Fluid Intelligence and Experience in Invention: Complementarity in Age-Heterogeneous Teams

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AEA Session: Life on the Edge
January 3, 2020

We are grateful to the Alfred P. Sloan Foundation for funding this research.
Motivation

Consider implications of rate and nature of invention in life course
  • Impact of different kinds of cognitive abilities over the life course
  • Delayed retirement age

Examine the life course of innovation in a broader context
  • Prior work looked at small and unusual groups
  • Patents provide rich information to examine the rate and the qualitative nature of invention
  • Invention is an economically important and reasonably widespread cognitive task
Roadmap

1. Previous Work
2. Age & Cognitive Ability Theory
3. Data
4. Rate of Patenting Over Life Course
5. Patenting Attributes Over Life Course
6. Age Composition of Teams & Patenting Attributes
7. Summary
8. Limitations & Future Work
Age & Creativity

• Focused on small and unusual groups
  • Major scientific accomplishments/important inventions (Jones, 2009; Jones & Weinberg, 2011; surveyed in Jones, et al 2014)
  • Nobel Prize Winners (Jones, 2010)
  • Artists (Galenson, 2000)
  • Health Sciences Publications (Yu et al 2019)
Age & Cognitive Ability

Shifting balance of gains and losses in cognitive abilities throughout adulthood (Baltes et al., 2006)

Age increases experience-based knowledge
(pragmatics or crystallized abilities - Gc)

Age decreases ability to process new knowledge and information quickly and efficiently (Hartshorne & Germine, 2015; Salthouse, 2009; Schaie, 2012)

(mechanics or fluid abilities - Gf)
Conceptual Model of Cognitive Abilities over Life Course
Hypotheses: Inventor Age & Patent Characteristics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Definition</th>
<th>Predicted relationship to age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patenting Rate</td>
<td>Number of successful applications/year</td>
<td>Inverted U</td>
</tr>
<tr>
<td>Forward Citations</td>
<td>Number of citations received from later patents</td>
<td>Inverted U</td>
</tr>
<tr>
<td>Disruptiveness</td>
<td>Changing the trajectory of technology (Funk and Owen-Smith)</td>
<td>Decreasing</td>
</tr>
<tr>
<td>Backward Citations</td>
<td>Number of citations made to previous patents</td>
<td>Increasing</td>
</tr>
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<td>Independent Claims</td>
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Data: Patent Data

- Patentsview (USPTO) database of patents and inventors 1976-2018
- 3,648,663 patents with an inventor residing in the U.S.
- 1,858,516 unique inventors (names disambiguated)
- Gender assigned based on first name and date of birth using The Gender Package by Lincoln Mullen (https://github.com/ropensci/gender)
Data: U.S. Inventor Ages

• Websites: Radaris, Spokeo, Beenverified and Peoplefinders provide ages
• Scrape based on First Name, Middle Name, Last Name, City, State
• Require at least match on first and last name
• 66.4-72.5% of inventors matched on each web site
• 92.6% of inventors matched on at least one web site
• After data cleaning 82% of inventors were included
• Most inventors patent once, but 300,000+ patent >1 over life course
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Patenting Rate over the Life Course

- Over a *given* inventor’s life, how does their patenting activity vary (on average)
- Our longitudinal data allows us to do this

Do we still see an inverse U-shape in inventive activity?
Estimating Patent Productivity Over the Life course

\[ Pro_{ia} = \beta \text{Age}_{ia} + \alpha_i + \varepsilon_{ia} \]

Where inventor, i, patents at age, a

- \( Prod \) is the normalized patenting rate
  - Patent rates normalized by application year
    - patent counts are divided by the number of patents per capita in the application year, and then normalized to 2012
    - e.g. in 1974 there were 300 patents per million people and in 2012 there were 856, so each 1974 patents is treated as \( 856/300=2.85 \) patents
  - \( Prod \) is full count of patents or fractionalized patents (1/team size)
Patenting Rate: Over Life Course by Gender

Cross Section Data
Patenting Rate: Estimated Effect

Graph showing the average patenting activity across different age groups, comparing males and females.
Patenting Rate: Previous Work

Jones, 2010
Patenting Rate: Previous Work

Jones, 2010
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Decline in fluid intelligence and increase in crystallized intelligence suggest inventors will produce different kinds of inventions as they age.

\[ Q_p = \beta A_{ge_{pi}} + \alpha_i + \varepsilon_{pi} \]

Q is an attribute for patent, p. Age is the age at which the inventor, i, applied for that patent.

Hypothesis tests are most straightforward for patents with just one inventor (‘solo’ patents).
Solo-inventor Patents
Decreases with Age: Forward Citations
Solo-inventor Patents
Decreases with Age: Disruptiveness
Solo-inventor Patents
Increases with Age: Backward Citations
Solo-inventor Patents
Increases with Age: Independent Claims
# Summary of Attribute Predictions

<table>
<thead>
<tr>
<th>Metric</th>
<th>Prediction</th>
<th>Actual</th>
<th>Confirmed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward</td>
<td>Inverted U</td>
<td>Decreasing</td>
<td></td>
</tr>
<tr>
<td>Disruptiveness</td>
<td>Decreasing</td>
<td>Decreasing</td>
<td>✓</td>
</tr>
<tr>
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<td>Increasing</td>
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Inventor Team Participation by age & gender

- Team participation slightly declines over life course
- Team size doesn’t change over life course
- Average team size is 4-5 people
- Women tend to participate in teams more
Age Composition of Teams

Hypothesis: if $G_f$ and $G_c$ are both important for an attribute, then the abilities of inventors of different ages might be complementary when brought together on a given team.

Do age-heterogeneous teams produce higher level of attributes of patents than inventor teams of any one age?

Not clear we would expect complementarity given solo-inventor results.
Age Composition of Teams

Age Definitions

• Younger <35
• Middle-aged 35-49
• Older 50+

Team Compositions

• Younger Only
• Middle Only
• Older Only
• Younger & Older
• Younger & Middle
• Middle & Older
• All Ages
Age-heterogeneous teams

\[ Q_p = \beta_1 \text{AgeComp}_{pj} + \beta_2 \text{FShare}_p + \beta_3 \text{Teamsizes}_p + \beta_4 \text{Field}_{pf} + \beta_5 \text{Yr}_{pt} + \alpha_i + \epsilon_p \]

- Patent as the unit of observation
  - Team size (up to 8 members)
  - Dummies for age mixes: all younger, younger and middle, middle and older, all older, all ages (all middle is excluded group)
  - Fraction of team members who are female (FShare)
  - Year, inventor and technology field (NBER) fixed effects
  - Apply this to all patents and subset of data (Medical Prep & Semiconductors)
Age Heterogeneity & Forward Citations
Age Heterogeneity & Forward Citations

Medical Prep

Semiconductor
Age Heterogeneity and Disruptiveness

![Graph showing estimated disruptiveness across different categories]
Age Heterogeneity and Backward Citations
Age Heterogeneity and No. of independent Claims

Estimated No. Ind. Claims

Solo-Y  Solo-M  Solo-O  Y  Y&M  M  M&O  O  Y&O  All  F-Share
## Summary of Age Composition

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<thead>
<tr>
<th>Metric</th>
<th>Highest Team Composition</th>
<th>Note</th>
</tr>
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<tbody>
<tr>
<td>Forward</td>
<td>Younger</td>
<td>Female Share</td>
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<tr>
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<td>Ind. Claims</td>
<td>Older</td>
<td>Female Share</td>
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<tr>
<td>Fields</td>
<td>Similar to Overall Trends</td>
<td></td>
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Limitations

- Team Formation
  - No observation on the ‘quality’ of teams that don’t get a patent
  - Inventors of different ages have different team participation patterns
  - Patent attribute is a function of team size

- Selection of invention characteristics
  - “Best” inventors may be more likely to remain active in later life
  - Attrition due to becoming a manager or changing jobs

- Inclusion of inventor fixed effects controls for selection to first order, but still not a causal model
Summary

Rate of Patenting
• Cross-sectional and within-inventor patenting rates are similar, peaking at around the late 30s for both women and men.

Patenting Attributes
• Experienced based patent attributes (Backward citations) peak later in life
• Novelty based patent attributes (Forward citations and disruptiveness) peaked at earlier ages
• Number of Independent Claims increased with Age (contrary to our predictions)

Age Composition & Teams
• No complementarity effect
• Similar trends as in solo-inventors results
  • Older teams are effective at backward citations & number of claims
  • Younger teams are effective disruptors & forward citations
Thank You!

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Future Research

• Modelling team formation and exit from patenting
• Distinguish age and experience
• Merge with other data to explore effects of education and other attributes
• Data set will be made public after cleaning is completed
Underway

- Likely that age is measured with error, and possibly non-randomly missing
  - Multiple-overimputation (Blackwell, Honaker and King, 2012) is a procedure that treats missing data and mismeasured data on a continuum
- Further estimation methods for robustness
Distribution of Observed Lifetime Patents Across Inventors
Unlike publications and research grants, age of first patent has NOT been rising.
Cohort: 1946-1956
Rate of Patenting by Tech Field: Women
Rate of Patenting by Tech Field: Men