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The Role of Location on the Inventor Gender Gap: Women are Geographically Constrained

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Abstract

This paper examines the inventor gender gap in the United States. While prior work has explored the role of location on innovation, little is known about the role of location on female inventor activity. The low presence of women who patent (i.e., ?female inventors?) has been documented across countries. However, prior studies abstract from variation across sub-national regions and their industry clusters. To explain the inventor gender gap, we need to better understand the potential differences in the regional context where female inventors (FI) and male inventors (MI) operate. The goal of this paper is to examine: Where are female inventors located? How do female versus male inventors source knowledge inside their organizations and in the external environment? We test the hypothesis that women are geographically constrained, and so, female inventors will be more likely to source knowledge that is closer by. To examine these questions we use novel data that maps the participation of women and men in patenting across regions, economic fields, type of organization, and time. We find that female inventors are more co-located with their team of co-inventors, suggesting that they exploit more intrafirm nearby knowledge.

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1. Introduction

This paper examines the inventor gender gap in the United States. While prior work has explored the role of location (in particular cluster agglomerations) in innovation and entrepreneurship, little is known about the role of location on female inventor activity. The limited presence of women who patent (i.e., "female inventors") has been documented across countries (see Milli et al., 2016). Some recent studies examine the variation in women's participation in patenting across countries and technology classes (e.g., Lax Martínez, Raffo, and Saito 2016), but they abstract from variation across sub-national regions and their industry clusters. The majority of patents (around 95%) are created by firms, and it is well-established that firms are geographically concentrated by economic field. Thus, to explain the inventor gender gap, we need to better understand the potential differences in the regional business environments where female inventors (FI) and male inventors (MI) operate. The goal of this paper is to bridge this gap in the existing research and examine: Where are female inventors located? Do female inventors source knowledge differently? If so, what are the optimal locations for women?

To examine these questions we use novel data that maps the participation of women and men in patenting across regions, fields (industry clusters and technology classes), and over time (see Delgado and Murray, 2019).

The limited presence of female inventors has been shown in top academic institutions, in the United States, and across countries (see a literature review by Milli et al., 2016). For example, Hoisl and Mariani (2016) have shown variations in female inventor participation and performance across countries. Within a more specific sub-set of potential inventors, Ding, Murray, Stuart (2006) have illustrated the lower rates of engagement in patenting by female faculty members in the life sciences.

What is even more puzzling and worrisome is the *persistence* of the invention gender gap across all U.S. utility patents in the period 2000 to 2015 (Table 1). The percentage of Female Inventors (FIs) has effectively remained unchanged over the last 16 years (*i.e.,* in 2015, 10.0% of all U.S. inventors were women versus 8.0% in 2000). In terms of the contribution of FIs to patenting, the percentage of female patents is even lower and the gap more persistent when a patent is allocated proportionally across its co-inventors (7.7% in 2015 versus 6.6% in 2000). For a further review of these dynamics see Delgado and Murray (2019).

To address the core question regarding the persistent gender gap in patenting and its locational drivers, we use new indicators of the geographic patterns of female inventors (FIs) versus male inventors (MIs). With this novel data, we investigate two empirical hypotheses regarding the low presence of FIs and the persistent gender gap: (1) women are not selecting STEM-based skills that are compatible with a gender-balanced participation in the innovation economy; and (2) locational attributes influence the inventor gender gap.

First, it is suggested that the skills women select are incompatible with gender-balanced participation in patenting. Certainly, the participation of women in STEM education remains lower than that of men (Siebens and Ryan, 2012) – although not at levels that are low enough to explain the female inventor gap (Delgado and Murray, 2019). As a baseline, a recent study by Landivar (2013) showed that in 2011, 26% of STEM workers were women while 74% were men, and yet the ratio of female participation is much lower in patenting activity (around 8% of patentees were women and 92% men in 2011).

Moreover, even as the inventor gender gap stagnated, the gender gap in STEM skills has improved markedly. Table 2 shows that the stock of female STEM graduates has grown from 17.7% of STEM PhD holders in 2000 to 25.9% in 2015. The gender balance of STEM PhDs with science and engineering jobs following a similar path, from 18.4% female in 2000 to 25.6% in 2000. Thus, investment in STEM skills cannot be the only factor driving the inventor gender gap. Murray and Delgado (2019) document in detail the large and increasing gaps between the gender balance of STEM skills and patent activity.

Second, locational attributes may influence the level of invention opportunities available to women. To the extent that patenting is related to location in strong regional clusters (e.g., biopharmaceuticals in Boston), the presence of women in these locations (versus others) may affect positively their relative ability to invent. Prior work shows that strong clusters improve patenting and entrepreneurship (see e.g., Feldman and Audretsch, 1999; Delgado, Porter, and Stern, 2010, 2014), but does not explore gender participation.

To understand this explanation, it is important to disaggregate patenting by gender at the regional level and link this to the attributes of the clusters of economic activity that may support invention broadly, and invention by women in particular. Whether strong clusters improve female inventor inclusivity is a new empirical question. If men are better able to optimize location choices

(Marvel and Lee, 2011; Rosenthal and Strange, 2012; Sorenson and Dahl, 2016) they could be over-represented in clusters as compared to women, thus contributing to the explanation of the inventor gender gap. On the other hand, economies of agglomeration that arise within clusters may reduce some of the barriers that women face to become inventors (i.e., produce patents). If women are, on average, more geographically constrained than men in their ability to access knowledge, they would benefit more than men from sourcing from geographically proximate knowledge to develop inventions. Hence, women could particularly benefit from locating in clusters.

2. Inventor Gender Gap in the US: Women are Geographically Constrained

This paper focuses on the second hypothesized explanation of the inventor gender gap: that geography influences the level of invention opportunities available to women.

Where are female patents? Figure 1 shows the share of patent activity by female inventors across Economic Areas. The inventor gender gap varies across economic areas, suggesting that location plays a role in the inclusivity of the innovation economy. In other words, whatever factors are hindering female patenting in Texas, they do not hold as strongly in New York. (Houston, Dallas, and Austin are all below 6% female patents (below the US average), while New York City and Rochester are both above 9%). Notably, even the locations with the highest share of female patenting lag significantly behind the national share of women among STEM PhDs (Table 2).

To date, most literature on the geographic dynamics that could affect the inventor gender gap has focused on the *initial location*: i.e., the place of early childhood. Bell et al. (2016) find that the exposure to innovation growing up matters for becoming an inventor: both role models at home (father is an inventor) and in the location (presence of inventors). We could argue that these initial barriers are greater for girls because there are fewer *female* role models, reducing their incentives to choose STEM education and jobs, and so, reducing women's subsequent probability of patenting. But this does not naturally explain why, even as the numbers of female STEM graduates and female STEM workers have improved rapidly, the number of female inventors has not kept pace. (Delgado & Murray 2019). The inventor gender gap is not just driven by women's initial locations and STEM choices.

Others have studied the impact of the additional constraints female workers face in choosing where to locate, and the impact this can have on their productivity, including patent activity. (Marvel and Lee, 2011; Rosenthal and Strange, 2012; Sorenson and Dahl, 2016).

We introduce a novel hypothesis of the role of location on the inventor gender gap: ***Women are geographically constrained***. Separate from choosing where to locate, women also face geographic constraints on collaboration and knowledge sourcing. Women take on a disproportionate share of familial and administrative responsibilities, which may limit their ability or willingness to travel, or even to collaborate electronically across time zones. Furthermore, if female workers are systematically less able to invest time and money in the knowledge collection and long-term collaboration necessary for patenting, these constraints may also manifest as geographic constraints – it is cheaper and more convenient to collaborate with local co-inventors. Some multi-location organizations may also give female workers fewer opportunities to collaborate across business units.

No matter the mechanism, geographic constraints on female inventors would limit their opportunities for patenting, relative to other colleagues who are able to collaborate and source knowledge from more distant locations. We propose this geographic constraint as a partial driver of the inventor gender gap.

This theory yields a testable prediction: if women are geographically constrained, to reduce this barrier, female inventors will source knowledge that is closer by. Thus, in section 2 we test whether female inventors are likelier to be co-located with the team of inventors. Further research will investigate whether female inventors cite more within-firm patents, and whether the patents they cite are geographically nearer.

3. Findings: Women search for knowledge that is geographically proximate

Writing a patent often requires drawing on the knowledge and expertise of multiple inventors. The share of patents with inventors in multiple MSAs grew from 27% in 2000 to 38% in 2015. Thus, any meaningful constraint on an inventor's ability to collaborate across distance is also a constraint on that inventor's productivity.

In a multi-inventor patent, each inventor must decide to collaborate with a team that may or may not share the inventor's location (MSA). To measure this behavior, we define a measure of co-location for each inventor and patent. Inventor *i*'s "share of co-location" on patent *p* is the percentage of the other inventors on the patent who co-locate with focal inventor:

$$Inventor\ Share\ of\ Co\text{-}Location\ With\ Team_{ip} = \frac{Co\text{-}Located\ Team\ Size_{ip}}{Team\ Size_p\ -\ 1} \tag{1}$$

Team Size refers to the number of inventors listed on patent p and *Co-located Team Size* refers to the number of other inventors on patent p who share an MSA with inventor i. This share varies from 0 to 1. For instance, if an inventor in Boston collaborates with two San Diego-based inventors on a patent, the Boston inventor has a co-location share of 0 for that patent. If on her next patent she collaborates with one Boston-based inventor and one living in San Diego, she has a co-location share of ½ for the second patent, since she is co-located with one of her two collaborators. If all three inventors lived in Boston, each inventor would have a co-location share of 1.

Table 3 averages this measure across inventor-patents and gender in 2015. The average *Inventor Share of Co-location* is 2% higher for female than for male inventors (0.65 versus 0.63). This modest effect was significant and persistent throughout the 2000-2015 period, and suggests an underlying difference in the geographic constraints on male and female inventors.

The gender effect is stronger in single-gender patents, as we would expect if each inventor's geographic constraints affect his or her collaborators. If every inventor on a project is constrained, collaboration across distances is even more difficult. Thus we see all-female teams patents have on average 6% higher share of co-location than all-male teams patents.

These patterns are consistent with geographic constraints on women. But they could also be explained by a theory in which female inventors are likelier to locate in the MSAs with high patent activity, or women tend to work in smaller teams and are thus less likely to need to collaborate across MSAs. Alternately, female inventors may concentrate in technology classes or organization types that feature less collaboration across distance. To isolate the effect of gendered geographic constraints on collaboration, we specify a model of co-location share as a function of gender, other attributes of the inventor and patent, and various fixed effects:

$$\begin{aligned} &Inventor\ Share\ of\ Co\text{-}Location\ With\ Team_{ip} \\ &\quad = \alpha\ Female_i + \lambda_1 Team\ Size_p + \lambda_2 Patent\ Count_i + \delta + \delta_{year} + \delta_{MSA} \\ &\quad + \delta_{tech} + \delta_{org\ type} + \epsilon_{ip} \end{aligned}$$

(2)

This model specifies co-location share as a function of the inventor gender, patent attributes (i.e. the size of the team) and other inventor attributes (i.e. their productivity). We also control for fixed effects by the patent's issue year, the inventor's location (MSA), the patent's technology class, and the assignee's organization type. Errors are clustered at the inventor level.

As mentioned earlier, we predict stronger geographic constraints for teams composed exclusively of female inventors. We test for that effect by estimating the following model:

$$\begin{aligned}
&Inventor\ Share\ of\ Co\text{-}Location\ With\ Team_{ip} \\
&\quad = \beta_f^1\ Female_i \times\ Single\ Gender\ Team_p + \beta_m^1\ Male_i \\
&\quad \times\ Single\ Gender\ Team_p +\ \beta_f^2\ Female_i \times\ Multi\ Gender\ Team_p +\ \beta_m^2\ Male_i \\
&\quad \times\ Multi\ Gender\ Team_p\ \text{(omitted)} +\ \lambda_1 Team\ Size_p +\ \lambda_2 Patent\ Count_i +\ \delta \\
&\quad +\ \delta_{year} + \delta_{MSA} +\ \delta_{tech} +\ \delta_{org\ type} +\ \epsilon_{ip}
\end{aligned}$$

(3)

Table 4 shows the results of estimating equations (2) and (3) on all multi-inventor patents granted in the US from 2000-2015. Female inventors are significantly more likely to co-locate – 2.1% likelier than male inventors, or 2.5% likelier when controlling for inventor productivity. This effect is strongest in single-gender teams, with all-female teams roughly 5% likelier to share a location than all-male teams. As we would expect, larger teams tend to see significantly more collaboration across location (MSAs) than smaller teams.

We also find that more productive inventors are more frequently co-located with their collaborators – their co-location share increases by 1% with each unit increase in the ln of their patent count. This is not a mere clustering effect of overall patent activity, since the model allows for fixed effects by MSA. Instead, the top inventors in each MSA are likelier to collaborate with local inventors. It could be that less-productive inventors are "squeezed out" of local networks of co-patenting, and must turn to less convenient, more distant co-inventors instead.

3.1. Inventor Co-location with Team in Industry Clusters

Patent activity is often clustered in few locations by technology class (Delgado, Porter, and Stern, 2010). Can industry clusters influence inventor co-location? We have already controlled for fixed effects by MSA, so we know the gender differences are not an effect of female inventors locating in areas with more overall patent activity. Now we will investigate whether it can be explained by female inventors locating in areas with more patent activity in their field of specialization (i.e., "good" locations).

To investigate the effects of industry clusters on inventor co-location, we estimate the following model:

$$\begin{aligned} &Inventor\ Share\ of\ Co\text{-}Location\ With\ Team_{\ ip} \\ &\quad = \alpha\ Female_i + \gamma_1 MSA\ Tech\ Specialization_{ip} + \gamma_2\ Female_i \\ &\quad \times MSA\ Tech\ Specialization_{ip} + \lambda_1 Team\ Size_p + \lambda_2 Patents_{\ i} + \delta \\ &\quad + \delta_{year} + \delta_{MSA} + \delta_{tech} + \delta_{org\ type} + \epsilon_{ip} \end{aligned} \tag{4}$$

Here *MSA Tech Specialization*$_{ip}$ is the specialization of inventor *i*'s region in the technology class of patent *p*. This will capture if the inventor is located in a "good" location for the particular technology class (e.g., Boston MSA is highly specialized in Drugs and Medical patents).[1]

Table 5 shows the result of estimating equation (4). The simplest model, in column 1, shows that inventors have higher co-location with their team if their MSA specializes in the patent's technology class.[2] Column 2 shows that the significant effects estimated above -- of inventor gender, inventor productivity and team size – are robust to controlling for MSA specialization. Column 3 adds the interaction between female inventor and *MSA Tech Specialization*, and finds that the MSA specialization effect on co-location is significantly stronger for female than male inventors. This suggests that female inventors take greater advantage of industry clusters to collaborate with local co-inventors.

The nature of industry clusters is that a few regions often have much stronger specialization that dwarf other parts of the country. To investigate the co-location effects in these top technology

[1] *MSA Tech Specialization* is defined using a location quotient (LQ) based on patents:
$\text{MSA Tech Specialization}_{ip} = \ln\left(\frac{\text{Patents}_{tech,r}}{\text{Patents}_r} \,/\, \frac{\text{Patents}_{\ tech,US}}{\text{Patents}_{\ US}}\right)$. MSA r specializes in the technology class of patent *p* if the LQ exceeds 1. This ratio can take large values, so we use the Ln (LQ) in the model specification.
[2] Co-location increases by 6.9% if we double *MSA Tech Specialization*.

clusters, we drop the continuous measure of MSA specialization, and use instead a binary classifier that captures only the top regional clusters *Top MSA Tech Specialization* (i.e., MSAs in the top quartile of specialization for each technology class).

Technology clusters remains a significant predictor of team co-location, and the model explains the data roughly as well as before (model 4). However, the interaction of top tech clusters and female inventor is negative.[3] One potential explanation is that, in the largest and most specialized MSAs, male inventors have better access to the local network, and squeeze out female inventors. This would be particularly detrimental to female inventors' productivity, given their potential geographic constraints. Another explanation is that geographic constraints push many female inventors to collaborate locally *regardless* of their MSA's degree of specialization, while male inventors are able to be more opportunistic and tailor their co-location behavior to their MSA's degree of specialization. This means female inventors' co-location is less responsive to MSA specialization than male inventors'.

4. Conclusion and Next Steps

Our findings suggest that female inventors are more co-located with team of inventors. This is consistent with the hypothesis that women are more geographically constrained in their collaboration. Future work will determine if they are similarly constrained in their knowledge sourcing from prior patents, and attempt to identify the mechanisms of these geographic constraints.

Mechanisms of Geographical Constraint. Many plausible mechanisms could underly the apparent geographic constraints on female inventors. Women may be hindered by familial responsibilities, lower pay, or fewer opportunities within firms. Alternately, female inventors are likely younger on average than male inventors, so they may have narrower, more local networks of potential collaborators. To better interpret the findings we plan to categorize inventors by their patent count, comparing top vs. non-top inventors (as in Delgado and Murray 2019). Top inventors may have broader networks. They may also be granted more leeway by their organizations to invest time and money in long-term and long-distance collaboration.

[3] Female inventors are 3% likelier than male inventors to collaborate locally, if they do not live in a top MSA for their patent's technology class – but if they do live in a top MSA, they are only 2% likelier than male inventors to collaborate locally.

Knowledge Sourcing. Are knowledge agglomerations particularly important for women to become productive inventors? If women are more geographically constrained, then female inventors will need to source knowledge closer by than male inventors. The finding that female inventors co-locate more with co-inventors suggests already that they exploit more nearby knowledge. To focus more closely on knowledge sourcing, we plan to investigate the geography of patent citations – testing whether female inventors are likelier to exploit "internal agglomerations" by citing a higher portion of intra-firm patents than male inventors; and whether they are likelier to exploit external agglomerations by citing more local inter-firm patents.

This research could offer policy and managerial implications to reduce the inventor gender gap, helping to build knowledge networks that are helpful to female inventors, and identifying location-based policies to unlock the potential of female inventors.

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Table 1. Female Inventor Inclusivity in U.S.: 2000 versus 2015

Granted Year	Female Inventors (FIs)	Male Inventors (MIs)	% FIs	% Female Patents
2000-15	104,317	921,941	10.2%	7.2%
2000	8,162	94,344	8.0%	6.2%
2015	**18,386**	**165,343**	**10.0%**	**7.7%**
Change$_{2000\text{-}15}$	10,224	70,999	2.0%	1.5%

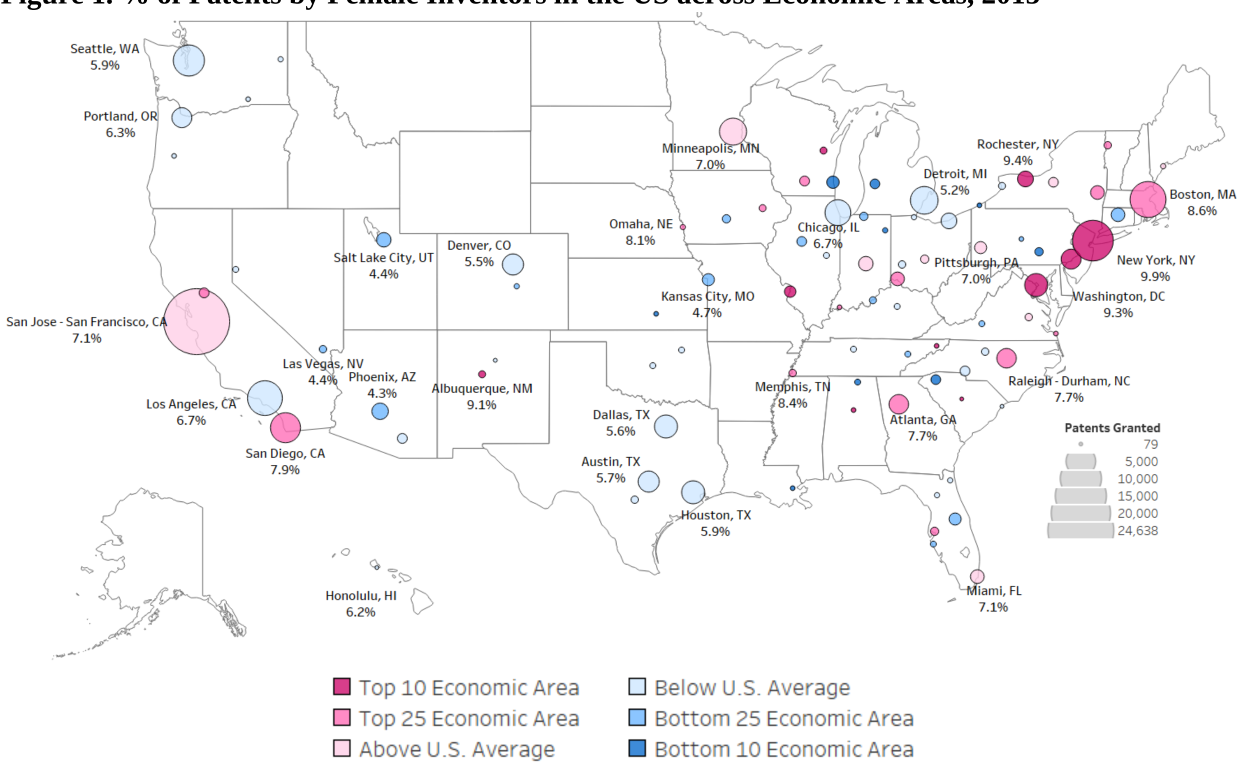
Notes: Sourced from Delgado and Murray (2019). The analysis uses patents of U.S. origin granted to organizations and the inventors located in the U.S (USPTO). The definition of inventor is organization specific (i.e., an individual with several patents granted in a particular organization count as one inventor). In our 2000-2015 sample, 91% of US inventors and 85% of university inventors have a matched gender.

Table 2. STEM PhDs and Inventors by Gender: 2000 versus 2015

	2000			**2015**			**2000-2015**
	Female	Male	Female Share	Female	Male	**Female Share**	Female Share Change
STEM PhDs Stock	78,870	367,760	17.7%	162,100	464,650	**25.9%**	**8.2%**
STEM PhDs in S&E Jobs Stock	57,750	255,930	18.4%	122,300	356,350	**25.6%**	**7.1%**
STEM PhDs Flow	5,285	13,054	28.8%	10,611	19,271	**35.5%**	**6.7%**

Notes: Sourced from Delgado and Murray (2019). STEM data sourced from NSF Survey of Doctoral Recipients. Estimated PhD holders residing in the US. STEM PhDs Flow refers to doctoral recipients that year. STEM PhDs Stock refers to all PhD holders less than 76 years of age.

Figure 1. % of Patents by Female Inventors in the US across Economic Areas, 2015



Notes: The *% Female Patents* for patents by all the organizations in the region (i.e., the number of patents by women divided by the number of gender-matched patents). This variable is based on the proportional allocation of each patent across inventors by gender, and then aggregating across the corresponding pool of patents. This variable captures the contribution of women to patenting. Circle size on map proportional to total patents granted in 2015. Circles in pink have FI inclusivity above the U.S. average. The map shows the top 90 EAs (out of 179) by patents. They account for 98% of patents issued. Patents distributed proportionally across inventors by gender.

Table 3. Mean Inventor Co-location with Team: Female vs Male Inventors, 2015

	All Multi-Inventor Patents 2015		Single Gender Patents 2015	
	Obs.	Mean	Obs.	Mean
Inventor Share of MSA Co-location with Team				
Female Inventors	25,375	0.65	723	0.69
Male Inventors	268,952	0.63	166,142	0.63
Mean(FI)-Mean(MI)		**0.02****		**0.06****
t-test of diff.		8.39		3.68

Notes: ** Significant at 1%. Unit of observation is an inventor-patent. We illustrate for 2015 data, but find the same results using 2000 granted patents. Single-gender patents are those patents in which all inventors are male or all inventors are female.

Table 4. Inventor Co-location with Team: Gender of Inventors, 2000-2015

	Y_{ip}=Inventor i Share of MSA Co-location with Team [0-to-1]			
	Multi-Inventor Patents (Granted 2000-2015; N=3,026,522)			
	1	2	3	4
Female Inventor (FI_i)	**0.021****	**0.025****		
FI x Single Gender $Team_p$			0.027**	0.032**
FI x Multi-Gender $Team_p$			0.010**	0.014**
MI x Single-Gender $Team_p$			-0.018**	-0.018**
Ln Team $Size_p$	-0.046**	-0.047**	-0.052**	-0.052**
Ln $Patents_i$		0.010**		0.010**
Issued Year FEs (2000-2015)	Yes	Yes	Yes	Yes
MSA FEs (912 regions)	Yes	Yes	Yes	Yes
Tech Class FEs (6 classes)	Yes	Yes	Yes	Yes
Organization Type FEs (4 types)	Yes	Yes	Yes	Yes
Adj. R-Squared	0.153	0.154	0.154	0.155

Notes: ** Significant at 1%. The unit of observation is inventor-patent (i*p*). Standard Errors clustered by inventor id *i.* Types of Organizations: U.S. Non-Gov; U.S. Gov; Foreign Non-Gov.; and Foreign Gov. Tech Classes (six categories). In models 3-4 the omitted category is *MI x Multi-Gender Patent*.

Table 5. Inventor Co-location with Team: Gender and Location of Inventor, 2000-2015

	Y_{ip}=Inventor i Share of MSA Co-location with Team [0-to-1]				
	Multi-Inventor Patents (Granted 2000-2015; N=3,026,522)				
	1	2	3	4	5
Female Inventor (FI_i)		0.025**	0.023**	0.025**	0.028**
Ln Team Size$_p$		-0.046**	-0.046**	-0.046**	-0.046**
Ln Patents$_i$		0.008**	0.008**	0.009**	0.009**
Ln MSA Tech Specialization$_{ip}$	0.069**	0.067**	0.066**		
FI x Ln MSA Tech Specialization			0.012**		
Top MSA Tech Specialization				0.061**	0.062**
FI x MSA Tech Specialization					-0.011**
Issued Year FEs (2000-2015)	Yes	Yes	Yes	Yes	Yes
MSA FEs (912 regions)	Yes	Yes	Yes	Yes	Yes
Tech Class FEs (6 classes)	Yes	Yes	Yes	Yes	Yes
Organization Type FEs (4 types)	Yes	Yes	Yes	Yes	Yes
Adj. R-Squared	0.157	0.163	0.163	0.157	0.157

Notes: ** Significant at 1%. The unit of observation is inventor-patent (i*p*). Standard Errors clustered by inventor id *i*. Types of Organizations: U.S. Non-Gov; U.S. Gov; Foreign Non-Gov.; and Foreign Gov. Tech Classes (six categories). *Top MSA Tech Specialization*: top region by both patent count and specialization (in the top quartile for the particular technology class).