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Contribution of female inventors to technological collaboration between high-tech firms and university in close proximity: Effect of innovative firm's characteristics

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ABSTRACT

Understanding the patterns of innovative technological collaboration between universities and clusters of high-tech firms, along with the involvement of female inventors, is crucial for both regional and national development. Here, we explore the technological collaboration between Silicon Fen (SF) firms and University of Cambridge (UoC) as a cluster of high-tech businesses and a main research university located in close proximity, respectively, focusing on the involvement of female inventors, based on the evaluation of join patent ownership, and examination of technological collaboration strength (*TCS*), with respect to the characteristics of firms such as age, size and sector. A quantitative bibliometric approach is utilised to analyse more than 93,000 patents generated by UoC and SF firms. According to the results obtained, smaller and older businesses exhibit greater collaboration bonds with the university, accommodating a greater proportion of collaborative female inventors. Pharma/Biotech sector of Silicon Fen has a greatest value of *TCS* (1.6×10^{-2}), and accommodates the greatest ratio of female inventors (20.8 %). Our findings suggest the need to encourage younger and larger businesses, and those beyond the Pharma/Biotech sector to involve more female inventors in their technological collaboration with university, given that university policies can have a positive impact in addressing the gender gap in technology and innovation. Theoretical and managerial implications of the results are discussed.

Introduction

Sustainable development of high-tech businesses depends on various factors, including the gender diversity in innovation and patenting (Corvello et al., 2023). Successful transferring technological knowledge across boundaries (Shao et al., 2022) has also become an important organisational competitive advantage in the global economy, for which the influence of gender diversity deserves to be studied in a systematic way. Knowledge transfer (KT) can be defined as the process of allowing scientific and/or technological findings to flow between different stakeholders, for instance, within and/or across boundaries of organisations (Ferrer-Serrano et al., 2021; Olan et al., 2022; Scarrà & Piccaluga, 2022). In particular, KT between universities and businesses has found to be an influential element contributing to local and national economies (Belitski et al., 2019; Compagnucci & Spigarelli, 2020), as a key source of acquiring external knowledge and technological ideas for innovative firms (Kleiner-Schaefer & Schaefer, 2022). Such university-industry KT is part of the resources needed to bridge 'the valley of death' often observed between laboratory discoveries and the marketplace, where a large number of excellent scientific ideas eventually die (Islam et al., 2018; Stefanelli et al., 2020).

Also, over the past few decades, increasing importance has been attached to university-industry knowledge transfer as part of the Third Mission considered for universities, which, in addition to teaching and research, shares the academic knowledge and serves as a catalyst for regional economic development (Conlé et al., 2023; Martin et al., 2018; Rossi & Sengupta, 2022; Rubens et al., 2017). Similarly, commercialisation of research has become a priority for many research organisations and universities to generate third stream income (Radko et al., 2022). Moreover, through university-industry collaboration, universities contribute to technological advancements, creating new possibilities for innovation. The success of such collaboration can be measured in terms of tangible outputs, including technological patents (Messeni Petruzzelli & Murgia, 2020; Nugent et al., 2022; Perkmann et al., 2011), technology licences (Morrison, 2017;

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Perkmann et al., 2011) and spin out companies (Martin-Rios et al., 2022). From this range of outputs, the joint patent can be considered to be a single easily measurable index of collaboration success (Messeni Petruzzelli & Murgia, 2020). Thus university-industry collaboration may be defined as research interaction between two or more organisations including at least one university and one firm, leading to the generation of joint patents (Delerue, 2018; Zeng et al., 2023). In this context, the geographic proximity of businesses and university is an important factor in building inter-organisational ties, promoting successful collaboration (Audretsch et al., 2022; Tang et al., 2020). For example, the influence of Stanford University in the rise of the nearby cluster of high-tech innovation businesses in California (US), Silicon Valley, is well documented (English-Lueck, 2022; Etzkowitz, 2022). In contrast with Silicon Valley, other innovation clusters formed around world-leading research universities are relatively less studied. One such business cluster is Silicon Fen (SF), located in close proximity to the University of Cambridge (UoC) in the UK.

Gap in the literature and the research objectives

The development of university-firm clusters can be strengthened through effective collaboration between firms and the university, supported by inventor gender diversity. Despite its importance, this topic has received limited attention in the literature. Thus, this study examines the technological collaboration between UoC and SF firms as a model for clusters of high-tech firms and a major research university located in close proximity. The study is based on the analysis of patents generated by UoC and SF firms, correlating their technological bonds with firm characteristics such as size, age, and the business discipline. A central focus of this article is the involvement of female inventors in these collaborations, based on firm characteristics. The following sections provide a brief review of previous research, offering the theoretical background that leads to the development of the hypotheses.

Theoretical background and hypothesis development

Women in innovation

The literature on women in innovation shows a continued gap in female participation in invention and commercialisation (Hunt et al., 2013; Kim et al., 2022; Whittington, 2018). The promotion of women involvement in innovation is of importance considering that a large number of talented women never become involved in innovation and patenting (Kim et al., 2022; Koning et al., 2021). In particular, women are much less likely to pursue careers in science, technology and engineering, although the number of students in these disciplines is increasing (Abreu & Grinevich, 2017; Kim et al., 2022). This makes women less likely than men to become inventors or to commercialise an invention (Lerchenmueller & Sorenson, 2018) in academia (Fox & Xiao, 2013; Giuri et al., 2020) and business (Woolley, 2019). In the UK, there is evidence that the proportion of female inventors has increased from less than 4 % in the early 1980s to over 8 % in 2015, with an average of 5.6 % over this period. However, in 2015, the proportion of women inventors in Cambridge was only 8 % (UK Intellectual Property Office, 2023), where a higher number of female inventors could be observed in particular sectors, with a bias towards medical or veterinary science hygiene, such as preparation of medical/dental substances and therapeutic activities (Kim et al., 2022; Koning et al., 2021; UK Intellectual Property Office, 2023). The involvement of women inventors in joint patenting activities between SF firms (as a cluster of high-tech firms located in Cambridge area in the UK) and UoC (as a main research university in close proximity of SF) deserves specific attention to inform policymakers looking at enhancing the participation of women in SF-UoC collaboration, for which the availability of data from various technology sectors of SF is important. Nonetheless, there is very limited information in the literature on the contribution of female inventors to the collaborative activities between SF firms and UoC. The current article aims to meet this gap by investigating the available data on women's contribution to technological knowledge transfer between SF and UoC by means of joint patent analysis.

Influence of the business size

In this study, we investigate the effect of firm size on the technological collaboration between SF firms and UoC, and further explore the effect of firm size of the presence of collaborative female inventors. A growing body of literature correlates innovation-based knowledge transfer between universities and business sectors with the size of the collaborating firm (Lin et al., 2015; Marra et al., 2022). Accordingly, the size of a firm can be an indicator of the firm's capability to make an effective collaboration with university leading to innovation.

There are studies suggesting that smaller firms are more likely to use their patents more actively than large firms (De Rassenfosse, 2012) which can be attributed, for instance, to strategic innovation aggressiveness and firm-level performance being stronger in small firms compared to large firms (Weinzimmer et al., 2023). Other observations, however, suggest that large companies invest more in research and development on average, and therefore, are more likely to be connected with universities (Giunta et al., 2016; Slavtchev, 2013) and to patent more than small firms (Athreye et al., 2021).

It should be mentioned that the sustainable competitive performance of firms can largely be influenced by the firm effect indicating the heterogeneity of resources, and/or the industry effect indicating the industry's structural characteristics (Chen et al., 2017). These effects are also influenced by the firm's size. For example, Fernández et al. (2019) found that in large firms, the influence brought about by their size and creative accumulation allows them to attain competitive advantages in both differentiation and costs. Also, small firms have an important advantage in terms of flexibility and dynamism, promoting their competition. They can respond more quickly to new opportunities or challenges, allowing them to be more competitive. Additionally, small firms may have less bureaucracy and more autonomy, which can foster a culture of innovation and creativity. In contrast to large and small firms, medium-sized firms are disadvantaged competitively, arising from their wrong size due to which their performance is largely influenced by the industry effect. It means their competitiveness can only be explained by their participating in a highly profitable industry in which competitive intensity is low. This can make it challenging for medium-sized firms to adapt to changing market conditions or to compete effectively against larger firms. Instead, the competitiveness of medium-sized firms can be largely determined by the industry in which they operate. If they are in a highly profitable industry with low competitive intensity, they may be able to thrive despite their size (Fernández et al., 2019).

Figueira et al. (2023) correlated the presence of women in open innovation with the overall performance of firms. Therefore, in order to examine the contribution of collaborative female inventors in technological collaboration between SF firms and UoC with respect to the size of firms, this is helpful to provide an insight into the technological collaboration bond between SF firms of various sizes and UoC. Based on the underlying theoretical framework, mentioned above, the first hypothesis in this study suggests the greater collaboration performance of micro and small firms of SF over larger firms due to their greater flexibility and dynamism, which can provide higher values of *TCS*:

H1: Technological collaboration between SF firms and UoC depends on size of firms: smaller firms have greater technological collaboration strength with UoC than larger firms.

Then, we explore the influence of SF firm size on the presence of collaborative female inventors. From a sustainability point of view, investigating the effect of firm's size on the involvement of women inventors in technological innovations is an important issue, indicating the levels of diversity and inclusion within the innovation ecosystem with respect to the size of firms. Despite its importance, however, there is little consideration of gender as an influencing factor in studies considering the innovation resulting from technological collaboration activities. The available literature often considers the involvement of women in innovation in general, with less consideration of collaboration. For example, Tahmooresnejad and Turkina (2022) explored the collaboration of female inventors in co-patenting using European Patent Office (EPO) data and found that the female inventors' overall involvement in patenting activity increased from 1.2 % in 1978 to 8.9 % in 2019. The authors also related the involvement of women inventors to the extent of available networks, which are likely to be bigger in larger firms (Tahmooresnejad &Turkina, 2022). Wellalage and Fernandez (2019) reported on the involvement of female inventors in patents published by companies in Eastern Europe and Central Asian, and concluded that the proportion of women inventors is greater in micro/small-sized firms. The current paper investigates the extent to which the size of SF firms influences their technological collaboration with UoC and the level of women's involvement in such collaborations with respect to the firm's size, shedding light on the role of gender in these collaborative efforts. Therefore, toward determining the influence of the size of SF firms on their technological collaboration and the presence of women inventors, our second hypothesis is derived as follows:

H2. Proportion of female inventors involved in joint patenting with UoC is greater in micro- and small-sized firms of SF.

Influence of the business age

We also study the influence of firm's age on technological collaboration between SF firms and UK, and further evaluate the contribution of female inventors to the collaboration, with respect to the firm's age. Earlier studies had suggested that the age of enterprises has no significant influence on their overall innovation activities (Fritsch & Lukas, 2001). However, recent studies conclude that the age can be an important indicator determining the level of technological collaboration between firms and university for various reasons. Asimakopoulos et al. (2023) suggest that older high-tech firms are more likely to have established routines, structures, slack resources, incentive programs, and other infrastructures for developing new technologies, leading to greater benefits from their collaboration with research organisations (Yu & Lee, 2017). Moreover, innovation failure may have a lower impact on firm's growth in older firms (Kim, 2022), and established firms may also have more experience working with academic researchers providing a better understanding of the research process, which could lead to more effective collaborations. However, these reports are in contrast with some other studies suggesting that younger firms are more likely to collaborate with universities due to their higher motivation, enabling them to draw more heavily from university research (Kleiner-Schaefer & Schaefer, 2022; Martínez−Ros & Kunapatarawong, 2019). We believe that the parameter of motivation is an important factor in collaboration behaviour of high-tech firms, and therefore, the third hypothesis of this research suggests that young research-active organisations are more likely to have higher technological collaborate strength with universities due to their closer alignment with university research and ability to identify potential areas of collaboration. This collaboration can provide them with access to resources and expertise that can help them develop innovative solutions and compete with established players. Based on the underlying theoretical framework, mentioned above, our third hypothesis is introduced as follows:

H3: Technological collaboration strength between SF firms and UoC is higher in very young and young firms.

The influence of age of firms on the involvement of women in their technological developments has also been investigated. For example, Beneito et al. (2022) found that women's participation is higher in older firms, indicating a relationship between the age of firms and gender diversity in patenting activities. Discovering such relationships is important as it can provide insights into the firm-level contribution of women in innovation, indicating the inclusivity of innovation (Agnete Alsos et al., 2013; Coad et al., 2016). The reason behind why women's participation is higher in older and established firms may be based on availability of more established systems for identifying and supporting innovation, and this could make it easier for women to participate in the patenting process. Additionally, older firms may have more diverse workforces in general, which could lead to greater gender diversity in innovation. In the context of the collaboration between SF firms and UoC, it would be of importance to investigate the presence of women inventors with respect to the age of firms. According to this underlying theoretical framework, the following hypothesis is provided:

H4: A greater involvement of female inventors can be observed in old/very old firms of SF in comparison with young / very young firms.

Influence of the business sector

The inclusivity and diversity of innovations brought about by the considerable involvement of female inventors can lead to better science and more innovative solutions to problems in various scientific and technological fields (Capozza & Divella, 2023). Unfortunately, it is known that women are underrepresented in many fields, and particularly, in science, technology, engineering and mathematic disciplines (STEM) (Hoisl et al., 2023). In the UK, the patenting activity of female inventors is greater in life sciences including biotechnology, pharmaceuticals, and medical devices (UK Intellectual Property Office, 2023), and topics related to innovative drug development and medical treatments (Whittington & Smith-Doerr, 2005; Ding et al., 2013; Koning et al., 2021). These observations suggest that the involvement of female inventors in technological innovations can also be a function of the business sector. Similar observation was reported for the US by Ding et al. (2006) where the involvement of female inventors from top-ranked US universities in patenting activities was studied based on patent analysis, suggesting that the proportion of women inventors involved in patenting is higher in the biological sciences in comparison with other business fields. Later, Ding et al. (2013) confirmed this outcome in a larger pool, beyond top-ranked universities. Other studies confirm that while the share of women as inventor in patents is rather low, it is relatively larger in certain sectors including biotechnology (9.8 %) where no significant differences were found across countries (Abramo et al., 2011; Morrison, 2017). Therefore, the last hypothesis of the current research is suggested based on the underlying theoretical framework mentioned above:

H5: There is a higher number of women involved in co-patenting with UoC in the Pharma/Biotech sector of SF, in comparison with other sectors.

Based on the above-mentioned literature review and hypothesis analysis, we seek to explore the correlation between the firm characteristics (age, size and sector) and the technological collaboration performance of the firms with a main research university in close proximity in terms of technological collaboration strength and the

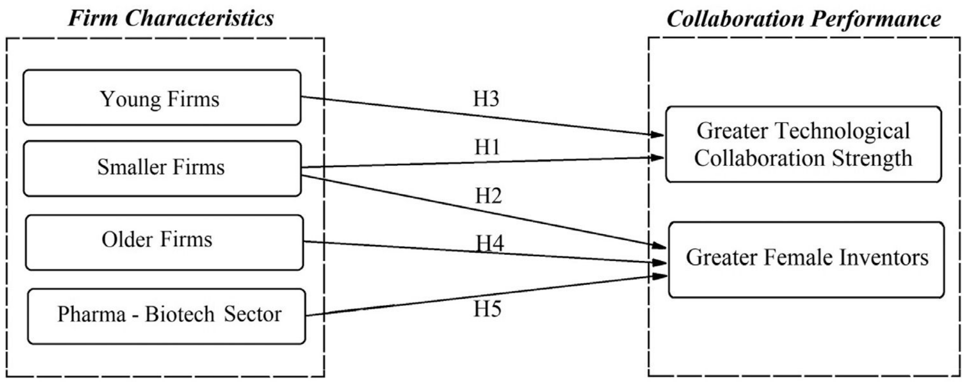

Fig. 1. Theoretical model.

contribution of female inventors to the collaboration, as shown in Fig. 1.

Methods

This study is based on a quantitative bibliometric approach (Donthu et al., 2020; Skute et al., 2019), which involves analysing co-patenting between Silicon Fen firms and the University of Cambridge, as a tool to examine the technological collaboration between two sectors. The primary objective of the study is to evaluate the strength of technological collaboration between the SF firms and UoC with regard to characteristics of firms (size, age and sector) and to explore the involvement of women inventors in technological collaboration by analysing the joint patent ownership. Bibliometric survey was used to extract information related to joint patents, including the topic of invention, author's name, affiliation and address. The latter is an important factor, to include the firms located in SF. For this, the following section defines the border of SF employed in the research.

Geographical borders of Silicon Fen

In this study, Silicon Fen is defined as a cluster of high-tech firms located in the vicinity of University of Cambridge. Geographic border of SF was identified in an earlier work by Koepp (2003), and updated recently (Rezaei & Kamali, 2022b). Accordingly, we define SF as the geographical location of firms with the postcodes starting with CB in the UK, namely CB1, CB2, CB3, CB4, CB5, CB6, CB7, CB8, CB9, CB10, CB11, CB21, CB22, CB23, CB24 and CB25 within five post towns. The areas covered by these postcodes are shown in Fig. 2, consisting the south and east Cambridgeshire, and small parts of Suffolk, Essex and Norfolk counties in the UK.

Sampling of SF firms

High-tech firms located in SF with joint patent(s) with the UoC in the period of 1999–2021 were sampled using secondary data extracted from the UK Companies House (UK Government, 2023), and the FAME Database (FAME, 2023) in combination with the annual

Fig. 2. The geographical location of SF comprising areas with postcode beginning with CB. *Source*: Adapted from Cambridge Postcodes (2022).

report of firms extracted from their websites. The year of 1999 was the earliest time that a joint patent between SF firms and UoC was published, as indicted in secondary databases employed in this study. The year 2021 represents the most recent year for which the data could be obtained at the time of this research. Therefore, the firms were sampled from 1999 to collect data included the size, sector and age of firms. These parameters are considered as independent variables in order to answer the research hypotheses.

According to the definitions given by the UK House of Commons Library (Ward & Hutton, 2022), we categorised high-tech SF firms based on their size into micro-sized firms (1–9 employees), small-sized firms (10–49 employees), medium-sized firms (50 to 249 employees) and large-sized firms (250 and more employees).

Moreover, SF firms were categorised into four different age groups based on the firm's foundation year, and the guideline given by the EU Scoreboards provided by The Organization for Economic Cooperation and Development (OECD, 2017). In the EU Scoreboards, the firms are classified based on the year in which the firm was established. Accordingly, firms of less than five years old were classified as very young firms; firms between five to ten years old as young firms; firms between ten and twenty years old as old firms; while firms with an age of more than twenty years old were classified as very old firms.

In order to divide the SF firms into different business sectors, the Standard Industrial Classification (SIC, 2018) was used. SIC provides a method of classifying businesses based on their type of economic activity into a uniform and common structure. In the UK, this standard was introduction in 1948, and revised six times. The most recent version of the UK's SIC was established in 2007 through a series of consultations in conjunction with the European Union's industrial classification system (Hughes et al., 2009). Thus the 2007 version of SIC was employed to categorise SF business, as shown in Table 1, based on which the firms could be distinguished into four sectors, representing the entire collaborative businesses located in SF.

Table 1
Categorisation of SF firms having joint patents with UoC, based on their business sector. *Source*: Adapted based on SIC (2018).

Sector of Firm	Definition
Pharma/ Biotechnology	Manufacture of basic pharmaceutical products
	Manufacture of pharmaceutical preparations
	Research and experimental development on biotechnology
Communications	Manufacture of telegraph and telephone apparatus and equipment
	Manufacture of communications equipment
	Other telecommunications activities
Computing and Advanced Electronics	Manufacture of computers and peripheral equipment
	Manufacture of electronic components and boards
	Manufacture of consumer electronics
	Manufacture of electronic industrial process control equipment
	Manufacture of electric motors, generators, transformers, electricity distribution and control apparatus
	Manufacture of batteries and accumulators
	Manufacture of fibre optic cables
	Manufacture of other electrical equipment
	Manufacture of machinery for metallurgy
Technical Consultancy Services	Engineering design activities for industrial process and production
	Engineering related scientific and technical consulting activities
	Technical testing and analysis
	Specialised design activities
	Environmental consulting activities

Sampling of joint patents

Patents are the primary source describing emerging technologies (Breitzman & Thomas, 2015; Santini et al., 2021), and joint patenting is a general tool for providing tacit knowledge on technological collaboration among co-assignees that own mutually complementary knowledge (Choe & Lee, 2017; Messeni Petruzzelli & Murgia, 2020; Murgia, 2021). In this research, joint patents between UoC and SF firms are considered as tangible indications of successful technological collaboration among them. In other words, the co-inventorship between high-tech firms located in SF and UoC is considered as a measure to evaluate the collaboration between two sectors. This assumption is based on the idea that the successful collaboration between two entities can lead to innovations in the form of patents (Robin & Schubert, 2013; Gulbrandsen, 2011; Perkmann & Walsh, 2007). Thus, analysing patent data can offer valuable insights into multiple aspects of innovation and intellectual property, including the technological collaborations.

In this study, bibliometric methods were used to extract patent-related data from secondary databases of European Patent Office (EPO) and Derwent Innovations Index (DII) provided by Thompson Reuter's database collection. These are employed as complementary sources to either obtain or confirm information about patents, including the applicants, inventors and the topic. EPO's patent search (Espacenet) contains patents from EPO and WIPO in addition to more than 90 national offices. The assumption of patent sampling is that each patent family is considered as one patent. In DII, the assignee organisations were searched to extract the joint patents. Firms in SF were searched with possible names containing different possible varieties including "Ltd" (Limited) and "Co." (Company). Patents owned by both UoC and SF firms published in the time period of 1999–2021 were considered in this study. The period of 12 years is sufficiently long to provide meaningful information on the trends observed based on joint inventions. 1999 was the earliest time that a joint patent between SF firms and UoC was published in employed secondary databases. Joint patents were sampled as the indication of collaborative invention, based on the criterion that at least one inventor from UoC and one inventor from an SF firm are included in the inventor list. Therefore, the inventors sampled using this criterion are considered 'collaborative inventors' in this study. Moreover, the year 2021 represents the most recent year for which the data could be obtained at the time of this research.

Statistical analyses

The number of joint patents between UoC and high-tech firms located in SF was obtained by mathematical counting of the joint patents, and correlated to firm's characteristics such as the size, age and sector. We adapted the Salton measure to evaluate the technological collaboration strength between SF firms and UoC as discussed shortly. The Salton measure is a similarity indicator used in information retrieval to evaluate the quality of links or similarities (Coşkun & Koyutürk, 2021; D'este et al., 2019). In particular, the Salton measure of collaboration can be used to evaluate the closeness between organisations (Coşkun & Koyutürk, 2021; Shashnov & Kotsemir, 2018). In the current study, the technological collaboration strength (*TCS*) was adapted based on the Salton measure to evaluate the strength of the technological collaboration bond (Rezaei & Kamali, 2022b) between each SF firm and UoC:

$$TCS_{i\text{-}j} = \frac{JP_{i\text{-}j}}{\sqrt{P_i \times P_j}} \quad (1)$$

where $TCS_{i\text{-}j}$ is the technological collaboration strength between organisations i and j; $JP_{i\text{-}J}$ refers to the number of joint patents generated in collaboration between organisations; and P_i and P_j are the total number of patents published by *i* and *j*, respectively. As can be observed, $TCS_{i\text{-}j}$ measures the strength of technological bond between organisations through dividing their joint patents by the square root of the product of the total output of the two organisations. Therefore, this is straightforward to assume that the value of $TCS_{i\text{-}j}$ can be between zero and unity. The value of zero implies the lack of any joint patents, while the *TCS* value of one indicates the maximum collaboration strength, where the entire patents owned by two organisations are joint patents. *TCS* was considered in this study as a variable to evaluate the hypotheses of the research. The Mann-Whitney U test was used to verify hypotheses of the research, based on the results obtained.

Results

Effect of firm size and age on the collaborative performance of firms with UoC

We have screened 78,873 firms located in SF and identified those firms with joint patents with UoC, as shown in Table 2. These firms are located in CB1, CB2, CB21, CB4, CB5, CB22, CB24 and CB25 areas of SF (Fig. 2). Accordingly, a total number of 55 UoC−SF joint patent families could be extracted, dating from 1999 to 2021. Table 2 also shows the size and age of firms according to the classifications presented in the section 3.2, the total number of patents owned individually by SF firms or UoC, the total number of their joint patents, and the corresponding values of *TCS* calculated based on the Eq. (1). Table 3 shows values of technological collaboration strength (*TCS*) calculated for those individual SF firms that published at least one joint patent with UoC. The table also exhibits the number of joint patents (*NJP*) and the total number of patents (*TNP*) generated by the firms vs. the size and age of firms.

Here, we correlate the collaboration performance of SF firms and UoC, based on the number of their joint patents, with characteristics of firms, comprising the size and age of firms. Fig. 3a shows the number of joint patents published by UoC and SF companies, based on the size of the companies. During the time period from 1999 to 2021, the majority of joint patents (38 %) belonged to the medium-sized firms of SF, while micro-sized firms accommodated 31 % of the total joint patents. Also, the small- and large-sized firms have 22 % and 9 % of the total joint patents, respectively. Therefore, we can draw the conclusion that UoC−SF collaboration has led to the generation of joint patents, and the majority of such joint patents are made in collaboration with the medium-sized firms of SF, followed by micro-/small- sized firms, and large-sized firms of SF at less extent. We would like to distinguish the number of joint patents with the collaboration bond, expressed as *TCS* between UoC and the SF firms. We calculated the values of *TCS* in order to identify a meaningful relationship between the characteristics of firms and their technological bonds with UoC. The values of *TCS* as the function of the firm size are shown in Fig. 3b. As can be observed, the *TCS* values of micro- and small-sized firms (7.3×10^{-2}, and 1.6×10^{-2}, respectively) are at least an order of magnetite larger than those of larger firms.

According to the research observations, collaboration between UoC and SF firms has generated joint patents; while micro-sized and medium-sized firms have been the most active collaborators. In contrast, the values of *TCS*, which indicate the strength of the technological bond between UoC and the SF firms, are larger for micro/small-

Table 3
The values of technological collaboration strength (*TCS*), the number of joint patents (*NJP*) with UoC, and the total number of patents (*TNP*) generated by SF firms vs. the characteristic of firms (the size and age). *Source*: Authors.

Parameter	Characteristic of firms	Calculated value
TCS	Large firms	0.00277
TCS	Medium firms	0.00255
TCS	Small firms	0.01648
TCS	Micro firms	0.07346
TCS	Very Young firms	0.0255655
TCS	Young firms	0.03615508
TCS	Old firms	0.004631208
TCS	Very Old firms	0.006157929
NJP	Large firms	5
NJP	Medium firms	21
NJP	Small firms	12
NJP	Micro firms	17
NJP	Very Young firms	1
NJP	Young firms	4
NJP	Old firms	38
NJP	Very Old firms	12
TNP	Large firms	4234
TNP	Medium firms	87993
TNP	Small firms	693
TNP	Micro firms	70
TNP	Very Young firms	2
TNP	Young firms	16
TNP	Old firms	88007
TNP	Very Old firms	4965

Table 2
List of firms located in SF having joint patent with UoC, their geographical location in SF, as well their size and age characteristics, total number of patents and joint patents, and calculated technological collaboration strength (*TCS*) between the firm and UoC. *Source*: Authors.

Firm	Location	Size	Age	Patent Number	Joint Patent	$TCS \times 10^{-4}$
AstraZeneca	CB2	L	V-O	3604	1	6.0
Camcon Technology- currently: Silverwell Energy	CB24	S	V-O	616	4	58.3
Camfridge	CB22	Mic	O	3	1	208.7
Cell Guidance Systems	CB22	S	O	19	1	82.9
FlexEnable	CB4	M	O	157	3	86.6
Fluidic Analytics	CB1	S	Y	12	2	208.7
Huawei Technologies	CB4	M	O	87,721	15	13.1
Medimmune Limited	CB21	L	V-O	301	2	41.7
Mission Therapeutics Limited	CB22	S	O	28	1	68.3
Novalia Limited	CB5	Mic	O	50	1	51.1
Nyobolt Ltd	CB4	Mic	V-Y	2	1	255.6
Plastic Logic	CB4	M	V-O	115	3	101.1
Psynova Neurotech	CB4	Mic	O	15	14	1307
Sphere Fluidics	CB21	S	O	14	2	193.2
Silicon Microgravity	CB25	S	Y	1	1	361.5
The Babraham Institute	CB2	L	V-O	329	2	39.9
Wren Therapeutics	CB2	S	Y	3	1	208.7

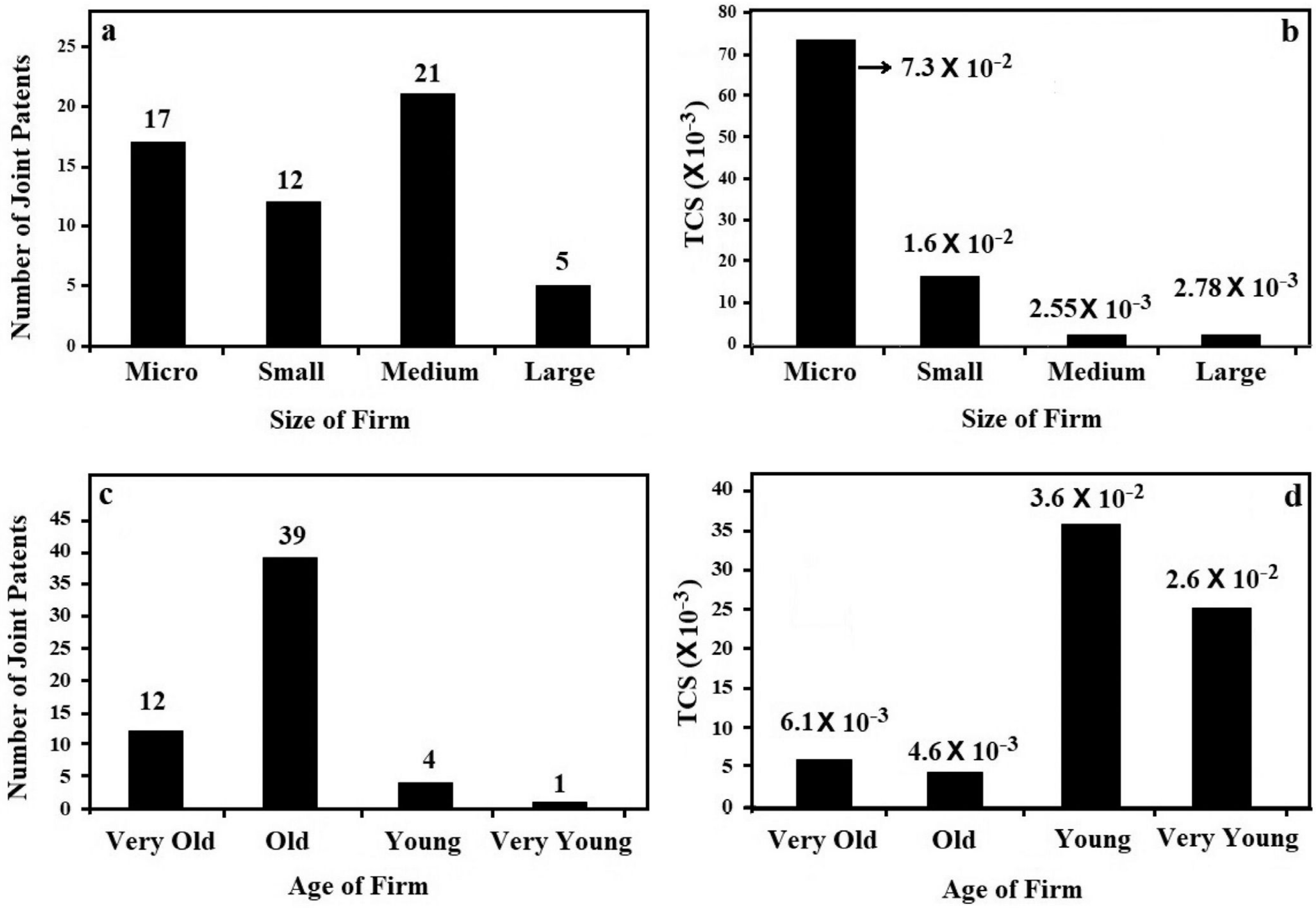

Fig. 3. The number of joint patents between SF firms and UoC, based on (a) the size and (c) the age of collaborative firms. Values of technological collaboration strength (*TCS*) between SF firms and UoC based on (b) the size, and (d) the age of firms. *Source*: Authors.

sized firms than for medium-sized/ larger firms, providing several implications. Hence, we may confirm the first hypothesis of the research; **H1**: Technological collaboration between SF firms and UoC depends on size of firms: smaller firms have greater technological collaboration strength with UoC than larger firms.

Fig. 3c and 3d show the number of joint patents and the values of *TCS*, respectively, as the function of the age of firms. Here, the age of firms is categorised as very young (<5 year old), young (5−9 year old), old (10−20 year old) and very old firms (more than 20 year old). As can be seen, old firms own majority of joint patents with UoC (69.6 %), followed by very old firms (21.4 %), young firms (7.1 %) and very young firms (1.8 %). This observation indicates that there is a positive correlation between the age of a firm and their likelihood of owning joint patents with UoC, suggesting that those SF firms with technological collaboration with UoC continue their collaboration over time, which shows the sustainability of the collaboration. While old/very old firms have greater number of joint patents with UoC than young/very young firms, however the *TCS* values of the latter (3.6×10^{-2} / 2.6×10^{-2}) are at least four times greater than those of the former (4.6×10^{-3}/ 6.1×10^{-3}).

The greater technological bonds between younger firms of SF and UoC suggests that a main research university in close proximity of a cluster of high-tech firms may be considered as the main technological collaborator for younger firms of the cluster. On the other hand, established high-tech firms of the cluster are more likely to have more established routines of collaboration with institutes beyond their geographical location, reducing their technological bond with the main research university in close proximity. Hence, we may confirm the third hypothesis of the research, **H3**: Technological collaboration strength between SF firms and UoC is higher in very young and young firms.

Women involvement

We have studied the number of female inventors affiliated with SF firms, who have been involved in joint patents generated by UoC and SF businesses. The number of such female inventors have been correlated to characteristics of the corresponding company comprising the age, sector and size of the firm. The results obtained are shown in Fig. 4. Fig. 4a and 4b show the number of female and male inventors, respectively, based on the sector of firms. As can be seen, UoC−SF collaboration has led to the generation of joint patents involving female inventors, with the majority of such joint patents in the Pharma/Biotech sector of SF (91 %), followed by the Communications, and Tech Consultancy Services sectors to a considerably less extent. Moreover, based on these observations, the proportion of female inventors in various sectors can be described as 5.88 % in Communications, 20.79 % in Pharma/Biotech, 11.10 % in Tech Consultancy Services and 0 % in Computing and Advanced Electronics. Therefore, the high proportional productivity of the Pharma sector is evident and the presence of female inventors in this sector is far more prominent. Fig. 4c and 4d exhibit the number of collaborative female and male inventors, respectively, as a function of the company size. As observed, the proportion of collaborative female inventors was 30.7 % in micro-sized firms, 12.9 % in small-sized firms, 2.4 % in medium-sized firms and 23.1 % in large-sized firms. Hence, it is evident that micro, small, medium and large firms accommodate 34.8 %, 34.8 %, 4.3 % and

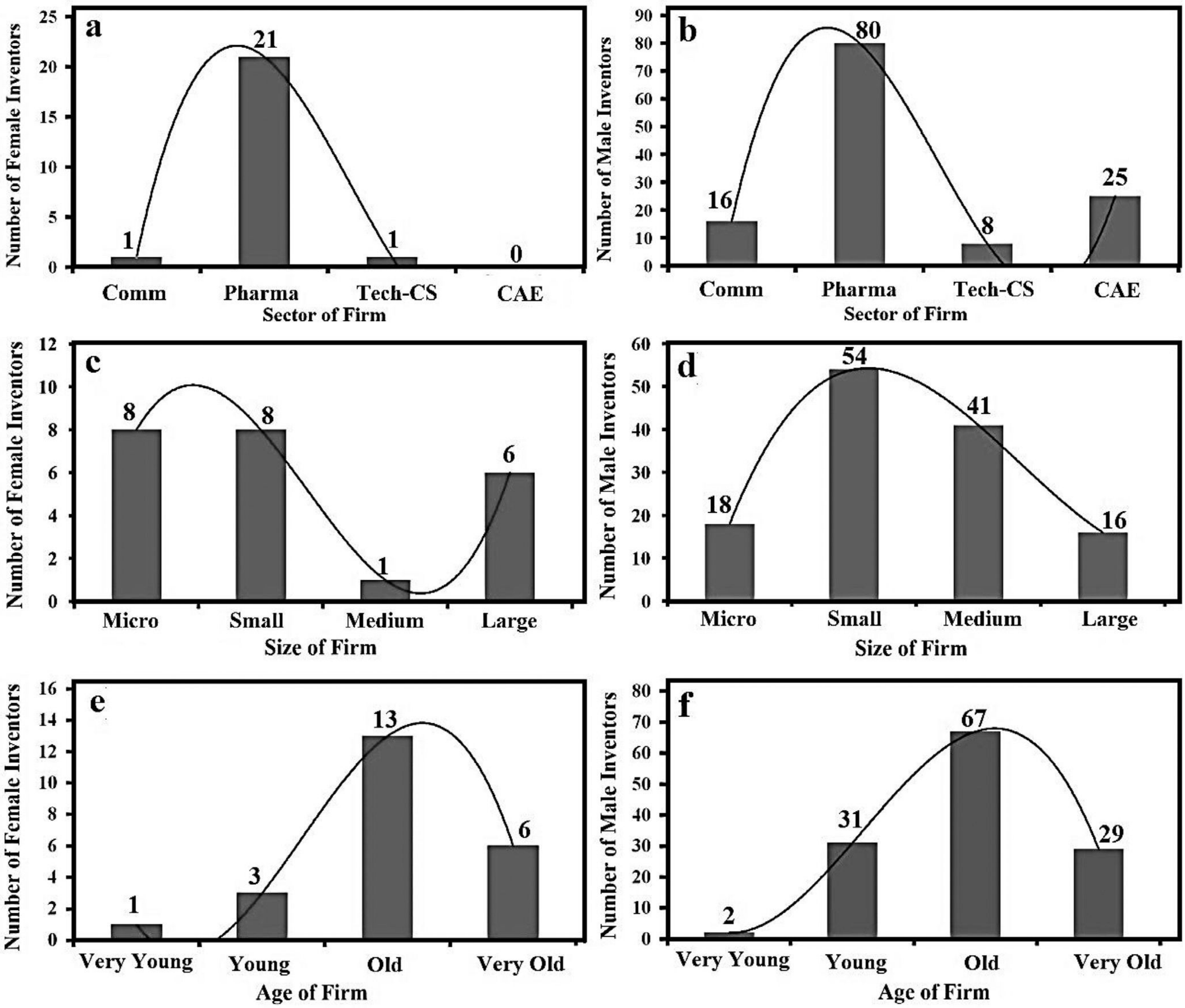

Fig. 4. Contribution from collaborative female and men inventors with respect to the size, sector and age of firms: (a) Female inventor-sector of firm; (b) Male inventor-sector of firm; (c) Female inventor-size of firm; (d) Male inventor-size of firm; (e) Female inventor-age of firm; and (f) Male inventor-age of firm. *Source*: Authors.

26.1 % of collaborative female inventors, suggesting a higher level in small and micro firms, with a low presence in medium-sized firms.

Fig. 4e and 4f show the number of collaborative female and male inventors, respectively, based on the age of firms. As seen, the proportion of collaborative female inventors with respect to collaborative male inventors can be detected to be 33.3 % in very young firms, 8.8 % in young firms, 16.2 % in old firms and 17.1 % in very old firms. In terms of number of collaborative female inventors in firms of various ages, it is noticeable that very young, young, old and very old businesses accommodate 4.5 %, 13.6 %. 59.1 % and 27.3 % of collaborative female inventors, confirming the lower presentence of collaborative female inventors in younger firms. Therefore, it can be concluded that older firms (those classified as old and very old) located in SF not only show a greater performance in collaboration with UoC, leading to the generation of joint patents, but also provide a platform for greater contribution of female inventors. The old firms of SF also accommodate the majority of collaborative men inventors (51.9 %), as can be depicted from Fig. 4f. In conclusion, Pharma sector of SF has greater technological collaboration with UoC, with a greater number of female inventors, in comparison with other sectors of SF. Furthermore, the smaller and older firms are more likely to have female inventors collaborating on joint patents, indicating greater participation in technological collaboration with UoC.

Furthermore, Fig. 5b shows the present of female inventors and *TCS* values of firms as the function of firm's size, based on which interesting observations can be made: Collaborative female inventors are most likely to be affiliated with micro/small firms (69.6 %) in contrast with medium/large firms (26.1 %). In addition, as shown in Fig. 5, the *TCS* value of micro/ small firms (8.99×10^{-2}) is considerably greater than that of medium/large firms (5.32×10^{-3}). Thus, it may be concluded that in firms with greater collaboration bond with the university, greater number of female inventors can be found. Hence, we may confirm the second hypothesis of the research; **H2**: Proportion of female inventors involved in joint patenting with UoC is greater in micro- and small-sized firms of SF.

Fig. 5c and Table 4 summarize the results concerning the correlation between female involvement in joint-patenting and the age of firms. As shown, the proportion of collaborative female inventors is substantially larger in old (59.1 %) and very old (27.3 %) firms in contrast with young (13.6 %) and very young (4.5 %) firms. In addition, Fig. 5 shows that *TCS* value of young/ very young firms (6.17×10^{-2}) is considerably greater than that of old/very old firms (1.07×10^{-2}).

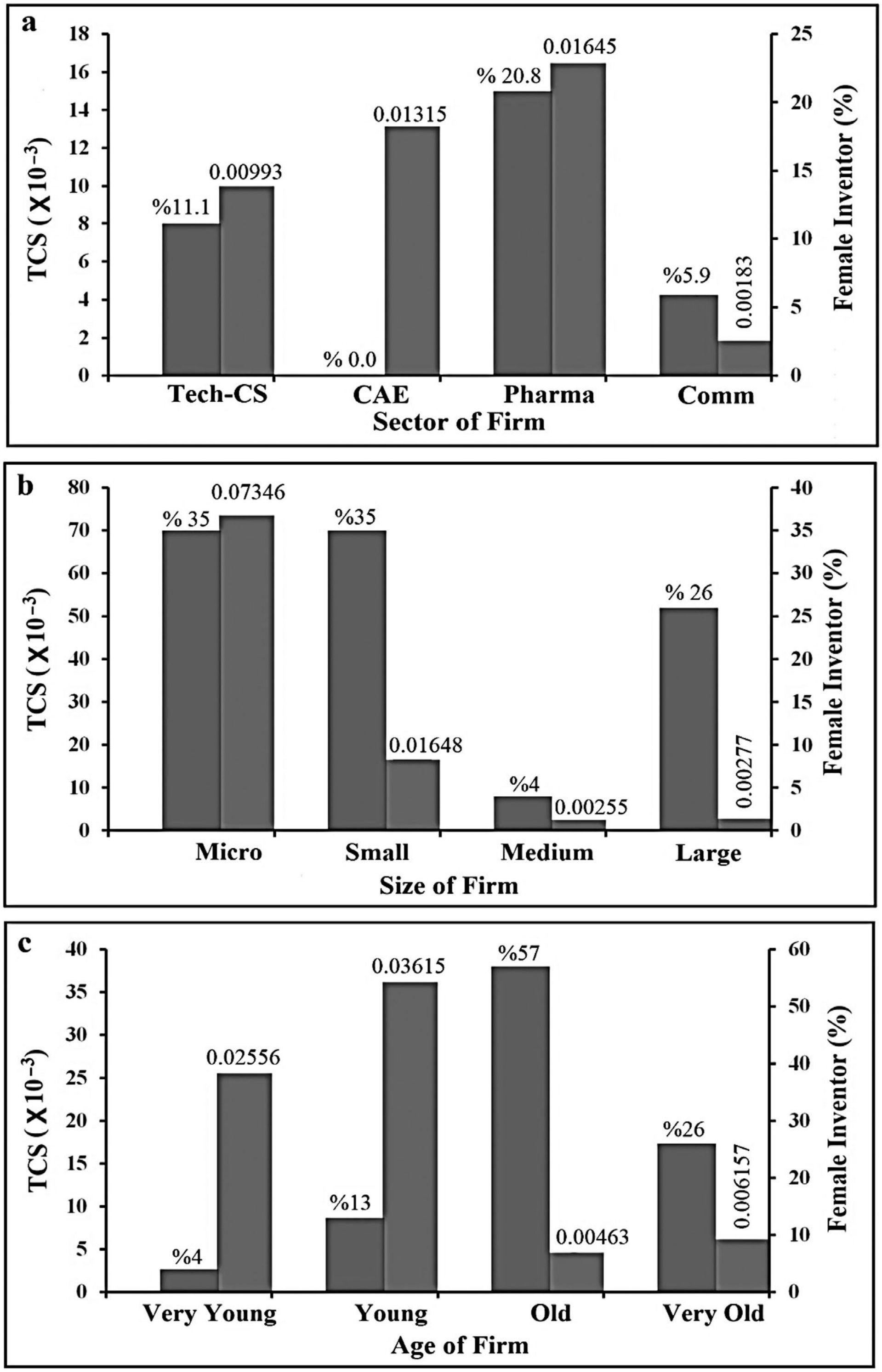

Fig. 5. Correlation between the values of *TCS* and the ratio of female inventors involved in the technological collaboration between SF firms and UoC, based on the sector, size and age of firms. *Source*: Authors.

Also, Table 5 shows the proportion of collaborative firms in terms of their size and age, demonstrating that micro-sized old firms form 17.6 % of the collaborative sector of SF. Therefore, our observations provide evidence that micro but established (old) businesses of SF form a relatively small fraction (17.6 %) of the collaborative firms, accommodating the greatest presence of collaborative women inventors. This observation suggests that there is a higher involvement of female inventors involved in technological collaboration with UoC in older firms, while the collaboration bond of these firms with UoC is weaker than younger firms. This finding implies that older firms may have a more diverse and inclusive culture that allows for greater participation and collaboration of women in the innovation process, while the collaboration of these firms may expand widely beyond the main research university located in close proximity. Based on the results obtained, we may confirm the fourth hypothesis of the research, **H4:** Old/very old firms of SF have the greatest involvement

Table 4
The proportion of female inventors involved in technological collaboration between SF firms and UoC, based on the sector, size and age of firms. *Source*: Authors.

		Female Inventor (%)
Sector of firm	Pharma	20.8 %
	Comm	5.9 %
	Tech-CS	11.1 %
	CAE	0.0 %
Size of firm	Micro	35 %
	Small	35 %
	Medium	4 %
	Large	26 %
Age of firm	Very Young	4 %
	Young	13 %
	Old	57 %
	Very Old	26 %

Table 5
Intersection of collaborative firms with various size and age values. *Source*: Authors.

Age of firms	Size of firms			
	Micro	Small	Medium	Large
Very Young	5.8%	-	-	-
Young	-	17.6%	-	-
Old	17.6%	17.6%	11.8%	-
Very Old	-	5.8%	5.8%	17.6%

of female inventors in contrast with young/ very young firms located in SF. To verify individual hypotheses, the Mann-Whitney U test was used, and the results are presented in Table S1. As shown, the p-values are less than the typical significance level of 0.05 (Meliá-Martí et al., 2024), ranging from 0.008 to 0.036, thereby providing statistical evidence to support the hypotheses of the study.

Discussion

Our study provides empirical evidence of knowledge transfer through technological collaboration between high-tech business clusters and main research university located in the same geographical area, by considering the Silicon Fen firms and University of Cambridge as the model, where the co-patenting between them can provide an indication of their technological collaboration. The sustainable development of such clusters of high-tech businesses not only depends on collaboration with the university, but also on the effective contribution of women in the knowledge transfer process. Therefore, we shed light on the participation of female inventors in these collaborative efforts, based on joint patent ownership between the businesses and the university. The study intends to investigate whether the characteristics of businesses such as age, size and sector have impacts on the level of technological collaboration between two sectors, and also whether the presence of female inventors in these collaborations is affected by such characteristics.

In order to answer hypotheses of the research, first, the correlation between the characteristics of firms and their technological collaboration is discussed to establish a baseline understanding of the factors that may influence the collaboration. Next, the contribution of women inventors from SF in co-patenting between SF firms and UoC is discussed, based on characteristics of firms to provide a benchmark against which the contributions of women in the technological knowledge transfer can be evaluated. Thus, the study contributes to the body of knowledge by providing an understanding of factors that contribute to successful technological collaboration between SF businesses and UoC, as a model for a cluster of high-tech business located in close proximity of a main research university, and how gender diversity may play a role in this.

Correlation between company characteristics and their collaboration outcome

Based on our observations, it can be inferred that the collaboration between UoC and SF businesses, particularly in generating joint patents, has strengthened the technological bond between the two parties. This suggests that both UoC and SF businesses have found value in working together, possibly through the exchange of knowledge (Rossi & Sengupta, 2022), resources (Schaeffer et al., 2021) or expertise (Henderson et al., 2023). Furthermore, it indicates that UoC's research areas are well-aligned with the needs and interests of the SF businesses, which is crucial for fostering successful collaborations. Here, micro-sized firms have been the most active collaborators in generating joint patents. Perhaps, these firms are more willing to invest in research and development (R&D) projects (Julião et al., 2022) or have a better understanding of the UoC's research areas. Alternatively, the UoC may have provided more support and incentives to these businesses, such as access to its facilities or research funding (Albats et al., 2022). It is also possible that the collaborative micro-sized firms were primarily spun off from the UoC. These startups may have stronger ties with the university as they may have been founded by UoC researchers or alumni who have a deeper understanding of the university's research areas and are more likely to collaborate with the university (Rezaei & Kamali, 2022b). Additionally, micro-sized firms can be more agile and flexible in terms of R&D (Julião et al., 2022) and able to move quickly to develop new technologies (Santini et al., 2021) and patent them in collaboration with the UoC.

The higher *TCS* values for micro and small-sized firms suggest that these firms have stronger technological ties with UoC, which may lead to more successful collaborations. On the other hand, the lower *TCS* values for larger and medium-sized firms may indicate a weaker collaboration bond, which could be due to various factors, such as differences in research priorities (Orazbayeva et al., 2019) or difficulty in communication and coordination (Arthur et al., 2023), while the smaller firms grow into larger ones. It suggests that smaller firms of SF are more eager to collaborate with UoC as the main source of collaboration than larger firms. Smaller firms are likely to have fewer resources and capabilities to develop technology and innovation in-house (Audretsch et al., 2022), and hence, they are more open to collaborating with external partners such as universities (Hewitt-Dundas et al., 2019). Also, the observation implies that smaller firms are more successful in establishing a strong technological bond with UoC. Smaller firms have generally a more focused and agile approach to innovation, with enhanced willingness to take risks and explore new ideas (Davis & Bendickson, 2021). Moreover, smaller firms can be more flexible in their approach to collaboration and more adaptable to changes in the research and development process (Sen et al., 2022). Lower *TCS* values for larger and medium-sized firms could indicate a weaker collaboration bond with the UoC. However, it is essential to consider that larger firms may have collaborations with multiple universities or research institutions (Fassio et al., 2023), and they may have their own in-house research and development with specialised expertise (Delgado-Verde et al., 2021). Due to their more established nature, larger firms may collaborate with various organisations in the same geographical proximity and beyond to access specialised expertise or opportunities (Speldekamp et al., 2020); hence the weaker collaboration bonds between larger firms of SF and UoC can be a natural response to their more complicated structure, in comparison with smaller firms.

We discussed the relationship between the age and size of SF firms, and their collaboration with UoC by analysing their joint patents and values of *TCS*. Our findings indicate that values of *TCS*, which indicate the strength of the technological bond, are larger for micro/small-sized firms than for medium-sized/large firms. Additionally, the *TCS* values associated with young/very young firms are considerably larger than old/very old firms of SF. With this in mind we investigate the contribution of female inventors to the collaboration in next section.

Women contribution

This section examines the influence of SF firm characteristics on the involvement of female inventors in joint patenting with UoC. Commercialisation of research has become a priority for many research organisations and universities to generate third stream income (Radko et al., 2022), leading to increased collaboration with firms across various sectors. In our case, a greater presence of collaborative female inventors was observed in Pharma/Biotech sector of SF compared to other sectors within the cluster. This can be related to the overall greater proportion of female inventors in this sector. For example, based on the report published by the UK Government (Gender profiles in worldwide patenting: An analysis of female inventorship, 2019), the proportion of female inventors in 2017 was recorded at 12.7 % worldwide (≈11 % in the UK), while the majority of patents with at least one female inventor was found to be substantially greater in Biotechnology/Pharmaceutical (slightly less than 50 %). Our findings can also be discussed based on other observations considering the contribution of female inventors to patenting activities. For example, Whittington and Smith-Doerr (2008) studied global Biotech patenting collaboration networks, and realised that women form 24 % of the biotech inventor population. The proportion of female inventors observed in the current study (20.8 %) is in agreement with Whittington's observation, while a slightly lower percentage was recorded for the case of SF. In contrast with the Biotech sector, the proportion of female inventors is considerably lower in other sectors of SF. At the same time, the *TCS* value of Pharma/Biotech sector (1.64×10^{-2}) is greater than those of other sectors.

This observation can be discussed based on the literature, suggesting that the life sciences are often held up as an example of a place where women have made inroads into the natural science domain (Ding et al., 2013; Whittington & Smith-Doerr, 2005) while male researchers are significantly more likely to be inventors of patents (Azagra-Caro et al., 2006; Boardman & Ponomariov, 2009; Hunt et al., 2013). The fact that women have made inroads into the life sciences field can be due to a variety of factors, such as a greater emphasis on collaborative research in life science that naturally involves more females than other fields (Kwiek & Roszka, 2021), a more supportive culture for women in life sciences, or a greater awareness of the importance of diversity in such fields (Lerchenmueller & Sorenson, 2018). However, despite these gains, the underrepresentation of women in patenting suggests that there are still significant barriers to overcome (Tesfaye & Wainikka, 2022). One possible explanation for the gender gap in patenting is the existence of implicit bias in the patenting process, where male inventors are more likely to be recognised and rewarded for their contributions. In this context, Hunt et al. (2013) found that only 5.5 % of US patent inventors are female. In our case, the percentage is higher at 15 % given that 23 collaborative inventors out the total number of 152 collaborative inventors involved in joint patenting with UoC are women. The female involvement observed in this study (15 %) is therefore considerably greater than the value observed by Hunt et al. (2013). The higher percentage of female inventors observed here can be attributed to the high activity of the Biotech sector of SF, which is known to be more female-oriented than other business sectors. In other words, the higher percentage of female inventors in this sector can be attributed to the thriving Pharma/Biotech industry in SF, demonstrated by a high level of *TCS* (Fig. 5a) showing its strong technological bond with UoC. The more extensive collaboration between the Pharma/Biotech industry and the university may have provided more opportunities for female inventors to participate and contribute to innovation in this field.

Moreover, our observations confirm that smaller but established (older) high-tech businesses may have greater involvement of female inventors who can effectively collaborate with the main university in close proximity. Gender diversity has been found to have a significant and positive relationship with innovation performance, as demonstrated by several studies (Ain et al., 2021; Corvello et al., 2023). In particular, the study conducted by Corvello et al. (2023) reveals that the size of firms plays a role in shaping attitudes towards innovation, patenting, impacting the gender diversity. Additionally, Wellalage and Fernandez (2019) reported on the involvement of female inventors in patents published by businesses in Eastern Europe and Central Asian countries, and indicated that the proportion of women inventors is greater in micro/small-sized firms. Furthermore, the study by Beneito et al. (2022), which found higher women's participation in older firms, suggests a relationship between the age of firms and gender diversity in patenting activities. Perhaps women have greater opportunity in such firms to be involved in collaborative innovation, leading to creation of a more diverse and inclusive innovation (Corvello et al., 2023). Small-sized companies may offer more supportive and inclusive work environment for women, helping to attract and retain female talent. Established (older) high-tech firms, on the other hand, may provide a more stable and secure work environment with a proven track record of success (Kim, 2022), as well as a strong mission and vision. They may also have more resources and connections, including relationships with nearby universities (Coad et al., 2016), which can provide women inventors with greater opportunities to collaborate and engage in innovative works.

In the current paper, we explored the collaboration performance between SF firms and UoC based on joint patents, and evaluated the contribution from female inventors. Our observations show that the Biotech sector of SF has the maximum involvement of collaborative female inventors. We further observed that collaborative female inventors are most likely to be affiliated with old and micro-sized firms, which form 17.6 % of the collaborative sector of SF. Therefore, our observations provide evidence that micro but established (old) businesses of SF form a relatively small fraction (17.6 %) of the collaborative firms, accommodating the greatest presence of collaborative women inventors.

Based on our observation the proportion of female inventors is very small in firms active in Communications (%5.9), medium-sized firms (4 %) and very young firms (4 %). These values are close to that reported by Hunt et al. (2013) indicating that only 5.5 % of US patent inventors are female. This form of gender gap should be addressed by implementing appropriate policies. Promising signs could be observed in regions such as Latin American countries, where female inventors can be as high as 22 %. Parameters such as fertility rate and the human developments in this region were reported to impact the women participation in patenting (Sifontes & Morales, 2020). These observations indicate that there is a need for more comprehensive policies to address the gender gap in patenting and commercialisation activities. Encouraging more women to participate in diverse fields can lead to more sustainable development of high-tech cluster of businesses such as SF. This gender diversity can be an essential factor for the success of high-tech businesses in the fourth industrial revolution (Dabić et al., 2023). Our results can support policymakers who plan for promoting the collaboration of SF and UoC, and particularly contribution of woman in technological knowledge transfer. Results also contributes to the theory of technological knowledge transfer between a cluster of high-tech businesses and a main research university in close proximity, with respect to the contribution of female inventors. These insights highlight the importance of promoting gender diversity and inclusion in order to fully leverage the potential of the fourth industrial revolution for sustainable growth and innovation.

Theoretical implications

This research contributes to the broader theory of knowledge transfer in university-industry collaboration, reinforcing the notion that such collaboration can play a critical role in fostering innovation, particularly in technology-driven industries (Rossoni et al., 2024). The findings further suggest that smaller and older SF firms demonstrate stronger collaborative bonds with the university, which aligns with prior theories indicating that organisational maturity and flexibility may drive stronger university-industry linkages (George & Tarr, 2024). The concept of technological collaboration strength (*TCS*) introduced in this research can add a quantitative dimension to the theory of collaboration (Rezaei & Kamali, 2022a). By correlating joint patents with firm characteristics (size, age, and sector), this study provides empirical support for how *TCS* varies across different types of businesses. The study supports the hypothesis that smaller firms exhibit stronger collaborative relationships within the cluster, aligning with resource dependence theory, which posits that smaller firms are more likely to seek external partnerships to compensate for internal resource limitations (Audretsch et al., 2023). Having mentioned this, the research also contributes to gender studies within the realm of innovation and knowledge transfer, highlighting the uneven distribution of female inventors across firm sizes and sectors, suggesting that women's involvement in technological collaboration is contingent on firm characteristics. The inclusion of female inventors in older firms and in specific sectors like Pharma/Biotech indicates the need for policies targeting larger and younger firms to promote gender equity in innovation. The research also suggests that sectoral characteristics, in high-tech industries like Pharma/Biotech, play a significant role in the involvement of female inventors. This finding extends sector-based studies of innovation (Caviggioli et al., 2023), providing a nuanced view of how gender inclusion and knowledge transfer are sector-dependent.

Managerial implications

The results obtained can provide managerial implications. For example, this study highlights the need to proactively strengthen collaborative ties with the university for managers of larger and younger firms located in SF. These firms may require developing specific strategies to enhance their engagement in joint research and innovation projects with academic institutions. This could involve fostering long-term partnerships and developing in-house capabilities for university engagement. The finding of this research indicates that older and smaller firms show higher participation of female inventors, suggesting a gap in gender inclusion for larger and younger firms. Managers in such firms may implement gender diversity initiatives, particularly in sectors where women are underrepresented in innovation. Firms may benefit from creating inclusive innovation environments (Sánchez et al., 2024), mentorship programs (Beck et al., 2022), and policies aimed at increasing the participation of women in patenting and technological collaboration efforts. On the other hand, less collaborative firms (such as those outside the Pharma/Biotech sector, according to the SF-UoC case) should take note of the sector's success in involving female inventors in university collaborations. This may involve adopting appropriate practices from the Pharma/Biotech sector, such as creating cross-functional teams that include women in leadership roles and encouraging diverse teams in innovation processes. Managers can also explore partnerships with universities to access expertise in diversity-focused research and innovation practices.

Policy and practice implications

The results obtained can offer important implications for both policy and practice. For instance, the university and SF associations may encourage policy reforms that incentivize larger and younger firms to engage with female inventors. These policies could include specific funding schemes for gender-diverse innovation projects, mentorship programs, and leadership development initiatives targeting women in STEM fields. University technology transfer offices may prioritise gender inclusivity in their partnership-building activities with industry. Finally, managers of smaller and older firms in SF may promote their stronger collaboration ties with university and their higher involvement of female inventors as a competitive advantage. By emphasising these strengths in innovation ecosystems, these firms can position themselves as leaders in diversity-driven innovation, attracting both talent and external funding. This study investigated the technological collaboration between SF firms and UoC located in proximity. The methodology and results obtained can be employed to study the alternative university-industry clusters (Lucena-Piquero & Vicente, 2019).

Conclusions and limitations

This research investigates the theory of knowledge transfer through university-industry collaboration and seeks to explore technological collaboration strength between the University of Cambridge and the businesses of Cambridge technology cluster (Silicon Fen) with a focus on the involvement of female inventors in the knowledge transfer between two sectors. The evaluation was based on their join patent ownership, with respect to the characteristics of businesses located in Silicon Fen such as age, size and sector using secondary data sources. The technological collaboration strength (*TCS*) was considered as the measure of collaboration strength between SF firms and UoC, calculated based on patent analysis. We correlated the number of joint patents and the values of *TCS* with characteristics of firms (age, size, and the business sector). Moreover, the involvement of female inventors was correlated with the characteristics of firms, and also values of *TCS*. The results obtained suggest that micro- and small-sized firms of SF provide maximum values of *TCS*; 7.3×10^{-2}, and 1.6×10^{-2} respectively, an order of magnitude greater than those of medium- and large-sized firms. At the same time, medium-size firms of SF exhibit the minimum ratio of female inventors involved in collaboration (4 %) in comparison with micro-/small-sized firms (70 %) and large-sized firms (26 %). Old/very old firms exhibit lower *TCS* values than very young/young firms; 3.6×10^{-2} and 2.6×10^{-2}, respectively. However, the involvement of female inventors in earlier (17 %) is substantially weaker than the latter (83 %). Pharma/Biotech sector of SF has a greater value of *TCS* (1.6×10^{-2}) in comparison with other sectors and accommodates the greatest ratio of Female inventors (20.8 %). Based on the results obtained our hypotheses are confirmed as (H1) Technological collaboration between SF firms and UoC depends on the size of firms, so that smaller firms have greater technological collaboration strength with UoC than larger firms; (H2) the proportion of female inventors involved in joint patenting with UoC is greater in micro- and small-sized firms of SF; (H3) the technological collaboration strength between SF firms and UoC is higher in very young and young firms; (H4) old/very old firms of SF have the greatest involvement of female inventors in contrast with young/ very young firms located in SF, and (H5) there is a higher number of women involved in co-patenting with UoC in the Pharma/Biotech sector of SF, in comparison with other sectors. Our findings indicate that smaller, but more established (older) high-tech companies may have greater involvement of women inventors who can effectively collaborate with a main university in close proximity.

This study sheds new light on the theory of knowledge transfer through university-industry collaboration between SF firms and UoC as a model of cluster of high-tech firms and a main research university located in close proximity. Sources of secondary data in this research were limited to IDD, EPO, Espacenet and FAME. Alternative databases may provide slightly different results due to differences in their coverage. Utilising alternative databases in future research can further strengthen the hypotheses presented in this study. Moreover, joint patent analysis was used as the single tangible measure to indicate the technological collaboration between SF firms and UoC. This measure is reliably accessible through available databases, providing clear evidence of successful collaboration leading to innovation. However, other indicators of collaboration, such as research agreements and technology licensing, could be explored in future studies to assess additional aspects of such partnerships. Moreover, although the geographical boundary of SF is clearly defined in this study (see Section 3.1), an alternative definition of SF could potentially influence the outcomes.

CRediT authorship contribution statement

Asma Rezaei: Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Lynn Martin:** Writing – review & editing, Supervision. **Ali Reza Kamali:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jik.2024.100594.

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