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

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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)

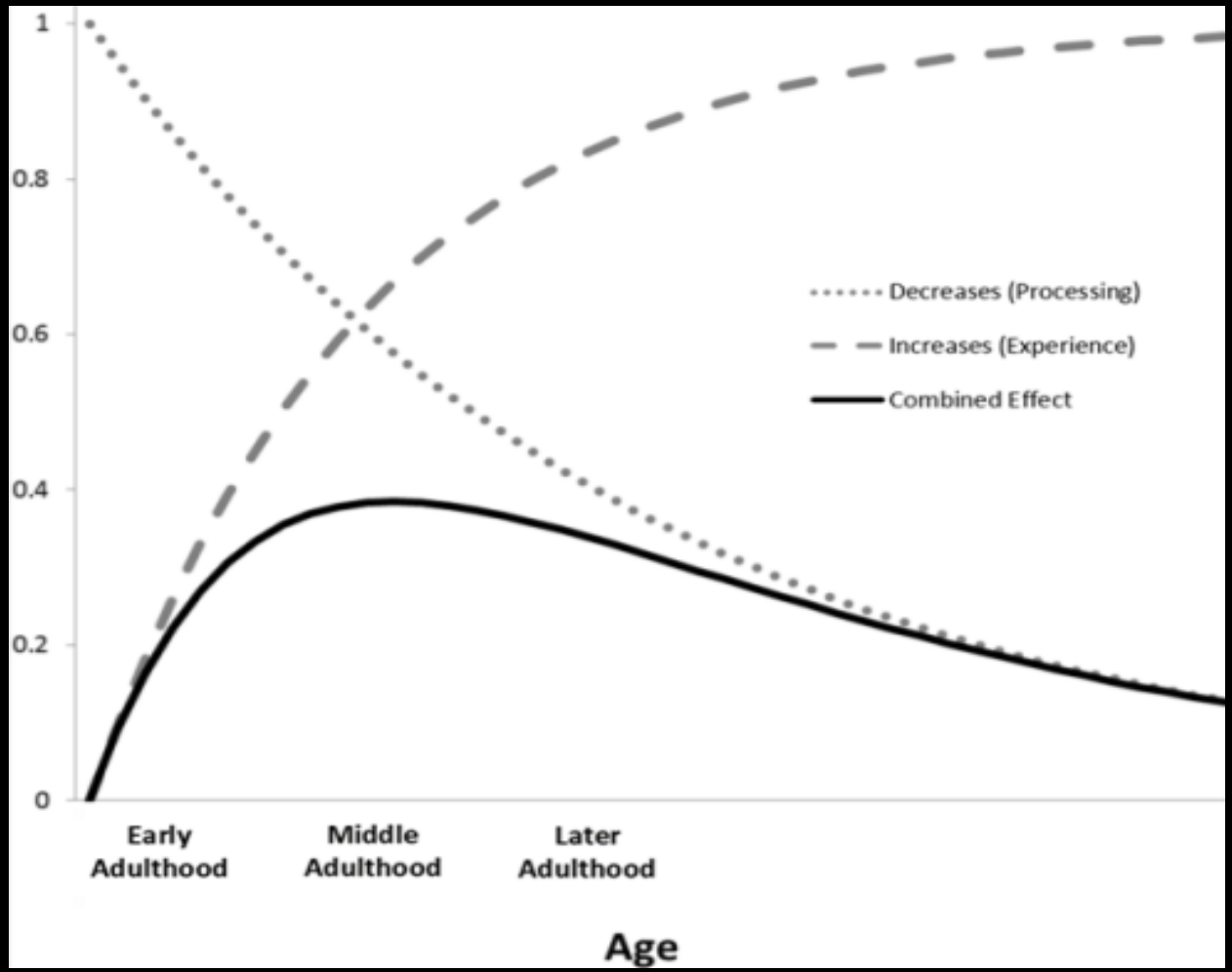
Age **increases experience-based knowledge**

(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

Metric	Definition	Predicted relationship to age
Patenting Rate	Number of successful applications/year	Inverted U
Forward Citations	Number of citations received from later patents	Inverted U
Disruptiveness	Changing the trajectory of technology (Funk and Owen-Smith)	Decreasing
Backward Citations	Number of citations made to previous patents	Increasing
Independent Claims	Number of independent claims	Inverted U

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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?

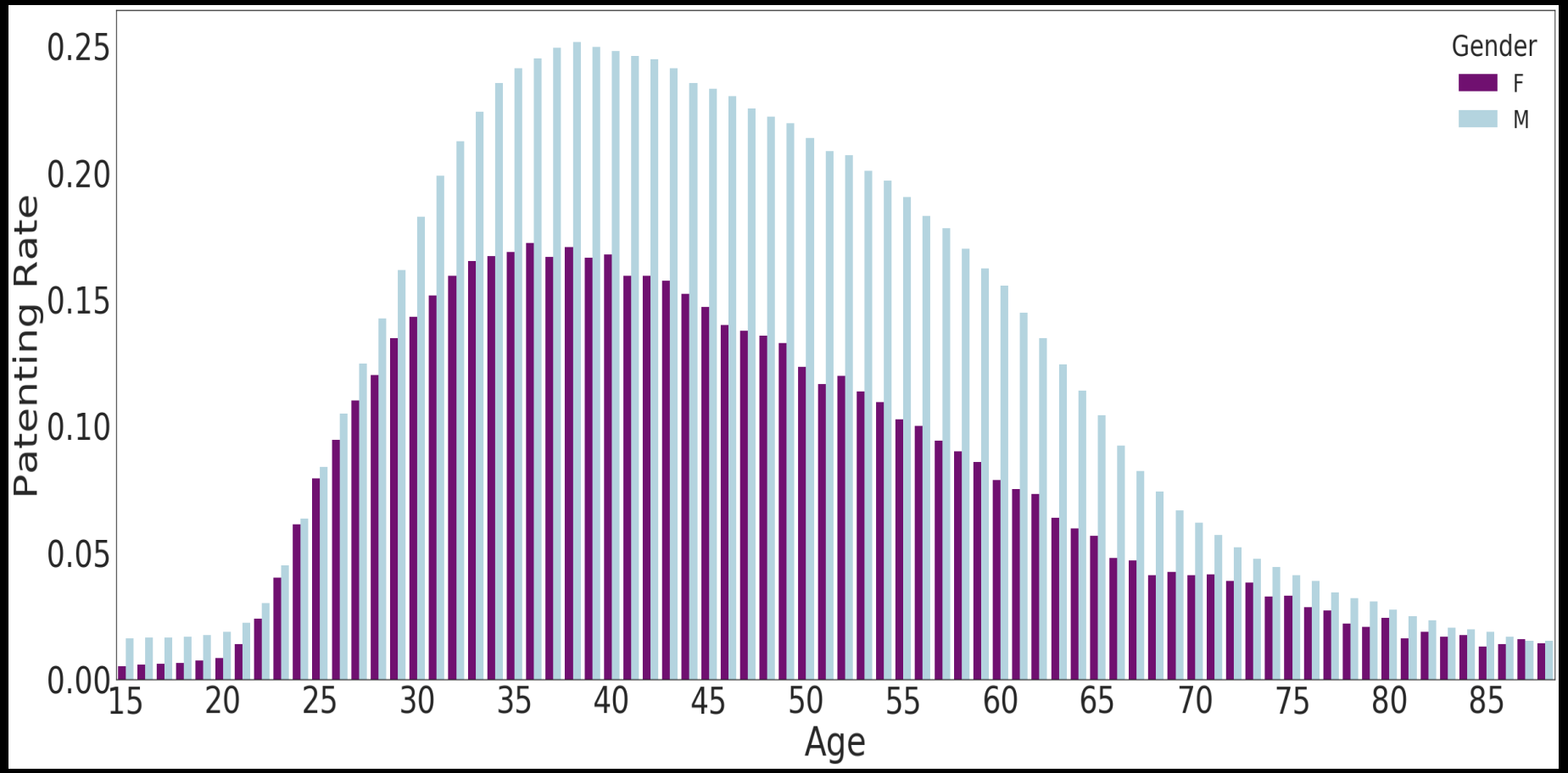
Estimating Patent Productivity Over the Life course

$$Prod_{ia} = \beta Age_{ia} + \alpha_i + \varepsilon_{ia}$$

Where inventor, i, patents at age, a

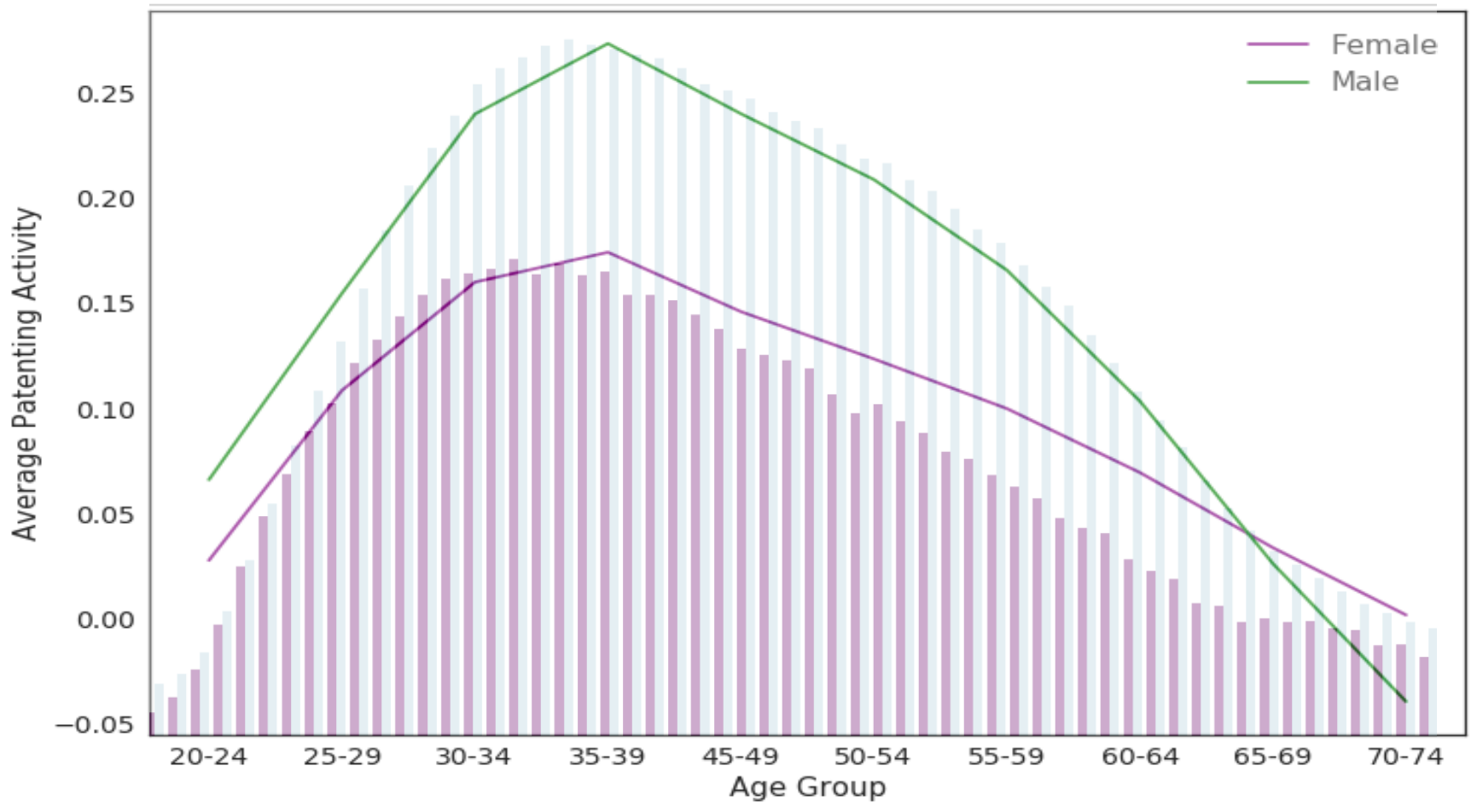
- *Prod* is the normalized patenting rate
  - Patent rates normalized by application year
    - patent counts are divided by the number of patents per capita in the application year, and then normalized to 2012
    - e.g. in 1974 there were 300 patents per million people and in 2012 there were 856, so 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

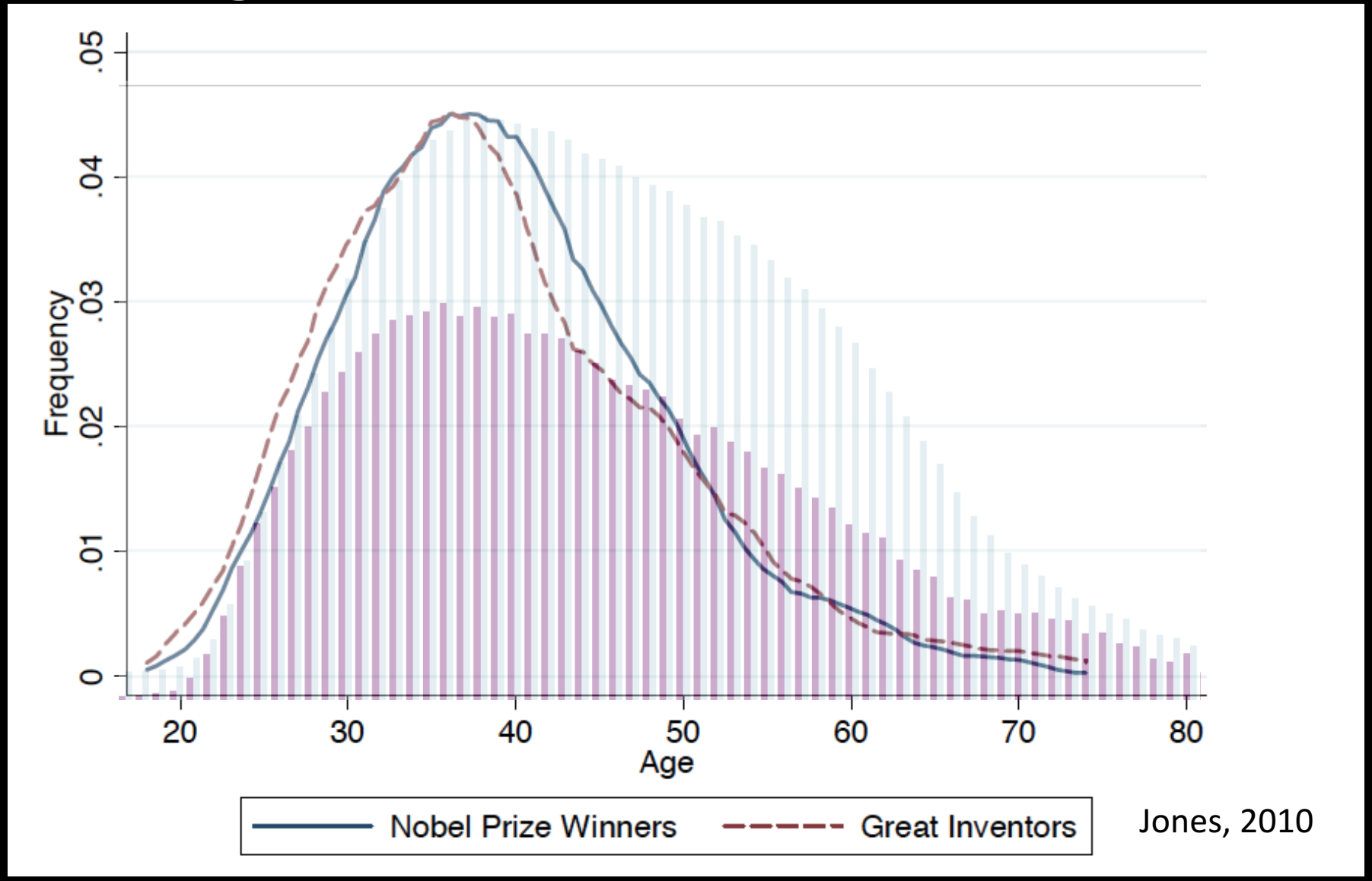


Cross Section Data

Patenting Rate: Estimated Effect

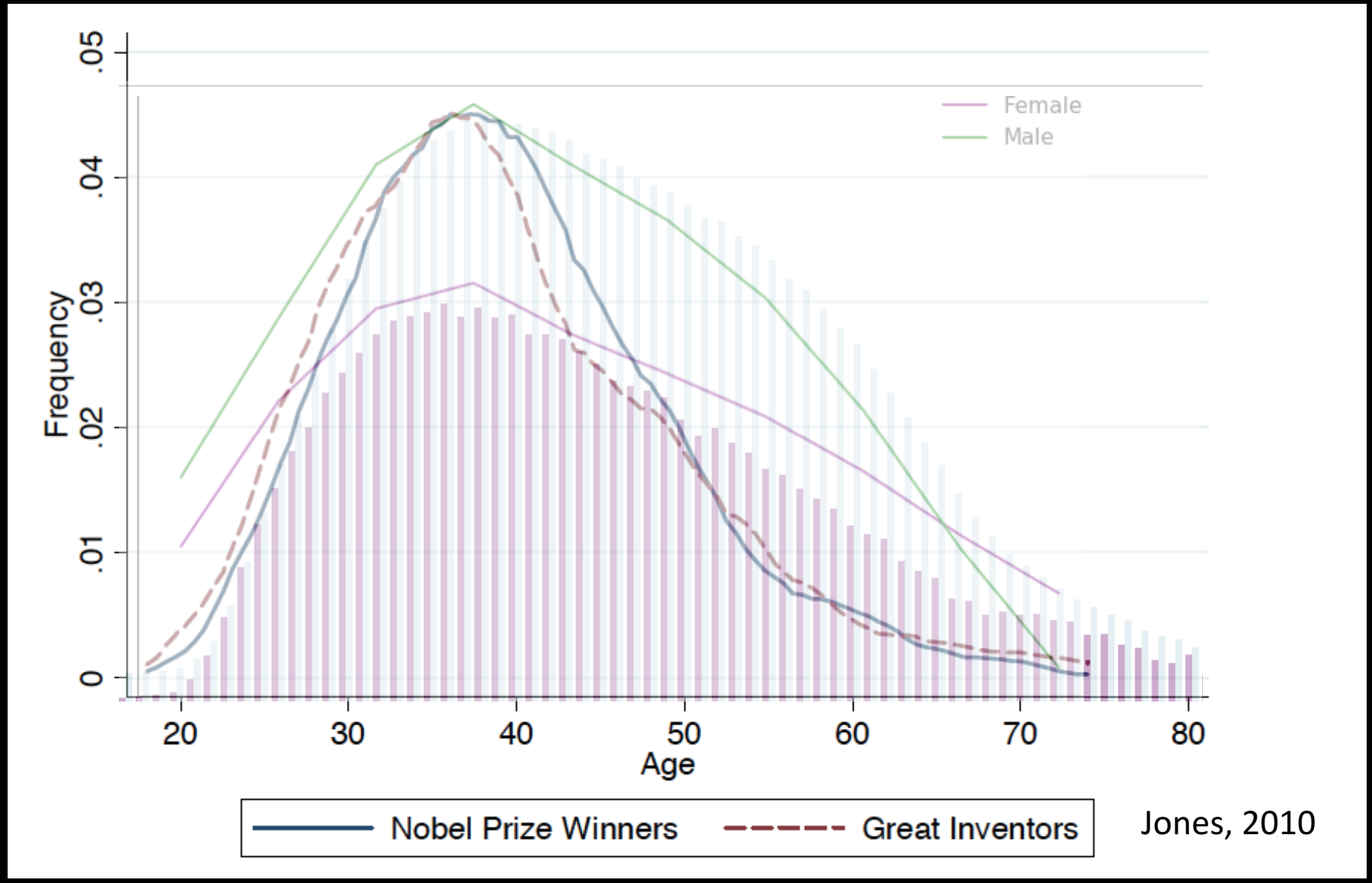


Patenting Rate: Previous Work



Jones, 2010

Patenting Rate: Previous Work



Jones, 2010

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Patenting Attributes & Life Course

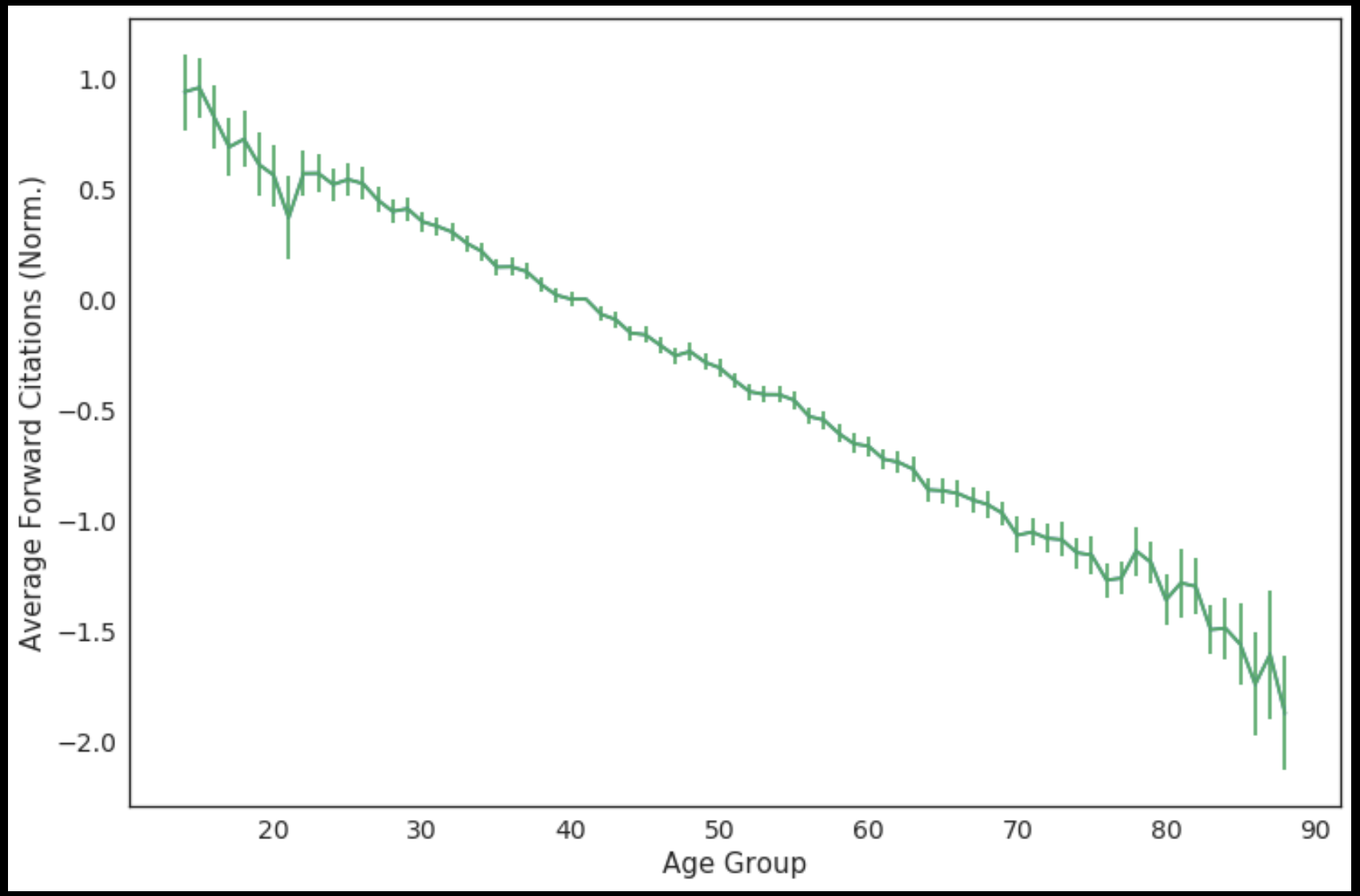
Decline in fluid intelligence and increase in crystallized intelligence suggest inventors will produce different kinds of inventions as they age

$$Q_p = \beta Age_{pi} + \alpha_i + \varepsilon_{pi}$$

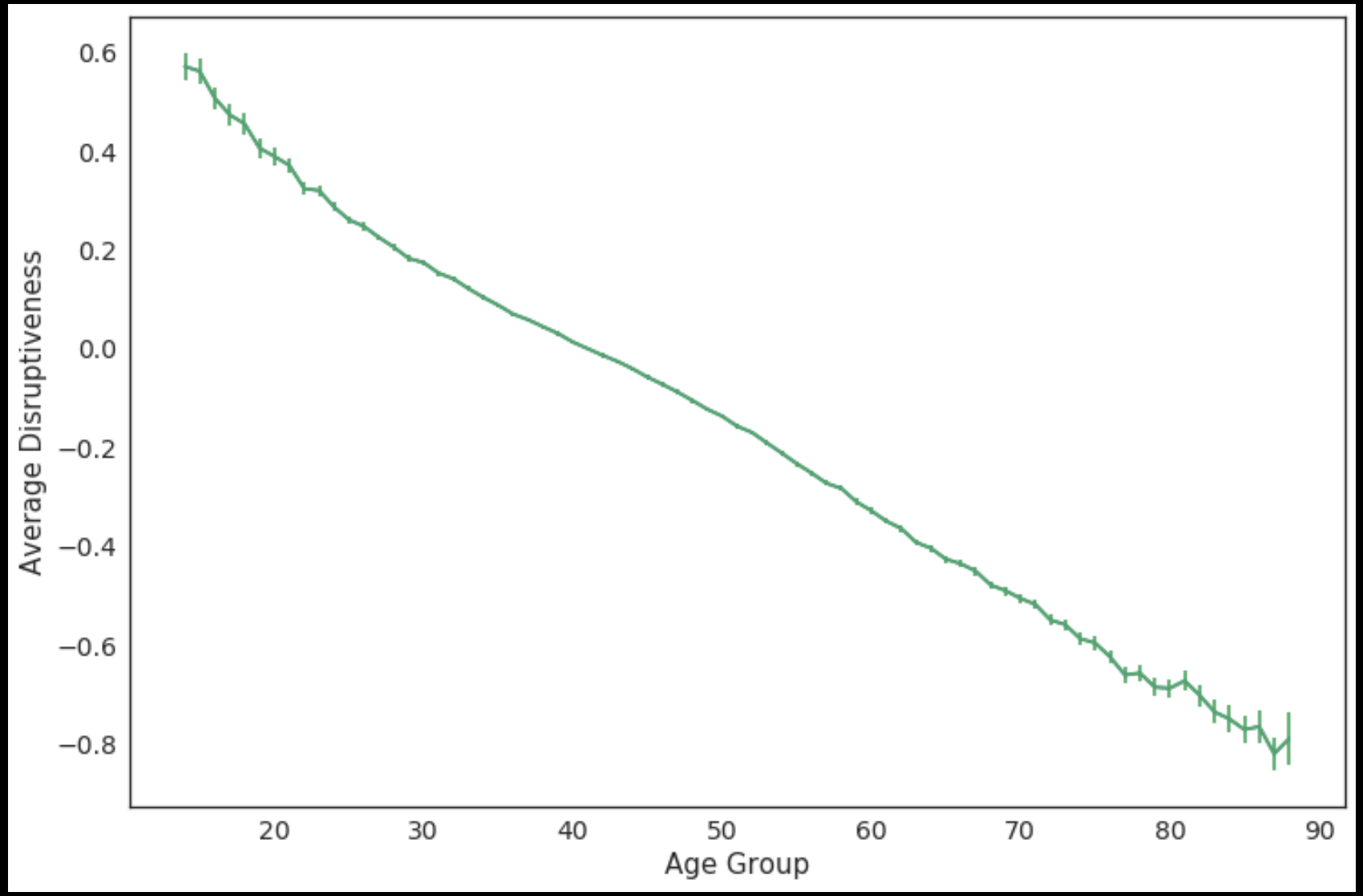
Q is an attribute for patent, p. Age is the age at which the inventor, i, applied for that patent

Hypothesis tests are most straightforward for patents with just one inventor (‘solo’ patents)

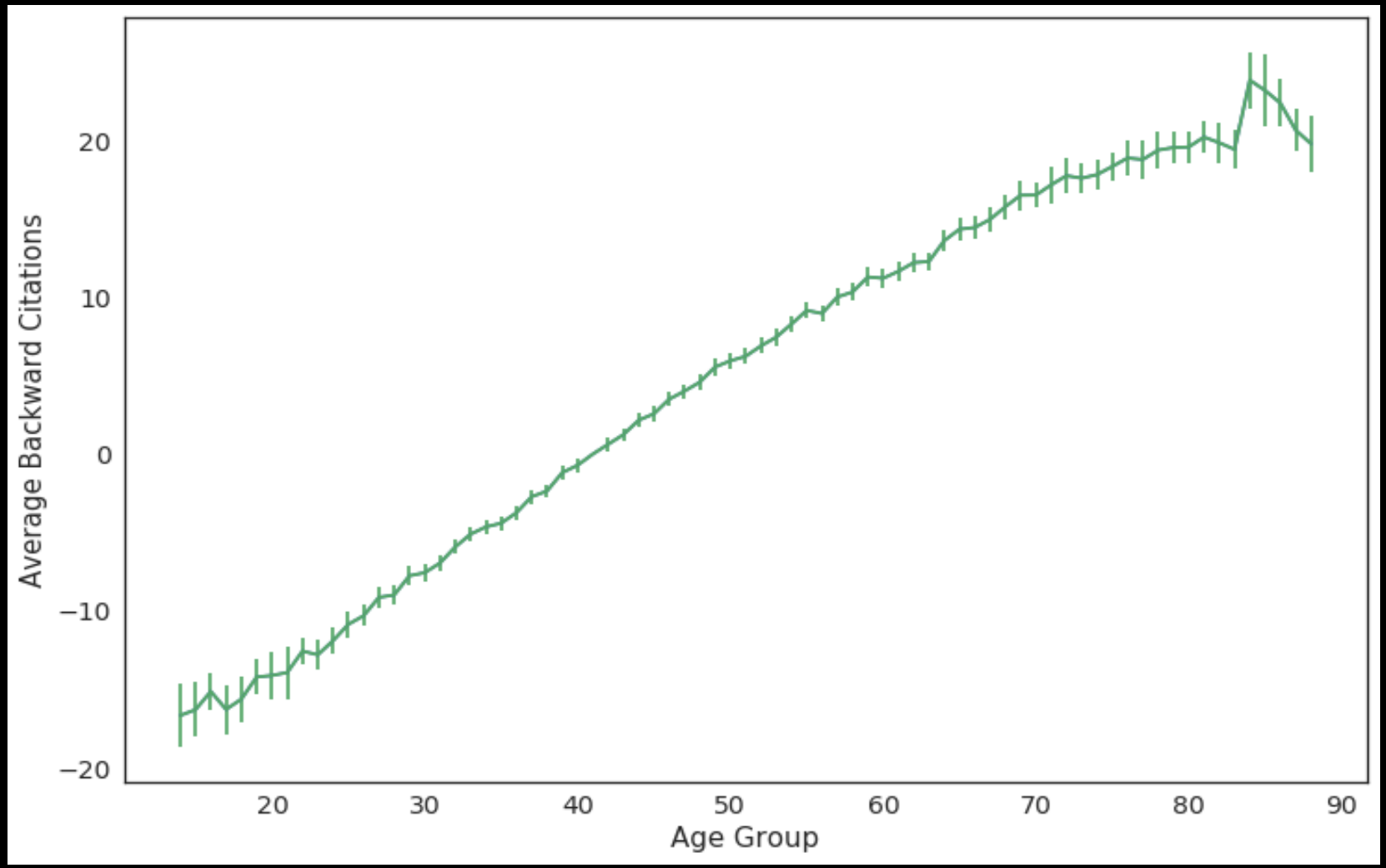
Solo-inventor Patents
Decreases with Age: Forward Citations



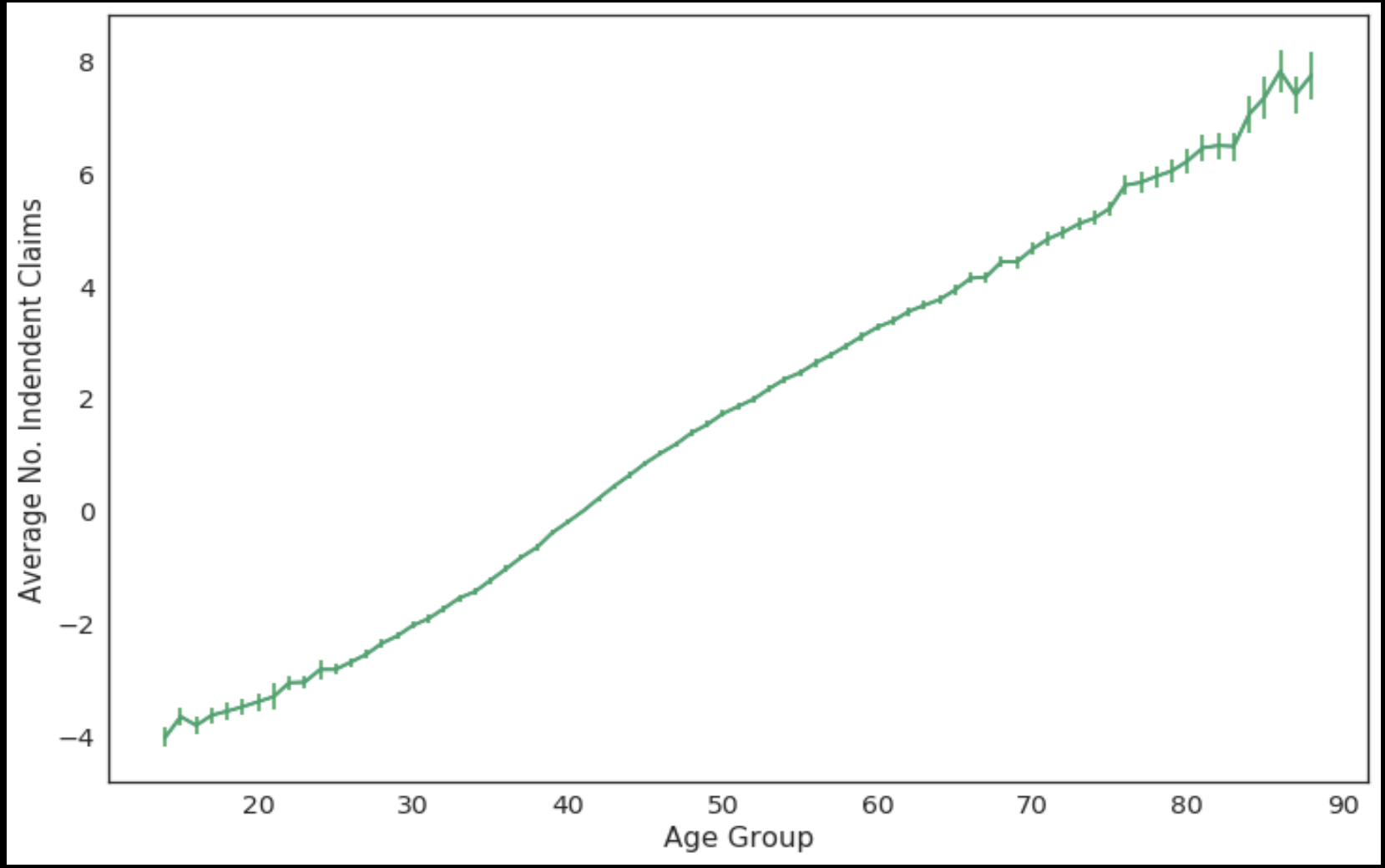
Solo-inventor Patents
Decreases with Age: Disruptiveness



Solo-inventor Patents
Increases with Age: Backward Citations



Solo-inventor Patents
Increases with Age: Independent Claims



Summary of Attribute Predictions

Metric	Prediction	Actual	Confirmed?
Forward	Inverted U	Decreasing	
Disruptiveness	Decreasing	Decreasing	✓
Backward	Increasing	Increasing	✓
Claims	Inverted U	Increasing	

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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

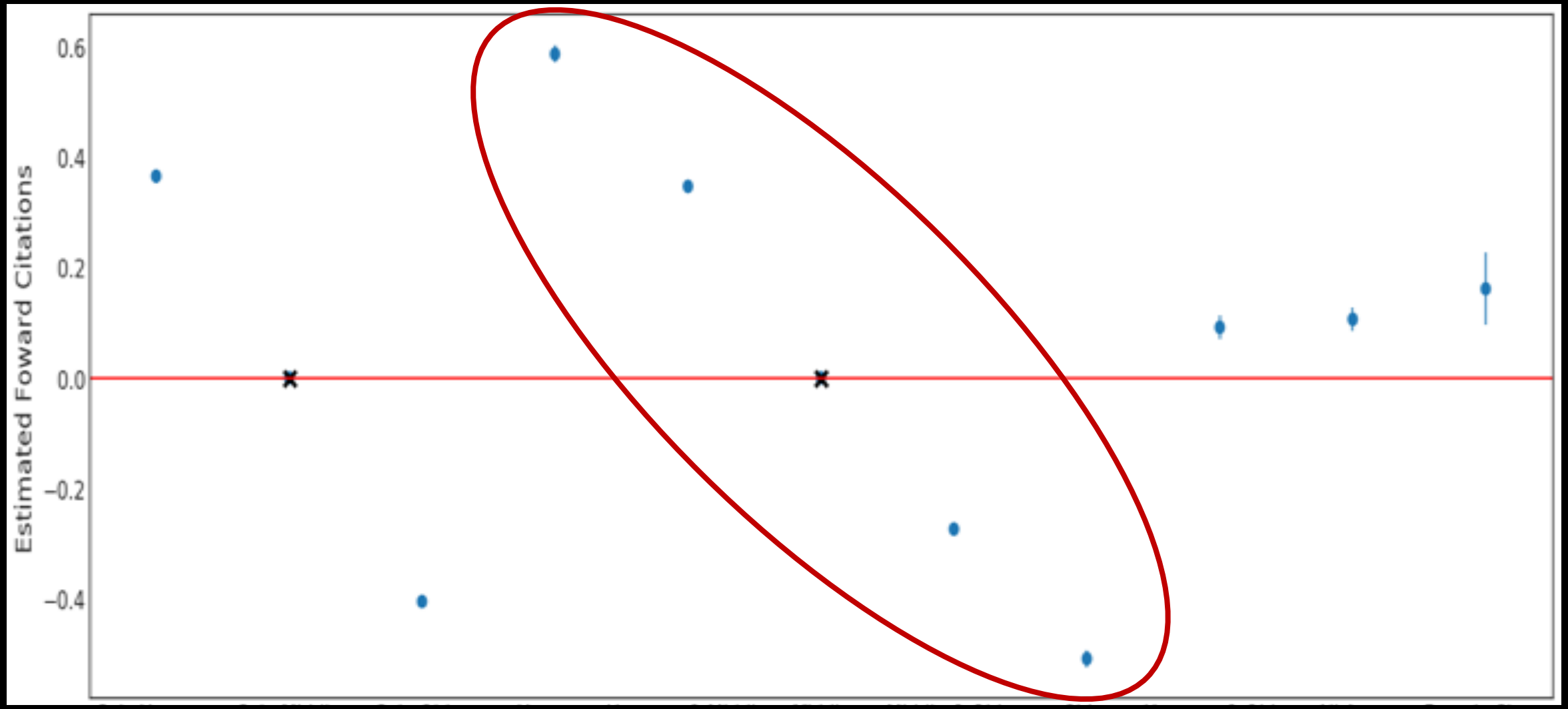
- Younger Only
- Middle Only
- Older Only
- Younger & Older
- Younger & Middle
- Middle & Older
- All Ages

Age-heterogeneous teams

$$Q_p = \beta_j AgeComp_{pj} + \beta_2 FShare_p + \beta_3 Teamsize_p + \beta_f Field_{pf} + \beta_t Yr_{pt} + \alpha_i + \varepsilon_p$$

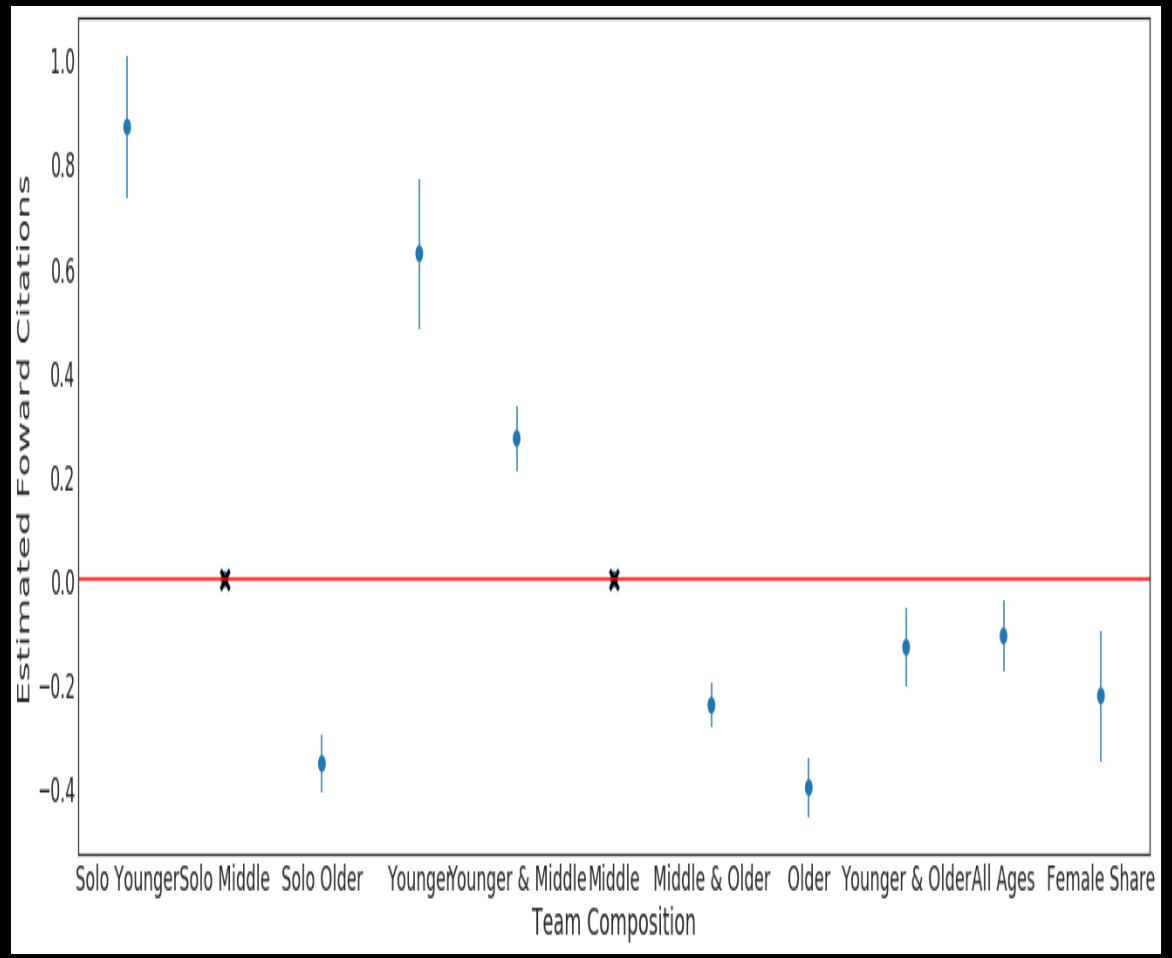
- Patent as the unit of observation
  - Team size (up to 8 members)
  - Dummies for age mixes: all younger, younger and middle, middle and older, all older, all ages (all middle is excluded group)
  - Fraction of team members who are female (FShare)
  - Year, inventor and technology field (NBER) fixed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

Age Heterogeneity & Forward Citations

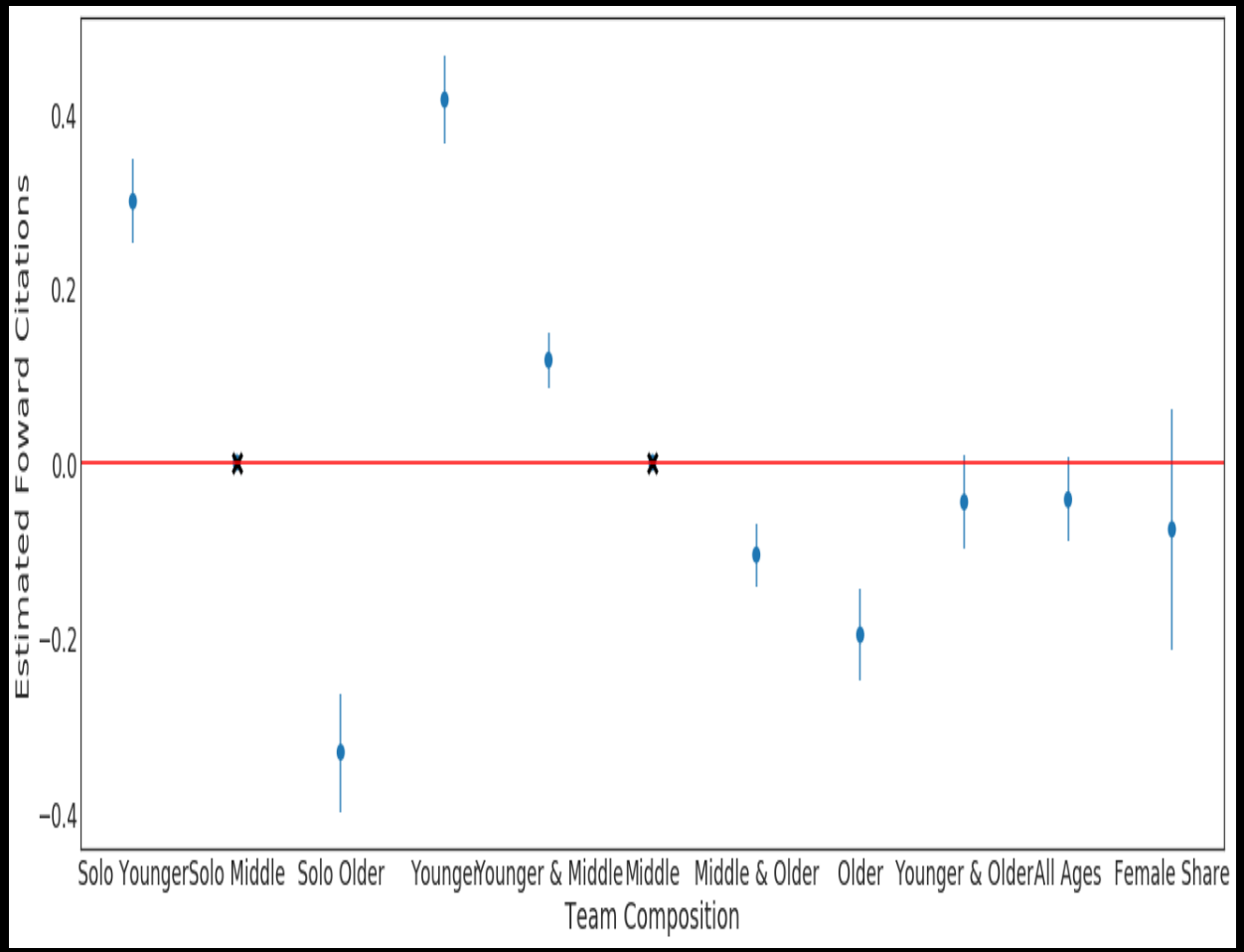


Age Heterogeneity & Forward Citations

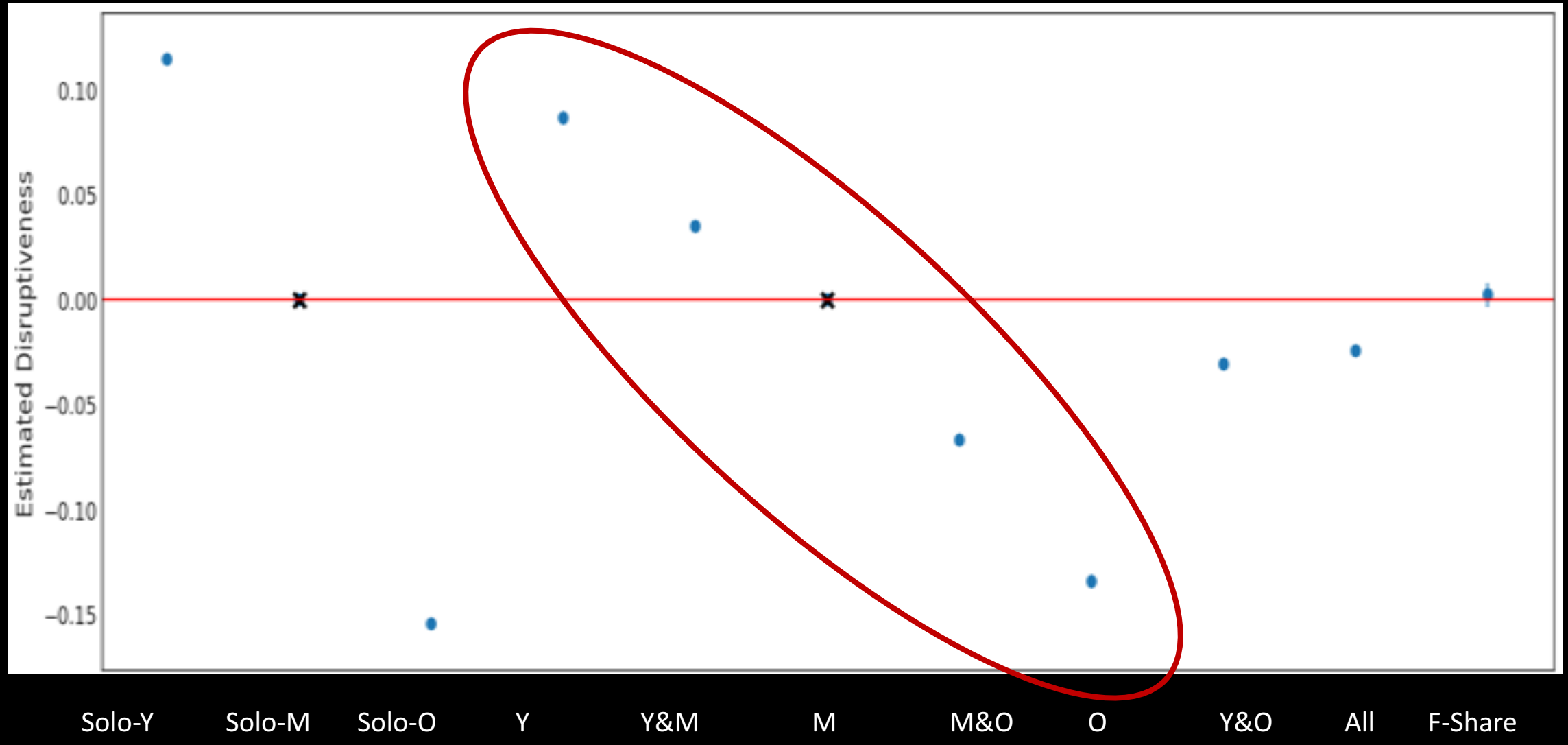
Medical Prep



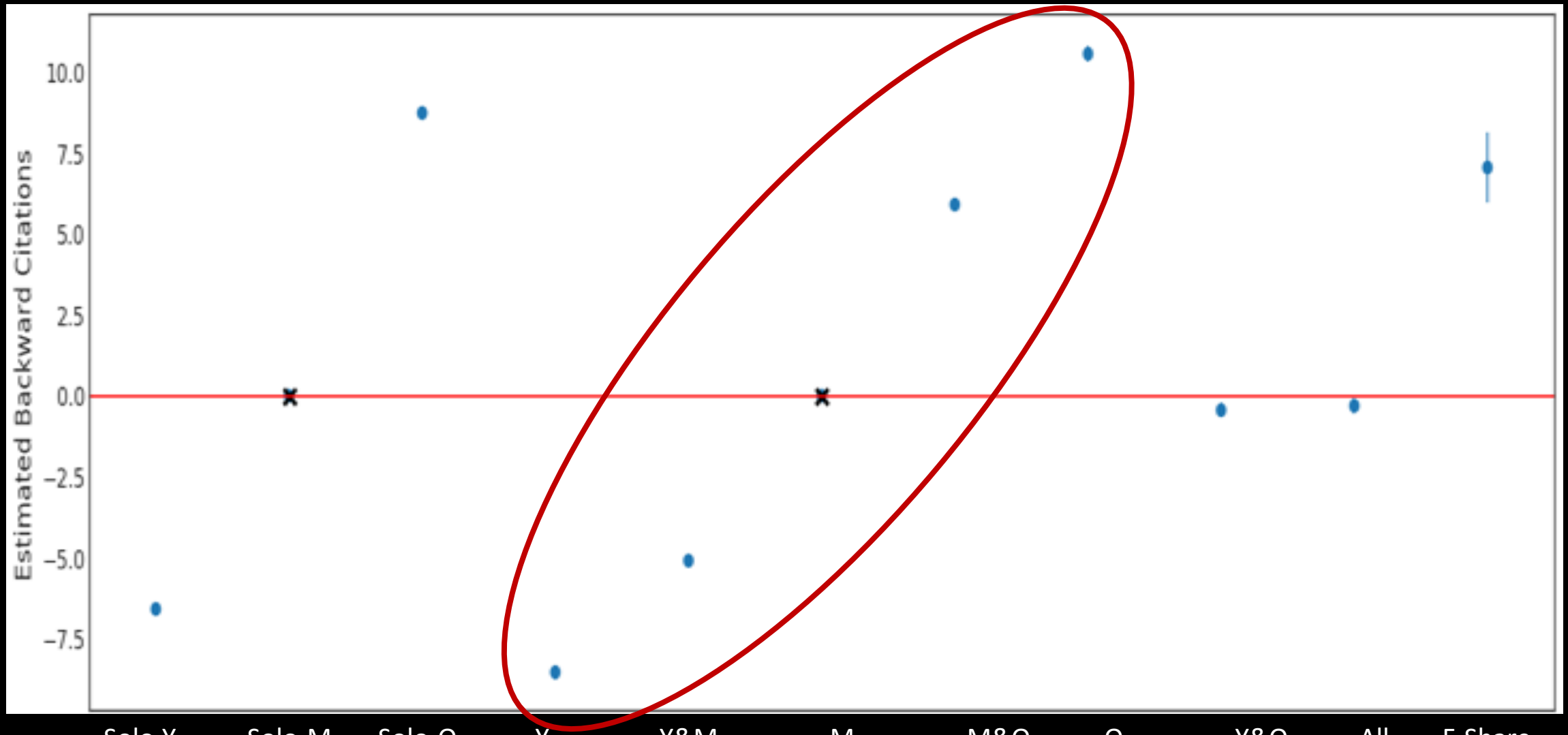
Semiconductor



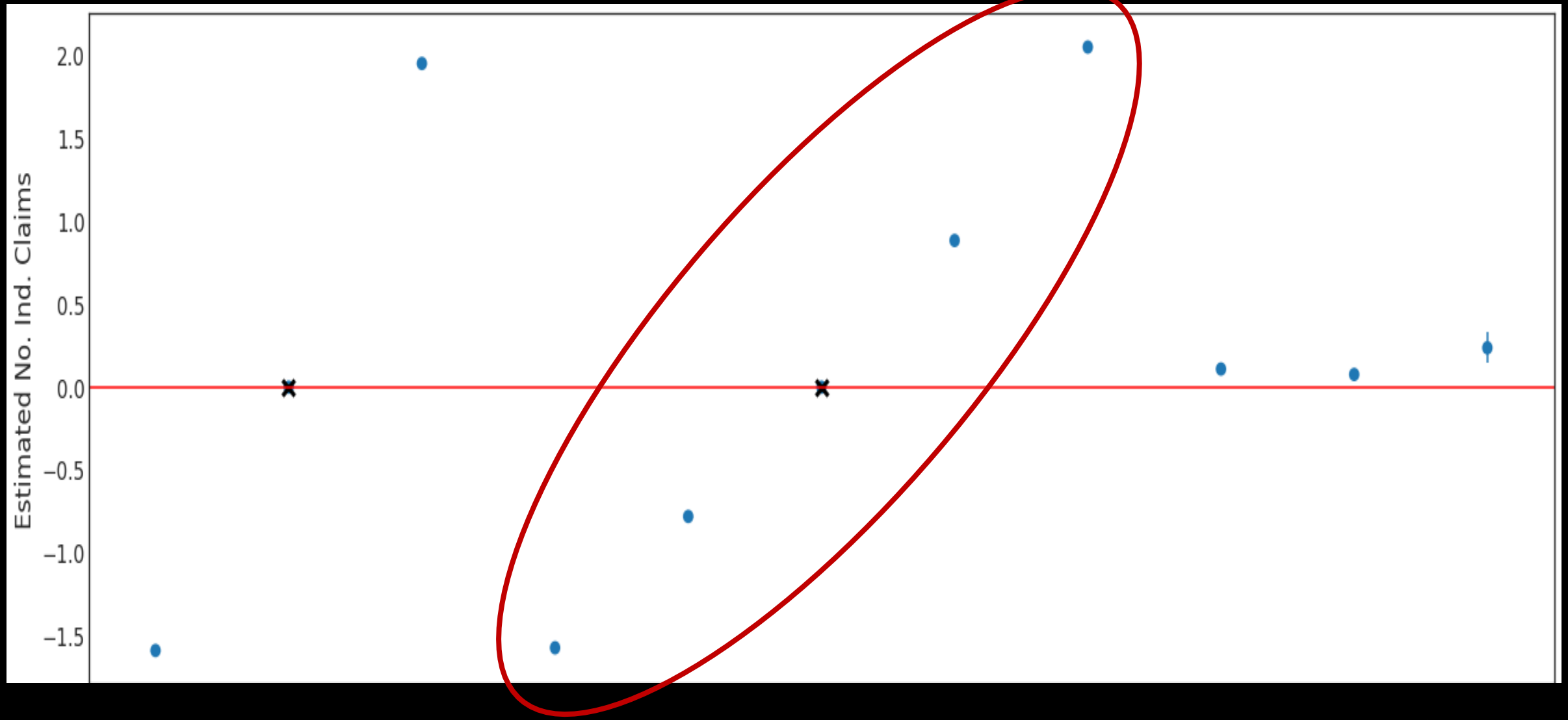
Age Heterogeneity and Disruptiveness



Age Heterogeneity and Backward Citations



Age Heterogeneity and No. of independent Claims



Summary of Age Composition

Metric	Highest Team Composition	Note
Forward	Younger	Female Share
Disruptiveness	Younger	
Backward	Older	Female Share
Ind. Claims	Older	Female Share
Fields	Similar to Overall Trends	

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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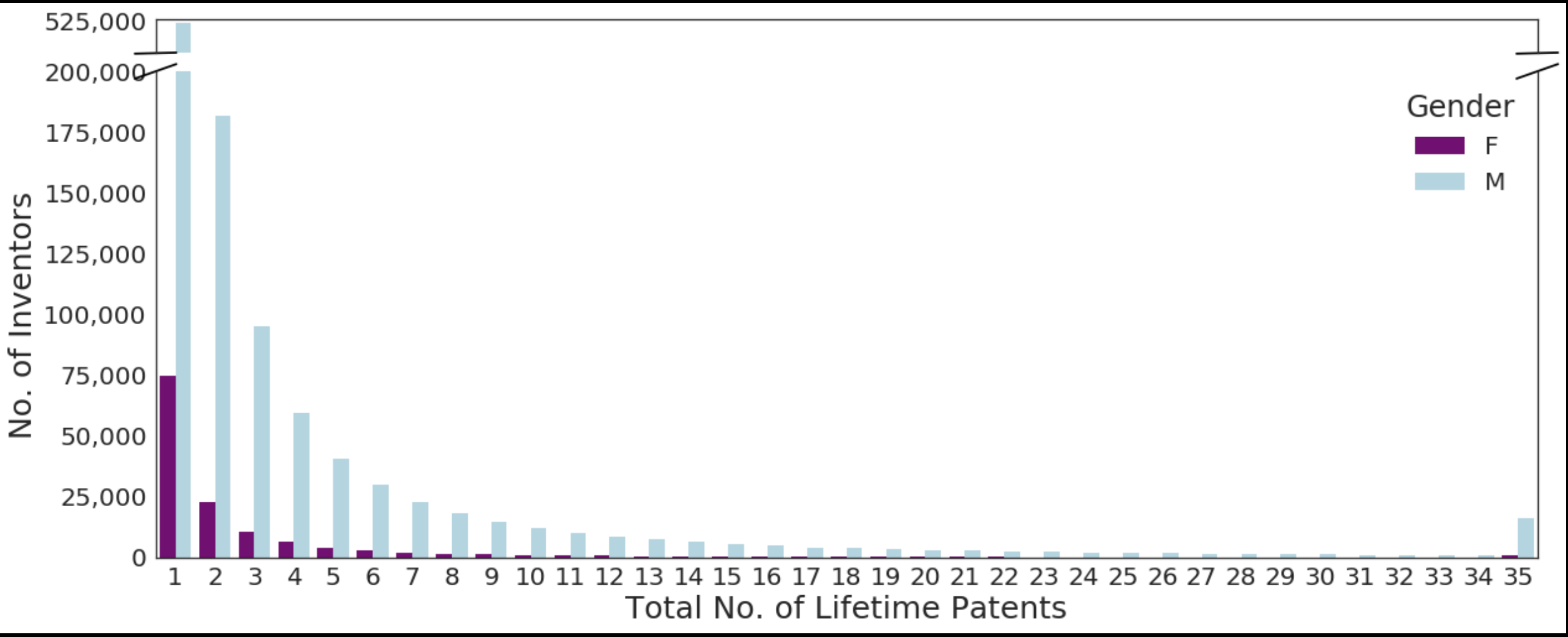
Future Research

- 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

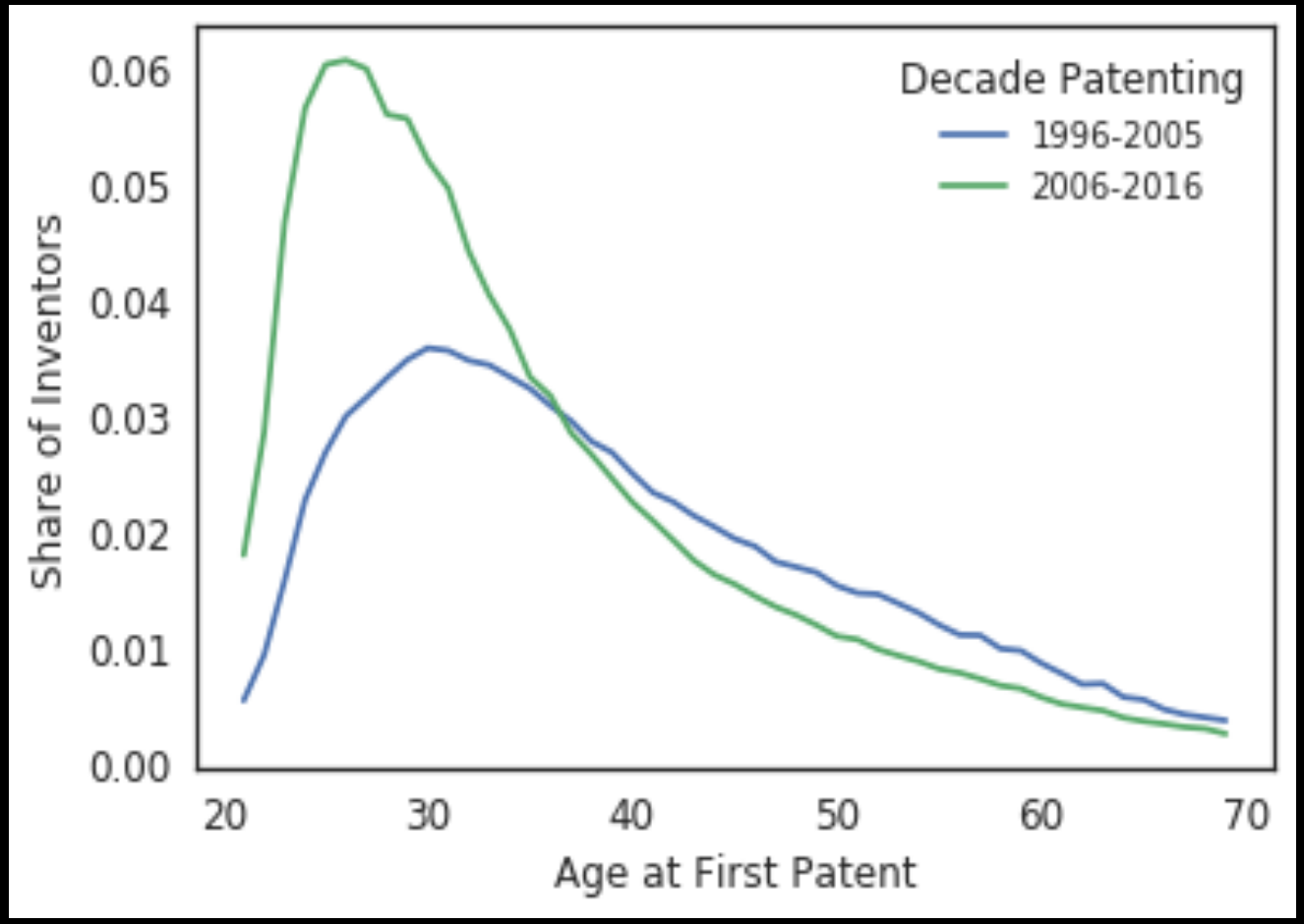
Underway

- 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

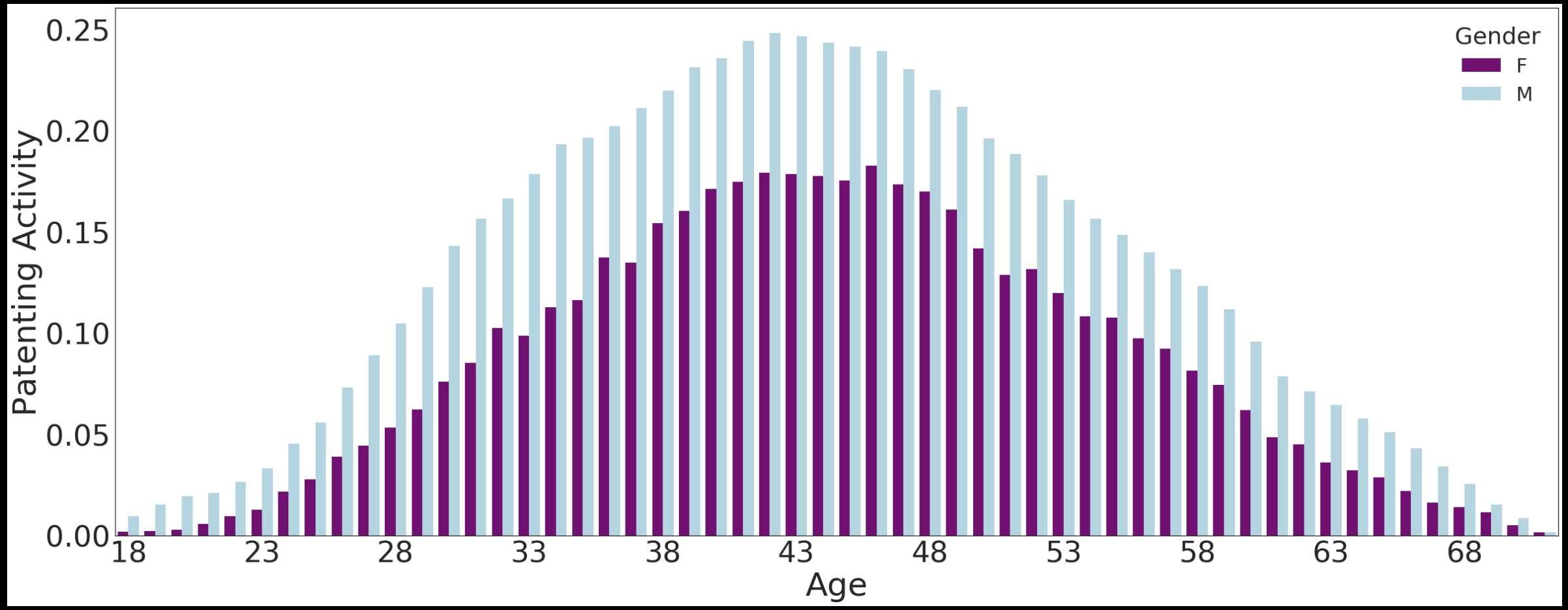
Distribution of Observed Lifetime Patents Across Inventors



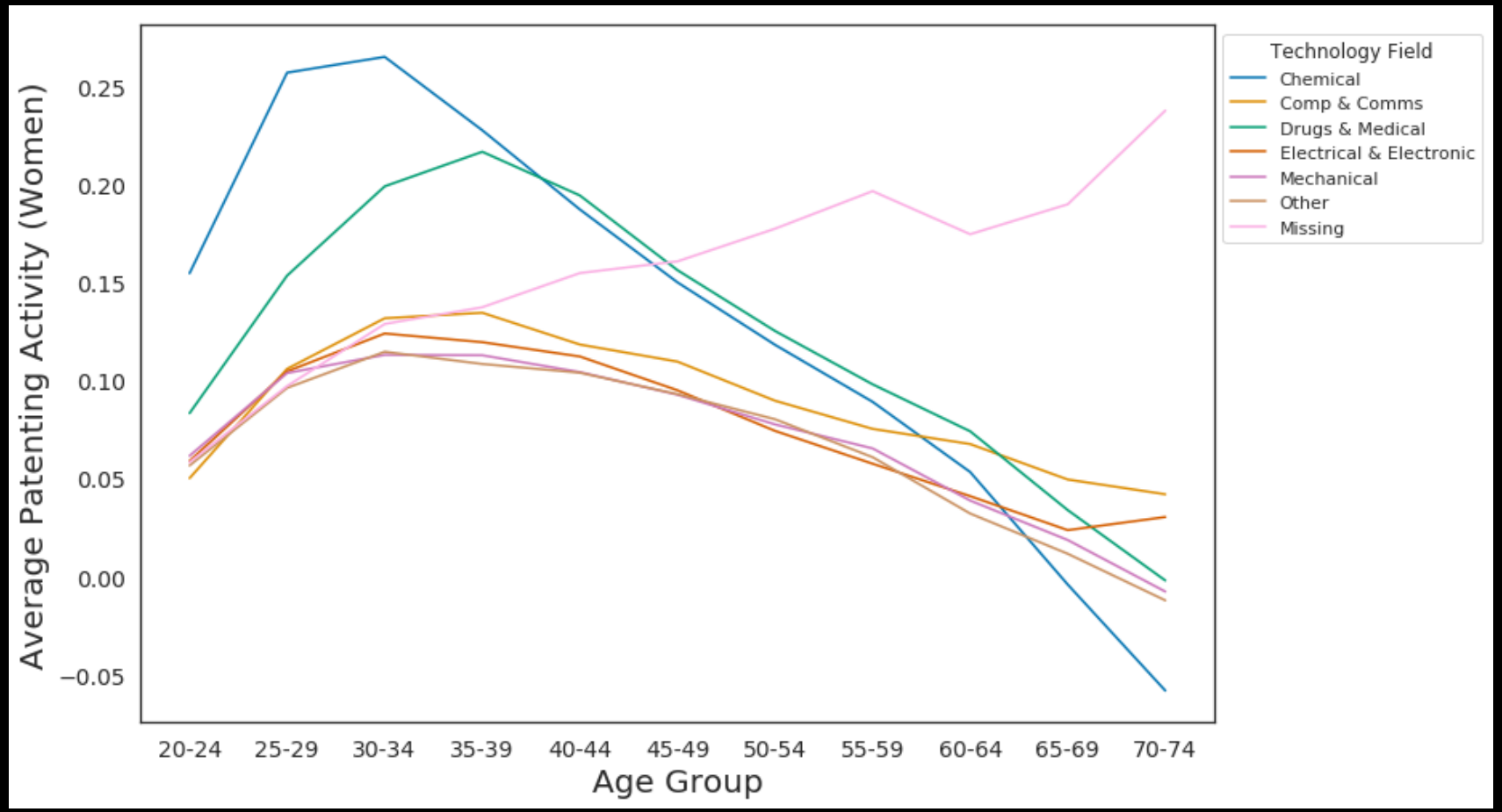
Unlike publications and research grants, age of first patent has NOT been rising



Cohort: 1946-1956



Rate of Patenting by Tech Field: Women



Rate of Patenting by Tech Field: Men