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Is It a Manâ€™s World? Gender Differences in University â€“ Industry Collaboration Activities

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Abstract
The field of science and technology has long been associated with the underrepresentation of women in leading positions. In recent years, the debate about women representation in academic science has started to include issues about women?s engagement with industry and participation in technology transfer activities. This study investigates if women academics engage less than their male colleagues in collaboration activities with industry, and if they choose different forms of engagement. Analyzing multi-source data for 1200 UK physical and engineering scientists and employing a matching technique we find that women researchers collaborate less than men and they tend to choose less rewarding channels of collaboration. Exploiting additional information on the individuals, we propose possible explanations of this phenomenon and we explore implications for research on gender stratification in commercial science and policies designed to encourage academics to engage with industry.

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IS IT A MAN'S WORLD?
GENDER DIFFERENCES IN UNIVERSITY – INDUSTRY COLLABORATION ACTIVITIES

INTRODUCTION

The field of science and technology has long been associated with the underrepresentation of women in leading positions. For example, although the first Nobel Prize awarded to a woman was granted to Marie Curie in 1903, just 15 have been awarded in scientific disciplines since. This is in stark contrast with the 521 men who have been awarded the Prize in scientific disciplines over the same period. Indeed, The Royal Society, which was founded in 1660 and is a fellowship of the world's most eminent scientists, waited until in 1945 to admit its first women fellows, Marjory Stephenson and Kathleen Lonsdale. Today, women represent just 5% of its fellows.

Of course, these concerns are not new. Almost 50 years ago, Alice Rossi was asking on the pages of *Science* why there are so few women in the scientific profession (Rossi, 1965). Indeed, the participation of women in science and in particular the presence of an ‘attainment gap’ has been for long a topic of both policy and scholarly debate. Several studies in the 1990s showed that there is a gender gap in science, with women scientists exhibiting lower scientific productivity, gaining fewer recognitions and rewards, and attaining promotion more slowly than their male colleagues (Long & Fox, 1995). Although some studies have shown that this attainment gap is narrowing (Holden, 2001), there is still a disproportionate lack of women in most scientific disciplines, especially at the upper reaches of the profession (Etzkowitz, Kemelgor, & Uzzi, 2000). Moreover, recent studies have shown that women also appear to be significantly less likely than their male colleagues to be engaged in formal technology transfer (Ding, Murray, & Stuart, 2006; Thursby & Thursby, 2005), which has become a relevant source of non-salary remuneration for faculty and may provide an important source of inspiration for future research.

In this paper, we contribute to our understanding about the differences (or similarities) between the collaborative behaviour of women and male academics with industry. In particular, we seek to understand if women collaborate less with private companies than their male counterparts, and if they collaborate in different ways. Although previous literature has brought this issue to the surface, our current understanding of gender differences in university-industry collaboration activities leaves something to be desired. Past studies have mainly focused on single measure of technology transfer, academic patenting, which is relatively rare for all university scientists (Agrawal & Henderson, 2002). Given that there are few women (and men) that are engaged in this form of technology transfer, there is a significant danger that the results of these studies are dependent on a small number of individuals working in selected institutions and disciplines. In addition, these studies have tended to focus on a single scientific discipline, life sciences, in which women are more likely to be represented than other scientific fields.

Another critical challenge to this area of research is gender stratification in science. It is likely that past studies have compared female and male populations with very different characteristics, such as tenure and quality of the department of affiliation, potentially leading to biased estimation of the effects of gender on technology transfer behaviour. In this study, our objective is to try to address these challenges by analysing a balanced sample of academic researchers in the physical sciences, who may (or may not) engage with industry. We also focus on a wide range of collaborative activities with industry, such as contract research agreements, joint research projects, consultancy, personnel training etc, overcoming the tendency in the preceding literature to focus on a limited range of formal technology transfer activities.

To explore our research questions, we combine data from multiple sources, including a large-scale survey, the records of the UK largest research council and other public records, such as publications data from ISI Web of Science, to build a rich picture of several thousand UK academics. The results of analysis demonstrate that women academics collaborate with industry less frequently than their male colleagues. They also tend to engage in collaboration activities (such as attending conferences with industry participations) that have lower added-value potential for their research, while they are less likely to be involved in more rewarding channels of interaction, such as joint research agreements or consultancy projects. We explore the implications of these findings for research on gender differences in science and policy to support engagement and women in scientific careers.

The paper is structured as follows. After reviewing some of the recent research about women's participation in science and their engagement with industry, we outline the existing methodological challenges for this kind of gender-based analysis. We then provide information about our approach and data, proposing a new methodology to try resolve those challenges. Finally, we present results and we conclude with a discussion of the possible explanations of our findings and the implications for policy.

ACADEMIC SCIENCE, INDUSTRY COLLABORATION AND GENDER STRATIFICATION

The presence of a gap in attainment in scientific disciplines between men and women has been repeatedly observed across countries. It is clear that women seem to face a specific series of gender related barriers to entry and success in scientific careers (Etzkowitz et al., 2000; Gupta, Kemelgor, Fuchs, & Etzkowitz, 2005). Gupta and colleagues (2005) observe that women suffer from a triple burden: unfavourable work environment, disproportionate domestic responsibilities and a social capital deficit. These three elements are interrelated to each other and help contribute to create a high level of career-related stress. Many women believe they do not belong in science and feel isolated, and as a consequence are discouraged from fully utilizing their potential. The male-dominated academic and professional cultures have been often referred as the "gentlemen's club", the "barrack yard" and the "locker room" (Maddock & Parkin, 1994). In these environments, women are under-represented (if not absent at all) and tend to occupy low-status positions. Moreover, women in science have less rich and diverse social capital and fewer bridging ties than their male colleagues (Etzkowitz et al., 2000). In this sense, women tend to be excluded from the "Kula ring of power", the informal gatherings in science where resources, knowledge and reputation is exchanged and developed (Etzkowitz et al., 2000). There is also a lack of relevant role models (Etzkowitz, Kemelgor, Neuschatz, Uzzi, & Alonzo, 1994). As Faulkner (2006) comments there are "far fewer alpha females than alpha males are available as role models." Women generally lead smaller labs, draw less resources and this might provide them fewer opportunities for advancement (Murray & Graham, 2007). Finally, domestic responsibilities tend to fall disproportionately on women. In some academic environments, women are often seen as risky employees, and their personal commitments are taken into account for hiring or promotion decisions, while they are often largely overlooked for men. In some cases, career gaps due to maternity leaves and childcare may not be fully considered in tenure decisions. Moreover, gender stereotypes and gender-related barriers mean that women may need to work harder than men to prove themselves (Gupta et al., 2005). In total, it is this set of continuous of pressures that are likely cause of the higher rate of withdrawal from scientific careers for women.

Although some studies have shown that this attainment gap in academic activities is narrowing (Holden, 2001), there is an additional and increasingly important area of activities in which university researchers are expected to take part: technology transfer. Indeed, external engagement activities have become a relevant source of non-salary remuneration for faculty and may provide an important source of inspiration for future research. The interest in universities' engagement with industry partners has grown considerably in recent years, from both a policy and an academic perspective: fiscal budget constraints are obliging policy makers to encourage universities to move towards more competitive sources of funding and to devote more efforts to technology commercialization through patenting and licensing

(Cohen et al., 2003; Siegel, Waldman, & Link, 2003). Since the 1980s, there has been a growing pressure on academics to collaborate with industry partners and to commercialize the results of their research projects. In the UK, funding decisions on research projects are now tied to the demonstration of a ‘pathway to impact’ of the research.

For individual researchers to decision to collaborate with industry depends on the institutional environment they work within, and on their individual perceptions of potential costs and benefits deriving from such collaboration (Owen-Smith & Powell, 2001). In particular, researchers may fear that engagement with industry may limit their freedom of enquiry, skewing public research agendas towards marketable research at the expenses of fundamental research (Tartari & Breschi, 2009; Nelson, 2001; Henderson, Jaffe, & Trajtenberg, 1998; Verspagen, 2006; Lee, 1996; Behrens & Gray, 2001) or may cause delays in the publication of scientific papers and data (Louis, Jones, Anderson, Blumenthal, & Campbell, 2001; Campbell, Weissman, Causino, & Blumenthal, 2000; Campbell et al., 2002; Blumenthal, Campbell, Causino, & Louis, 1996). Alongside these negative factors, collaboration with industry may provide many positive benefits. Engagement may enable academics to gain increased resources, both financial and in-kind (such as access to equipment, data and materials), for their research. It could also be an important source of inspiration for new research projects (Mansfield, 1995; Agrawal & Henderson, 2002; D’Este & Perkmann, 2010).

In recent years, the literature of university-industry collaboration has started to explore the issue of women participation in technology transfer activities in universities (see for example a double special issue on this topic in the Journal of Technology Transfer in 2005 (Gaughan, 2005)). Ding et al. (2006) showed that in life sciences women academics tend to patent 40% less than their male colleagues, even controlling for scientific productivity and “patentability” of results. Thursby and Thursby (2005) found a similar result: in their sample of over 4,500 academics from 11 major US universities, women (who represent just over the 8% of the population) are less likely to disclose inventions than men despite the fact that there are no significant differences in publication patterns. Along the same lines, Whittington and Smith-Doerr (2005) investigate gender disparities in commercial outcomes for scientists in both the academic and industrial sectors, showing that female scientists engage in and produce less commercial work than their male counterparts, and that the degree of disparity remains constant across time while the quality and impact of women’s commercial work remains the same or becomes even better than that of men scientists. Finally, a more recent contribution by Colyvas and colleagues (2010) analysing the technology transfer activities of a sample of US medical school faculty find no significant difference in the likelihood of reporting inventions or successfully commercializing them for men and women, finding however differences in the volume of inventions.

Despite these important contributions, our current understanding of gender differences in university-industry collaboration activities leaves something to be desired. Past studies have tended to focus on academic patenting or inventions, which are relatively rare for all university scientists (Agrawal & Henderson, 2002). In addition, these studies have also mainly explored a single scientific discipline, life sciences. The life sciences are a discipline in which women are better represented than other scientific fields and therefore it is not clear whether similar patterns operate in more male-dominated disciplines. Given that there are few women (and men) that are engaged in patenting or invention disclosures, there is also a significant danger that the results of these studies are dependent on a small number of individuals working in selected institutions and disciplines.

Moreover, studies of performance differences between the sexes in science face some important methodological challenges, as gender stratification is still very much present (women scientists are to be found predominantly in junior positions). This means that past studies are likely to have compared female and male populations with very different characteristics, such as tenure and scientific productivity, potentially leading to biased estimation of the effects of gender on technology transfer behaviour. This unbalance presents an interesting challenge in the study of gender differences, as its consequences on the consistency of estimation cannot be solved fully by the introduction of control variables: as suggested by Ho and colleagues (2007), reducing the link between the treatment variable and control variables makes estimates less dependent on modelling choices and specifications. Therefore, it is necessary to look at other approaches to understand the differences between men and women when it comes to external engagement with industry. Such an approach should seek to look at a broad range of collaboration mechanisms with industry, and compare differences across disciplines and institutions. Moreover, it is important to find a way to ensure to lower the impact of the unbalanced nature of the two populations so that it does not shape the sign and size of any estimation of gender differences with respective to technology transfer.

DATA AND METHODOLOGY

To overcome these empirical and methodological issues, we draw information from a unique dataset, covering a population of 6,200 academic researchers in the UK listed as principal investigators or co-investigators in grants awarded by the EPSRC (Engineering and Physical Sciences Research Council) from 1992 to 2006. The EPSRC is the largest funding body for research in the UK (it distributed £740 million of research funding in 2008) and funds research in all fields of engineering, mathematics, chemistry, and physics. Although all research projects are funded on the basis of peer review, the EPSRC encourages partnerships between researchers and third parties, such as private firms, government agencies, local authorities, non-profit organizations etc. There is, however, no requirement for industry engagement in EPSRC funding. Therefore, in the grant portfolio, we can observe a mixture of collaborative (involving industrial or non-industrial partners) and response mode grants.

To understand academics engagements with industry, we addressed a survey questionnaire to all EPSRC-funded researchers, focussing on a broad range of collaborative activities with industry, such as contract research agreements, joint research projects, consultancy, personnel training etc. This approach was driven by a desire to overcome the tendency in the preceding literature to focus on a limited range of formal technology transfer activities. After considerable effort, we obtained a total of 2,194 completed questionnaires, corresponding to a response rate of 36%. Each respondent has then been matched with the population of academics included in the Research Assessment Exercise (RAE) conducted in 2008. The RAE assesses the quality of research in universities and colleges in the UK: 2,344 submissions were made by 159 Higher Education Institutions in 2008 (covering the period 2001-2007). The RAE is conducted jointly by the Higher Education Funding Council for England, the Scottish Funding Council, the Higher Education Funding Council for Wales and the Department for Employment and Learning of Northern Ireland. These bodies use these quality profiles to determine the level of direct research grants given to the institutions. We then matched the universities included in our sample with data collected by the Higher Education Funding Council for England (HEFCE) through the Higher education-business and community interaction survey (HE-BCI), which covers the years 2005-2007. The annual HE-BCI survey examines the exchange of knowledge between universities and the society in a wider sense: it collects financial and output data per academic year at university level on a range of activities, from the commercialization of new knowledge, through the delivery of professional training, consultancy and services, to activities intended to have direct social benefits. Finally, we collected detailed information about the scientific productivity of the respondents through ISI Web of Science: for each researcher in our sample we have identified the detailed history of their publications.

The UK is a particularly interesting case to explore differences in behaviour between men and women academics as it often suggested that it lags behind other industrialised countries in terms of women representation in science and engineering faculties (Etzkowitz et al., 2000). For example, as late as 1991, there was no female full professor of chemistry in the UK. Even today, of almost 5000 full-time professors in science and engineering in the UK, only 345 are women. The current distribution of women in different academic disciplines reveals that women are concentrated in life sciences and medicine, while they still represent a small minority in physical sciences and engineering (see Table 1).

Insert Table 1 about here

Dependent variables

Our dependent variables cover a broad range of industry engagement forms, from attending conferences with industry participants to joint research agreements to venture creation. This approach allows us to capture more common and diverse forms of technology transfer activities than simply looking at patents or invention disclosures. By looking at this range of mechanisms of engaging industry, we are able to explore the differences in both the breadth and depth of academic engagement with industry.

We use two different approaches to analyse these differences. First, in order to capture in a synthetic measure both the variety of forms of engagement and the intensity of collaboration, we build an individual *industrial involvement index* (III), as a modified version of the index developed by Bozeman and Gaughan in 2007 (Bozeman & Gaughan, 2007). Our survey data contains information on the types and frequencies of academics' industry engagement which we used for constructing the index (see Table 2). The industrial involvement scale is constructed as follows. For every type of industry engagement, we established whether a researcher had collaborated or not ('occurrence', denoted by b_j) (see Table 3 for how we coded response items). We then computed the frequency for each type of engagement for the whole population:

$$f_j = \frac{\sum_{n=1}^{N} b_j^n}{N} \qquad (1)$$

where j is the type of industry engagement, n is the individual and N is the total sample (N=1,895). We then constructed the index by multiplying the actual number of interactions declared by each academic for each channel (*Tj*) and the frequency of its non-occurrence (1 - f_j) and summing all the scores together:

$$III^n = \sum_{j=1}^{8} T_j^n \cdot (1 - f_j) \qquad (2)$$

The index takes into account the "difficulty" and rareness of certain activities, such as the creation of new physical facilities, relative to others, such as attending industry sponsored meetings. We extend the measure proposed by Bozeman and Gaughan (2007), as we use more granular information taking into account the actual volume of occurrence of the different types of engagement for every individual, as opposed to the simple occurrence. Second, in order to understand if women and men engage in different types of collaborative activities, we use the volume of each channel of interaction by itself (T_j).

Insert Table 2 and Table 3 about here

Control variables

Gender stratification in science means that women in academia tend to be concentrated in the bottom of the career pyramid, with women occupying mostly low status position, such as post-docs or assistant professors. The higher one advances in the career progression ladder, the fewer women are present. This is phenomenon is due to what has been called a "leaky pipeline" (Etzkowitz et al., 2000). This means that on average women researchers are likely to present different characteristics from their male colleagues, both in demographic and in productivity terms. In turn, these characteristics are likely to influence academics' engagement behaviour with industry. Given this, we use a range of variables to match women to men academics. Our goal is to create two groups of academics that are similar in many of their structural features so that we can compare differences in engagement patterns between men and women of equal academic standing, experience, productivity, training and location. To do so, we first control for researchers' academic rank (coded as a dummy which identifies the group of professors): several authors have found a positive effect of being tenured on collaboration activities with industry (Link, Siegel, & Bozeman, 2007). Secondly, we control for training effects (see Berkovitz and Feldman 2008), including the researchers' academic age (defined as their age today minus their age when they have been awarded their PhD), a dummy variable identifying holder of British doctoral degrees (British PhD) and a proxy for the quality of the institution where the PhD was awarded (elite PhD), coded as a dummy variable indicating if the institution is part of the Times Higher Education Supplement (2004) list of worldwide top universities. Third, we control for the quality and productivity of the researchers. We include the total amount of research funds received from EPSRC in the period 2000-2006, and the total number of publications and citations received during the entire career of the researcher until 2009. Several authors find that faculty with industrial support or performing entrepreneurial activities publish at least as much as the rest of faculty or even more (Bikhchandani, 1992; Manski, 1993; Agrawal & Henderson, 2002; Azoulay, Ding, & Stuart, 2007; Fabrizio & Di Minin, 2008; Breschi, Lissoni, & Montobbio, 2007), while others fail to identify a clear relationship between collaboration activities and academic productivity (Blumenthal et al., 1996; Gulbrandsen & Smeby, 2005; Lee & Bozeman, 2005), or identify an inverse U-shaped relationship claiming that researchers with industrial exposure publish less if their whole career is taken into account (Agrawal & Henderson, 2002). Fourth, we account for differences in scientific disciplines between researchers. The researchers' scientific fields tend to define the extent of their engagement in collaborative activities with industry: academics in more applied fields of science, such as engineering, are more likely to collaborate with industry (Lin & Bozeman, 2006). It has also been observed that for researchers working within the so-called Pasteur's Quadrant (Rosenberg & Nelson, 1994), practical problems provide a powerful stimulus to the development of new ideas (Stokes, 1997). Moreover, as shown above, women representation varies highly from one discipline to another and it is important to take these differences in distribution into account. Finally, we control for the research quality of the department of affiliation (measured as the percentage of staff rated 4* and 3* in the RAE 2008). On one hand, it is clear that collaboration and entrepreneurial activities are enhanced by the presence of formal support infrastructure and institutional incentive mechanisms (Van Dierdonck, Debackere, & Engelen, 1990), often with a stronger effect at the level of department or research group (Baldini, 2007; Chrisman, Hynes, & Fraser, 1995; Landry, Amara, & Rherrad, 2006; Owen-Smith & Powell, 2001; Renault, 2006; Sellenthin, 2009). On the other hand, however, the impact of the overall academic quality of the institution on the likelihood to participate in technology transfer and commercialization activities remains unclear. Some authors find a positive relationship between academic excellence and participation in technology transfer (Baldini, 2007; Chrisman et al., 1995; Landry et al., 2006; Owen-Smith & Powell, 2001;

Renault, 2006; Sellenthin, 2009), while others find a negative relationship (Kenney & Goe, 2004; Krabel & Mueller, 2009).

Estimation

To compare women and men directly, we employ a non-parametric matching method. Matching estimators are usually applied to evaluate the effect of a certain treatment (for example the administration of a drug) on the sub-population of individuals exposed to the treatment (treated) and the sub-population not exposed to it (non-treated) (Heckman, Ichimura, & Todd, 1998). The idea behind the matching estimator technique is to match each woman with men presenting similar observable characteristics and to compare the average collaborative behaviour for the two sub-samples of individuals. The matching estimator is based on the following formulation: let T be the treatment (an indicator of the individual being a woman); let $Y_i(1)$ be the outcome for the treated individual (i.e. the industrial involvement index that would be observed if the individual was a woman); and let Yi(0) be the outcome of the non-treated individual (i.e. the industrial involvement index that would be observed if the individual was a man). What we want to measure is the mean effect on the industrial involvement index for a woman (the sample average treatment effect on the treated individual – SATT):

$$(1)\quad SATT = E\big[Y_i(1) - Y_i(0)\,\big|\,\mathrm{T}=1\big] = E\big[Y_i(1)\,\big|\,\mathrm{T}=1\big] - E\big[Y_i(0)\,\big|\,\mathrm{T}=1\big]$$

Of course, it is not possible to observe the value of $Y_i(1)$ and $Y_i(0)$ for the same individual: the matching estimator approach will use the average outcomes for similar individuals that were not treated. In other words, we will need to find men with similar observable characteristics for each woman. This approach helps to overcome the estimation problems related to the strong gender stratification that exists in science: it has indeed been shown that the use of regression techniques on unbalanced samples can lead to biased estimates of the coefficients (Ho et al., 2007). We test the balance of the sample along several dimensions, which we will describe in the next section. We then employ a nearest neighbor matching estimation for average treatment effects across the dimensions which showed to be unbalanced in the sample (Abadie, Drukker, Leber Herr, & Imbens, 2004). We choose this method because the control group (men) is significantly large and also because this procedure does not require to specify and estimate a model describing the selection mechanism. The algorithm used pairs observations (in our case female academics) to the closest m matches in the opposite treatment group (male academics) to provide an estimate of the counterfactual treatment outcome. Let N_1 be the number of women, and let w(i,j) be the weight placed on the jth observations of men used to construct the counterfactual for the ith woman. The weight w(i,j) is derived using the distance from the vector of covariates of the ith woman, X_i, to that of the j nearest men . This weight can be set equal to 1 for a certain set of covariates, meaning that the woman and the matched men will show exactly the same values for that particular set of covariates. Following the formalization of Abadie et al. (2004), the SATT will be computed as:

$$(2)\ SATT = \frac{1}{N} \sum_{i \epsilon (T_i = 1)} \left[Y_i(1) - w(i,j) Y_j(0) \right]$$

To perform the matching, we utilize the program *nnmatch* for STATA11 (Abadie et al., 2004), which allows exact matching for a subset of variables (in our case academic position and discipline), bias correction of the treatment effect and also allows for heteroskedastic errors. For every observation, we use two matches in the treatment group. As a robustness check we run the same matching procedure with one or three matches in the treatment groups and the results are consistent.

RESULTS AND DISCUSSION

Before reporting the results of the matching procedure, we examine the extent to which women and men differ with respect to the matching variables. This is important to understand the balance of the sample. We begin by looking at the balance between the two populations in terms of academic age, academic position, scientific productivity (number of papers and number of citations), amount of grants received from 2000, scientific discipline, quality of the department of affiliation, PhD granted from an elite university and PhD granted from a British university. The balance for academic age, scientific productivity, amount of grants received, and quality of the department of affiliation has been tested with a Wilcoxon-Mann-Whitney test as the variables are ordinal but not normally distributed (see Table 4). The distribution of these variables for mem and women is also been compared through the creation of quantile-quantile plots (see Figure 1). As it can be observed both from the tests and the graphs, the sample is balanced along the dimension of quality of the department of affiliation, while it shows imbalance along all the other dimensions. In particular, it is evident that men tend to be more senior, to have published more, to have received more citations and to have won more grants than women in the sample. The balance for academic position, discipline, PhD granted from an elite university and PhD granted from a British university has been tested with a chi-square test as the variables are categorical and the expected frequency for every cell is larger than five (see Table 5). The variables relative to academic training appear to be balanced in the sample, while academic position and discipline are not. This suggests that women tend to occupy lower status positions in the university and they are heavily underrepresented in engineering disciplines (with the exception of mechanical engineering), while in mathematics, physics and chemistry, the situation appears more balanced. These checks we have performed in order to ensure the robustness of our subsequent results are also interesting per se as they clearly support the claims about the persistence of both a strong gender stratification in academic science and a confinement of women to specific scientific disciplines.

Once performed the matching, we check again for unbalance in the sample across the same dimensions as before. We employ the same techniques used before, and as expected, we can confirm that the new sample is correctly balanced (see Table 4, Table 5 and Figure 2). These results suggest that matched men can be considered sufficiently similar to women in the sample, and it is therefore possible to estimate the SATT. To be clear, this new balance sample includes two men that have nearly identical academic age, discipline, productivity and rank to each women in our sample.

Insert Table 4 and Table 5 about here

Table 6 presents the estimates for the SATT of being a woman on the different collaboration measures. The results of analysis demonstrate that female researchers collaborate less than their male colleagues (difference = -0.74, *p-value* < 0.05). We also find that women tend to engage in collaboration activities (such as attending conferences with industry participations) that have lower added-value potential for research, while they are less likely to be involved in more rewarding channels of interaction, such as joint research or contract research agreements. Men in the matched sample have participated in on average 1.5 joint research agreements and 1.4 contract research agreements with industry during 2007 and 2008, while in the same period women participated in just on average 1.0 joint and contract research agreements.

Insert Table 6 about here

Several explanations have been put forward in the literature to explain these differences. First of all, it has been claimed that women exhibit a lack of exposure to the commercial sector and that the composition of their professional networks is different from those of men. We have explored this explanation by looking at the differences in the number of years of work experience in the private sector (two-sample Wilcoxon rank-sum test, Prob > |z| = 0.5042) and their experience as entrepreneurs (Chi-square test, Pearson $\chi^2(1)$ = 0.0302, Pr = 0.862). In the analysis, neither of these variables is statistically significantly different between women and men in the matched sample. From this analysis, female academics seem to have similar work experience outside academia than men. However, the results of the matching procedure show that women are less likely to attend industry-sponsored meetings than their men counterparts and therefore they may have fewer occasions to build a professional network including people working in industry.

Another possible explanation present in the literature highlights the importance of collegial support and institutional assistance given by women who want to be involved in collaborative activities with industry. Looking at our matched sample, we can see that women are more likely to perceive their department as an obstacle to their engagement activities (Fisher's exact = 0.073) and this may lower their willingness to participate in these activities.

We have also explored if there are any differences between junior and senior female scientists and we found that the difference in engagement activities is not significant (Two-sample Wilcoxon rank-sum test, Prob > |z| = 0.1589). There are two mechanisms at play regarding seniority that may lead to a confounding overall effect: younger women may have higher constraints from family (for example children) and therefore have less time to pursue commercial activities. On the other hand, younger women have been trained in a period in which commercial activities inside universities are seen as more legitimate and in which women participation in science has increased across all disciplines. To try to separate these two effects, we examine if there are any differences in the shape of the distributions of the dependent variable III for junior women, junior men, senior women and senior men. The distributions of junior vs. senior women are quite similar, while junior men present a much more skewed distribution with fatter tails than senior men. This indicates that male scientists are undergoing a transformation in their research behaviour and are increasingly collaborating with industry, while women seem to stick to a more traditional way of working in academia (see Figure 3).

In sum, it appears from our results that women engage in less rewarding collaborative activities than their male counterparts. This pattern of behaviour may engender a vicious circle for women: low value engagement leads to fewer possibilities for publications in scientific outlets from their external engagement, and as a result, women end up being less productive and therefore less likely to be promoted, delaying opportunities to obtain higher autonomy and greater responsibility in their careers. In this sense, women academics appear to be to be trapped in a "double ghetto" (Armstrong & Armstrong, 1984). They work in male-dominated environments within their universities and their disciplines (especially in physical sciences) and, when they seek to collaborate with industry, they lack access to rewarding sources of industry engagement, in part because they are again faced with male-dominated environment. It is, therefore, not only the lack of role models in academic life which hinders the possibilities of career development for women researchers, but is also the lack of peers of the same gender in industry.

Our analysis suggests not only that women are less involved than men in collaboration with industry, but also that strong gender stratification persists in academia, at least for science and engineering disciplines. There are several interrelated issues around the pathway of women towards full citizenship in the Republic of Science. First of all, it has been observed that there is a "critical mass" paradox: a meaningful increase in the number of women in academic science seems unlikely to occur simply by increasing the supply of women at the beginning of scientific careers (Etzkowitz et al., 1994). At the same time, we observe a growing interest in faculty's commercial and technology transfer activities from university administrators and policy makers. Of course, if universities become more interdependent with industry, then women's lower access to industrial opportunities and lower exploitation of industrial contacts may serve to acerbate differences with male colleagues. Murray and Graham (2007) highlight how the gender gap in academic science have had an impact on women's participation in technology transfer activities, especially for senior faculty, by limiting the early entry of women scientists into commercial science (while this activity was still seen as largely not legitimate) and therefore contributing to its identification as a "male" activity.

As governments are placing increasing pressure on academics to engage with industry, often targeting funding towards those who do successfully, there is a danger that this focus produces unintended negative consequences for women in academe. It is therefore crucial that policy makers and university administrators implement effective measures to reduce the gender gap in academic science, while at the same time encouraging women to participate more actively in collaboration activities with private companies. Such a process needs to be handled with considerable care. In the US, the system of quotas for minorities (being either women or different ethnic groups) may create a stigma on the beneficiaries, making them appear of lesser worth than their peers (Etzkowitz et al., 2000). We should also remember that much of the process by which disadvantages are created and reinforced occurs at the level of universities and departments. It will therefore be crucial to design policies not only at the national level, but also at the university and department level. These policies might for example incentivising bottom-up initiatives aimed at celebrating women role models in engagement, creating time and space for industry collaboration, and dedicating resources to support young women scientists to build and broaden their professional network so that they can access to the "Kula ring of power". Finally, it is clear that many of the approaches that may support women in science will benefit male and women academics alike, as they will provide much need support for academics that wish to engage with industry.

LIMITATIONS AND FUTURE RESEARCH

Our paper has some important limitations, which provide avenues for future research. Although we think that our matching procedure ensures a more precise estimation of gender differences in academic technology transfer activities, we are not fully able to test the potential explanations of why these differences persist. This is because we rely on information from a limited number of women, even if this reflects the actual compositions of UK departments in science and engineering disciplines. Moreover, we do not have information about men and women academics' domestic responsibilities, such as children, and for breaks in the career due to those responsibilities. Although we control for productivity differences – which is the primary impact of these domestic responsibilities for women academics, information about children and career breaks may explain some of the differences in engagement patterns we observe.

A critical issue for future research will be to analyse the impact of local effects on this gender differences in engagement with industry. As we have highlighted in the previous section, many disadvantages for women in science appear to be located inside universities and departments. Therefore, it would be useful to analyse not only the impact of role models, but also the role of universities' policies and the attitudes of heads of department towards the challenges women face in their academic careers and their engagement with industry. It may be at the local level that useful and support mechanisms could be developed to help women scientists realize their full potential for engagement.

Finally, previous literature has clearly signalled a difference in behaviours between older and younger cohorts of scientists, regarding both the legitimacy of technology transfer activities and the role of women in science. A study of female faculty's changes in behaviours towards collaboration with private companies over time will be clearly beneficial to an understanding of the dynamics of this phenomenon. Such a study would researchers to investigate cohorts of academics and their engagement efforts as they move through their academic careers, while exploring the impact of domestic responsibilities and the support mechanisms in place in their local environment.

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TABLES AND FIGURES

Table 1: scientific discipline distribution of women full-time academics in the UK, 2007/2008

Discipline	% women
Biological sciences	39%
Business/administrative studies	40%
Computer science/librarianship	30%
Creative arts/design	41%
Education	61%
Engineering	15%
Humanities	35%
Languages	52%
Law	46%
Mathematical sciences	22%
Medicine and dentistry	29%
Physical sciences	18%
Social/political/economic studies	41%
Subjects allied to medicine	61%
Unknown and combined subjects	44%
Veterinary sciences/agriculture/related subjects	40%

Source: HESA data 2007/2008, authors' elaboration

Table 2: Types of researchers' interaction with industry

Type of interaction (j)	Frequency %, men (b_j=1)	Frequency %, women (b_j=1)
Attendance at conferences with industry and university participation	83	88
Attendance at industry sponsored meetings	64	63
A new contract research agreement (original research work done by University alone)	58	54
A new joint research agreement (original research work undertaken by both partners)	58	51
Postgraduate training with a company (e.g. joint supervision of PhDs)	49	44
A new consultancy agreement (provision of advice that requires no original research)	48	41
Training of company employees (through course enrolment or through temporary personnel exchanges)	31	27
Creation of new physical facilities with industry funding (e.g. new laboratory, other buildings in campus)	18	9

Table 3: Coding of occurrences of researchers' engagement with industry

Questionnaire answer (category)	0	1-2	3-5	6-9	>10
Occurrence (b_j)	0	1	1	1	1
Volume of interaction (T_j)	0	1.5	4	7.5	10

Table 4: Wilcoxon-Mann-Whitney tests

	Before the matching		**After the matching**	
	z	**Prob > $\|z\|$**	**z**	**Prob > $\|z\|$**
Academic age	7.189	0.0000	1.111	0.2664
Grants from 2000	2.679	0.0074	0.205	0.8373
Publications	5.877	0.0000	0.855	0.3927
Citations	4.364	0.0000	0.508	0.6113
Quality of the department of affiliation	-0.423	0.6723	-0.193	0.8470

Table 5: Chi-square tests

	Before the matching		**After the matching**	
	Pearson χ^2	**Prob**	**Pearson χ^2**	**Prob**
Academic rank	29.6200	0.000	0.5016	0.479
UK PhD	1.8960	0.169	0.0001	0.994
Elite PhD	0.0000	0.995	0.0446	0.833
Discipline	39.1255	0.000	3.8612	0.993

Table 6: results of neighbour matching procedure

	Coeff.	**Std. Error**	**P-value**
Industrial Involvement Index	-0.7391	0.3197	0.021
Creation of new physical facilities with industry funding	-0.1790	0.0611	0.003
A new joint research agreement	-0.3460	0.1431	0.016
A new contract research agreement	-0.3324	0.1371	0.015
A new consultancy agreement	-0.2007	0.1310	0.126
Training of company employees	-0.0796	0.1480	0.591
Postgraduate training with a company	-0.0084	0.1373	0.951
Attendance at conferences with industry and university participation	0.0080	0.2191	0.971
Attendance at industry sponsored meetings	-0.3793	0.2157	0.079

Figure 1: Quantile-Quantile plots, before the matching

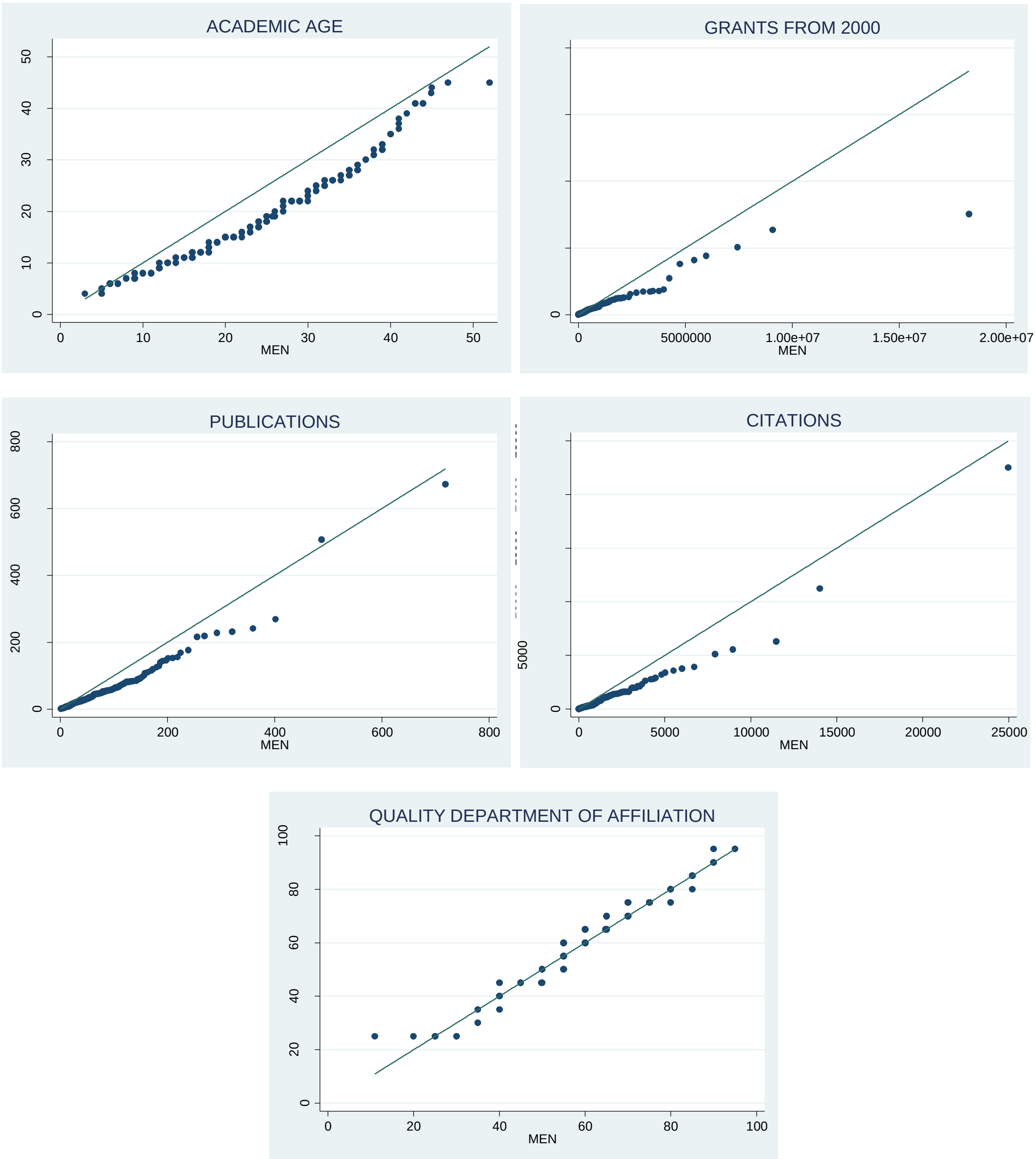

Figure 2: Quantile-Quantile plots, after the matching

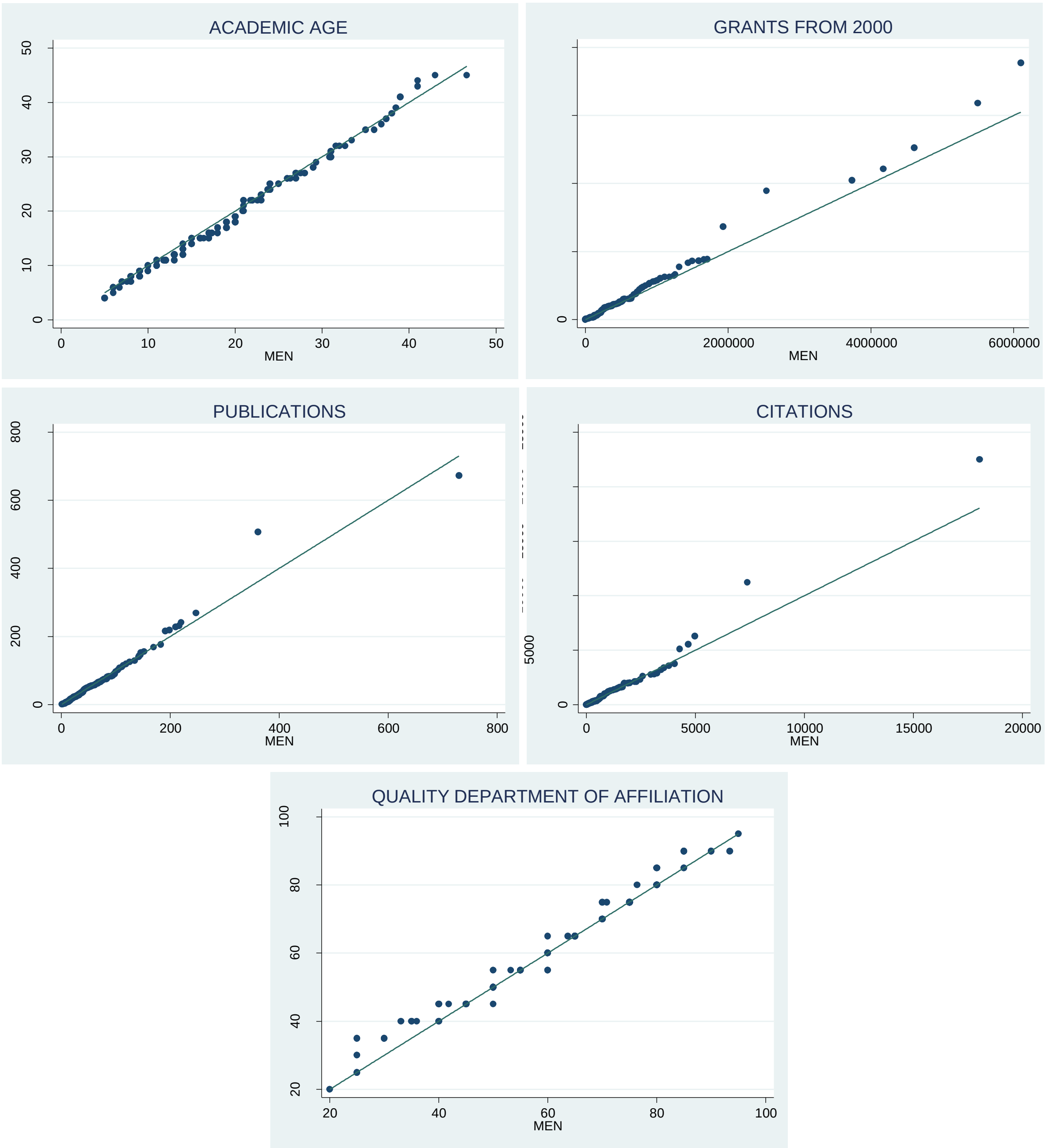

Figure 3: Distribution plots of Industrial Involvement Index, senior vs. junior