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Demographic patterns and trends in patenting: Gender, age, and education of inventors

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ABSTRACT

This paper uses register-linked patent records covering an extended period 1985-2007 to analyze detailed demographic profiles of inventors. The analysis covers about 80 percent of all inventors with Swedish addresses listed on European Patent Office records. Examining temporal trends of gender, age, and education shows that the body of inventors is becoming more balanced in gender, younger, and more educated. However, the rate at which female inventors are entering into patenting has slowed down since the early 2000's compared to the mid-1990s. Moreover, comparing the inventor sample with the entire population of Sweden reveals that 1) the closing of the gender gap in inventing is not taking place at the same rate as among Ph.D. holders and that 2) the dependence of inventing on the highly educated (especially, Ph.D. holders) is being intensified over time, but the number of highly educated is growing faster among the general population than among inventors. Finally, the analysis shows that there is significant heterogeneity in the composition and tendency of gender, age, and education of inventors across technology fields.

Keywords: inventor; patent; gender; age; education

JEL codes: I23; J16; O31; O34

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Abstract

This paper uses register-linked patent records covering an extended period 1985-2007 to analyze detailed demographic profiles of inventors. The analysis covers about 80 percent of all inventors with Swedish addresses listed on European Patent Office records. Examining temporal trends of gender, age, and education shows that the body of inventors is becoming more balanced in gender, younger, and more educated. However, the rate at which female inventors are entering into patenting has slowed down since the early 2000's compared to the mid-1990s. Moreover, comparing the inventor sample with the entire population of Sweden reveals that 1) the closing of the gender gap in inventing is not taking place at the same rate as among Ph.D. holders and that 2) the dependence of inventing on the highly educated (especially, Ph.D. holders) is being intensified over time, but the number of highly educated is growing faster among the general population than among inventors. Finally, the analysis shows that there is significant heterogeneity in the composition and tendency of gender, age, and education of inventors across technology fields.

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1 Introduction

Invention is a complex process that combines physical and organizational skills with knowledge and human resources. In such processes, inventors are not just one of the necessary inputs but also their architects. They generate ideas and concepts to direct the process, mobilize and allocate resources to solve technological problems, and design and coordinate work procedures. Certainly, inventors are not the only actors coordinating the whole invention process, especially not in a large invention project carried out within highly organized corporate R&D departments, but their central roles in inventing should not be underestimated.

This paper provides a statistical snapshot of inventors and focuses on their demographic attributes such as gender, age, and education and their changing composition across different technologies and over time. One of the main purposes of this paper is to reveal an empirical reality about the population of inventors and level the ground for further research. Therefore, it is driven by data rather than by theory and oriented towards an empirical description rather than causal analysis. This paper focuses on three demographic attributes of inventors: gender, age, and education. We select these attributes for three reasons. First, they are fundamental attributes of human resources. Second, at the same time, they have important policy and scholarly implications. Finally, albeit their importance, we have limited knowledge of basic facts about them, such as distribution of inventors by gender, age, and level of education. These points are elaborated in the next three paragraphs.

Gender disparities in science and engineering professions have long been a topic of both policy and scholarly debate. According to a recent study by Hunt et al. (2012), closing the gender gap in science and engineering degree holders in the US would increase US GDP per capita by 2.7%. Gender studies in invention have a long tradition but most early studies present either an anecdotal or historical appraisal of women inventors (Khan 2000; Pursell 1981; Gage 1883). It is only recently that systematic accounts of contemporary women inventors started to appear, most of which, however, examined only a particular segment of inventors such as academic inventors (Ding et al. 2006; Whittington and Smith-Doerr 2008; Whittington 2011), a particular technology field such as nano-technology (Meng and Shapira 2011), or a particular period (Kugele 2010; Naldi et al. 2005; Giuri et al. 2007). Hence, they are limited in the sense of not providing a holistic and dynamic picture of women inventors across different fields as well as over time. This paper utilizes almost population-level longitudinal data to overcome the weakness in the literature.

Age has been one of the central study variables for researchers assessing lifecycle effects of academic performance (Levin and Stephan 1991; Stephan and Levin 1992; Bonaccorsi and Daraio 2003). This literature consistently finds that the productivity of academic scientists varies with age. While a substantial body of literature studies the age structure of academic researchers, only a few studies examine the age of inventors. Moreover, by focusing on a specific topic such as great inventors (Jones 2010) or productivity effects (Mariani and Romanelli 2006), they do not provide an overall picture of inventors by age structure and shifts associated with technological change. We try to fill this void in the literature by examining the age of inventors in terms of technology and its longitudinal changes.

Finally, the education of inventors is also important but little examined in the literature. Two key questions already addressed include whether (and, if so, how) education affects 1) the propensity of becoming an inventor and 2) inventive productivity. Studies by Väänänen (2010) and Hunt et al. (2012) address the former question while Jones (2010) and Mariani and Romanelli (2006) the latter. As with gender and age, these studies examine a small sample of inventors. In this paper, we provide an overall picture of both level and fields of education of inventors, and focus on compositional difference regarding technology and temporal trends. In sum, the paper aims to establish a firm factual ground on which we can further advance the knowledge on human factors of inventions.

Despite the scholarly and practical importance of this topic, it is a scant area of research in existing literature, which probably should be ascribed to difficulties in acquiring personal information about inventors. While academic scholars disclose personal information such as age, gender, and education via public CVs, inventors, most of whom are affiliated with private firms, usually do not. Therefore, studies on inventors are generally restricted to a small segment of the inventor population whose demographic information is public in some ways or, for a large-scale study, resort to costly methods such as surveys. The end result is that we know little about inventors – even concerning basic demographic data on gender distribution, level of education, age, and the interdependence of these variables. Only recently have some of these aspects been investigated thanks to a large-scale survey (Giuri et al. 2007; Mariani and Romanelli 2006) and availability of population data linked to inventors (Väänänen 2010).

This paper aims to fill this gap in the literature by providing demographic information about Swedish inventors. As mentioned, information on inventors is usually confined to survey data which suffer from potential problems of selection and response biases. Thus while many studies report on descriptive statistics for inventors, there is always a sneaking suspicion that things may not be as accurate as hoped for. This paper, we argue, suffers fewer of these problems as it is based on a near-complete sample of inventors with addresses in Sweden listed on European Patent Office records. From now on we refer to this group as Swedish inventors. Moreover, we claim our data are not only representative for the last few years, but also over the extended time period 1985-2007. Thus we are in a unique position to describe not just the present profile of Swedish inventors, but developments over time as well.

Sweden is a small but inventive economy of 9.5 million inhabitants with a (still) relatively industrialized business profile. Business R&D to GDP is around 3%, which counts among the highest in the world. The dominant share of R&D activities is conducted in the telecommunications, automotive and medical sectors. In addition, the country has produced many multinationals with origin or partial origin in the country, such as Ericsson, Sony Ericsson, ABB, SKF, Scania, Volvo, Saab, Astra (now AstraZeneca), and TetraPak, to name a few. Partially as a consequence of this domination of multinationals, Sweden has a high trade ratio to GDP. All in all, Sweden can be considered to be at the forefront of technology development. In relation to the size of the economy or R&D, Sweden develops considerable new technology as measured by patent activity (OECD 2009).[1]

We have organized the paper as follows. The next section provides a *Literature review* of what we know about the gender, age, and education of inventors from previous studies. In particular, we discuss some methodological issues potentially arising from the extensive use of survey data. In contrast, this paper uses register data which circumvents data issues connected to surveys. Our *Data construction* section describes in detail how the data were collected and some remaining issues that call for caution. We then provide the *Analysis and results* in the following way. We first distinguish inventors by basic data on gender and age. Female participation in invention is also analyzed by technology. A focus on female participation is warranted as it may show a potential for raising inventiveness of the economy by exploiting an under-utilized resource. We then divide the inventors by education length and type. Moreover, we report on cross-tabulated trends where we discuss gender and age characteristics by sector, technology and education.

2 Literature review

Before we go into our own analysis, we survey methodological approaches taken by the literature. We then review the literature to identify what is known about inventors, focusing on demographic characteristics.

2.1 How do we know about inventors?

Clearly, major initial sources of information on inventors are patent records. It should be noted that patents do not list all active inventors. Inventors may choose not to file a patent at all, since other protection methods such as secrecy may be deemed more efficient; alternatively, inventors may choose not to disclose the information required for patenting (Levin et al. 1987; Griliches 1990). Also, not all patents follow the same route; some inventors stick to specific patent bureaus. Still, patenting at major patent bureaus, such as USPTO/EPO/JPO should indicate higher presumptive commercial or strategic value.

Patent documents, however, do not even provide basic demographic data on inventor age, level of education, and gender and therefore need to be complemented. Collecting data on inventors from patent data can be divided into four categories: i) survey methods, ii) identification of inventors, iii) links to register data and iv) Analyses of CVs, used to analyze academic inventors (Lissoni 2010; Lissoni et al. 2008) and a sample of Italian inventors (Lenzi 2009). For particular demographic information such as gender, some researchers developed probabilistic name-matching techniques (Frietsch et al. 2009). Cross-matching of inventors with published, self-reported profiles restricts the sample to only the

[1] Several of these characteristics are shared by other countries, e.g. Finland, South Korea and Switzerland.

publicly-known inventors such as academic inventors. The name-matching technique for identifying gender has inherent cultural bias in that it is not applicable to inventors from cultures not following gender-distinctive naming conventions.

Survey methods retrieve information on a specific subset, determined by the sampling frame. The reliability of results may therefore be affected by low response rates and sample selection issues. Low response rates affect the precision of estimates, while sample selection issues may bias estimates. This is the case if the characteristics of non-responding inventors systematically differ from those of sampled inventors.

Most of the data on inventors have been collected through surveys, which may raise questions about representativeness of the sample and potential biases arising from self-selection bias, subjectivity and social-desirability in response bias. Mattes et al. (2006) review eight studies which collect inventor survey information (Macdonald 1984, 1982; Dagenais et al. 1991; Amesse et al. 1991; Mattes et al. 2005; Tijssen 2002; Sirilli 1987; Rossman and Sanders 1957). These surveys have response rates between 23-55%. Although they are surveys, Mattes et al. (2006) find that very little effort is made to check for sample response biases. Surveys that do check for biases (Tijssen 2002; Jaffe et al. 2000; Mattes et al. 2005) tend to find no differences. Mattes et al. (2005) and Ejermo and Gabrielsson (2008) conduct formal tests for sample selection effects. The latter also check for quality characteristics of patents responded to in a survey of Swedish inventors without finding consistent differences along any dimension.

The three recent inventor surveys mentioned above (i.e. PatVal-EU and RIETI/Georgia Tech) use either EPO patents or the triadic patents as sampling frames. The response rates of all three are too low (ranging from 27.1% to 32.8%) to be safe from non-response bias. Hence, they test whether the responses are different from non-responses (or those not selected into the sample) by comparing some known characteristics of patents. Fortunately, RIETI/Georgia Tech surveys report that there are no significant biases (Jung 2009; Nagaoka and Walsh 2009). The PatVal-EU survey only reported the test of item response between inventors and managers for the French survey (Giuri et al. 2007).Thus, while sample selection problems seem not to be a general problem, the reliability of estimates may still be an issue.

In recent years, great efforts have been made to identify inventors. The original effort in this direction is Trajtenberg et al. (2006), who matched inventors from the USPTO for the period 1963-1999 (the NBER patent data base).[2] The major obstacle to inventor identification using USPTO data is that name and street address are only given for non-firm applicants; in other cases only name and city are stated. This implies severe problems in ascertaining whether ”Michael Johnson, Chicago” is actually “Michael Johnson, Chicago”. In Trajtenberg et al. (2006), inventor names are phoneticized using the Soundex

[2] Other studies using lots of USPTO inventor data include Jones (2009) and Marx et al. (2009). Raffo and Lhuillery (2009) compare different matching algorithms.

system. Moreover, candidates to be the same inventor are compared by means of middle names, geographical names, technology areas, and common co-inventors. Trajtenberg et al. (2006) identify an impressive 1.5 million unique inventors with their scoring method. The data can be used to examine e.g. inventors' productivity distributions, teams of inventors and so on in panels. They do not give insight, however, into demographics of inventors and firm characteristics without being complemented with other types of data. To our knowledge, Väänänen (2010) is the first and only study so far to complement inventor data with firm information. In her Ph.D. thesis, NBER patent data were matched to individual registers for Finland. This resulted in a 73% matching rate of Finnish inventors for the period 1988-1996. Our data can be seen as a continuation of this type of work.

2.2 What do we know about inventors?

It may seem that we know a lot about inventors. Many people may have read stories about Thomas Edison and James Watt and know not just how they invented the light bulb and steam engine, respectively, but also have some recollection regarding who they were. Hence, besides anecdotal portrayal of a few famous inventors from history, we may not know much about contemporary inventors. One of the pioneering works undertaken to understand inventors in a systematic way was by Jacob Schmookler (1957). Surveying 87 U.S. patentees who were awarded patent grants in 1953, he found that 64% of inventors were employed and 50% were educated at least on college-level. There have been several small to medium scale surveys of inventors in other countries since then. Surveying 601 Australian individual inventors who filed for patents in 1978, Macdonald (1986) reports that 42.2 percent did obtain some sort of tertiary education. For Italian inventors who filed for patents in 1981, Sirilli (1987) reports from a survey of Italian inventors that 40 percent are individual inventors and 77.5 percent of all inventors obtained tertiary education. Of 374 Canadian individual inventors who were granted Canadian patents in 1978 or in 1983, Amesse et al. (1991) report that 46 percent hold university degrees.

The studies probably most relevant to this paper are those based on large-scale inventor surveys separately conducted in Europe, Japan, and the United States. The European inventor survey (or PatVal-EU) provides information on 9,017 inventors who had filed for patents to the EPO between 1993 and 1997 (Giuri et al. 2007). The Japanese and the US study conducted by RIETI and Georgia Tech (Walsh and Nagaoka 2009) report the results from surveys of 3658 and 1919 inventors residing in the respective countries and having triadic patents (i.e. patent equivalents filed to both the JPO and the EPO and granted by the USPTO). These three surveys provide cross-sectional snapshots of the inventors in the respective countries. Table 1 shows summary statistics regarding gender, age, and education. Female inventors constitute 1.7% of Japanese inventors, 2.8% of European inventors, and 5.2% of US inventors. The average age and the level of education (as measured by the proportion of Ph.D. degree holders) are highest for US inventors followed by European inventors.

Table 1 Gender, age, and level of education of inventors from recent inventor surveys.

	Europe	Japan	US
Study	Giuri et al.(2007)	W & N (2009)	W & N (2009)
Sample size	8861-9017	3658	1919
Years of patents (priority years)	1993-1997	1995-2001	2000-2003
% female	2.8	1.7	5.2
Average age of inventors	45.4	39.5	47.2
% of inventors with tertiary education	76.9	87.6	93.6
% of inventors with Ph.D. degree	26.0	12.9	45.2

Note: W & N stand for Walsh and Nagaoka

Gender aspects of inventors have been studied much more than other aspects thanks to the fact that the first name works as a gender identifier in most cultures. According to Frietsch et al. (2009), women's contribution to patents filed by European countries ranges from 2.9% (Austria) to 14.2% (Spain) in 2005. Across 14 countries examined in their study, women's contribution show upward trends between 1991 and 2005. For Swedish patents in particular, women's contribution to patents filed to EPO increased from 5.2% in 1991 to 8.6% in 2005. Kugele (2010) also finds a similar result from a broader set of European countries. According to his study, the proportion of women inventors for patents filed in 2001-2003 to the EPO ranges from 5% (Austria) to 23% (Lithuania) with Sweden at 8%.

Gender distribution also varies by technology. One consistent finding based on the first-name-based gender identification methods is that women's participation or contribution is most active in pharmaceutical technology, followed by chemicals, and least active in mechanical engineering and machinery in Sweden and other European countries alike (Frietsch et al. 2009; Kugele 2010; Naldi et al. 2005).

The other two demographic attributes of inventors – age and education- are much less known. Besides the survey-based research as shown in Table 1, Toivanen and Väänänen (2011) report detailed statistics of age and education for Finnish inventors adopting similar methods to those used in this study. The average Finnish inventor who had US patents between 1988 and 1996 was 37 years old, had at least a university degree (67%; 13.6% with doctoral degree), and had studied either natural sciences, engineering, agriculture and forestry, or health and welfare (82.4%). Using a large scale survey of European inventors as their main source of data, Mariani and Romanelli (2006) found that higher levels of education, employment in a large firm, and involvement in large-scale research projects increased an inventor's productivity as measured by number of patents. Jones (2010) investigated the average age of great inventors and found them to be older in recent decades than in the past.

3 Data construction

In order to study demographic characteristics of inventors, we construct a Swedish inventor database by combining two population-level databases. First, we extract information about inventors and their inventions from the Worldwide Patent Statistics (or PATSTAT) database[3] provided by the European Patent Office. The investigated population of inventors consists of those that have filed patent applications with the EPO and have their addresses in Sweden. We select only EPO patents for several reasons. First, the EPO is one of the most popular filing offices for Swedish inventors (along with the Swedish Patent Office and the USPTO). Second, the EPO patents are mostly targeted for protection in multiple European countries and are generally of higher quality than a single destination national patent. Most importantly, the EPO patents provide street-level addresses of inventors that we need to identify and match with other sources. In total, we found 44,615 patent applications comprising 81,386 patent-inventor pairs filed between 1978 and 2009.

Second, detailed demographic information on inventors comes from population register data provided by Statistics Sweden. In Sweden researchers can access detailed demographic information on the entire population, updated and maintained by one central authority, Statistics Sweden. By combining this information with our inventor database, we can understand the whole gamut of inventions ranging from career and demographic backgrounds of inventors to technology and patent characteristics. The matching process consists of several steps and uses multiple methods as explained below.

The first stage of this process was done in a project for the Swedish Agency for Growth Policy Analysis (Tillväxtanalys 2011). First, the material was cleaned and honed for errors. Then the inventor material was sent to the Swedish population register (SPAR) for an individual identification number (ID) to be added to each inventor. This ID follows a standard used for the entire population. After additional manual matching, the material was sent to Statistics Sweden for matching with anonymous individual records from 1985-2009 that comprise every individual in Sweden above 16 years of age. This match used name and address information to identify inventors in the general population. Because SPAR only holds addresses for the last three years, the match ratio was initially much higher the later the record. To reduce potential sampling issues, we embarked on additional matching, mainly based on a DVD that shows address information of the whole Swedish population in 1990 (Sveriges släktforskarförbund 2011). This material gave us a much higher match ratio over time and enabled us to raise the match ratio substantially. Finally, we decoupled several hundreds of matched inventors who were under 18 at the time of patent filing.

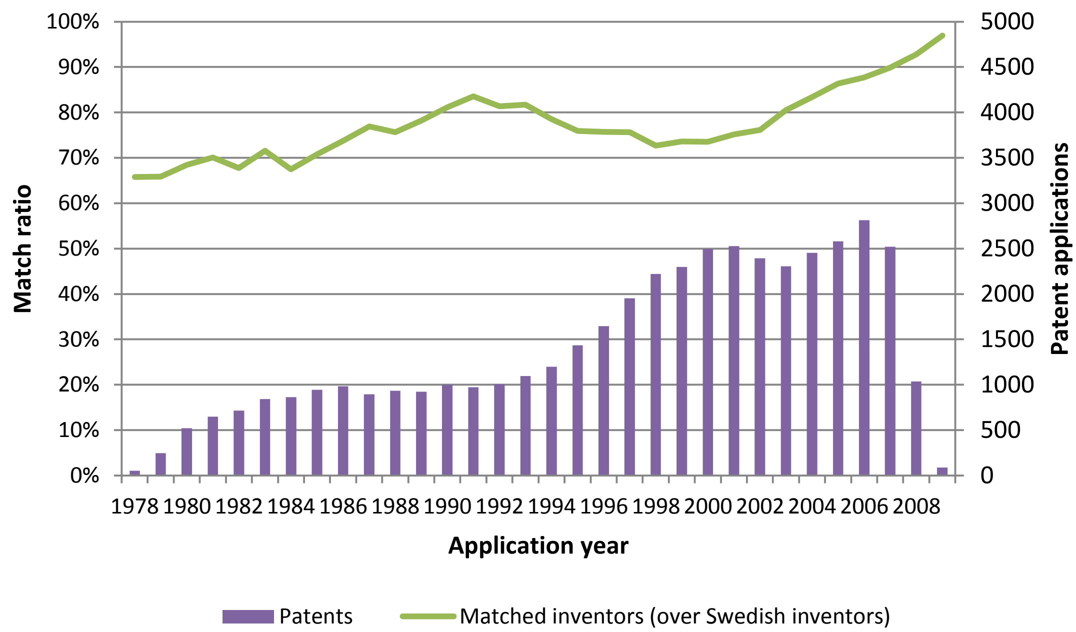
In all, we matched 78.9% of inventors overall. Out of 81,386 patent-inventor combinations we were able to identify 64,225 or close to 23,000 unique inventors. Figure 1 shows the overall match rate (solid line, left axis) and the number of patents (bar, right axis). The inventor match rate is above 80% for inventors

[3] We based the list of patents and inventors on the April 2010 version, but supplemented them with updated information from the April 2011 version.

who filed patents in the early 1990s and after 2003, and 70% or above for all years in the analysis period 1985-2007. This high match rate enables us to carry out inferences on the inventor population with a high degree of precision. We analyze patents filed in 1985 or later, and stop at 2007 to avoid right truncation of filing for recent years.

The link with Statistics Sweden data enables us to characterize inventors by means of demographic information including age, gender, and education (both type and length of education). The following sections report analyses of these data.

Figure 1 Match rate and patent applications by year of filing



4 Analysis and Results

The following 4 sections contain the results of our analyses of gender, age, education, and gender by age and level of education, consecutively. We analyze the temporal trends and composition by technology for all demographic attributes, but for some of them we conduct additional analyses such as comparisons with population data. Our main unit of analysis, except when otherwise specified, is the patent-inventor combination where the same inventor may appear multiple times across patents. A given inventor with multiple patents for a given year is thus counted as many times as the number of patents associated with him/her. We count inventors based on their appearance in patents ('full counts') instead of their contribution to patenting ('fractional counts'), because the former conveys simpler, more intuitive, and more comparable interpretation of the results in most analyses[4].

[4] We also conducted the same analysis using the latter definition and found no significant difference from the current definition.

4.1 Gender profiles

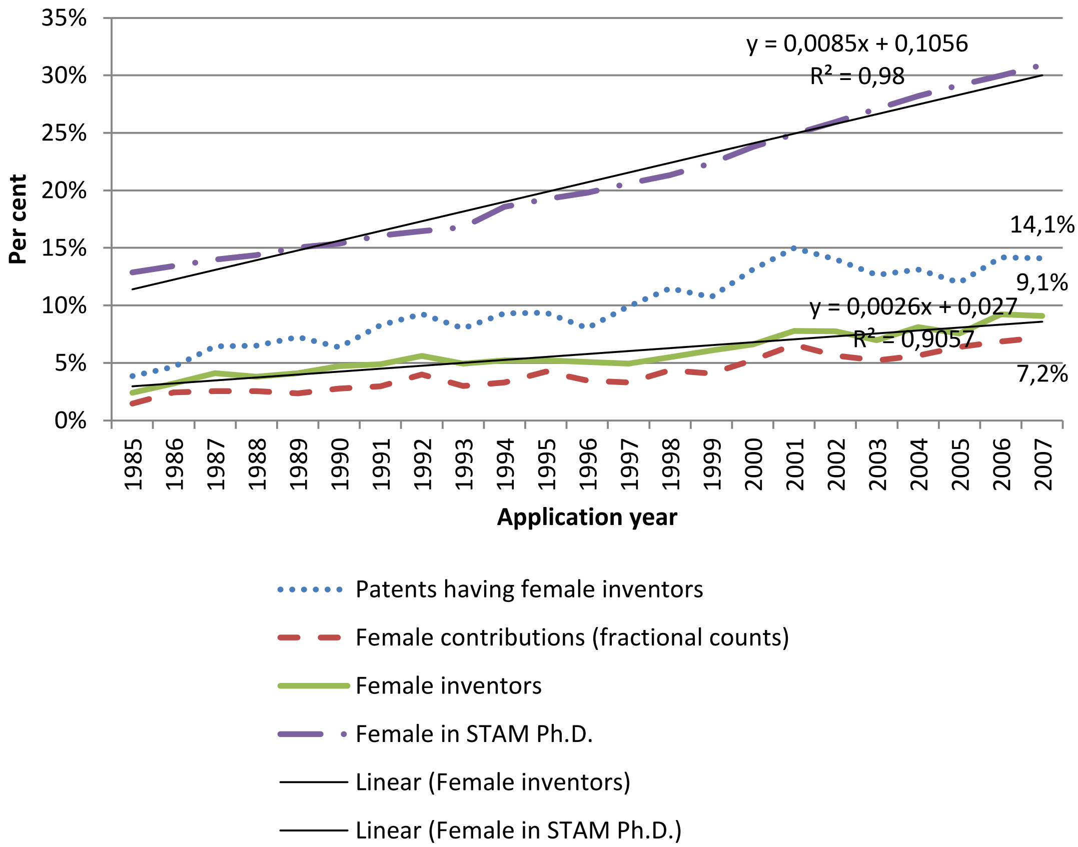
Figure 2 shows the share of female inventors by means of three different measures and the share of female Ph.Ds in science, technology, agriculture, and medical (STAM) education for comparison. The dotted line is the share of patents with at least one female inventor in the patents where we have identified all inventors (‘fully identified’). The dashed line shows the contribution from female inventors to patents as defined by Frietsch et al. (2009)[5]. The solid line is the share of female inventors in all Swedish inventors in the sample. Three points are worth mentioning here. First, the number of female inventors has grown faster than the number of male inventors over the last three decades as indicated by upward trends in the shares of female in all three measures. The share of female inventors has increased from 2.4% in 1985 to 9.1% in 2007. This is not surprising given that gender gaps in almost every social activity previously dominated by men have become narrower (Frietsch et al. 2009).

Secondly, the speed of female catching-up in invention is slower than in education. When we compare the female share in invention with that of Ph.Ds in STAM, the female share in STAM Ph.Ds has grown more than 3 times faster than the female share in invention. On average, the female share in STAM Ph.Ds has grown 0.85 percentage points every year between 1985 and 2007, while the female share in invention has grown only by 0.26 percentage points per year during the same period. If the estimated increase of female participation is sustained, it would take 22.5 years from 2007 before the gender gap disappears in doctoral degree holders in STAM and 157.3 years in invention. Moreover, it is hinted that the increase in female participation rate has already started to decelerate (see Figure 3 and the texts above it). Therefore, we project that inventing will remain a male-dominant sphere for the foreseeable future unless notable changes in environment or policy asymmetrically favor women’s inventing.

Finally, women are more likely to be in teams of inventors than men. The female contribution to patents (dashed line) is always lower than the share of female inventors. This is either because there are more male solo inventors than female solo inventors, or because female inventors work in a larger team than male inventors. For patents filed between 2005 and 2007, the average number of inventors for the patents having at least one female inventor is 3.26, while the team size of male-only patents is 2.14. The difference is statistically significant (t-statistic=19.11; $p<0.001$). For non-solo inventor patents the team size of mixed-gender patents is 3.71, while it is 2.97 for male-only patents and 3.01 for female-only patents). Therefore, an inventor team of a patent comprising inventors of both genders is larger than a single-gendered inventor team. For the same period, male solo-inventor patents account for 38.2 percent of the patents involving male inventors (i.e. union of male-only and mixed-gender patents), whereas female solo-inventor patents account for only 13.3 percent of female-involving patents.

[5] This indicator is a summation of the fractional count of female inventors by patent, i.e. the sum of female count divided by the number of all inventors for each patent.

Figure 2 Trends of female inventors - comparisons with female STAM Ph.D.



Next, we examine the general tendency of a disproportionate increase of female inventors in more detail. Table 2 summarizes the results of statistical tests for differences in the gender of inventors over three different periods and five technology fields. Technology fields are assigned based on the International Patent Class (IPC) of patents and a nomenclature provided by the World Intellectual Property Organization (Schmoch 2008). The female share has continuously increased in all five technology areas. Consistent with previous studies (Frietsch et al. 2009; Mariani and Romanelli 2006), female inventors are most active in chemistry (18.6% for 2005-7) followed by instruments (13.7%). On the other hand, electrical engineering, mechanical engineering, and other fields are dominated by male inventors (only about 4% of inventors are female). There are statistically significant differences as indicated by F-statistic and Scheffe statistics in the share of female inventors in patenting in chemistry vs. instruments vs. remaining categories. When we further break down technology sectors, we can more clearly observe the 'gender divide' in invention by field. Even in instrument technologies, female presence is only strong in medical related instrument technologies (see Table 7 in Appendix). In sum, we find that chemical and biomedical technologies attract more female inventors, but the female presence in electrical and mechanical engineering is still marginal.

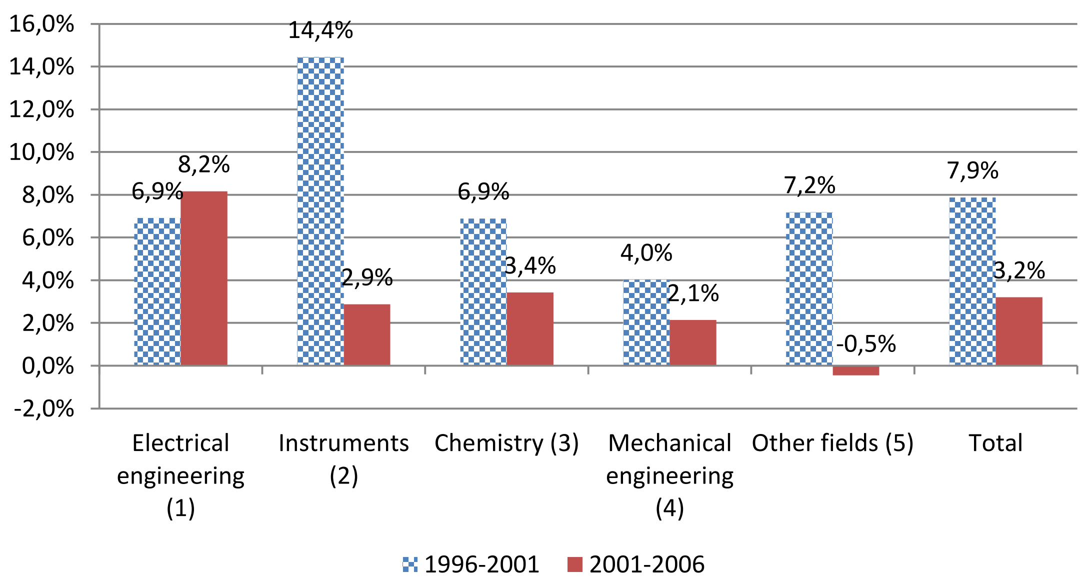
Table 2 Female inventors by technology fields and period.

	1985-7		1995-7		2005-7		F- test between 1990s and 2000s
	Percent	N	Percent	N	Percent	N	
Electrical engineering (1)	0.4%	280	2.0%	1708	4.2%	4412	16.92***
Instruments (2)	5.6%	585	6.1%	1335	13.7%	2469	52.49***
Chemistry (3)	7.1%	829	11.3%	1311	18.6%	2574	35.00***
Mechanical engineering (4)	1.0%	1244	3.3%	2043	4.4%	3760	4.62**
Other fields (5)	0.3%	298	3.3%	429	4.5%	731	1.09
Total	3.3%	3236	5.1%	6826	8.6%	13946	85.97***
F-statistic	21.94***		40.27***		160.84***		
Scheffe's test	3,2>1,4,5		3>2>1,4,5		3>2>1,4,5		

Looking at changes over time, the most dramatic increase in the share of female inventors is found in instruments (from 6.1% for 1995-7 to 13.7% for 2005-7) and electrical engineering (from 2.0% for 1995-7 to 4.2% for 2005-7), in which the share of female inventors has doubled in 10 years.

However, the pace of narrowing of the gender gap has slowed down in all fields but electrical engineering. Figure 3 shows the compound annual growth rate of the female share for two different periods: from 1996 to 2001 and from 2001 to 2006. The figure illustrates a fast catching-up by women between 1996 and 2001 (CAGR=7.9%, the rightmost checked bar) and a huge drop between 2001 and 2006 (CAGR=3.2%).

Figure 3 Compound annual growth rate (CAGR) of female share, by technology field



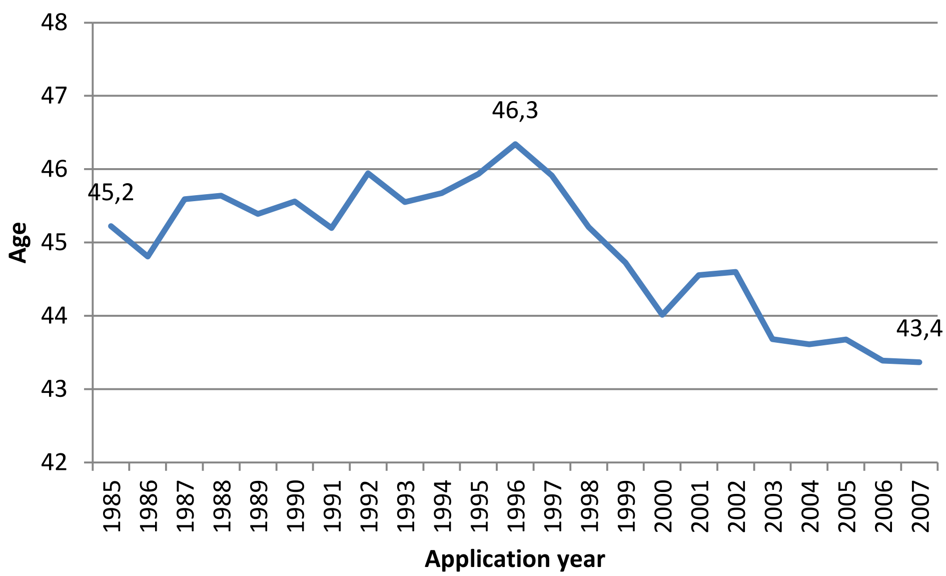
Note: Female shares are calculated from aggregate data of 3 years centering on the focal year to mitigate annual fluctuation (e.g. the female share in 2006 is the share of female inventors in all inventors between 2005 and 2007).

4.2 Age profiles

Both scientific performance (Stephan and Levin 1992) and inventive productivity (Jones 2010; Mariani and Romanelli 2006) vary with age. While many studies have addressed age and its relation to scientific performance, there is a dearth of literature examining age profiles of inventors. Clearly, a better understanding of age profiles of inventors would have important implications for innovation policy and management. This section provides an overview of age profiles of Swedish inventors.

We start from observing overall trends of the age of inventors over time. As shown in Figure 4, the average age of inventors increase slightly until 1996 peaking at 46.3 years and then rapidly decrease to an average of 43.4 years in 2007.

Figure 4 Average age of inventors, 1985-2007



We find that there is a clear difference in age composition over different technology fields. Table 3 shows the average age of inventors across five technology fields and different time periods, as well as test statistics of the differences between them. The youngest technology field is electrical engineering in which the average age is 40.6 years in 2005-7. The next youngest fields are instruments and mechanical engineering in which the average age of inventors is higher by about 4 years. In all fields, the average age has dropped significantly in 2005-7 compared to 1995-7. This is interesting as the average length of education has gone up during this time, which could be expected to delay the starting age of invention for the highly educated and result in a higher average age.

Next, we break down the 5 broad technology fields into 35 more fine-grained fields (see Table 7 in Appendix). In terms of 35 technology fields, the youngest field in the 2005-7 period is micro-structural and nano-technology (37.4 years old), followed by computer technology (37.8 years old), audio-visual technology (39.2 years old), and digital communication (39.8 years old). They are all linked to emerging and fast-growing industries. This finding constitutes a serious challenge to Jones' claim (2010) that an increasing burden of absorbing the existing body of knowledge adds to the time for developing an important invention. Our analysis shows that there are clear shifts in age trends from upward to downward after the mid-1990s (which was not covered in Jones' analysis) and, more importantly, that emerging new technologies provide more favorable playing fields for young technicians than for their older counterparts. Perhaps, a secret of success in these fields may be found in the agility and adaptability to changing environments rather than in the breadth and scope of knowledge. Therefore, the development of categorically new technologies may lessen or remove a burden of absorbing ever-cumulating knowledge in invention.

Table 3 Age of inventors by technology fields and by years

	1985-7		1995-7		2005-7		F- test between 1990s and 2000s
	Mean	N	Mean	N	Mean	N	
Electrical engineering (1)	43.4	280	42.4	1708	40.6	4412	50.26***
Instruments (2)	43.2	585	46.2	1335	44.0	2469	35.67***
Chemistry (3)	44.5	829	47.0	1311	45.6	2574	16.31***
Mechanical engineering (4)	46.6	1244	47.9	2043	44.5	3760	136.23***
Other fields (5)	47.0	298	48.6	429	46.6	731	9.10***
Total	45.2	3236	46.1	6826	43.5	13946	284.60***
F-statistic	16.95***		90.91***		136.93***		
Scheffe's test	4,5>3,2,1		4,5>=3,2>1		3,5>4,2>1		

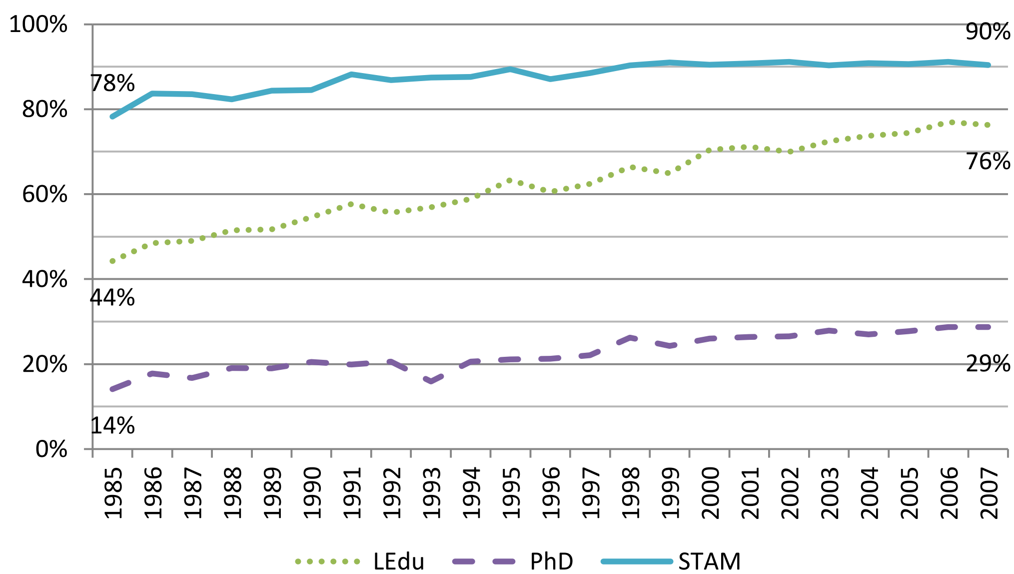
4.3 Education profiles

Figure 5 shows the level of education of inventors and the share of inventors with STAM education. Clearly, the level of education is high and rising. The share of inventors with a minimum of two years of higher education ("Long educated", LEdu) has gone up from 44 percent in 1985 to close to 76 percent in 2007.[6] The share for Ph.D. educated is rising too. In Sweden a doctoral degree takes four years.[7] The share of inventors with education on doctoral level rises from about 14 to 29 percent during the period, which suggests that inventing has become more specialized, requiring more highly educated inventors.

[6] This definition is equivalent to college level education.
[7] In this category of educated we also find individuals pursuing a shorter version, a "licentitate", which takes two years and ends with a shorter thesis than a doctoral one.

The share of inventors with education in STAM is also very high, and even rising somewhat from 1985 to 1995. Note that STAM only defines the type, not the level, which implies that there are non-university educated inventors in this group. However, there are only university educated inventors among science educated inventors, and virtually all medicine educated inventors also have university level education. Its share seems now to be stable around 90% of inventors[8], suggesting that science and technology knowledge prevail as sources for patenting.

Figure 5 Education level of inventors and the share of inventors in STAM.



Figures in Toivanen and Väännänen (2011) show that 67% of Finnish inventors have a university degree and 78% have some form of post upper secondary school education. The latter category comes closest to our definition of long educated. Since the data from Toivanen and Väännänen (2011) is from the early 1990s, the statement that Finnish inventors attained higher education levels earlier than their Swedish counterparts is probably correct. A reason for this might be more conscious and concerted efforts to increase engineering education in Finland (ibid). Data from PatVal, a survey sent to inventors around Europe, reveal that 77 percent of respondents have a university degree and 26 percent had a doctoral degree in the mid-90s (Giuri et al. 2007). Thus, based on observable data, it seems fair to conclude that the Swedish inventor education level, at about 60 percent attaining Long education during the mid-90s, was lagging behind other European countries at the time.

As with gender and age, we test whether the shares of the long educated (Table 4) and Ph.D. holders (Table 5) among inventors are different between different time periods (1995-1997 v. 2005-2007) and

[8] Clearly, though, the share of STAM educated inventors rises sharply among inventors with at least two years (LEdu) higher education. Among Ph.D.s, the STAM share is almost always 100%.

different technologies (5 aggregate classes). Temporal comparisons confirm that the rise in education level, at either college or Ph.D.-level, over time is indeed statistically significant (except for Other fields for Ph.D.), as indicated by F-test statistics in the last columns of both tables.

The level of education also varies significantly by technologies. While 54.8% of inventors in Chemistry hold doctoral degrees for the period 2005-2007, only 12.6% hold doctoral degrees in Mechanical engineering. The long educated account for almost 90% of inventors in Electrical engineering and Chemistry in the same period, while the share is only 62.8% in Mechanical engineering. In sum, we find that inventing in science-based technologies such as Chemistry and highly complex product technologies such as electrical engineering is indeed carried out by the highly educated inventors. In order to test the relationship between the highly educated inventors and science-relatedness of technologies, we plot the share of Ph.D. holders against citations made to non-patent literature across 35 technology fields for the patents filed in 2005-2007 (Figure 6). As expected, the data fit very well with log-linear form (R-squared=0.80).

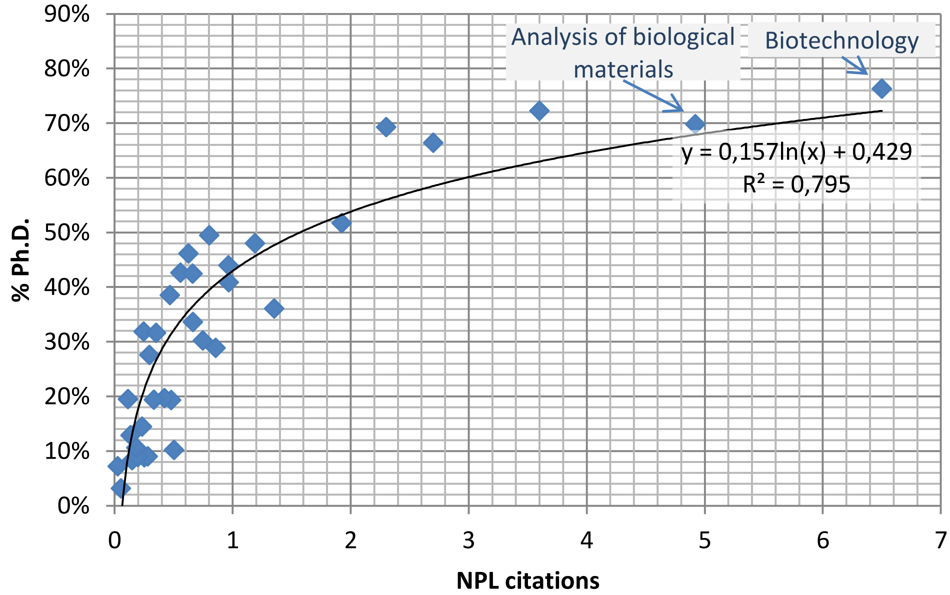
Table 4 "Long educated" (including Ph.D.) by technology fields and by years

	1985-7		1995-7		2005-7		F- test between
	Percent	N	Percent	N	Percent	N	1990s and 2000s
Electrical engineering (1)	52.5%	278	76.5%	1677	86.7%	4380	94.90***
Instruments (2)	63.2%	582	69.8%	1325	81.1%	2456	62.79***
Chemistry (3)	73.9%	824	79.3%	1307	88.1%	2557	53.28***
Mechanical engineering (4)	37.7%	1235	50.3%	2031	62.8%	3725	85.66***
Other fields (5)	29.7%	296	37.7%	427	58.1%	728	46.53***
Total	52.2%	3215	65.4%	6767	78.0%	13846	381.97***
F-test: difference between technologies	97.24***		154.12***		278.70***		
Scheffe's test	3>2>1>4,5		1,3>2>5>4		1,3>2>4,5		

Table 5 Ph.D. holders by technology fields and by years

	1985-7		1995-7		2005-7		F- test between
	Percent	N	Percent	N	Percent	N	1990s and 2000s
Electrical engineering (1)	10.8%	278	24.6%	1677	33.0%	4380	40.52***
Instruments (2)	28.7%	582	27.3%	1325	32.2%	2456	9.87***
Chemistry (3)	40.0%	824	48.1%	1307	54.8%	2557	15.65***
Mechanical engineering (4)	8.1%	1235	9.7%	2031	12.6%	3725	10.75***
Other fields (5)	3.4%	296	5.6%	427	6.6%	728	0.44
Total	19.8%	3215	24.0%	6767	30.0%	13846	81.63***
F-test: difference between technologies	118.13***		205.10***		421.12***		
Scheffe's test	3>2>1,4,5		3>2,1>4,5		3>1,2>4>5		

Figure 6 Citations to non-patent literature v. share of Ph.D. holders by 35 technology fields



Inventor education and education in the general population

Inventing has become more common among highly educated people. The propensity among Ph.D s to become an inventor (dashed line, right axis) has increased from 0.6% in 1985 to about 1.3% in 2007, as shown in Figure 7[9]. The propensity among university graduates without Ph.D. degrees to become an inventor is only about 0.1% in 2007.

[9] In order to compare with population statistics, we compute inventor statistics based on unique inventor instead of the patent-inventor combinations we did for the previous sections. Therefore, each inventor is counted once each year.

Figure 7 Propensity to become an inventor by level of education, 1985-2007

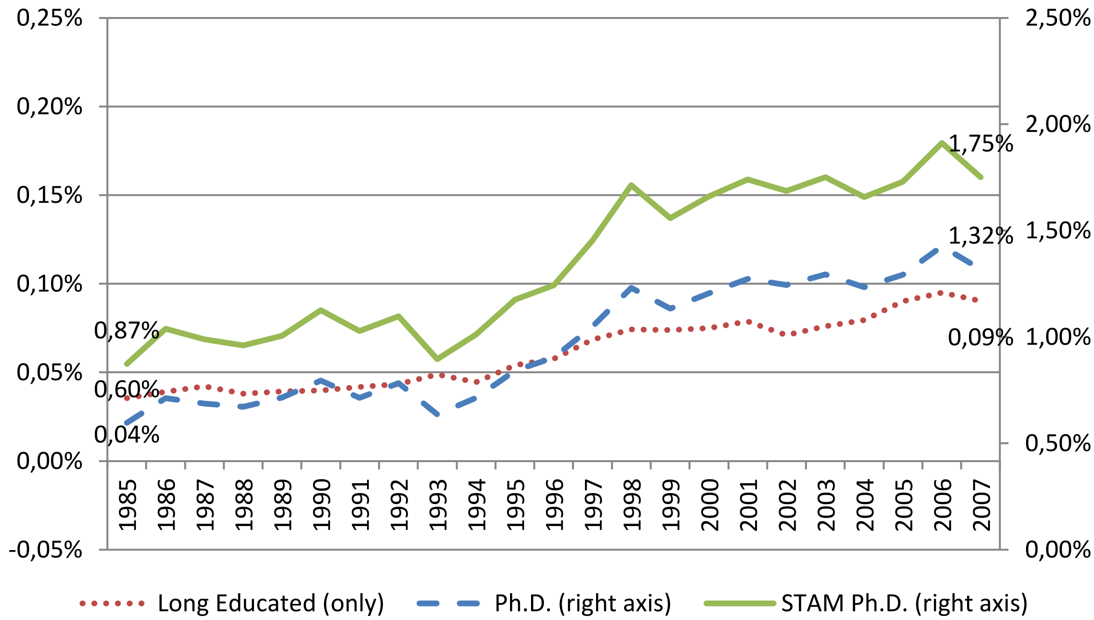


Figure 8 shows the level of education and the share of inventors with STAM education relative to their population counterpart; that is, the share of inventors in each education category is divided by that of the entire population in the same year. The figure shows that inventing is indeed conducted by the highly educated. In 2007, the share of Ph.Ds among inventors is 30 times the share of Ph.Ds in the Swedish population (dashed line, right axis). Inventing is also carried out disproportionately more by scientists and engineers, as indicated by the STAM share in inventors being 2.8 times the population counterpart. These facts are not so surprising given that invention is generally a knowledge and technology intensive endeavor. What is more interesting is observed in their temporal trends.

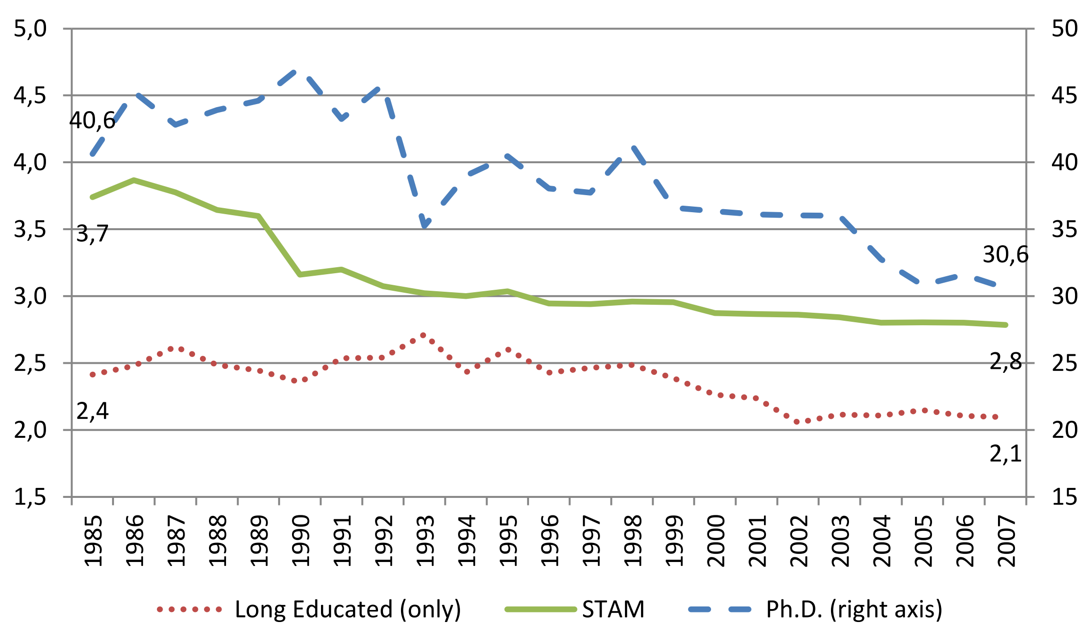
For all categories, the respective shares among inventors decline relative to their population counterpart. Though STAM and long educated were 2 to 3 times, and Ph.Ds more than 30 times as common among inventors as among the general population for the last decades, these relative differences have not been upheld in recent years. In fact, the rate of decline is rather similar across this group. As shown above, the level of education among inventors has not leveled off, but just does not increase at the same rate.

While Figure 7 shows the ratio a/b, where a is the number of inventors with e.g. long education and b is the number of long educated in the population, Figure 8 shows (e) = $(a/b)/(c/d) = (a/b)*(d/c)$, where c denotes long educated in the general population and d the population size. The differences between the figures arise from multiplying with (d/c). To give an example of the meaning of (e), assume that the inventor quotient of Ph.D. in 1985 (which is 40.6) is maintained in 2007. Then, we would have 1118 Ph.D. inventors in 2007, which exceeds the actual number by 282 (33.7%). The propensity of a Ph.D.

holder to become an inventor for this counterfactual case would then be 1.76% (note that the actual propensity rate is 1.32%). In sum, we can conclude that the dependence of inventing on highly educated (especially, Ph.D. holders) has intensified over time but not to the extent of the increase of highly educated in society.

Clearly, the number of inventors grows faster than population over the time period, and this ratio grows faster than the rate at which inventor education rises. This relative 'lack' of growth in (*a*/*b*) might be given two explanations. First, a saturation process, reminiscent of the S-shaped curves we can observe for diffusion of innovations, carries some explanatory value. Simply stated, the share of inventors with higher education can only increase to some upper value (maximum 100%), and especially for STAM and to some extent longer education these saturation levels are beginning to be approached (see Figure 5). When a large number of inventors already has attained some education, it becomes increasingly difficult to increase the education level of the rest. The second explanation is that the demand for educated has outpaced the demand for educated to become inventors. This is interesting, as in the same period of time the supply of educated has increased dramatically. For instance, our data show that among the general population the shares of long educated, Ph.Ds and those with STAM education were 11%, 0.3% and 21%, respectively in 1985, while the corresponding shares were 23%, 0.8% and 33% in 2007.

Figure 8 Share of inventors with a certain education relative to population shares. Note: Ph.Ds relative to population shown on the right y-axis.



4.4 Age and level of education by gender

Finally, we examine differences in age and level of education between male and female inventors. Table 6 cross-tabulates age averages, the share of the long educated and the share of Ph.D. holders with gender for two time periods (1995-1997 and 2005-2007). First, the average age of female inventors is lower than that of male inventors by 4.7 years in 1995-1997 and by 4.1 years in 2005-2007. From the first to the second period the average age has decreased for both genders but more for male inventors. Second, the level of education is much higher for women than for men. In 2005-2007, 90.1% of female inventors are educated at least at tertiary level and 40.5% at doctoral level, while 76.9% and 29.0% of male inventors are at tertiary and doctoral levels, respectively. Despite this already high level of education among female inventors early on, the growth of the share of doctoral female inventors has outpaced that of men by a factor higher than 2 from 1995-1997 to 2005-2007 (11.4 percentage points growth for women and 5.3 percentage points growth for men). In sum, we find that female inventors are much younger and have higher education than male inventors.

Table 6 Age and education level by gender

	Age		Long Educated (inc. Ph.D.)		Ph.D.	
	1995-7	2005-7	1995-7	2005-7	1995-7	2005-7
Male	46.3	43.8	64.5%	76.9%	23.7%	29.0%
Female	41.6	39.7	82.6%	90.1%	29.1%	40.5%
Total	46.1	43.5	65.4%	78.0%	24.0%	30.0%

Note: Differences in all variables between two different time periods and between two values of gender are all statistically significant at a conventional level, P<0.01.

5 Summary

In this paper we investigate gender, age, and education of Swedish inventors, focusing on compositional differences between different technologies and temporal trends. To do this we construct a unique dataset by combining a patent database with the population register of Sweden. Our dataset enables us to examine demographic dynamics of Swedish inventors at almost population level (covering 78.9% of all Swedish inventors) for an extended time period (1985-2007) and with great accuracy.

Our analysis shows that the gender gap in patenting is substantial but decreasing. The share of women increased from 2.4% in 1985 to 9.1% in 2007. However, the speed of the reduction of the gender gap was much slower in patenting (by about 30.6%) than the corresponding gap in Ph.D. education in science, technology, agriculture and medicine. Although the rate of catching-up by women in patenting accelerated over the last two decades, the rate at which the gap closed seems to slow down. Our analysis shows that the gender gap in patenting decreased by 7.9% per annum in the late 1990s, but only by 3.2% in the early 2000s (Figure 3). The growth rate of the female share increased only in electrical engineering in the latter period. Thus, inventing will, in all likelihood, remain a strong male-dominated area of activity in the near future.

We also find that inventors became younger while their education level rose over time, especially for the last two decades. In 2005-2007, the average age of inventors in our sample was 43.5 years which was lower by 2.6 years than a decade before. The share of university-educated (including Ph.Ds) and Ph.D. holders increased from 65.4% and 24.0%, respectively, in 1995-1997 to 78.0% and 30.0% in 2005-2007. Indeed, invention must be a highly knowledge- and technology-intensive endeavor as shown by the share of the highly educated among inventors being much higher than the population share. The escalation of educational qualification among inventors is not just a reflection of a general increase in education level in population (or compositional effect), but the result of conscious efforts to recruit more highly educated into inventing. Actually, we find that the propensity to become an inventor among the highly educated doubled between 1985 and 2007. Interestingly, the dependence on highly educated (especially Ph.D. holders) grew over time in invention but not to the same extent as society increased its level of highly educated. This difference may be interpreted as an unexploited pool of inventors. It seems that there is much higher potential than we observe in promoting invention especially by recruiting more Ph.D. holders. According to our simple calculation, if the ratio of the educational composition of inventors to population in 1985 had been sustained in 2007, then we would have seen about 34% more 'new' Ph.D. inventors. Of course, extrapolating such trends does not take into account the demand for inventors originating from firm patenting activities, which is in turn governed by, among many factors, trends in technological opportunities and the developments of final markets. It is possible that a more elaborate analysis of the market for inventors could give us more insights into the outlook for Swedish technology development.

The demographic profiles of inventors vary substantially according to technology. The gender distribution by technology in our sample shows a pattern consistent with previous studies (e.g. Frietsch et al. 2009), with women being most active in biotechnology and chemistry and least active in mechanical engineering. We present novel findings on age and education by technology. The average age of inventors is much lower in electrical engineering than in other technologies. This conforms to the popular belief that ICT industries are driven by young geniuses armed with bright ideas. We think that the renewal of technologies poses an interesting potential subject for further studies as it could contribute to discussion about the nature of the R&D-growth relationship (Jones 1995). For example, it would be interesting to study if returns to R&D decrease over time in specific technologies, thus requiring larger teams and subsequently more efforts. A potential research topic using our data would therefore be different technologies (younger vs. older) to check if inputs, as gauged by e.g. team size, differ across technologies and over time.

As for the level of education, we find that science-based technologies are invented more by highly educated inventors. On the other hand, technologies with more synthetic knowledge (Asheim and Coenen 2005), such as mechanical and machinery, may be developed more by field inventors who receive relatively little formal education. Our analysis supports this explanation.

Furthermore, we find substantial differences in age, level of education, and inventing behavior between male and female inventors. In sum, female inventors are much younger and have higher education than male inventors. Also, women tend to invent in larger teams than men.

We thus conclude that demographic characteristics have changed substantially over time for Swedish inventors. Typically a Swedish inventor is nowadays much more highly educated, more frequently a woman and also younger than before. Inventors therefore seem to follow general population trends in the sense of a closing of the gender gap and higher education level, but inventors are also atypical in maintaining a higher level of education, and are still less frequently women, than the general population. This suggests an underutilized resource that might consist of budding female inventors. The strong link to education suggests that education policies, perhaps particularly addressing women's education, might influence future innovativeness.

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Data Appendix

Table 7 Summary statistics by 35 technology fields: 2005-2007 aggregates

Field	N (gender and age)	N (education)	Women	Age	Ph.D.	Long education
Electrical machinery, apparatus, energy	666	662	6.3%	45.9	31.9%	77.0%
Audio-visual technology	329	326	1.2%	39.2	19.3%	85.3%
Telecommunications	879	872	3.4%	40.4	38.5%	87.2%
Digital communication	1536	1529	4.7%	39.8	28.8%	88.6%
Basic communication processes	156	156	3.2%	40.1	46.2%	91.7%
Computer technology	668	660	3.4%	37.8	36.1%	90.6%
IT methods for management	61	59	11.5%	40.1	10.2%	81.4%
Semiconductors	117	116	3.4%	43.2	66.4%	91.4%
Optics	199	197	6.0%	42.8	42.6%	92.4%
Measurement	441	437	5.2%	44.2	33.6%	82.6%
Analysis of biological materials	194	192	18.6%	43.9	69.8%	94.8%
Control	286	285	5.2%	41.5	19.6%	75.4%
Medical technology	1349	1345	18.8%	44.6	27.6%	78.1%
Organic fine chemistry	442	439	18.1%	45.2	69.2%	95.2%
Biotechnology	286	283	33.2%	43.2	76.3%	96.8%
Pharmaceuticals	462	458	25.5%	48.3	72.3%	93.9%
Macromolecular chemistry, polymers	203	200	15.8%	45.6	49.5%	91.0%
Food chemistry	50	50	20.0%	49.5	48.0%	80.0%
Basic materials chemistry	147	146	25.2%	44.6	42.5%	89.0%
Materials, metallurgy	225	225	14.2%	45.1	40.9%	88.0%
Surface technology, coating	267	266	15.0%	44.8	44.0%	82.0%
Micro-structural and nano-technology	29	29	3.4%	37.4	51.7%	96.6%
Chemical engineering	266	265	6.8%	46.1	30.2%	72.5%
Environmental technology	197	196	8.6%	45.2	31.6%	73.0%
Handling	530	521	5.5%	44.7	8.8%	56.0%
Machine tools	482	481	1.7%	46.3	8.3%	53.8%
Engines, pumps, turbines	459	456	3.1%	43.6	19.5%	77.4%
Textile and paper machines	327	325	11.6%	45.4	19.4%	63.7%
Other special machines	469	467	4.1%	45.7	9.0%	56.7%
Thermal processes and apparatus	176	168	3.4%	48.4	8.9%	54.8%
Mechanical elements	376	374	2.1%	44.9	14.4%	66.8%
Transport	941	933	4.8%	42.0	12.9%	66.5%
Furniture, games	222	222	6.8%	45.6	3.2%	60.4%
Other consumer goods	132	132	8.3%	44.9	10.6%	62.9%
Civil engineering	377	374	1.9%	47.9	7.2%	55.1%
Total	13946	13846	8.6%	43.5	30.0%	78.0%

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