\bar{q}_t$ for all firms.

Innovations

- Two types of innovations for each product line:
  1. *incremental innovations:* improvements within a given *technology cluster*.
  2. *radical innovations*: combining ideas for innovation in a new area.
- If the firm chooses incremental innovation, these arrive at the rate ξ and improve the current quality of product line j by a step size

$$\eta_n(q_j, \bar{q}_t) = [\kappa \bar{q}_t + (1-\kappa)\, q_j]\, \eta \alpha^n$$

where $\alpha < 1$ and n is the number of prior incremental innovations in this technology cluster.

Innovation: Radical Innovations

- Radical innovations start a new technology cluster based on the product line j drawn uniformly at random from $\mathcal{C}$, with productivity:

$$q_j^0 = (1 + \eta_0)\, q_j,$$

- Two types of firms: $\theta \in \{\theta_H, \theta_L\}$ where $\theta_H > \theta_L = 0$, distinguished by their "corporate culture" determining their openness to disruption and radical innovation.
  - Low type firms are unable to engage in radical innovation.
  - High type firms with the manager of cohort b, or equivalently of age a, generate a flow rate of radical innovation of

$$\Lambda\theta \frac{\bar{q}_b}{\bar{q}_t} = q_a, \tag{1}$$

    where $\Lambda < 1$ captures the institutional restrictions on radical innovation.

Equilibrium with $\kappa = 1$: Low-Type Values

- Focus on *stationary equilibrium*.
- Given Klette-Kortum structure, we can work with product-line value functions.
- Low-type value function for a product line

$$rV_L(q_j, n) - \dot{V}_L(q_j, n) =$$
$$\max_{a \geq 0} \{\pi q_j + \bar{q}_t f(a) - w_{a,t}\} + \xi \begin{bmatrix} V_L(q_j + \bar{q}_t \eta \alpha^n, n+1) \\ -V_L(q_j, n) \end{bmatrix} - \tau V_L(q_j, n$$

where τ is the aggregate creative destruction rate.

- Equilibrium managerial wage satisfy

$$w_{a,t} = \bar{q}_t f(a).$$

- Substituting this into the value function:

$$rV_L(q_j, n) - \dot{V}_L(q_j, n) =$$
$$\pi q_j^n + \xi [V_L(q_j + \bar{q}_t \eta \alpha^n, n+1) - V_L(q_j, n)] - \tau V_L(q_j, n).$$

Low-Type Values

Proposition

The value function for low types the following form

$$V_L(q_j, n) = Aq_j + B\bar{q}_t \alpha^n$$

where

$$B \equiv \frac{\xi\eta}{r - g + \tau + \xi(1-\alpha)}$$

and

$$A \equiv \frac{\pi}{\tau + r}.$$

High-Type Values

- For high-types:

$$rV_H(q_j,n) - \dot{V}_H(q_j,n) =$$
$$\max\left\{\begin{array}{c} \pi q_j + \max_{a\geq 0}\left\{\begin{array}{c} \bar{q}_t f(a) - w_{a,t} \\ +\xi\left[V_H\left(q_j + \bar{q}_t\eta\alpha^n, n+1\right) - V_H(q_j,n)\right]\end{array}\right\}; \\ \pi q_j + \max_{a\geq 0}\left\{\bar{q}_t f(a) + \Lambda\bar{q}_a\theta\mathbb{E}V_H(\bar{q}_t) - w_{a,t}\right\}\end{array}\right.$$
$$-\tau V_H(q_j,n).$$

- Here $\mathbb{E}V_H(\bar{q}_t)$ is the expected (average) value of a new product line at time t.

Managers and Innovation

- Equation (1) implies that younger managers have the comparative advantage in radical innovation.
- Then there will exist a maximum age a^* such that only managers below this age will work in firms attempting radical innovation.
- Then profit maximization for high-type firms implies for all $a < a^*$:

$$\bar{q}_t f\left(a^*\right) + \Lambda \bar{q}_{a^*} \theta_H \mathbb{E} V_H(\bar{q}_t) - w_{a^*,t} = \bar{q}_t f\left(a\right) + \Lambda \bar{q}_a \theta \mathbb{E} V_H(\bar{q}_t) - w_{a,t}.$$

and the oldest manager working for radical innovation earns

$$w_{a^*,t} = \bar{q}_t f\left(a^*\right).$$

Managerial Wages

- Hence

$$w_{a,t} = \begin{cases} \bar{q}_t f(a) & \text{for} \quad a > a^* \\ \bar{q}_t f(a) + \Lambda \theta_H [\bar{q}_a - \bar{q}_{a^*}] \mathbb{E} V_H(\bar{q}_t) & \text{for} \quad a \leq a^* \end{cases} \tag{2}$$

- Substituting into the high-type value function, we get

$$rV_H(q_j, n) - \dot{V}_H(q_j, n) = \max \left\{ \begin{array}{c} \pi q_j + \xi \left[V_H(q_j + \bar{q}_t \eta \alpha^n, n+1) - V_H(q_j, n) \right]; \\ \pi q_j + \Lambda \bar{q}_{a^*} \theta \mathbb{E} V_H(\bar{q}_t) \end{array} \right\} - \tau V_H(q_j, n)$$

High-Type Values

Proposition

The high-type value function takes the following form

$$V_H\left(q_j, n\right) = \tilde{A} q_j + \bar{q}_t \tilde{B}\left(n\right), \tag{3}$$

where

$$\tilde{A} = \frac{\pi}{r+\tau},$$

and $\tilde{B}\left(n\right)$ *is given by*

$$\left(r - g + \tau\right) \tilde{B}\left(n\right) = \begin{cases} \xi\left[\tilde{A}\eta\alpha^{n+1} + \tilde{B}\left(n+1\right) - \tilde{B}\left(n\right)\right] & \text{for } n < n^* \\ \Lambda \bar{q}_{a^*}\theta_H\left[\left(1+\eta\right)\tilde{A} + \tilde{B}\left(0\right)\right] & \text{for } n \geq n^* \end{cases},$$

where $n^* \in \mathbb{Z}_{++}$ *is the number of incremental innovations within a technology cluster at which there is a switch to radical innovation such that*

$$n^* = \left\lceil n' \right\rceil \text{ s. t. } \xi\left[\tilde{A}\eta\alpha^{n'+1} + \tilde{B}\left(n'+1\right) - \tilde{B}\left(n'\right)\right] = \Lambda \bar{q}_{a^*}\theta_H\left[\left(1+\eta\right)\tilde{A} + \tilde{B}\left(0\right)\right]$$

Stationary Equilibrium Characterization

Proposition

At time t managers with $a \geq a^*$ *("young" managers) will be hired on product lines for which firms are pursuing radical innovations, which are those operated by high-type firms and that have had more than* n^* *prior incremental innovations. Managers with* $a^* < a$ *("old" managers) are hired by firms that undertake incremental innovations.*
A higher Λ *(corresponding to the society being less restrictive towards radical innovations) will reduce* n^* *(so that a higher fraction of high-type firms will pursue radical innovation), and will increase the wages of young managers (because there is greater demand for the knowledge-base of young managers).*

Stationary Equilibrium (cont'd)

- Empirical work will be partly motivated by this proposition.
- Look at the relationship between managerial age and creative innovations across companies and countries.
  - Partly capturing the effect of firm type (more open to disruption), partly capturing the contribution of young managers, and partly capturing societal or industry-level variations in Λ affecting radical innovations and organizations of firms.

General Equilibrium

- Determine aggregate growth rate and stationary distribution of firms.
- Equilibrium rate of entry x (exogenous or endogenous). Entrants replace an existing product line drawn uniformly at random, and then realized that type, high or low, with probability ζ and $1-\zeta$.
- Define aggregate creative destruction rate as

$$\tau = x + \int_0^{a^*} \Lambda \bar{q}_a \theta dF(a).$$

- Decomposed into creative destruction rates from low- and high-type firms:

$$\tau^L = x(1-\zeta) \quad \text{and} \quad \tau^H = x\zeta + \int_0^{a^*} \Lambda \bar{q}_a \theta_H dF(a).$$

- Clearly $\tau = \tau^H + \tau^L$.

Stationary Distributions

- Denote the fraction of product lines occupied by high- and low-type firms with n prior incremental innovations by μ_n^H and μ_n^L.
- Naturally
$$\sum_{n=0}^{\infty}\left[\mu_n^H+\mu_n^L\right]=1.$$
- Stationary distributions for high types given by

$$\begin{array}{rclll}
\underline{\text{Outflow}} & & \underline{\text{Inflow}} & & \\
(\tau+\xi)\,\mu_0^H & = & \tau^H & \text{for} & n=0 \\
(\tau+\xi)\,\mu_n^H & = & \xi\mu_{n-1}^H & \text{for} & n^*>n>0 \\
\tau\mu_{n^*}^H & = & \xi\mu_{n^*-1}^H & \text{for} & n=n^* \\
\mu_n^H & = & 0 & \text{for} & n>n^*
\end{array}$$

Stationary Distributions (continued)

- For low types:

$$
\begin{array}{rcl}
\underline{\text{Outflow}} & & \underline{\text{Inflow}} \\
(\tau+\xi)\,\mu_0^L & = & \tau^L \qquad \text{for} \quad n=0 \\
(\tau+\xi)\,\mu_n^L & = & \xi\mu_{n-1}^L \qquad \text{for} \quad n>0
\end{array}
$$

- These can be solved for the following geometric distributions for high- and low-type firms:

$$
\begin{aligned}
\mu_n^L &= \left[\frac{\xi}{\tau+\xi}\right]^n \frac{\tau^L}{\tau+\xi} \text{ and} \\
\mu_n^H &= \begin{cases} \left[\frac{\xi}{\tau+\xi}\right]^n \frac{\tau^H}{\tau+\xi} \text{ for } n<n^* \\ \left[\frac{\xi}{\tau+\xi}\right]^n \frac{\tau^H}{\tau} \text{ for } n=n^* \end{cases}.
\end{aligned}
$$

Aggregate Growth Rate

- Growth driven by quality improvements. That is,

$$Y_t = \frac{L}{1-\beta}\bar{q}_t.$$

- During $\Delta t > 0$, the average quality evolves according to the following law of motion:

$$\bar{q}_{t+\Delta t} = \bar{q}_t + \eta\bar{q}_t\left[x + \mu^H_{n^*}Q\Lambda\theta\right]\Delta t + \bar{q}_t\xi\eta\Delta t\left[\sum\nolimits_0^{n^*}\mu^H_n\alpha^n + \sum\nolimits_0^{\infty}\mu^L_n\alpha^n\right] + o(\Delta$$

where $Q \equiv \frac{1}{F(a^*)}\int_0^{a^*}\bar{q}_a dF(a)$

- Then, the stationary equilibrium aggregate growth rate is:

$$g = \eta\left[x + \mu^H_{n^*}Q\Lambda\theta\right] + \xi\eta\left[\sum\nolimits_0^{n^*}\mu^H_n\alpha^n + \sum\nolimits_0^{\infty}\mu^L_n\alpha^n\right].$$

Equilibrium with $\kappa < 1$

- Insights similar with $\kappa < 1$, but some new results.

Proposition

Consider the economy with $\kappa < 1$. Then, for a product line with current quality q operated by a high-type firm, the manager will be younger and will pursue radical innovation when the number of prior incremental innovations is greater than or equal to $n_t^*(q)$, where $n_t^*(q)$ is increasing in q. That is, a high-type firm is more likely to pursue radical innovation when its current productivity is lower and the number of its prior innovations in the same cluster is higher.

Data Sources

- USPTO Utility Patents Grant Data (PDP)
- Compustat North American Fundamentals - Annual
- Executive Compensation Data (Execucomp)
- The Careers and Co-Authorship Networks of U.S. Patent-Holders
- National Culture Dimensions
- Worldwide Governance Indicators of the World Bank.
- Barro-Lee data set
- World Bank's World Development Indicators database.

Measures of Creative Innovation

- Focus on five different measures of “creative innovation”:
  1. **Innovation Quality:** average number of claims for patent
  2. **Fraction of superstars**: fraction very highly cited patents.
  3. **Tail innovations**: citations at the tail vs. median

  $$Tail\_innv = V_{ct}\left(p, q\right) \equiv \frac{s_{ct}\left(p\right)}{s_{ct}\left(q\right)}$$

     where $s_{ct}\left(p\right)$ is the fraction of patents that are above the p^{th} percentile of the year t distribution that are from company or country c, and we take $p = 99$ and $q = 50$.
  4. **Originality**: how original is a patent based on its citations

  $$\text{Originality}_c = 1 - \sum_{i \in I} s_{ij}^2$$

     where s_{ij} is the share of patent j's cites in tech class i.
  5. **Diversity of innovation**: how much does innovation follow existing paths.

Measures of Creative Innovation (cont'd)

- Diversity of Innovations:
  - Let $i = 1, 2, ...I$ denote a technology class and $s_{ij} \in (0, 1)$ denote the share of backward citations of patent j given to patents in technology class i ($\sum_{i=1}^{I} s_{ij} = 1$).
  - Then *distance* from the previous generation patents:

$$d_j = \frac{1}{\left\|\mathcal{J}_j\right\|} \sum_{j' \in \mathcal{J}_j} \frac{1}{I} \sum_{i=1}^{I} \left(s_{ij} - s_{ij'}\right)^2$$

    where $\mathcal{J}_j$ is the set of all patents cited by j.
  - **Our measure**: average distance of all patents from firm f or country c in year t:

$$Diversity\_innv = d_{ct} = \frac{1}{J_t} \sum_{j \in c}^{J_t} d_{jt}$$

    (where $J_t =$ the total number of patents from country or company c in year t).

Country-Level Results

- All regressions weighted by total patent counts of the country.
- They include: log GDP per capita, years of secondary education, and log total patent counts.
- Also robust standard errors in parentheses.

Country-Level Results: Individualism

Table 2: Baseline Regressions

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
	Panel A: Individualism				
individualism	4.75	12.1	118	7.84	4.53
	(2.38)	(2.61)	(30.2)	(.615)	(1.60)
log income	-1.11	-3.25	-24.7	-.876	.434
	(1.37)	(1.49)	(18.9)	(.510)	(1.55)
2ndary yrs sch	-.635	-.478	-4.89	.303	.470
	(1.19)	(1.31)	(15.4)	(.348)	(.668)
log patents	1.51	1.47	14.8	.389	-.832
	(.487)	(.509)	(6.29)	(.188)	(.354)
R^2	0.71	0.85	0.79	0.91	0.48
N	50	50	48	50	50

Magnitudes

- Moving from the country at the 25th percentile of individualism in our sample to that to the 75th percentile (from 0.19 to 0.73) increases average citations by 17% relative to the weighted sample mean (14.5).
- Quantitative magnitudes for originality and diversity innovations similar.
- For superstar fraction, quantitative magnitudes are larger: 82% and 67%.

Country-Level Results: Uncertainty Aversion

Table 2: Baseline Regressions

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
	Panel B: Uncertainty Avoidance				
uncertainty av	-8.12	-15.8	-159	-8.80	-2.71
	(2.88)	(3.06)	(33.8)	(1.32)	(2.36)
log income	-.264	-1.38	-6.12	.238	.928
	(1.13)	(.604)	(9.85)	(1.04)	(2.37)
2ndary yrs sch	-.922	-.406	-4.91	.595	1.03
	(1.12)	(1.26)	(14.5)	(.397)	(.643)
log patents	1.57	1.60	16.2	.462	-.808
	(.431)	(.476)	(5.97)	(.269)	(.378)
R^2	0.78	0.88	0.83	0.86	0.32
N	50	50	48	50	50

Country-Level Results: Average Manager Age

Table 2: Baseline Regressions

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
Panel C: Average Manager Age					
avg manager age	-.463	-1.16	-11.2	-.687	-.343
	(.217)	(.245)	(2.69)	(.081)	(.172)
log income	-.425	-1.55	-8.28	.203	1.11
	(1.31)	(1.16)	(15.8)	(.610)	(2.01)
2ndary yrs sch	-1.16	-1.77	-16.9	-.303	.313
	(1.44)	(1.66)	(18.9)	(.528)	(.793)
log patents	2.08	2.91	28.7	1.23	-.409
	(.680)	(.762)	(9.13)	(.300)	(.363)
R^2	0.71	0.86	0.79	0.88	0.43
N	37	37	37	37	37

Magnitudes

- Moving from the country at the 25th percentile of average manager age in our sample to the 75th percentile (from 51.4 to 54.5) reduces average citations by 10% relative to the (weighted) sample mean (14.5).
- Again, moving from the country at the 25th percentile to the 75th percentile reduces:
  - superstar fraction by 45%
  - tail innovations by 36%
  - originality by 8%
  - diversity by 3%

  all relative to their (weighted) sample means.

Country-Level Results: Rule of Law

Table 2: Baseline Regressions

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
			Panel D: Rule of Law		
rule of law	15.3	30.8	307	15.5	3.92
	(7.60)	(12.9)	(130)	(7.82)	(7.62)
log income	-2.75	-6.35	-55.7	-2.32	.210
	(1.46)	(2.57)	(25.9)	(2.02)	(2.58)
2ndary yrs sch	-.567	.225	1.66	1.04	1.22
	(1.26)	(1.85)	(20.4)	(.983)	(.817)
log patents	1.95	2.37	23.8	.841	-.712
	(.693)	(1.02)	(11.4)	(.525)	(.394)
R^2	0.68	0.70	0.66	0.69	0.28
N	54	54	52	54	54

Country-Level Results:Distance to Frontier (I)

Table 5: Stock of Knowledge, Opportunity Cost and Creative Innovations

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
	Panel A: Individualism				
individualism	6.94	15.1	149	8.96	3.69
	(1.55)	(1.39)	(18.6)	(.409)	(1.34)
individualism ×	3.52	4.72	48.8	1.79	-1.33
log patents	(.926)	(.763)	(10.9)	(.298)	(.632)
log patents	1.26	1.14	11.5	.264	-.739
	(.338)	(.274)	(3.92)	(.141)	(.305)
R^2	0.81	0.94	0.88	0.94	0.52
N	50	50	48	50	50

Country-Level Results:Distance to Frontier (II)

Table 5: Stock of Knowledge, Opportunity Cost and Creative Innovations

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
	Panel D: Rule of Law				
rule of law	31.2	70.6	682	16.5	22.5
	(12.9)	(15.7)	(177)	(8.73)	(10.6)
rule of law ×	5.38	13.5	127	-.298	6.33
log patents	(2.81)	(3.49)	(41.2)	(.946)	(2.17)
log patents	1.76	1.88	19.2	.858	-.942
	(.590)	(.735)	(8.84)	(.541)	(.362)
R^2	0.72	0.83	0.76	0.69	0.44
N	54	54	52	50	54

Firm-Level Results

- Use average manager age (of top management) as a proxy for a corporate culture or approach more open to disruption.
  - In line with the model: firms targeting radical innovation are more likely to hire younger managers with more up-to-date knowledge base.
  - Only companies with relatively open corporate cultures will allow young managers to rise up the hierarchy.
- All regressions are weighted by patent counts and include: firm age, log employment, log sales and log patent counts.
- Robust standard errors are in parentheses.

Firm-Level Results

Table 6: Baseline Regressions: Firm Level

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
avg manager age	-.381	-.380	-9.91	-.322	-.201
	(.192)	(.179)	(4.32)	(.121)	(.098)
firm age	-.054	-.061	-.856	.007	-.012
	(.052)	(.054)	(.596)	(.024)	(.031)
log employment	-2.74	-3.97	-53.1	-1.63	.333
	(1.37)	(1.90)	(25.9)	(1.03)	(1.29)
log sales	2.86	3.34	48.0	1.41	-1.10
	(1.43)	(1.89)	(24.6)	(.964)	(1.76)
log patents	.280	.278	10.3	.377	.628
	(.611)	(.844)	(13.5)	(.468)	(.663)
R^2	.64	.59	.43	.69	.66
N	1,120	1,120	1,009	1,120	1,119

Magnitudes

- Economically, as well as statistically significant and similar to the cross-country magnitudes for average manager age..
- Moving from the 75th percentile of the average manager age distribution to the 25th percentile increases average citations by 13.2% relative to the weighted sample mean.
- For superstar fraction, the same number is 21.3%.
- For tail innovations, 51.3%.
- For the originality index, 8.6%
- For diversity of innovations, 5.1%.

Robustness: Alternative Specifications (I)

Table 8: Robustness (Alternative Specifications)

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
	Panel A: Robustness with SIC3 Sector Controls				
avg manager age	-.463	-.500	-10.1	-.152	-.094
	(.141)	(.144)	(3.39)	(.147)	(.106)
R^2	.56	.51	.35	.58	.59
N	1,120	1,120	1,009	1,120	1,119
	Panel B: Robustness with Additional Firm Controls				
avg manager age	-.386	-.384	-9.98	-.325	-.196
	(.192)	(.177)	(4.12)	(.121)	(.095)
R^2	.65	.60	.43	.69	.67
N	1,110	1,110	1,003	1,110	1,109

Robustness: Alternative Specifications (II)

Table 8: Robustness (Alternative Specifications)

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
			Panel C: Robustness with R&D Intensity Control		
avg manager age	-0.383	-0.405	-10.337	-0.319	-0.216
	(0.193)	(0.184)	(4.149)	(0.126)	(0.102)
R^2	0.66	0.60	0.45	0.71	0.68
N	860	860	814	860	860
			Panel D: Robustness with CEO Age		
CEO age	-.210	-.221	-6.82	-.177	-.124
	(.100)	(.115)	(2.50)	(.079)	(.058)
R^2	.66	.60	.44	.69	.67
N	1,078	1,078	982	1,078	1,077

Stock of Knowledge, Opportunity Cost and Creativity of Innovations

Table 10: Stock of Knowledge, Opportunity Cost and Creative Innovations

	Innov Quality	Superstar Frac	Tail Innov	Originality	Innov Diversity
avg manager age	-.380	-.313	-6.85	-.246	-.090
	(.163)	(.181)	(2.93)	(.086)	(.095)
log sales	2.94	3.48	54.6	1.61	-.808
	(1.41)	(1.86)	(25.4)	(.925)	(1.47)
log patents	.096	.113	.241	.076	.174
	(.504)	(.824)	(11.2)	(.420)	(.560)
avg manager age x log patents	-.077	-.073	-4.37	-.130	-.195
	(.108)	(.097)	(2.04)	(.049)	(.076)
avg manager age x log sales	.032	.093	4.60	.125	.185
	(.106)	(.132)	(2.35)	(.057)	(.103)
R^2	.65	.59	.44	.69	.67
N	1,120	1,120	1,009	1,120	1,119

Modeling Technological Leadership

- Acemoglu, Robinson and Verdier (2012): consider a model of international technological diffusion, where countries can benefit from the world technology frontier on the basis of limited innovations or engage in more radical innovations that push the world technology frontier forward.
- To encourage more radical innovations, society needs to provide greater rewards entrepreneurs (more entrepreneurial inequality) which is costly.
- Main result: the world equilibrium will often be asymmetric, one or a few countries undertaking the bulk of the radical innovations with a more "cutthroat" style capitalism, while followers can adopt a more "cuddly" style capitalism.
    - Followers may in fact be better off, because of better risk sharing. But this is made possible by the fact that they are "free riding" on the more radical innovations of the technological leader.

The Burden of Knowledge

- Jones (2009): creativity becomes harder over time. This is because there is more knowledge to be absorbed before becoming creative in every field.
- Model: the burden of knowledge creates a "anti-scale effect": more knowledge and bigger size may have the downside of more absorption be necessary before innovation.
- Evidence: research takes place more in teams and takes longer now than in the past.

Conclusion

- The tail of innovations might be much more important for knowledge creation and growth, and we still only have a limited understanding of what determines these tail innovations.
- Much that can be done theoretically and empirically on creativity of the nations and the effect of economic trade-offs, social attitudes and institutions on creativity.
- Important area to be explored: internal organization of firms and creativity.