Mapping the Regions, Organizations & Individuals that drive Inclusion in the Innovation Economy

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ENTREPRENEURSHIP, INNOVATION POLICY AND THE ECONOMY, 2021

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MAPPING THE REGIONS, ORGANIZATIONS & INDIVIDUALS THAT DRIVE INCLUSION IN THE INNOVATION ECONOMY

MOTIVATION

- Increased focus on diversity and inclusion in the innovation economy - as an important dimension of social progress (e.g. UN SDG #5) and as a driver of economic growth (e.g. Romer 1990, Acemoglu et al. 2020)
- Many arguments focus on a narrow STEM pipeline – prior to, and during, Bachelor’s degrees (Bell et al. 2019) BUT:
  - Aggregate data show that gender inclusion % in patenting runs well below inclusion % of STEM bachelors and PhD dates;
  - Wide variation in rates of gender inclusion in patenting, leadership etc. – across fields, regions, organizations and individuals suggests opportunities to explore organizational and individual - drivers of inclusion.
- Variation in inventor inclusion in the highest patent-production regions, organizations and individuals provides a window into catalysts for change.

AGENDA

1. **BACKGROUND** – benefits of diversity, persistent inequality in the innovation economy & evidence of current levels of diversity below pipeline levels (with high levels of variation)
2. **METHODS** – new approaches to map levels of inventor inclusion across the economy – metrics and indices
3. **RESULTS**

   I – comparing overall inventor inclusion to the overall STEM pipeline

   II – looking at skewed production of patents across regions, organizations and individuals

   III - examining inclusion metrics in top patenting regions, organizations and individuals to understand variation in inclusion and potential catalysts
4. **CONCLUSIONS** – from insight to action – next steps for leaders and policymakers

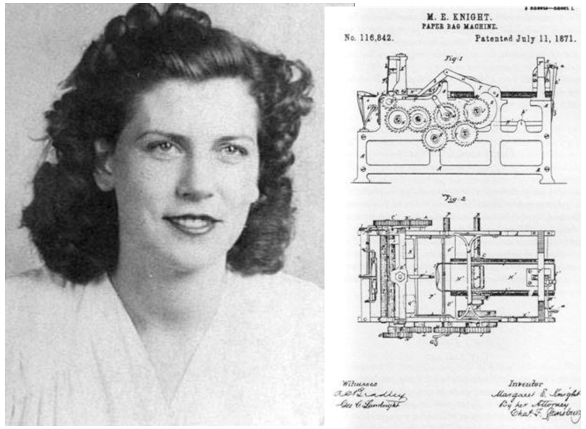
BACKGROUND
Economic Imperative for Diversity & Inclusion in the Innovation Economy

- It is inefficient to use only part of our talent pool – we have “missing Einstein's” or more appropriately “missing Curies” (Bell et al., 2019, Cook 2020)
- More diverse inventors and researchers are more likely to search solution space more widely and emphasize different problem domains (Honing et al. 2020, Hofstra et al. 2021)
- More diverse teams incorporate more sources of information, with better outcomes (Apesteguia et al 2012, Joshi 2014, Joshi & Knight 2015) & higher ’collective intelligence’ (Woolley et al. 2010)
- More diverse senior leadership in firms may lead to higher rates of performance (e.g., McKinsey 2020, Post & Byron 2015)

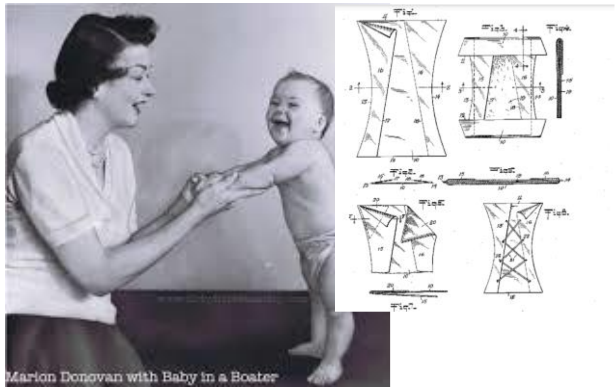
BACKGROUND
Women have trained in STEM for centuries, but we continue to have 'missing' inventors

Ada Lovelace
(1815-1852)

Marie Curie
(1867-1934)



Margaret Knights
(1838-1914): **27 Patents**



Marion Donovan
(1917-1998): **20 Patents**

BACKGROUND
Not simply a pipeline problem but instead a **persistent inventor gender gap**

- Arguments for low inventor inclusion include the lack of STEM role models early in careers (Bell et al., 2019, Cook, 2019, 2020) **BUT**
- STEM pipeline data suggests improvement (for Bachelors, Masters & PhDs), not reflected in inventor inclusion:
  - **Female participation in STEM PhDs is about 35% (2010-15 graduates), BUT female inventors constitute only 10% of U.S. inventors in 2015 (Delgado/Murray, 2020)**
- **AND**, women's inclusion in innovation varies by type of organizations – university versus firms (e.g. Whitting ton & Smith-Doer 2008), across organizations - due to differing practices (Stuart and Ding, 2006) and across regions (Rosenthal & Strange, 2012; Delgado et al., 2018)
- Suggesting that we examine how different **regions, organizations and individuals** use their pipeline to a greater or lesser extent to support the innovation economy.

METHODS
Mapping female inventors, inventor inclusivity across regions, organizations & individuals

Female inventors & PhDs

- Data on **all US inventors** (2000-2015) with utility patent granted (within organization) with **Name-Gender matching algorithm** to establish gender of inventors
- Define inventor-level inclusion (**% Female Inventors** in a pool of inventors) not just patents "with at least one female"
- Measure **New Inventors (NIs)** – "new" if his/her first ever patent granted in a specified period - capture potential for long term change (Merton 1968, David 1993, Acemoglu et al. 2020).
- Measure BS & PhD **STEM supply** in the US economy and by university/region

Inclusivity index

- Build **Inclusivity Score —Female New Inventor %** as the % NIs coded as female in a set of patents
- Create an **Inclusivity Index -** weighted average of FNIs tech-class sub-scores to account for variation in patent composition;
- Accounting for **differences in levels of inclusion** (and talent availability) **across patent classes**, to allow for clear comparisons;
- Accounting for **different supply of female across STEM fields** e.g. Computers & Comm. versus Life Sciences

Mapping contexts

- Map **variations in inclusivity score/index** across regions, organizations & individuals
  - **Regions** – regional policies, norms and culture shape inclusive outcomes
  - **Organizations** –organizational policies, climate & culture shape inclusive outcomes (Ding et al. 2006, Settles et al. 2006, Bhaskarabhatla/Hegde 2014);
  - **Individuals** –e.g. faculty influence graduate students (e.g., Settles et al. 2006, Sheltzer/Smith, 2014, Pezzoni et al. 2016, Delgado/Murray 2020) and likewise managers (Castilla 2011).
- Exploit the fact that **patenting is highly skewed** to look at contexts where inclusion may be catalyzed (O'Neale et al 2012)

RESULTS I
Measuring Female Inventors in the United States – a persistent gender gap

	Granted Year	Patents Granted	Female Inventors (FIs)	Male Inventors (MIs)	Female New Inventors (FNIs)	Male New Inventors (MNIs)	% FIs	% FNIs	% Female Patents	% Patent with 1 FI
US	2015	127,300	18,740	168,134	6,300	37,688	**10.0%**	**14.3%**	**7.8%**	**18.9%**
US	2000-2015	139,4632	106,243	939,836	73,511	486,129	**10.2%**	**13.1%**	**7.2%**	**17.1%**
US	ppa						**0.15%****	**0.26%****	**0.11%****	**0.34%****

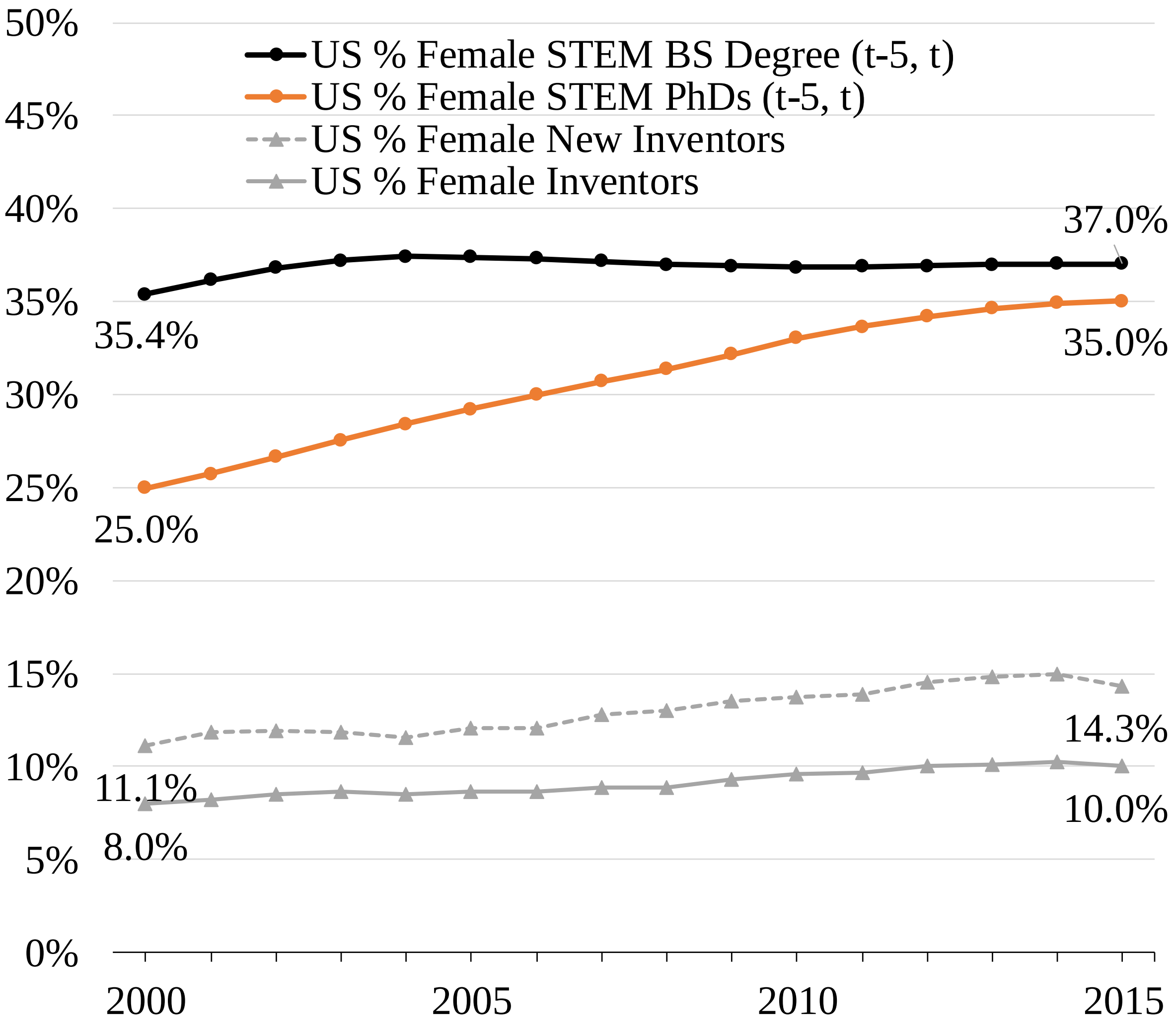
Notes: Utility patents of U.S. origin granted to organizations, and the inventors located in the US (USPTO). The def. of inventor is organization specific (i.e., an individual with patents granted in 2 organizations counts as 2 inventors). An inventor is "new" if his/her first patent has been granted in the particular period.

- The inventor gender gap is persistent: at the current rate of improvement since 2000, it will take **139 years to reach parity in % Female New Inventors** (266 years for Female Inventors; 93 years for Patents with 1 FI)
- Similar **gap in other countries** in % Female Inventors (WIPO, 2016; Hoisl/Mariani, 2017)

RESULTS I

The Low Presence of Female Inventors not simply STEM Skills Problem

- We compute STEM PhDs and BS granted by gender (t-5, t)
- % Female STEM PhDs was +2 times higher than % Female New Inventors in 2015 (**35% vs. 14%**)
- Female Inventor Inclusion is not rising as fast as women in STEM:
  - Female PhDs – **21 years** to parity
  - Female new inventors – **139 years**



U.S. Economy

	Annual Change	Years to Parity
% FBS	0.04%	(117, **317**, +1,000)
% FPhDs	0.71%**	(19, **21**, 23)
% FNIs	0.26%**	(117, **139**, 171)
% FIs	0.15%**	(235, **266**, 307)

Adapted from Delgado/Murray (2020)

RESULTS I

Presence and Patenting of Female Inventors in the U.S. by Technology Class, 2000-2015

Technology Class	**% Patents 2000-15**	**No. FNIs**	**% All FNI**	**% Female Inventors** (All inventors)	**% Female New Inventors** (Of all NIs)	**% Female Patents** (Of all Patents)
1. Chemical	11%	10836	14%	13.0%	17.7%	10.1%
2. Computers & Comm	36%	24519	33%	9.1%	**12.1%**	6.7%
3. Drugs & Medical	13%	18291	24%	17.9%	**25.5%**	13.0%
4. Electrical & Electronic	18%	7561	10%	6.4%	8.7%	5.1%
5. Mechanical	11%	5228	7%	5.4%	7.0%	3.8%
6. Other	11%	8563	11%	8.2%	11.3%	6.1%
U.S. Total (2000-2015)	100%	74998	100%	10.2%	13.1%	7.2%

Note: Technology Class definitions are based on Hall/Jaffe/Trajtenberg (2001).

- **Computers & Comm** 12% FNI, but as a large class, account for 33% of all FNIs and 36% of U.S. patents
- **Drugs & Medical** 25% FNI, but as 2nd largest, account for 24% of all FNIs and 13% of U.S. patents
- **Is the STEM pipeline limiting Female New Inventors in these fields?**

RESULTS I
Large New-Inventor Gender Gap relative to STEM PhDs

2000-2015	% Female New Inventors
U.S. Economy Patents	13.1%
Chemical	17.7%
Computers & Comm.	**12.1%**
Drugs & Medical	**25.5%**
Electrical & Electronic	8.7%
Mechanical	7.0%
Other	11.3%

1995-2015	% Female Bachelors	% Female PhDs
U.S. STEM Degrees Flow	36.7%	31.1%
Agriculture	47.1%	36.8%
Computer & Comm.	22.7%	**20.4%**
Biological & Biomed.	58.7%	**48.8%**
Engineering Tech	18.1%	19.1%
Math & Statistics	44.7%	27.8%
Natural Resources	45.0%	39.4%
Physical Sciences	40.1%	29.2%

- **Drugs & Medical patents** have the **highest inventor inclusivity score**: the *% Female New Inventors* is 25.5% (2000-15 patents) & yet this score is about **24 pp lower than expected** since women's participation in Biological & Biomedical PhDs is 49% (1995-2015 graduates). Likewise in Computers & Comm.12% of new inventors versus 20% of PhDs
- **The inventor gender gap is not just about STEM education choices**

RESULTS II
Mapping variations across regions, organizations & individuals to find catalytic contexts

- Identifying **skewness of patenting activity** in three different contexts:
  - Regions
  - Organizations – firms and universities
  - Individuals within organizations

- Determining the degree to which, among the top patent producers, some regions, organizations and individuals **are more inclusive than others** – (which will inform best practices for change):
  - Rankings (score, technology-class weighted indices)
  - Comparing organizations to their regions
  - Comparing top inventors within their organizations

RESULTS II
Patenting Concentrated in Few Regions and Organizations

	Patents, 2000-2015	% of US Patents	New Inventors (NIs)	% of US NIs
Total U.S. Economy	1,394,632	100%	607,732	100%
10-Economic Areas (179)	763,992	**55%**	311,381	**51%**
30-Firms	346,033	**25%**	116,320	**19%**
All Universities (201)	59,105	4%	45,823	**8%**
25-Universities	32,032	**2%** (54% univ patents)	23,940	**4%** (52% univ NIs)

- Top patenting regions (EAs):
  - Patents are highly geographically concentrated by field (Audretsch/Feldman 1996; Delgado, 2020)
  - Top 10 patenting EAs account for 55% of patents and 51% of NIs in 2000-15 patents (vs. 34% of jobs in 2015)
- Organizations:
  - **Firms** shape overall levels of inclusion since the vast majority of STEM women will work at firms
  - **Universities** play key role **shaping attitudes toward innovation of PhDs** (Pezzoni et al., 2016; Azoulay et al., 2017), and early access to resources may have **cumulative advantages** (e.g. Merton,1968)

RESULTS II

Top Inventors Within Organizations Generate Many Patents and New Inventors

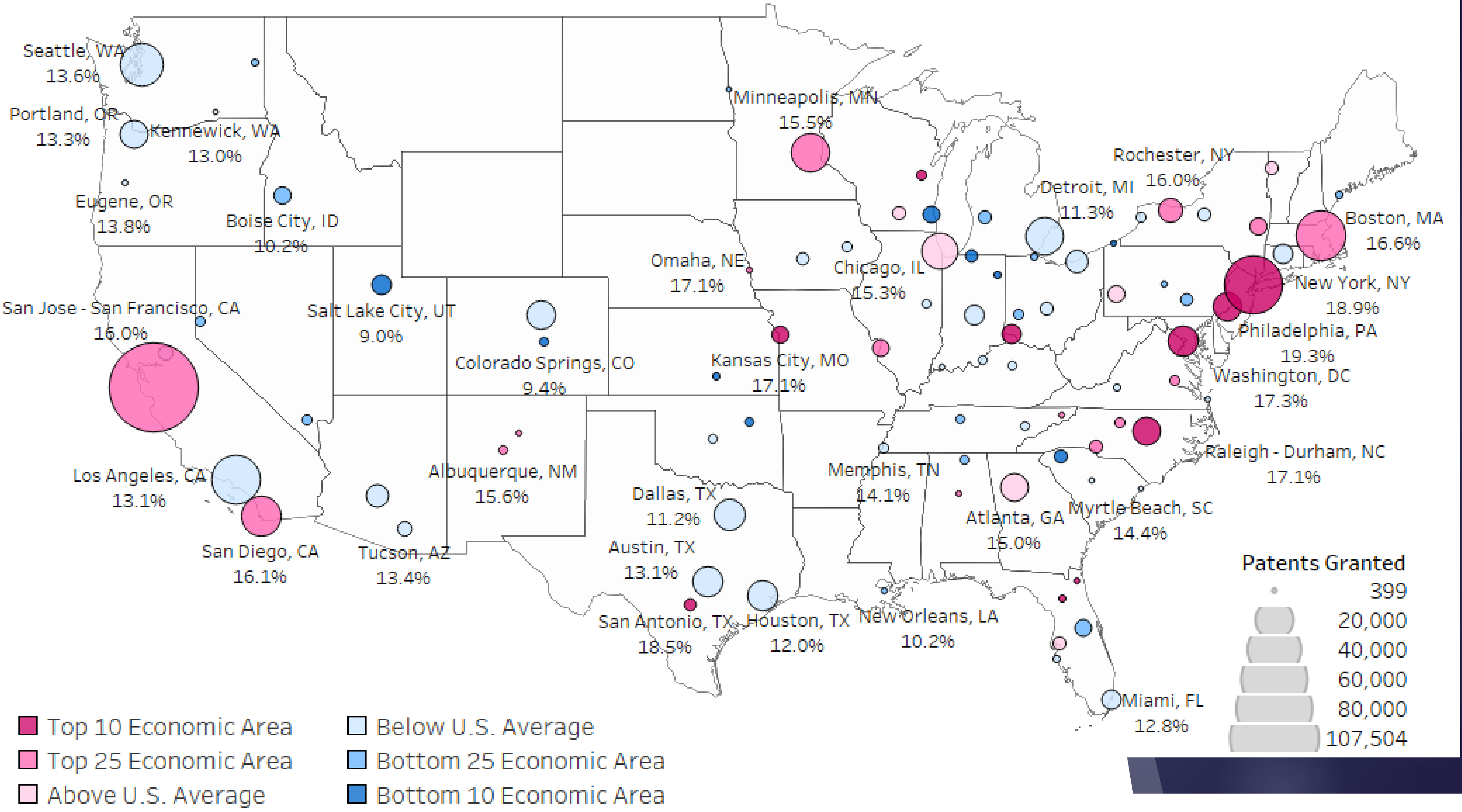
	Inventors	%	Patents	%	Team Size Mean	New Inventors	%
US Patents, 2000-15	1,130,834	100%	1394632	100%	2.7	607732	100%
Top Inventors (7+ patents)	114,071	**10%**	873878	**63%**	2.9	241317	**40%**
30-Firms Patents, 2000-15	183933	100%	346033	100%	2.8	115952	100%
Top Inventors (7+ patents)	34167	**19%**	289,038	**84%**	3.0	75948	**65%**
25-Univ Patents, 2000-15	37,314	100%	32032	100%	2.8	23,940	100%
Top Inventors (7+ patents)	2,243	**6%**	18,956	**59%**	3.0	10,664	**45%**

- Within organizations there are 'superstars' in science who shape outputs and micro-climate (Azoulay, Fons-Rosen, Zivin 2019) & superstar inventor CEOs driving firm patenting (Islam & Zein 2020)
- We define **Top Inventors** as those with 7+ patents granted within an organization during 2000-15 (90^{th} percentile value in the U.S.)
- **Many** of the **patents** are produced **by few Top Inventors** (TIs):
  - 30-Firms: **TIs represent 19% of inventors, generate 84% of patents, and account for 65% NIs**
  - 25-Univ: **TIs represent 6% of inventors, generate 59% of patents, and account for 45% NIs**

RESULTS III
FEMALE INVENTOR INCLUSIVITY ACROSS THE MOST PATENT INTENSIVE REGIONS, ORGANIZATIONS & INDIVIDUALS

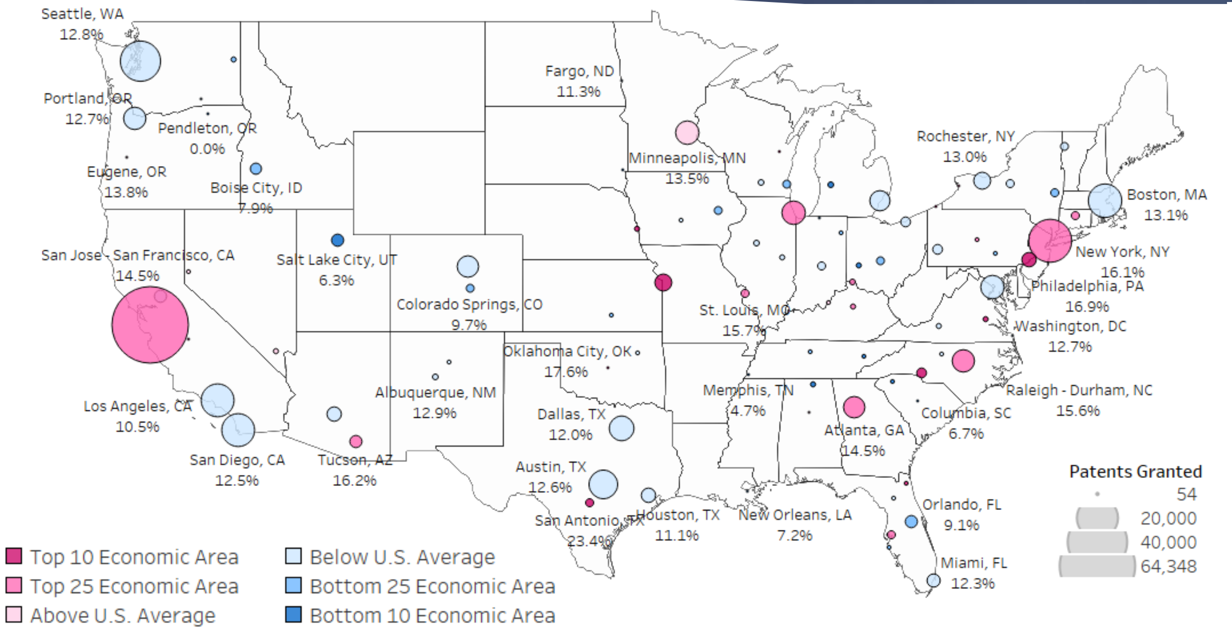
Female Inventor Inclusivity Varies Across Regions

% Female New Inventors, 2011-2015 (U.S. score is 14.5%)

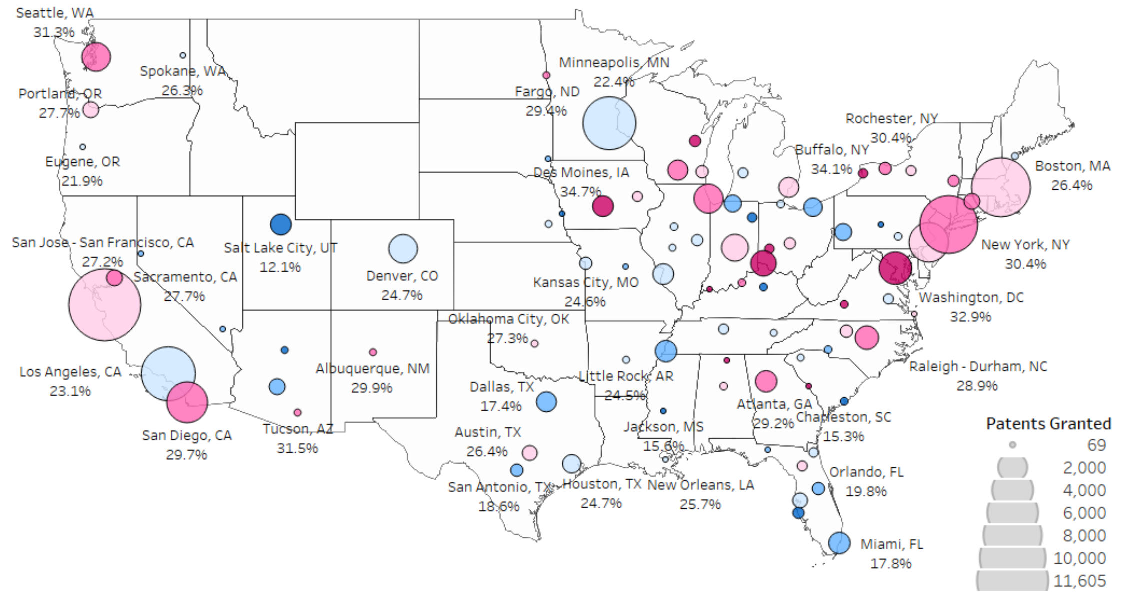


Not just a region-level but also a field-level effect:
Computers & Communications vs. Drugs & Medical, 2011-2015

Computers & Comm
% FNI 13.4%



Drugs & Medical
%FNI 26.4%

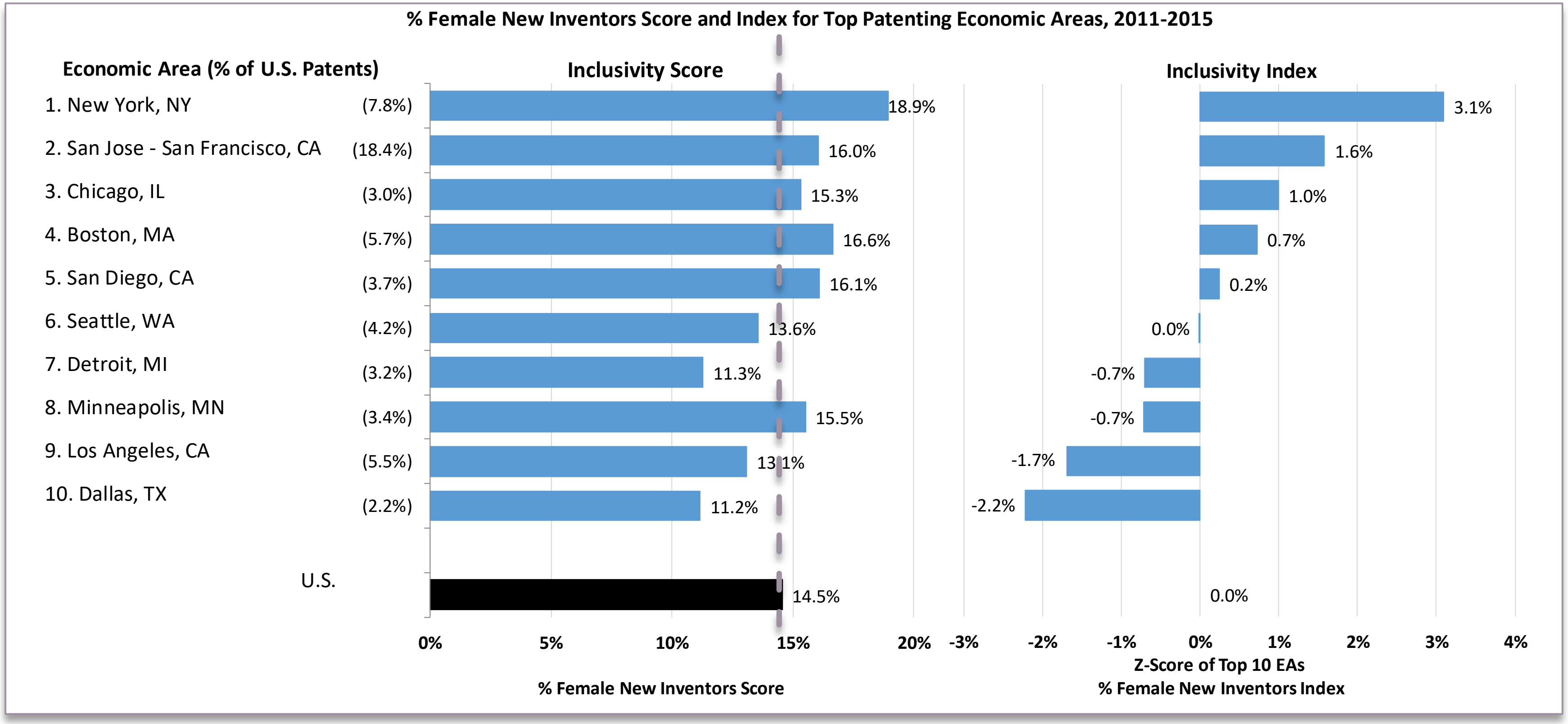


- C&C patenting is very skewed while Drugs & Medical is distributed across more regions. New York is inclusive for both as is SFO. Salt Lake City low inclusivity in both. Boston is close to the US mean in both.
- **There is variation in inclusion across fields for the same region** e.g. Seattle is inclusive for Drugs & Medical but not for C&C (Amazon) …suggesting **firm & ecosystem effects**.

RESULTS III

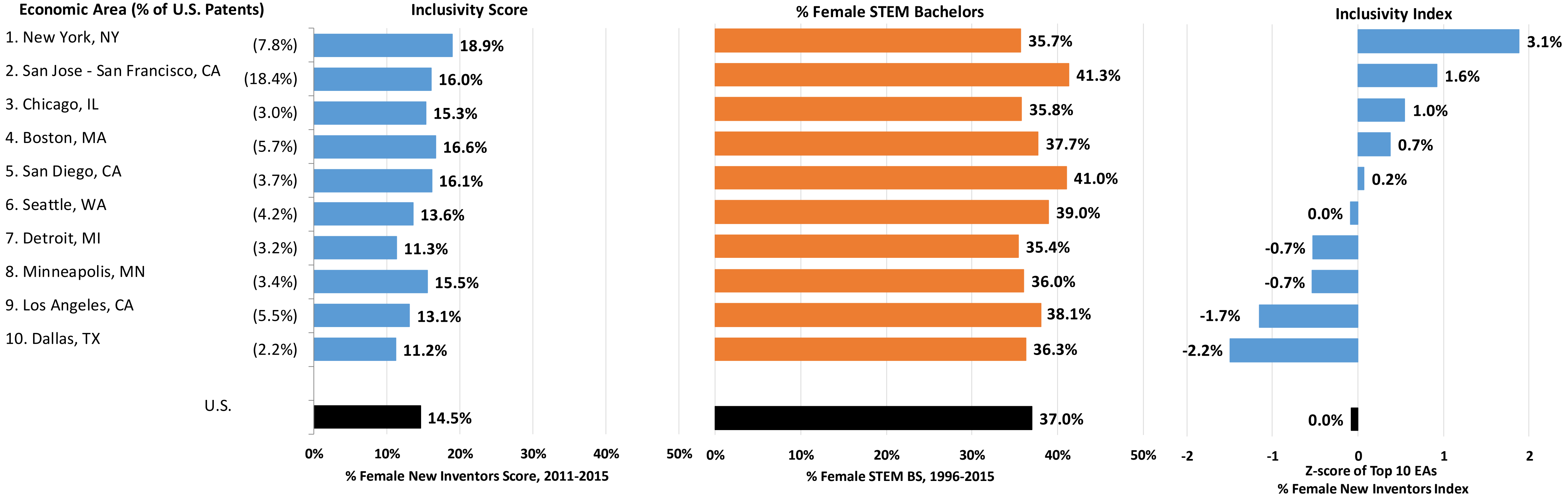
Patent inclusion is high in top Economic Areas but varies

- The **%FNI** scores **range – lowest is 11% - Dallas**
- **New York is 19%** (with highest index too)
- With a strong influence from the sector. BUT…
- **…some EAs perform better than US** in both Score/ Index: e.g., **Top 3.**
- **Other EAs underperform** relative to U.S. economy



RESULTS III

Patent inclusion high in top Economic Areas but varies & **does not match the supply of STEM talent**

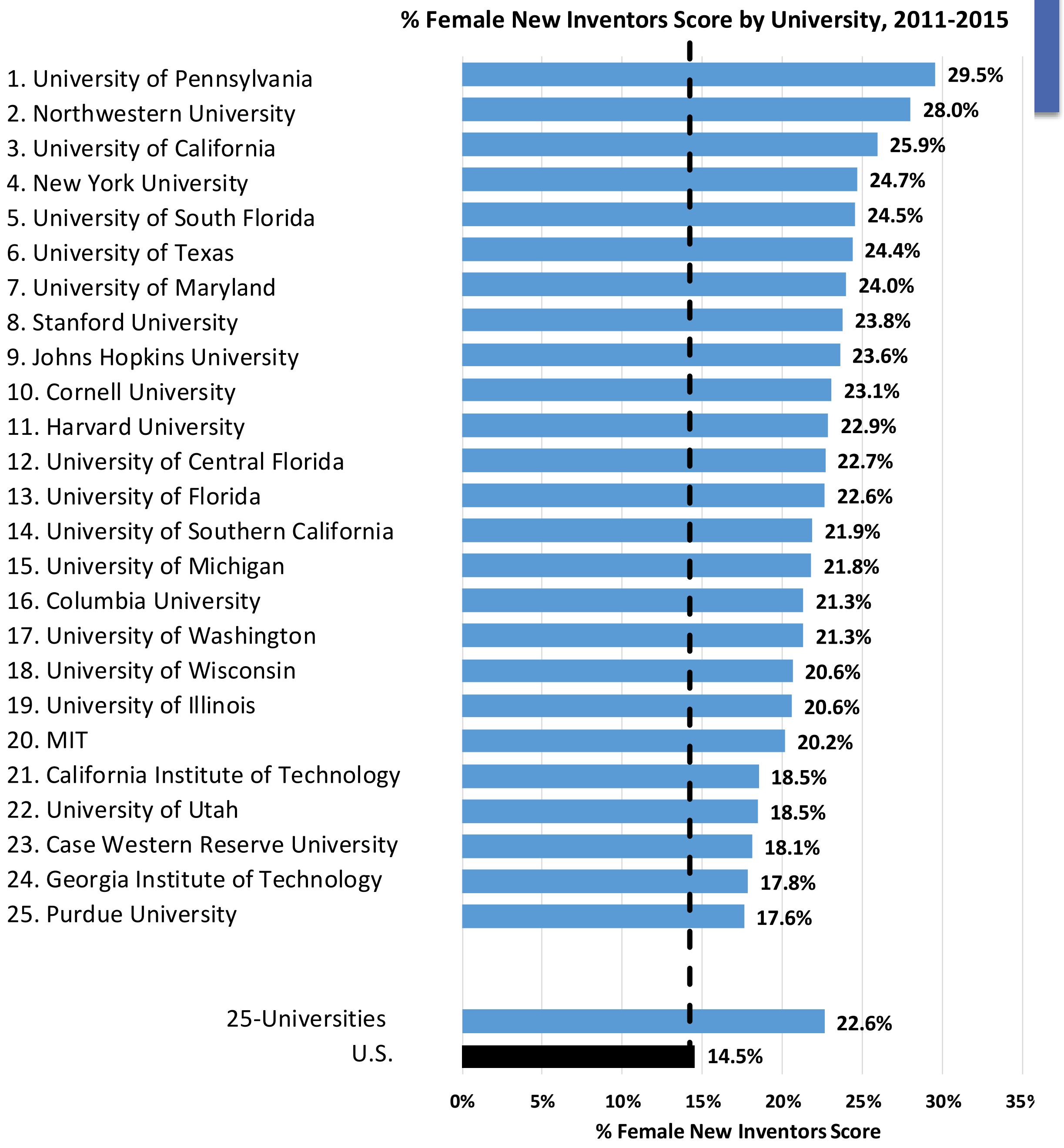


- **The %FNI scores range from 11% (Dallas) to 19% (New York** with highest Index too)
- **But % Female STEM Bachelors ranges from 35%** (Detroit) **to 41%** (San Jose/SFO)
- The ratio of %FNIs to % Female STEM is the highest at New York, yet it is only 0.53

“What organizations
drive these regional differences?
Do leading research universities
influence region inclusivity?”

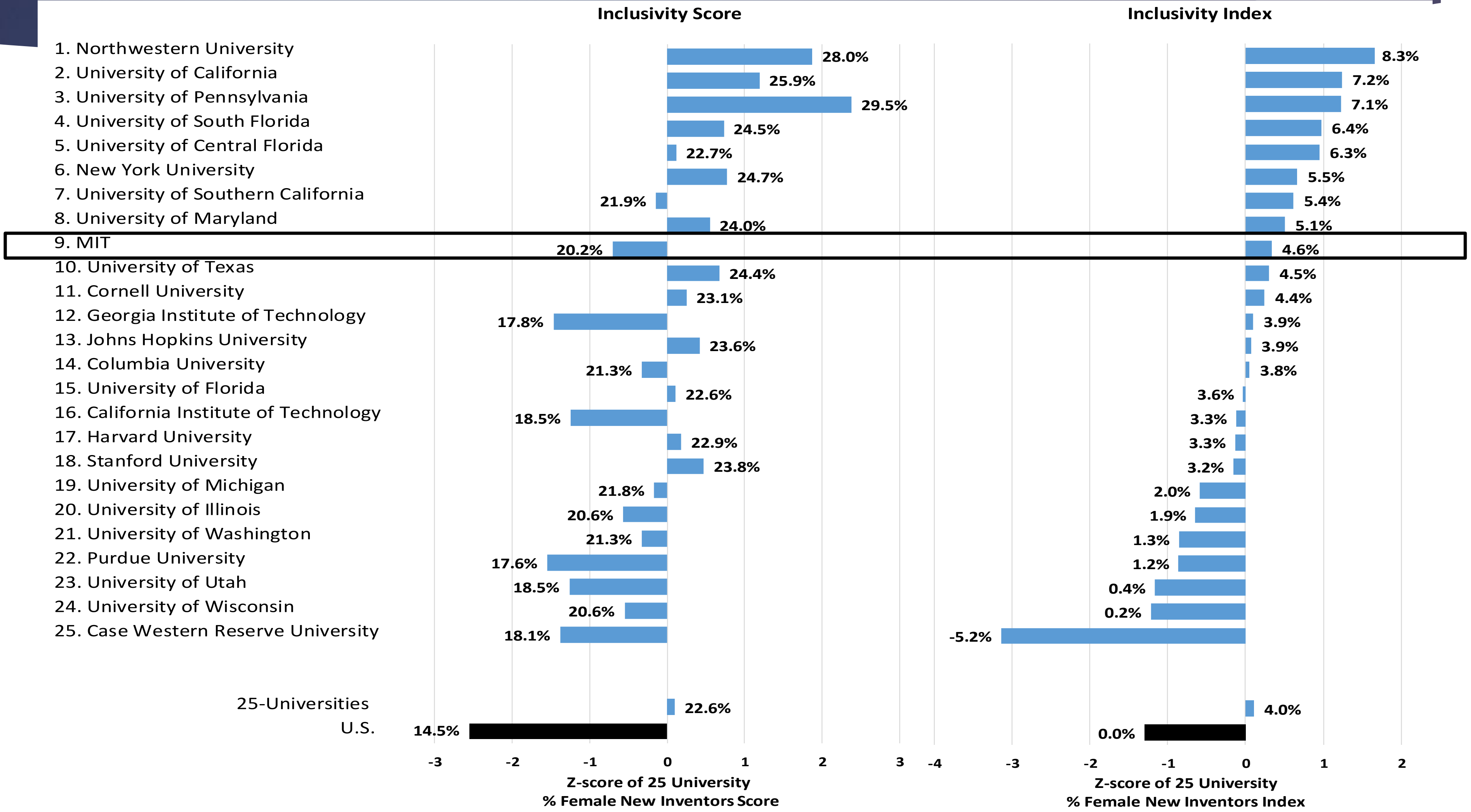
RESULTS III
University inclusivity higher than the US economy

- Top Univ generate **4% of the NIs** in the economy
- % FNIs 22.6% in universities vs. 14.5% in U.S. economy in 2011-2015 (8 pp gap)
- But wide variation across universities from 18% (Purdue) to 30% (UPenn) suggesting opportunities to learn best practices
- Some differences driven by technology composition



Our Inclusivity Index accounts for university variation in technology - all (but one) do better than US average

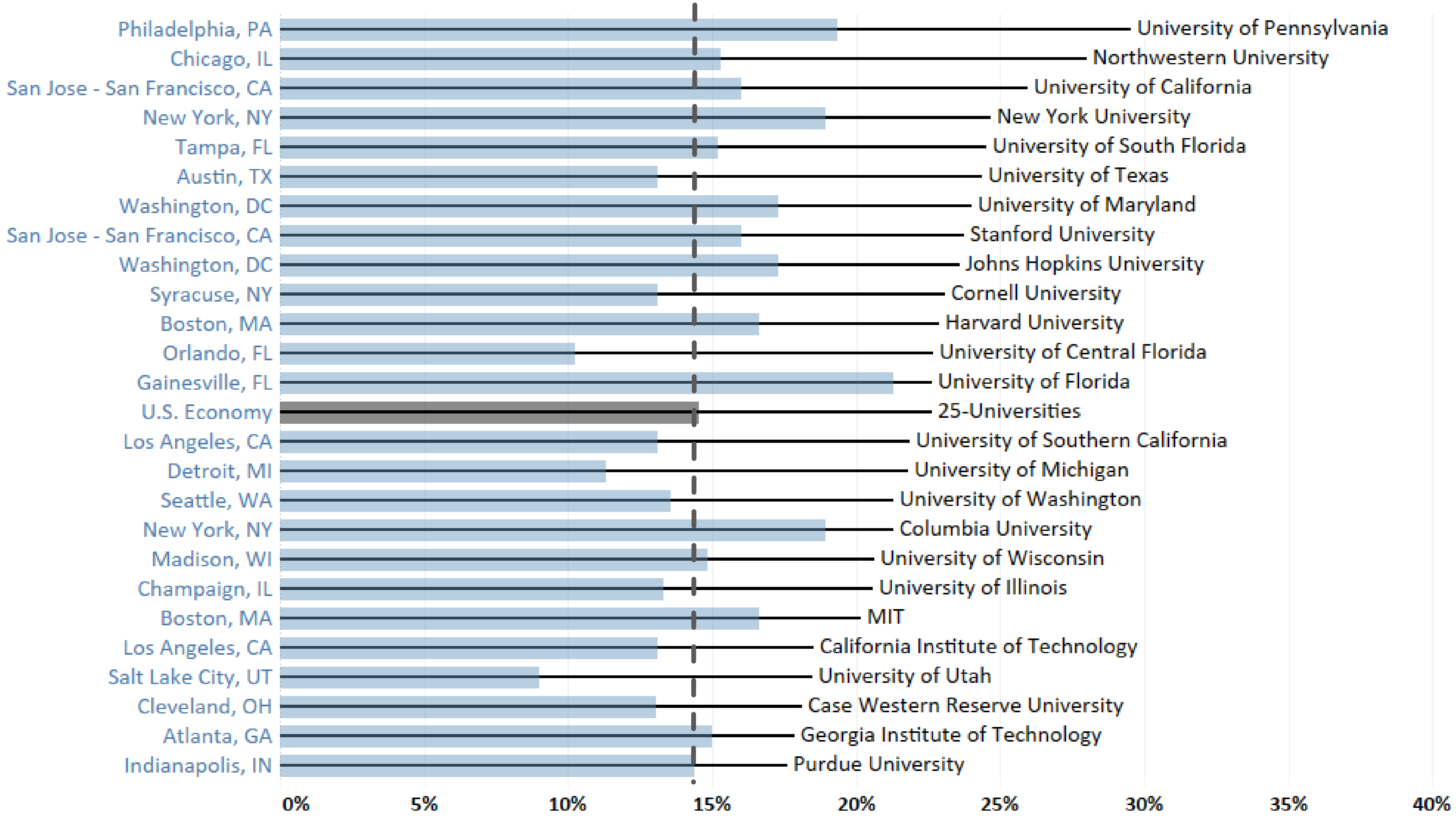
- **Index controls for tech composition** e.g. MIT moves up from #20 to #9
- Index allows us to compare university inclusion to that in the US economy
- % FNIs **index was 4% for Universities**
- Only Case Western does worse than U.S. average



UNIVERSITIES CAN BE CATALYSTS IN THEIR REGIONS

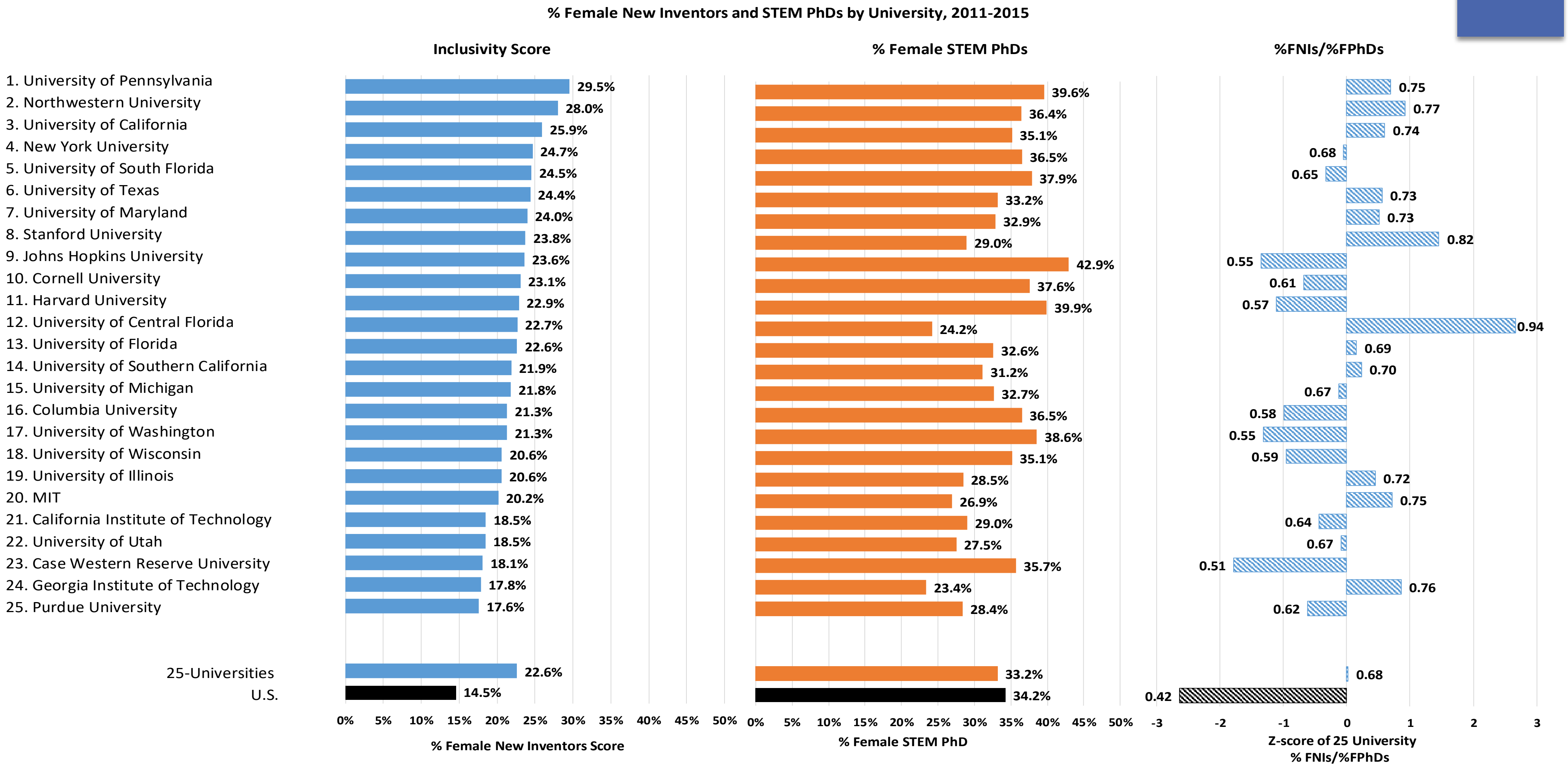
Top universities are more inclusive than their regions

- All universities have a % FNI score greater than their region
- This gap ranges from 13 pp for Northwestern to 1 pp for UFlorida
- Mean University-vs-Region gap is 7.3% in the %FNI Score (and 3.6% in the Index)
- All universities (but one) have an index value greater than their region



Inclusivity of University vs. Region (EA): % Female New Inventors Score, 2011-2015

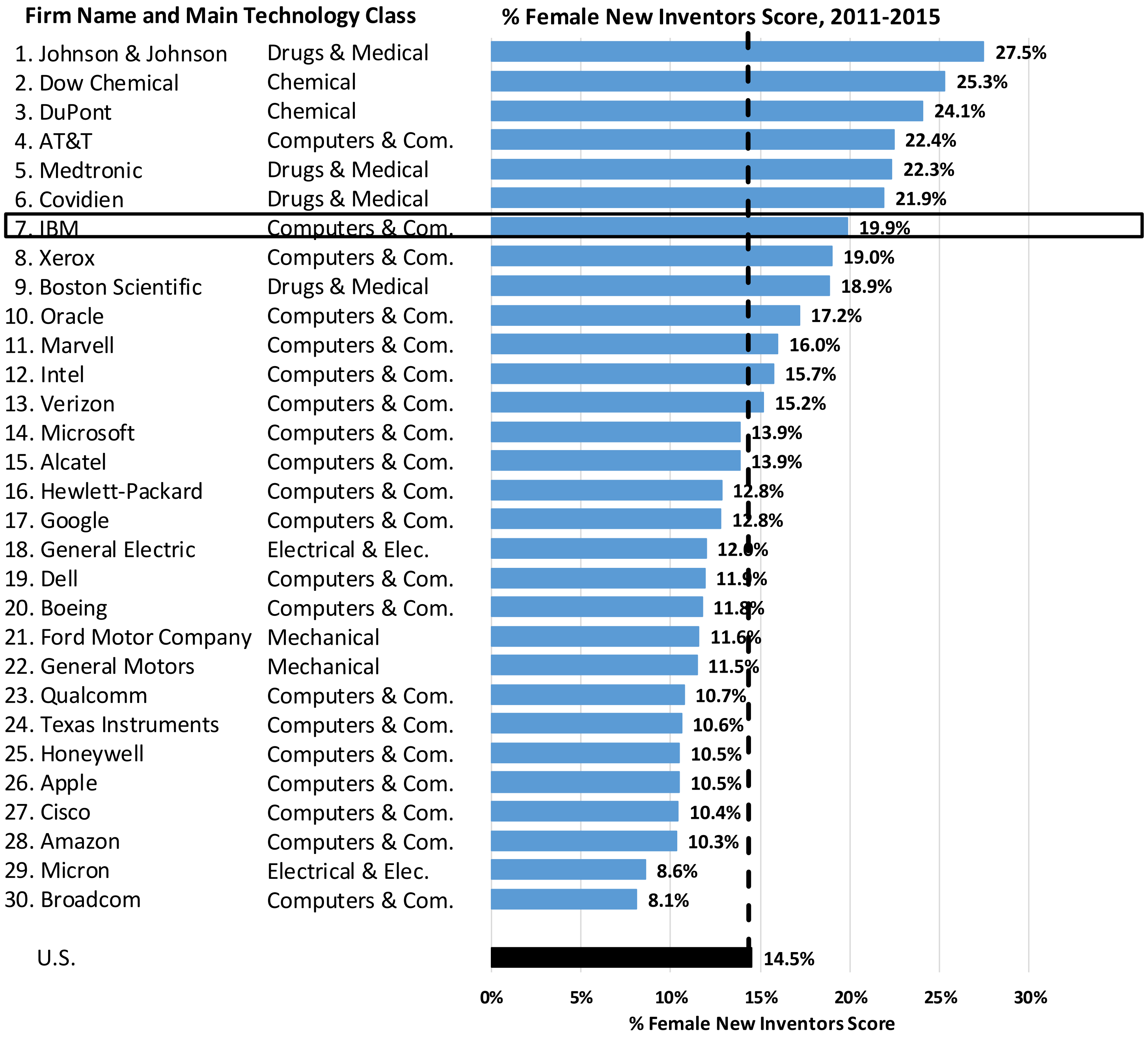
UNIVERSITIES "UNDER UTILIZE" THEIR FEMALE STEM PHD PIPELINE:
Large STEM female PhD to female New Inventor Gap across Universities



- 25-university ***% Female STEM PhDs* is 10 p.p.** higher than ***% Female New Inventors*** (33% vs. 23%).
- For each university there is a large STEM PhD-Inventor gap
- Rate at which women PhDs engage in university patenting is much lower than that of men Delgado/Murray (2020)

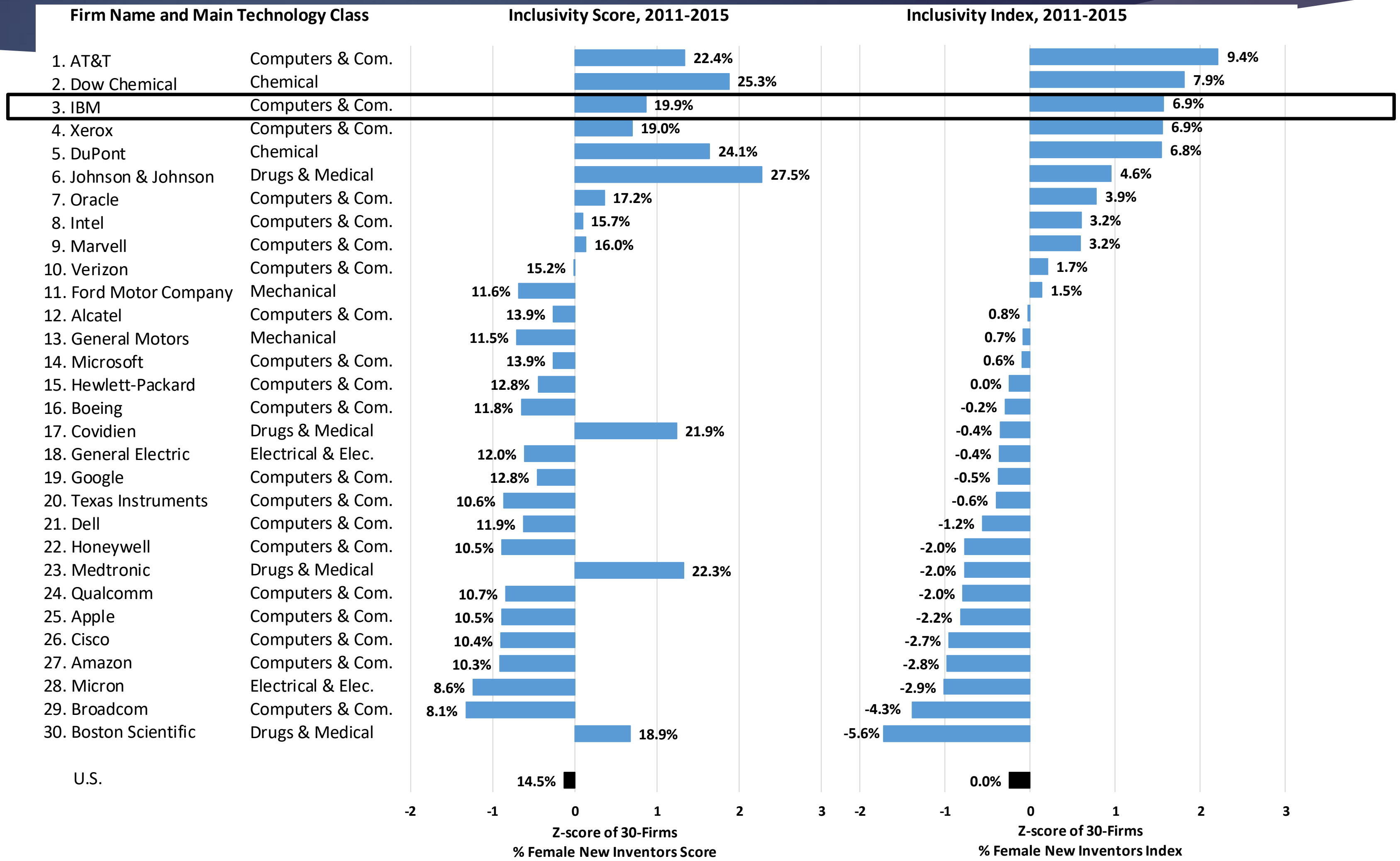
RESULTS III
Large Variation in the % Female New Inventors across Firms (2011-2015)

- Top 15 firms (in the top 30 by patenting) are above US average for inclusion by up to 13 pp
- But most firms have scores lower than % Female STEM Degrees in their Main Tech:
- % Female STEM BS is 37% (2006-2015):   **19% in Computers & Com.** and **59% in Biological & Biomed**
- % Female STEM PhDs is 34% : 21% in Computers & Com. and 52% in Biological & Biomed
- Largest patent producer (IBM) is close to STEM supply at 19.9%



Inclusivity Index essential to account for firm-level variation (and concentration) in tech fields

- % FNIs index for 30 firms is 1.3% - top 11 firms are higher
- IBM moves up from #7 to #3 in the ranking
- Medtronic moves down to #23
- Suggests need for insights into **organizational drivers of large variation in index**
- Focus on issues associated with **spatial nature of innovation**
- Examine **the role of key individuals** inside organizations



To what extent might key individuals - Top Inventors – serve as catalysts of Female Inventor Inclusion?

- **Many** of the **patents** are produced **by few Top Inventors** (TIs – are 90th percentile - those with 7+ patents in 2000-15)
  - 25-Univ: **TIs represent 6% of inventors and are listed in 59% of patents and account for 45% NIs**
  - 30-Firms: **TIs represent 19% of inventors and are listed in 84% of patents and account for 65% NIs**
- Their autonomy, reputation, and patenting intensity give them a **key role in shaping the organizational culture for patenting** and thus more specifically for female inventor inclusion
  - At universities, **as faculty** and PIs of labs they will have a **role in training and mentoring new inventors among their graduate students.** This can have long-lasting effects on their careers (Pezzoni et al. 2016; Gaule/Piacentini, 2018; Delgado/Murray, 2020)
  - **At firms,** TIs may have less discretion in building their teams (although this is poorly understood in the literature) but have some autonomy in how they pursue their projects

Male vs. Female Top Inventors as Catalysts for Change

	# TIs	**% Female New Inventors Score** (exc. TIs)	Gap TI vs No-TI	Gap FTI vs MTI
25-Universities 2000-2015				
No-Top Inventor Patents		20.9%		
Top Inventors Patents		22.4%	**1.5%**	
Female Top Inventors (FTIs)	208	29.2%		
Male Top Inventors (MTIs)	2,035	22.0%		7.2%
30-Firms 2000-2015				
No-Top Inventor Patents		12.3%		
Top Inventors Patents		15.7%	**3.4%**	
Female Top Inventors (FTIs)	2,538	22.9%		
Male Top Inventors (MTIs)	28,717	15.5%		7.4%

- TI patents higher inclusivity score than no-TI patents – in university and firm settings
- University TIs are more inclusive than firms in the same period – difference of 6% for TI patents
- 25 universities: Female TIs are only 9% of all TIs. Female TI Patents higher inclusivity scores than Male TI (7%)
- 30 firms: Female TIs are 8% of all TIs. Female TIs have higher inclusivity than Male TIs (7%)
- Same findings with the index….

Large Variation in Inclusivity even across Top Inventors within given Organizations

	Patents 2000-15	**% FNI Score**	TI Patents	TIs (1+ NI)	**TI % Female New Inventors**					
					Mean	**SD**	**Pc25**	**Pc50**	**Pc75**	**IQR**
MIT	2,578	19.3%	1,805	185	21.4%	23.5%	0%	17%	33%	33%
25-Universities	32,032	21.2%	18,956	2,077	21.2%	24.0%	0%	17%	33%	33%
IBM	60,554	17.9%	55,305	5,937	18.5%	24.5%	0%	9%	33%	33%
30-Firms	346033	13.8%	289,038	30,365	15.1%	22.7%	0%	0%	25%	25%

- Among Top Inventors with at least 1 New Inventor:
  - There is large variation within organizations in TIs' % FNIs: the **Interquartile Range (IQR)is 25-33% p.p.**
  - 25% of TIs have zero Female New Inventors (50% for 30-Firms TIs)
- Same findings hold for specific technology fields e.g. Computers and Comms
- Many TI attributes could influence their inclusivity: Field, Pool of PhD advisees, Gender, the extent to which they engage new inventors in patents, … (we examine this in Delgado & Murray 2021)

ACCELERATING CHANGE IN GENDER INCLUSION IN INNOVATION: LESSONS FROM UNIVERSITIES & FIRMS

- Improving participation of female STEM PhDs in the innovation economy as inventors is a critical challenge – supply of PhD STEM talent is not the central issue;
- Variation in inventor inclusion in the highest patent-production regions, organizations and individuals - provides a window into catalysts for change;
- Mapping top patenting organizations and individuals can identify places to examine practices that increase participation, and serve as role models and catalysts;
- Improve the inclusivity of Top Patenting Organizations – firms and universities, and Top Inventors themselves.

IMPLICATIONS FOR FUTURE RESEARCH TO CATALYZE CHANGE

- Understand the **pipeline of potential female inventors**: from hiring, to invention, and disclosing and patenting
- Understand the role of **culture and organizational drivers**
- Understand drivers of **variation even among top inventors within organizations** (e.g., Delgado & Murray, 2020).
- Help design and **assess** initiatives to engage female/minority inventors
- Examine implications of COVID-19 on female inventor inclusion

SUPPORT MATERIAL

- Support Material: References, Tables and Figures, and Appendix with Method Explanation
- Link: **Here**