Women in Patenting: Does Nanotechnology Make a Difference?

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Abstract:

Using data pooled from a unique nano-related patent database, the research attempts to investigate gender disparities in patenting nanotechnology innovations. Our systematic analyses offered new, even preliminary, information on gender differences in technological productivity in this particular interdisciplinary field, showing the relationships between gender and time, collaboration, research preference, and workforce sector. Our main argument based on the findings is that interdisciplinary fields such as nanotechnology would be a strategic niche to attract more women to work, invent, and contribute to technological development.

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1. Introduction

The history of technology has long been considered as a history of men's technological activities and contributions. Does this mean technological genius is gender related? To respond to this inquiry, many scholars dedicate themselves to the study of women in science and technology. Their studies, although shed a light on our understanding of individual and institutional reasons for women's under-representation in technology, have limitations on several respects. Historians[1] tend to provide anecdotal narratives rather than systematic results on large-scale quantitative data analysis. Other researchers focus more on scientists in academia than those in other sectors(Fox 2001; Thursby and Thursby 2005), and rarely investigate the productivity difference other than publications and citations (Cameron 1978; Cole and Zuckerman 1984; Corley 2005; Long and Fox 1995). Furthermore, traditional studies based their analysis on established disciplines have been suspected to capture changes occurred with the emerging interdisciplinary fields.

Overcoming those limitations embedded in previous work can not only extend our knowledge on women's status in and contribution to the development of technology, but also pave the path for motivation and full utilization of women as an important human resource. Given the critical role of technological advancement and innovation under the globally competitive conditions (Nelson and Rosenberg 1993) and the importance of women as human resources to the size, creativity, and diversity of the S&T workforce (Fox 2008; Hanson 1996; Pearson

[1] Examples are Anne L. Macdonald, *Feminine Ingenuity: How Women Inventors Changed America*; Autumn Stanley, *Mothers and Daughters of Invention: Notes for a Revised History of Technology*; Ethlie Ann Vare and Greg Ptacek, *Mothers of Invention: From the Bra to the Bomb, Forgotten Women and Their Unforgettable Ideas*; Farag Moussa, *Women Inventors*; Susan Casey, *Women Invent!*; Fred Amram, *From Indian Corn to Outer Space: Women Invent in America*; and Ethlie Ann Vare and Greg Ptacek, *Patently Female: From ZAT to TV Dinners, Stories of Women Inventors and Their Breakthrough Ideas*

and Fechter 1994), further comprehensive investigation is pressingly needed. The current research attempts to continue the investigative efforts by examining gender disparities in patenting across various workforce sectors. More importantly, we conduct the examination within the context of nanotechnology, with a hope of offering new, even at an exploratory level, information on gender difference in technological productivity in the interdisciplinary field identified by NSF (NSF 2003).

The rest of the paper is organized in four sections. In the following section, a review on theoretical arguments for the gender disparity in patenting (with women in a disadvantage position) is provided and related hypotheses are proposed. The second section describes the data used in the research and a matching procedure for inventors' sex identification. Analytic results corresponding to proposed hypotheses are presented in the third section. And finally, we summarize the findings and discuss how to interpret and generalize these findings carefully.

2. Theoretical Background and Hypotheses

2.1 Gender, productivity, and patenting

Despite an increasing proportion of S&E degrees awarded to women (NSF 2007), a volume of evidence has shown the long-standing and widespread existence of gender difference that favors men in the scientific workforce (Evetts 1996; Fox 1999; Fox 2001; Long and Fox 1995; Reskin 1978; Sonnert and Holton 1995a; Sorensen 1992; Thursby and Thursby 2005; Whittington and Smith-Doerr 2005). Among various viewpoints on gender difference in S&T, the focus on productivity is of particular interest and attracts the most attention (Allison and

Long 1987; Astin 1969; Cole and Zuckerman 1984; Creamer 1998; Fox 1983; Leahey 2006; Levin and Stephan 1991; Levin and Stephan 1998; Long 1992; Long 2001; Pripic 2002; Reskin 1978; Xie and Shauman 1998). This is so because not only such a difference is impressive in terms of its size and persistence but also it has created and perpetuated other forms of gender inequality, such as reward and cognition (Fox 2001; Fox and Stephan 2001).

Unfortunately, the concept of productivity is most often operationalized as counts of referred journal articles, limiting our knowledge of an otherwise much broader concept connotation and its related social phenomena. The measure is even misleading under the condition that the line between public and private sectors has become blurry (Jaffe and Lerner 2001; Nelson and Rosenberg 1993; Stephan, Gurmu, Sumell, and Black 2007) and the standards for scientists' career rewards have undergone a fundamental change. Among myriad measures of scientific productivity, commercial activity indicators, especially those assessing patenting activities, have increasingly become crucial criteria to evaluate scientists' performance and contribution, and this is especially true in applicable fields (Whittington and Smith-Doerr 2005). As publication is the means though which new knowledge can be shared in timely fashion to confirm the priority of discovery (Merton 1957; Stephan 1996), patents indicate a pursuit for pecuniary rewards. With the notice of differences between the two types of scientific outcomes, it would be interesting to examine gender disparities in the new niche of patenting.

Recently, some scholarly concerns have been devoted to gender difference in patenting. In a study comparing women and men's patenting in life science, Whittington and Smith-Doerr

(2005) found that female are less likely to patent than male scientists and the gap holds across generational cohorts. On average, male scientists have higher patent counts through their careers than female scientists, but the difference shrinks when only looking at those who patent. Although female scientists participate and produce less, the quality and impact of their patents measured by patent citation is equal to or better than that of their male counterparts. In another study on academic life scientists' patenting activity, Ding and colleagues discovered that a statistically significant gender difference remains after holding constant the effects of productivity, networks, field, and employer attributes, with women patent at only 40% of their equivalent male counterparts (Ding, Murray, and Stuart 2006). The few studies, although inspiring and instructive, only target life science – a discipline emerging in 1970s and matured in 1980s – and lead to our wonder of the robustness of their conclusions when considering an interdisciplinary field that is burgeoning recently and differ from established disciplines in nature.

2.2 Nanotechnology and its interdisciplinary characteristic

Nanotechnology is a technology creating novel products and processes by way of manipulating molecular-sized materials (Lux Research 2007). The rapidly increasing concern in nanotechnology during recent years stems from: 1) its promising role as a powerful driver of future economic growth (Huang, Chen, Chen, and Roco 2004); and 2) its interdisciplinary nature that is expected to bring fundamental changes to both S&T work and institutions conducting the work. Relevant to our focus on gender differences, the interdisciplinary feature of nanotechnology is particularly of our interest as some studies have triggered a discussion on whether and why scientists are drawn to engage in interdisciplinary research

(Carayol and Thuc Uyen Nguyen 2005; Corley and Gaughan 2005; Rhoten and Pfirman 2007).

In their study, Carayol and Thuc Uyen Nguyen (2005) utilize two measures for the concept **interdisciplinarity** – *multidisciplinarity* and *interdiciplinarity*. The former one measures the organizational respect, namely, to what extend researchers in a given unit affiliate to different disciplines. The latter one is related to research processes and outcomes, measuring tools adopted from and results applied to different disciplines. Multidisciplinary implies more interactions, more intellectual support, more access to equipment, and hence it would provide more opportunities for women scientists. While interdisciplinarity associated with fuzzy standards and risks in "being scooped" (Stephan 1996) may discourage male scientists to get involved in nanotechnology, female scientists may be attracted to such a field and especially in its early stages of development because they are less interested than males in pursuing priority and recognition (Barinaga 1993; Sonnert and Holton 1995b). Rhoten and Pfirman's (2007) *interdisciplinarity* is more similar to the second measure in Carayol and Thuc Uyen Nguyen's study. Specifically, they identify four characteristics of interdisciplinary research, including *cross-fertilization, team-collaboration, field-creation, and problem-orientation*. Thinking of the characteristics of interdisciplinary science together with women's preference for complexity and diversity as well as their reluctance to commit to the traditional social rules of science and style of interaction, and based on exploratory analysis on data borrowed from three studies, they argued that women scientists are more likely to engage in interdisciplinary research.

Given those features attached to interdisciplinary fields that possibly encourage women's participation and productivity, we are curious about to what extent the gender gap within the field of nanotechnology would be narrower than that found in traditional disciplines; and how the gap varies over time and on several critical cultural and institutional variables.

2.3 Masculine culture in S&T workforce

When an egalitarian relationship between sexes was broken and a shift towards a male advantage occurred at some point in the history of human beings (Stanley 1993), the decline of women's status and power had been significantly and negatively affect their participation and achievement in the development of technology. The negative impact has worked in both explicit and implicit way. Explicitly, women were limited in a very narrow (domestic) domain socially, economically, and legally. For instance, women were not admitted in public high school until 1852 in the United States and they were not allowed to patent an invention in their own names (but their husbands') until the Married Women's Property Acts passed in the 19th century. Implicitly, androcentric views penetrate at every corner of the society. It is not surprising to find scientific role, work style, and performance standards are created and developed by men based on "masculine" epistemology (Bleier 1986; Fehr 2004; Harding and O'Barr 1987; Rhoten and Pfirman 2007; Sorensen 1992).

As opposed to masculinity, women hold a *Caring* value that is ingrained in their cognitive procedure and behaviors (Sorensen 1992). The caring value referring to *empathy* and *rationality of responsibility*, unfortunately, may distinguish women from men scientists and marginalize them from the masculine system by labeling them as less competitive researchers. As increasing enrollment and graduate rates achieved by women in scientific education indicate women's comparative capability, continuous small proportion of women in scientific labor force suggests stronger masculine rules playing in the culture of S&T workplace. McIlwee and Robinson (1992), grounded on their study about women's experience in engineering workplace, argued that while school culture values academic achievement that favors women, workplace culture emphasizes masculine characteristics such as "a fascination with technology, expertise as a tinkerer, and an aggressive style of self-presentation" (p.50), making the transition from education to occupation a difficulty for women. Today, with higher technical standards and higher requirement for experiment facility, it is reasonably assumed that most patents are inventive products of employed scientists or engineers in the S&T workforce. Combining with the strong masculine culture in the S&T workforce and the interdisciplinary feature of nanotechnology, our first group of hypotheses is yielded as:

H1a: The amount of patents granted to women is less than that granted to men.

H1b: Due to the interdisciplinarity of nanotechnology, the gender gap is narrower than that found in established disciplines, and it is shrinking over time.

2.4 Gender and research collaboration

On one hand, representing masculinity, individualism and aggressiveness suggest independent work be highly honored in the scientific system. On the other hand, the complexity of modern scientific work and expensive facilities require more emphasis and efforts on collaboration. Research has found a strong correlation between productivity and collaboration (Price and Beaver 1966; Zuckerman 1967; Pravdic and Oliuic-Vukovic 1986; Durden and Perri 1995). Several elements in collaboration have even been identified affect productivity, such as complementary skills, intellectual stimulus, access to equipment, and exchange of opportunity information (Lee 2005). Moreover, collaborated papers are found more likely to be accepted in journals (Zuckerman and Merton 1971; Presser 1980; Gordon 1980; Lawani 1986; Bayer and Smart 1991; Hollis 2001).

Some psychological studies argue that women are inclined toward teamwork while men prefer more independent work (Hayes 2001). Empirically, nonetheless, the argument is not consistently supported. Earlier research found that women scientists were less likely to collaborate (Cameron 1978; Cameron and Blackburn 1981; Chubin 1974; Cole and Zuckerman 1984; Hunter and Leahey 2008; Kyvik and Teigen 1996; Scott 1990) and recent research provided evidence that women scientists are as likely as, but not more than, men to collaborate (Corley 2005). The disconnection between psychological inclination and revealed behavior is most likely due to the masculine culture that marginalizes and excludes women from resource and information networks. Along the line, we would hypothesize:

H2a: Women, compared with men, are more likely to have patent(s) granted individually or with fewer collaborators.

H2b: Again, the gender gap is narrower than that found by collaboration studies focusing on traditional disciplines.

2.5 Gender and research preference

With respect to research problem choice, as empirical evidence is scare, a strategic solution is to look at the highly uneven distribution of women and men scientists/engineers across disciplines/fields. It has been argued applicable disciplines such as medicine and social sciences tend to attract more women than do theoretically oriented ones like physics, chemistry, or engineering because applicable ones seek to advance knowledge toward people/community to meet their needs and improve their living standards (Photen and Pfirman 2006). As of 2003, according to statistics released by National Science Foundation (NSF 2007; see Figure 1), women employed in S&E occupations were most likely in biology/life science (43.4%), psychology (64.4%), and social sciences (43.0%), but less likely in computer science (27.6%), physics (28.5%), and the least in engineering (11.1%). In addition, a qualitative study conducted by Elisabeth Piene suggests the existence of gender difference in preference for research questions even in the same discipline – women, compared with men, are less interested in pure technical dimensions of their discipline (cited from Sorensen 1992). Similarly, some scholars found there is a difference between women and men, on average, in their intention to work with "people" versus "things" (Pinker 2005).

[Figure 1]

Research preference can also be understood as a certain way of conducting research. It is deemed, based on psychological studies, women tend to assemble information from various sources while men like to isolate objects and problems under study (Haier, Jung, Yeo, Head, and Alkire 2005; ScienceDaily 2005), upon which Rhoten and Pfirman (2007) draw their discussion on women scientists' more interdisciplinary way of doing research – more endeavor on cross-fertilization and field-creation. Then, in our focused area of nanotechnology, two hypotheses built on the gendered preference are concerned with subfields of women's patents:

H3a: women's patents tend to be in fields where women's preferences are reflected and also where they are concentrate;

H3b: women's patents cover more subfields than men's.

2.5 Gender and workforce sectors

Both literature and statistics offer support for gender difference in workforce sectors: more female scientists and engineers are working in public sector like government (especially local government), academia, and nonprofit organizations whereas their male counterparts in industry and self-employed business. Women are not equally distributed throughout workforce both horizontally (across employment sectors) and vertically (across occupations in the same sector), and are clustered in sectors and occupations associated with less prestige, authority, and pay (Crewson 1995; Kaufman 1995; Lindsey 1997). Statistics from NSF (2007) are also evident that women are overrepresented in nonprofit organizations, almost equally represented in academia [2] and local governments, and less likely represented in self-employed business, federal government, and industry (See Figure 2).

[Figure 2]

While the sectoral segregation is another consequence and reflection of exclusion of women from masculine system, workforce sector is such a broad concept that might blur the organizational characteristics that more directly affect women's productivity. Suggested by Whittington and Smith-Doerr (2005), women in small firms characterized by flatter and

[2] only refers to universities and 4-year colleges

flexible organizational structure are more likely to patent than those in hierarchical organizations, whether in private or public sector. The contradictory arguments and the reality that most nanotechnology research is conducted in both small firms and academia lead us to anticipate that ***gender difference in patenting would vary across sectors, but the pattern of variation is unpredictable.***

3. Data Source

3.1 Nanotechnology patent database

The nanotechnology patent database is a large database created by Porter and his colleagues (Porter, Youtie, Shapira, and Schoeneck 2007). It contains 53,720 patent records in total for the period 1990-2006(mid-year). Data used in this research are pooled from the unique patent database, restricted only to the patents granted by the United States Patent and Trademark Office (USPTO) from 2002 to 2006 (mid-year). A descriptive summary of the sub-database is presented in Table 1. Keep in mind that patents are successful inventions that have been assessed as ones with highly technical and potentially commercial values. The results from the current study, therefore, cannot be generalized to all inventions but those that have successfully gone through the evaluation process and been granted the property right.

[Table 1]

3.2 First-name algorithm and matching procedure

The key variable *Gender*[3] is unavailable in the database, which requires us to develop a strategy to identify inventors' gender. Even though a gender identification method has never been fully developed, a few studies did offer heuristic clues on identifying gender from first names. Using them as reference, then, we endeavored to create a firstname-gender algorithm which can be applied to inventors in our database.

Our algorithm has three origins. The first and the most developed one is a name list adopted by Frietsch and his colleagues (Frietsch, Haller, Vrohlings, and Grupp 2009) who are conducing similar research on patent applications filed to EPO. However, it has its limitation in application only for European names. Another source to extend the list comes from US Social Security Administration[4]. Since we assume the inventors in our database are at their 20s to 40s, we select the "Top 1000 names" in three decades, 1960s, 70s, and 80s. Copying all male and female names in the three decades, removing duplicates, and marking out the names popular for both male and female, we finally got a list applicable for American names with three gender categories – female, male, and both. In addition, we found two, but not so authoritative, online sources for identifying gender of Japanese names and Indian names[5]. After deriving the four name-gender lists, we apply them separately to all standardized first names in the database, check those conflicts (e.g. Debra is identified as *female* by using European list but as *both* by using American list) and code these names as non-identified, and

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[3] Gender is a social term, but here it is used instead of Sex to refer to both physical and social difference between women and men

[4] www.ssa.gov/OACT/babynames

[5] http://www.indianchild.com/indian_baby_names.htm for Indian names, and http://www.languageisavirus.com/namedatabase/db.cgi?db=default&uid=&ID=&Letter=---&Name=&Gender=---&Origin=Japanese&Meaning=&view_records=Search&nh=1 for Japanese names

get a relatively consistent name-gender algorithm[6]. We also conducted a verification procedure on the algorithm by using the "U.S. Inventors and Their Invention" survey data[7]. A rough comparison[8] only offered a correction rate of 43%, but the rate is dramatically improved to 99% when only focusing on those having been certain on their gender category – male or female.

We created a thesaurus based on the algorithm and ask VantagePoint[9] to match the first names in the thesaurus and inventors' names in the database so as to identify their gender. As a result, we identified 3,013 female inventors and 23,944 male inventors with 14,640 unable to be identified (most are Chinese and Korean names but some are those falling into *both* category). The corresponding percentage of female, male, and non-identified inventors is 7.2%, 57.6%, and 35.2% respectively. After adjustment by excluding those non-identified, the percentage becomes 11.2% for female versus 88.8% for male inventors, and the ratio of female to male inventors is 1:8. Even not based on a completely identified data, we still get the sense that female inventors are less than male inventors in the field of nanotechnology.

4. Analysis and Findings

Bearing in mind that the patent data does not provide rich individual information for analysis at individual level, we took a strategic approach of undertaking the analysis at the patent level

[6] It is not presented here but will be provided if request

[7] The survey was conducted in the summer of 2007 under the leadership of Dr.Walsh, professor in the School of Public Policy in Georgia Institute of Technology

[8] all names falling into different categories "don't know," "both," and "non-identified" are included in the two lists that are compared

[9] This is a bibliometric data mining and analysis software

and correspondingly aggregate the *Gender* variable coded for inventors at the level of patent. In other words, the value of *Gender* of a given patent indicates its gender combination of inventors in the team, which could be *female* (if all inventors are women), *male* (if all inventors are men), and *mixed* (some are women and some are men). Since we have many non-identified inventors in the dataset, we still included them in our analysis, constructing another vague measure of *Gender* that only has two values: *male* patents and patents *with at least one female*. Although the two created variables at the patent level have some disadvantages (e.g. cannot directly indicate the characteristics and behaviors of individual scientists and one individual scientist may own multiple patents), they are acceptable and because: 1) scientists who own those patents were actually in different disciplines and thus the field of nanotechnology of our interest was identified from patents rather than disciplinary affiliation of these scientists; 2) the variables can help us understand one important characteristic of patents – gender combination of inventor team – which has not been noticed in previous research; 3) they reflect, albeit indirectly, the status and contribution of women and men in the development of technology.

4.1 Descriptive results

Patent counts. Table 2 shows, in general, the share of patents granted to male inventor(s) (34.4%) is greater than that of patents to inventors including at least one female (16.7%) during the five-year period, with the former being more than twice as large as the latter. However, the gap between these two groups shrunk gradually from 21.4% in 2001 to 14.5% in 2006. Obviously, the share of patents involving female inventor(s) remains small, but is higher than 14.2%, the highest share of women's patent applications in Frietsch and his colleague's study (Frietsch, Haller, Vrohlings, and Grupp 2009). When we focus more on the three categories – *female, male,* and *mixed* – that we are certain about the combination of the inventors' gender (see Figure 3), we find that the patents with all male inventor(s) are dominating and those with all female inventor(s) only account for a very small proportion, between 2% and 3%, only trivially higher than the percentage, 1%, reported in Khan's research on patents in the 19th century (Khan 2000).

[Table 2]

[Figure 3]

Research collaboration. It can be seen, from Table 3, that the patents *with at least one female* tend to have larger inventor team size than *male* patents, with the mean 4.23 for the former group versus 2.12 for the latter one. Among the patents *with at least one female*, only 5.1% were granted to one inventor but 35.8% granted to a team with five or more inventors. In contrast, about 41% were granted to one inventor while only 5.5% granted to a team with five or more inventors among *male* patents. But the difference is primarily rooted in the fact that a large proportion of patents involving female inventors is *mixed* patents involving both female and male inventors. When looking closer at only *female* and *male* patents in Figure 4, we observed that *female* patents are more likely to be product of individual inventive activity while *male* patents are more likely to be collaborative outcome. This finding suggests that women are still excluded from collaboration and network regardless of the interdisciplinary nature of requiring more collaboration than traditional

S&T disciplines. In many studies on gender disparities in collaboration, only Lee and Bozeman's (2005) research offered comparable information on collaboration to ours which allowed us to make the comparison regarding hypothesis H2b. Based on data collected from university professors and researchers in engineering, bioscience, computer science, chemistry, physics, and other science fields, they found that, on average, men have 10.2 while women only have 3.6 collaborators (Lee and Bozeman 2005). The difference revealed in our study within nanotechnology is apparently smaller than that in their research.

[Table 3]

[Figure 4]

Research preference. Using primary IPC class as an indicator, we summarize subfields in Table 4 on which the patents *with at least one female* and *male* patents differ from each other at least 0.5 percent. Interestingly, it is easy to discover that patents involving female inventor(s) have an advantage[10] in biology (A61, C08, C12, and C11) and chemistry (C01 and C07) while male patents in electronic (H04, H01, G06, H03, and H02) and mechanic (G01 and B23) fields. The finding is accord with literature that argues and evidences women scientists tend to work in the field of biology and life sciences, fields related more to "people" than to "thing"(NSF 2007; Rhoten and Pfirman 2007; Sorensen 1992). Considering that women scientists and engineers only account for less than half (43%) of

[10] in terms of magnitude of percentage difference

total employees in biology/life sciences released by NSF (2007), our finding here favors women inventors in the specific sub-field. If only comparing *female* with *male* patents, in addition to biology and chemistry, we observed that women have also an advantage in some traditional "feminine" fields, such as printing and spinning, associated with domestic role and secondary status in workplace (see Table 5).

[Table 4]

[Table 5]

To examine our hypothesis regarding gender difference on ways of undertaking research, we used the variable *comprehensiveness* which is operationalized as the number of IPC classes assigned to each patent. Looking at the summary information in Table 6, we found that patents *with at least one female* are more comprehensive than *male* patents. In terms of mean value of *comprehensiveness*, *male* patents have 1.61 IPC classes that is statistically significantly less comprehensive than both *female* patents and patents *with at least one female* (1.70 and 1.67 respectively). In terms of specific value of *comprehensiveness*, the share of patents only being assigned one IPC class is 56.6% among the patents *with at least one female* , whereas the share among *male* patents is 60.4%; and for each category along the dimension of number of IPC classes that is more than one, the share of patents *with at least one female* is larger, albeit slightly, than that of *male* patents, with 28.7% vs. 25.9% for two classes, 9.1% vs. 8.8% for three classes, 3.7% vs. 3.1% for four classes, 2% vs. 1.8% for five and more classes. With a closer focus on those three certain categories of patents, Figure 5 illustrates that *female* patents are more interdisciplinary than both mixed patents and male patents since more of them fall into the categories indicating larger number of IPC classes.

[Table 6]

[Figure 5]

Workforce sectors. Table 8 illustrates the distribution of patents over five types of assignee. Generally speaking, *male* patents, compared to *with at least one female*, are slightly more likely to come from industry or individual (41.1% vs. 38.7% and 51% vs. 49.3%), but less likely from government (1.3% vs. 2.7%), academic (5.9% vs. 7.7%), and nonprofit organizations (0.7% vs. 1.5%). Look more specifically at the distribution of the three sex combination categories – *female*, *male*, and *mixed* – on the types of assignee from Figure 5. More *female* patents are in governmental organizations and less are in industry, and *male* patents are in the exactly opposite way, while *mixed* patents are more in nonprofit and academic organizations, although the industry sector and individual invention account for the two largest parts in all three types of patents. Compared to NSF (2007) statistics (Figure 2), nonetheless, the gender difference in industry, academia, and nonprofit revealed from our data is much less. One more thing that is worthy notice is the *mixed* patents are apt to come from nonprofit or academic organizations, suggesting the possible lower level of hierarchical segregation and higher level of collaboration in such organizations. This might be an interesting hypothesis investigated in future research.

[Table 7]

[Figure 6]

4.2 Econometric results

After getting the idea of the relationship between gender and several variable of interest from above bivariate analyses, we would go further to consider those variables relative to gender in an econometric model, that is to say, the relationship between a given variable and gender holding constant the value of other variables. Keep in mind, however, this is also descriptive because we do not account for potential variables (e.g. individual level variables) that should have been accommodated in a formal model but are unavailable in our current dataset. Considering those potential important variables missed in the preliminary model and then developing a well-specified econometric model is imperative in future research.

With a focus on the three certain types of patents – *female*, *male*, and *mixed*, we use multinomial logit regression. Independent variables include four time dummy variables *Year2003, Year2004, Year2005, and Year2006* (where 2002 is excluded), dummy variable *Public sector* (where 1 indicates assignee is an academic, non-profit, or government organization while 0 industrial organization or individual[11]), and two continuous variables *Team size* and *Comprehensiveness*. They are regressed on the dependent variable *Gender* where 0 is assigned to *male* patent, 1 *female* patent, and 2 *mixed* patent. Results are in Table 8.

[11] We combined the three organization types – academic, government, and nonprofit organization – because the number of female patents in each of these types is observed very small in previous bivariate analysis.

[Table 8]

Overall, there are 7,980 observations and the pseudo R^2 is 0.147. The coefficients of independent variables in the model show that *Public sector*, *Team size*, and *Comprehensiveness* are good predictors of *Gender* of a patent. Holding fixed other variables in the model, the team size of *female* patents is significantly smaller than that of *male* patents while the team size of *mixed* patents is significantly larger than that of *male* patents, which is consistent with the bivariate results seen before. Anything else equal, *female* patents are significantly more comprehensive than *male* patents, while *mixed* patents seem more comprehensive than *male* patents but the difference is not statistically significant. Hold other variables constant, both *female* and *mixed* patents, compared with *male* patents, are significantly more likely to come from public sector versus industry or individual. With a suspicion the noticeable quantity difference between male and female patents would be an issue, we randomly selected only 3 percent of the male patents (to make the size of the two groups similar), ran the logit regression, and repeated the procedure for several times. The coefficients yielded are slightly different from those in Table 8, but the sign and significance remain the same[12].

5. Conclusion and Discussion

In this paper, we attempts to investigate women's involvement in patenting nanotechnology. The findings offered from our systematic analysis on nano-related patent data suggest the

[12] An exception is the significance of gender difference on Public sector disappeared when only selecting 3 percent of male patents, suggesting the overrepresentation of male patents in private sector. Results are not presented here but will be provided as request.

existence of gender disparity in the specific technological field and some unique aspects of the disparity related to the interdisciplinary nature of nanotechnology.

In regard to patent amount, *female* patents or even patents *with at least one female* are less than *male* patents, but the gender gap is narrower than the general gap discovered in some discipline-based studies that offered comparable information. The comparison suggests that the interdisciplinary feature of nanotechnology may attract more women as assumed before. The observation that the gap between patents *with at least one female* and *male* patents are shrinking over time while the gap between *female* and pure *male* patents seems unchanged over time could be attribute to the increase of *mixed* patents, or the increase of collaboration between women and men in nanotechnology. Related to research collaboration, *female* patents tend to be individual inventive products while *male* patents tend to be products of collaboration. *Mixed* patents have larger team size that suggests they welcome collaboration between women and men, and encouragingly, their increase over time is referred from the information about patent counts. Relevant to research preference, both patents *with at least one female* and *female* patents have an advantage over *male* patents in biology, chemistry, and a few traditional "feminine" fields where women's interest and preference are reflected and where they are concentrated, and a disadvantage in "male" disciplines – electronic and mechanic engineering that are more theory-oriented, technical, and "thing" related; In addition, *male* patents are less comprehensive compared with patents *with at least one female* or *female* patents, suggesting women are more likely to adopt interdisciplinary approach and involve in interdisciplinary research. As workforce sector is concerned, *female* patents tend to come from organizations in the public sector, but the gender difference in this regard is less than that revealed by NSF statistics (2007).

These findings are inspiring, but we should interpret and apply them with cautions. First, as mentioned before, the data used for the research are patents that only refer to successful inventions, and then the conclusions can only be generalized to successful inventions with significant technical and market values. Secondly, the key variable *Gender* is constructed based on identification of individual inventor's gender but only about 68% of total inventors' gender has been identified, meaning that the analysis and conclusion are incomplete (at least the gendered pattern found in the research is not applicable to Asian inventors given most non-identified inventors are Asians). Caution should also be given to the adoption of the rather broader variable *Workforce sector*. Suggested by Whittington and Smith-Doerr (2005), organizational characteristics (e.g. the structure of organization) are more influential in women's involvement and performance in patenting, they are more appropriate than the sector variable and should be specified and taken into account in future research. Furthermore, the analysis on the relationships between gender and other key variables (e.g. team size and interdisciplinarity) are simply descriptive, and a well-specified econometric model with individual and organizational level variables should be developed to fully understand women's status and performance in patenting nanotechnology. With all these cautions, this preliminary study still offer us scientific evidence to support the insight that interdisciplinary fields such as nanotechnology would be a strategical locus to attract more women to work, invent, and contribute to technological development.

Reference

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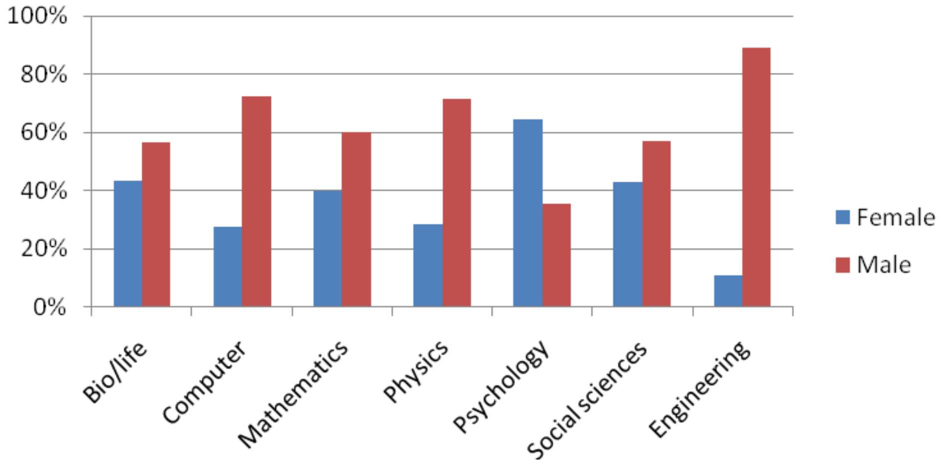
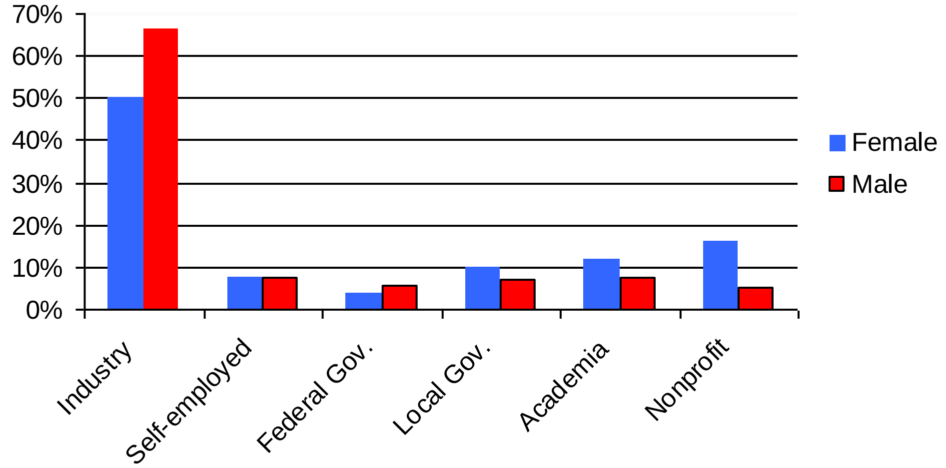
Figure 1: Employed scientists and engineers, by sex and fields: 2003



Source: NSF, Division of Science Resources Statistics, Scientist and Engineers Statistical Data System (SESTAT) 2007

Figure 2: Employed scientists and engineers, by sex and types of employer: 2003



Source: NSF, Division of Science Resources Statistics, Scientist and Engineers Statistical Data System (SESTAT) 2007

Figure 3: Percentage of patents, by gender and year

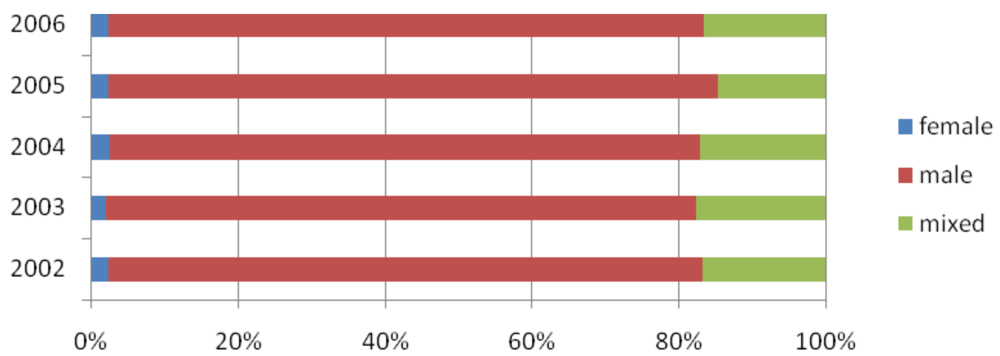


Figure 4. Percentage of patents, by sex and team size

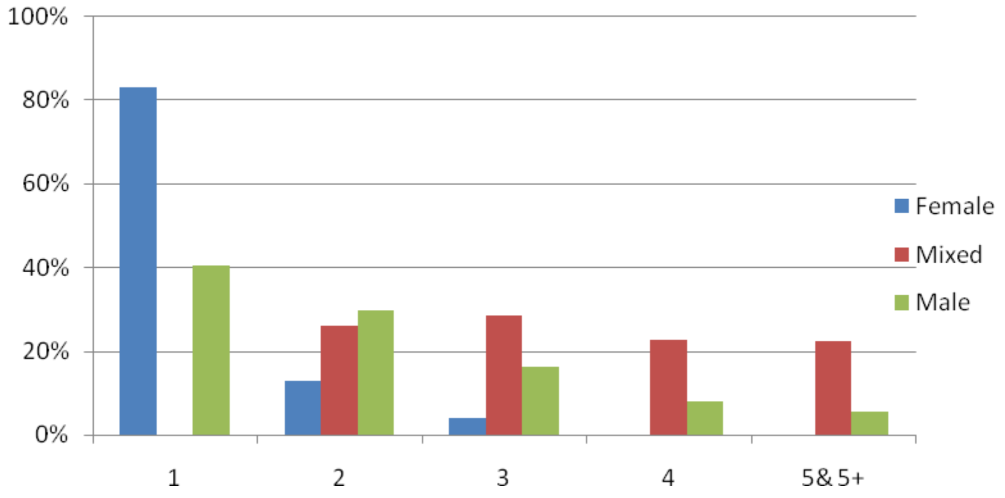


Figure 5: Percentage of patents, by sex and number of IPC classes

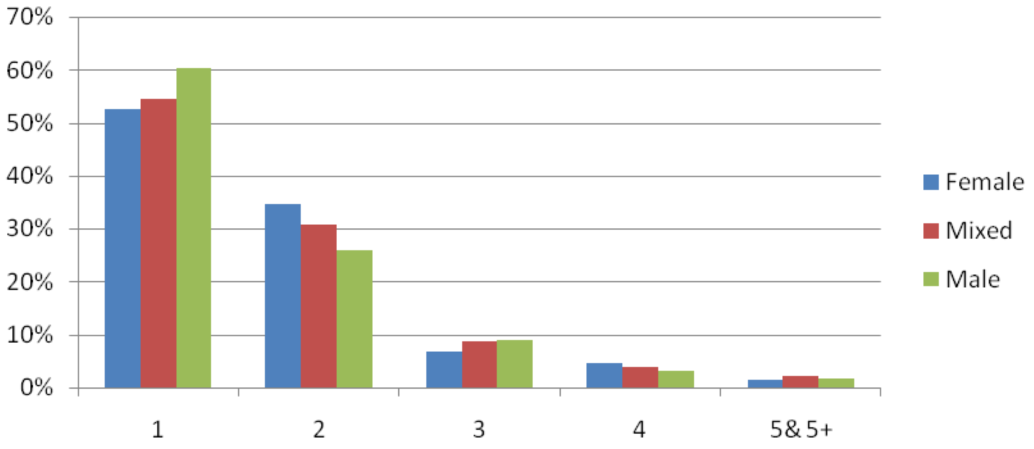


Figure 6: Percentage of patents, by gender and type of assignee

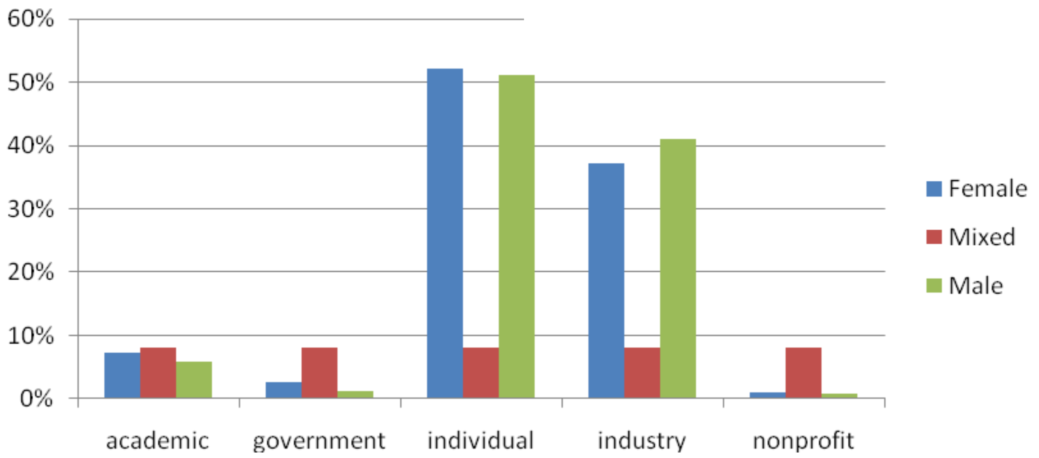


Table 1. Summary of selected patent data

Year			
	2002	2621	13.9%
	2003	2974	15.8%
	2004	3948	21.0%
	2005	5377	28.6%
	2006	3897	20.7%
	total	**18817**	**100%**
Team Size			
	1	4250	22.6%
	2	4752	25.3%
	3	3912	20.8%
	4	2724	14.5%
	5 & 5+	3179	16.9%
	total	**18817**	**100%**
Number of IPC classes			
	1	11474	61.0%
	2	4765	25.3%
	3	1666	8.9%
	4	586	3.1%
	5 & 5+	326	1.7%
	total	**18817**	**100%**
Type of Assignee			
	Individual	9113	48.4%
	Nonprofit	317	1.7%
	Academia	1355	7.2%
	Government	345	1.8%
	Industry	7687	40.9%
	total	**18817**	**100%**

Table 2: Counts and percentage of patents, by gender and year

		Year					
Sex		**2002**	**2003**	**2004**	**2005**	**2006**	**Grand Total**
At least one female inventor	**f**	30	29	47	52	36	194
	f+m	210	238	307	303	248	1306
	f+m+n	181	190	249	352	264	1236
	f+n	39	57	99	123	94	412
	sub-total	*460(17.6%)*	*514(17.3%)*	*702(17.8%)*	*830(15.4%)*	*642(16.5%)*	*3148(16.7%)*
All male inventor	**m**	1022	1082	1441	1725	1210	6480
	sub-total	*39.0%*	*36.4%*	*36.5%*	*32.1%*	*31.0%*	*34.4%*
non-identified	**m+n**	710	868	1082	1696	1120	5476
	n	429	510	723	1126	925	3713
	sub-total	*1139(43.5%)*	*1378(46.3%)*	*1805(45.7%)*	*2822(52.5%)*	*2045(52.5%)*	*9189(48.8%)*
Grand Total		2621	2974	3948	5377	3897	18817

Note: f-female, m-male, n-not identified

Percentages in parentheses refers to the proportion of each sex category in a given year

Table 3: Counts and percentage of patents, by gender and team size

Sex		Team Size 1	2	3	4	5& 5+	Grand Total	Mean (S.D.)
At least one female inventor	**f**	161	25	8			194	1.21(0.50)
	f+m		342	371	298	293	1304	3.66(1.70)
	f+m+n			194	293	749	1236	
	f+n		152	99	76	85	412	
	Sub-total	*161(5.1%)*	*519(16.5%)*	*672(21.4%)*	*667(21.2%)*	*1127(35.8%)*	*3146(100%)*	*4.23(2.29)*
All male	**m**	2625	1920	1061	522	355	6483	2.12(1.29)
	Sub-total	*40.5%*	*29.6%*	*16.4%*	*8.1%*	*5.5%*	*100%*	
Non-identified	**m+n**		1406	1598	1136	1336	5476	
	n	1464	907	581	399	361	3712	
	Sub-total	*1464(15.9%)*	*2313(25.2%)*	*2179(23.7%)*	*1535(16.7%)*	*1697(18.5)*	*9188(100%)*	
Grand total		4250	4752	3912	2724	3179	18817	

Note: f-female, m-male, n-not identified

Percentages in parentheses refers to the proportion of each team size within a given sex category

Table 4: Field comparison between patents with *at least one female* and *male* patents

IPC-primary	Corresponding field	Involving female	Male	Difference
A61	Medical or veterinary science; Hygiene	18.7%	14.2%	4.6%
C08	Organic macromolecular compounds	7.3%	4.6%	2.7%
C12	Biochemistry; mutation or genetic engineering	5.2%	2.7%	2.5%
C01	Inorganic chemistry	3.6%	2.1%	1.5%
C07	Organic chemistry	3.1%	1.7%	1.4%
B41	Printing	1.9%	1.2%	0.8%
B32	Layered products	3.3%	2.5%	0.7%
C11	Animal or vegetable oils	0.6%	0.1%	0.5%
A24	Tobacco	0.5%	0.0%	0.5%
G01	Measuring; testing	5.7%	8.9%	-3.2%
H04	Electric communication technique	0.3%	1.6%	-1.3%
G02	Optics	3.3%	4.5%	-1.2%
H01	Basic electric elements	15.1%	16.1%	-1.0%
G06	Computing; calculating; counting	0.6%	1.5%	-0.9%
B29	Plastics	0.9%	1.7%	-0.8%
B23	Machine tools	0.4%	1.1%	-0.7%
H03	Basic electronic circuitry	0.1%	0.8%	-0.7%
G11	Information storage	3.0%	3.7%	-0.6%
H02	Generation, conversion, or distribution of electric power	0.1%	0.6%	-0.6%

Table 5: Field comparison between *female* and *male* patents

IPC-primary	Corresponding field	Female	Male	Difference
A61	Medical or veterinary science; Hygiene	25.8%	14.2%	11.6%
B41	Printing	11.3%	1.2%	10.2%
C08	Organic macromolecular compounds	9.3%	4.6%	4.7%
C12	Biochemistry; mutation or genetic engineering	5.2%	2.7%	2.5%
G11	Information storage	5.2%	3.7%	1.5%
C03	Cements; Ceramics	1.5%	1.0%	0.6%
C01	Inorganic chemistry	2.6%	2.1%	0.5%
C30	Spinning	1.0%	0.6%	0.5%
G01	Measuring; testing	2.6%	8.9%	-6.3%
B01	Physical or chemical processes or apparatus in general	1.0%	6.1%	-5.0%
G02	Optics	1.5%	4.5%	-3.0%
G03	Horology	1.0%	2.9%	-1.8%
C09	Dyes; paints; polishes; natural resins; adhesives	0.5%	2.0%	-1.5%
B29	Plastics	0.5%	1.7%	-1.2%
H01	Basic electric elements	14.9%	16.1%	-1.1%
G06	Computing; calculating; counting	0.5%	1.5%	-1.0%
C23	Coating metallic material	1.0%	1.9%	-0.9%
B32	Layered products	2.1%	2.5%	-0.5%

Table 6: Counts and percentage of patents, by sex and comprehensiveness

		Number of IPC classes						
Sex		**1**	**2**	**3**	**4**	**5&5+**	**Grand Total**	**Mean (S.D.)**
At least one female inventor	**f**	102	67	13	9	3	194	1.70(0.97)
	f+m	712	402	115	50	27	1306	1.70(1.03)
	f+m+n	729	322	123	37	25	1236	
	f+n	238	113	34	19	8	412	
	Sub-total	*1781(56.6%)*	*904(28.7%)*	*285(9.1%)*	*115(3.7%)*	*63(2.0%)*	*3148(100%)*	*1.67(1.01)*
All male	**m**	3916	1676	573	200	115	6480	1.61(0.97)
	Sub-total	*60.4%*	*25.9%*	*8.8%*	*3.1%*	*1.8%*	*100%*	
Non-identified	**m+n**	3328	1365	526	161	96	5476	
	n	2449	820	282	110	51	3713	
	Sub-total	*5777(62.9%)*	*2185(23.8%)*	*808(8.8%)*	*271(2.9%)*	*147(1.6%)*	*9189(100%)*	
Grand Total		11474	4765	1666	586	325	18817	

Note: f-female, m-male, n-not identified

Percentages in parentheses refers to the proportion of each assignee type within a given sex category

Table 7: Counts and percentage of patents, by gender and type of assignee

		Type of Assignee					
Sex		**Industry**	**Government**	**Academic**	**Nonprofit**	**Individual**	**Grand Total**
At least one female inventor	**f**	72	5	14	2	101	194
	f+m	492	26	106	16	666	1306
	f+m+n	506	36	103	11	580	1236
	f+n	148	19	20	19	206	412
	Sub-total	*1218(38.7%)*	*86(2.7%)*	*243(7.7%)*	*48(1.5%)*	*1553(49.3%)*	*3148*
	m	2661	83	382	47	3307	6480
All male	***Sub-total***	*41.1%*	*1.3%*	*5.9%*	*0.7%*	*51.0%*	*6480*
Non-identified	**m+n**	2314	101	533	63	2465	5476
	n	1494	75	197	159	1788	3713
	Sub-total	*3808(41.4%)*	*176(1.9%)*	*730(7.9%)*	*222(2.4%)*	*4253(46.3%)*	*9189*
Grand Total		7687	345	1355	317	9113	18817

Note: f-female, m-male, n-not identified

Percentages in parentheses refers to the proportion of each assignee type within a given sex category

Table 8: Multinomial logit regression of gender (*male* patent as reference group)

	Female	**Mixed**
Year2003	-0.0308	0.175
	(0.27)	(0.11)
year2004	0.164	0.0562
	(0.24)	(0.11)
year2005	0.0744	-0.0718
	(0.24)	(0.11)
year2006	0.0118	0.172
	(0.25)	(0.11)
Public sector	0.530**	0.344***
	(0.24)	(0.11)
Team size	-1.460***	0.655***
	(0.15)	(0.022)
Comprehensiveness	0.150**	0.0267
	(0.071)	(0.032)
Constant	-1.625***	-3.545***
	(0.29)	(0.12)
Observations	7980	
Pseudo R-square	0.1465	

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1