The gender innovation and research productivity gap in Europe

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Abstract: Considering that the economic dimension of sustainable development relies on innovation, the under-representation of women in science and technology in the European Union is of special concern. Statistical analysis of patents shows that the low percentage of female researchers (an input indicator) within the EU Member States is accompanied by an even lower percentage of female inventors (an output indicator). We use a simple mathematical model to shed light on the relationships between these findings. The model has one parameter which represents the working conditions, e.g., the distribution of resources by gender. The model allows an estimation of the development of the input-output gap as well as the research productivity gap if the share of female researchers is increased without adequate resources. In this case, a productivity loss for the economy is to be expected.

Keywords: innovation; gender; research productivity; sustainable development; European Union; female researchers; female inventors.

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1 The Lisbon Strategy, gender and innovation

The Lisbon Strategy, aims to transform the European Union into the most competitive and dynamic knowledge-based economy in the world by the year 2010 (EC, 2003). The economic growth and social welfare of the industrialised countries relies largely on innovation and the creation of economic value from technological knowledge (Corsi and Akhnov, 2000). According to the Organisation for Economic Cooperation and Development (OECD), it is essential to focus on sustainable development, social welfare and ecological sustainability as key to growth. The OECD postulates the inclusion of ecological and human dimensions and points out that it is crucial to investigate the different aspects of sustainable development from a gender perspective (OECD, 2008).

To reach the goals of the Lisbon strategy, there is a growing demand for highly educated workers in science and technology, such as researchers and engineers. But sustainability and growth will only be enhanced if all human resources and the full range of innovative and inventive potential of European society are included. A more gender-balanced society and economy is a central requirement to achieve the ambitious economic, social and environmental goals. Workforce diversification in engineering and technology and the incorporation of gender aspects in research, product and technology development are seen as vital factors for economic achievement and successful competition in a globalised economy (Schraudner and Lukoschat, 2006; Rübsamen-Waigmann, 2006). Research on gender and innovation shows that uniformity is a severe hindrance for creativity, innovation and economic success (Matthies, 2006).

Women's full participation in the economy and innovation is a long way from being achieved. The OECD states that "as a group, women – and their potential contributions to economic advances, social progress and environmental protection – have been marginalized" (OECD, 2008). Even though the proportion of women in higher education has risen significantly in the EU, pronounced horizontal and vertical segregation in education and employment is present. Women are especially under-represented in industrial research, where in 2003 only 18% of all researchers were women (EC, 2006a).

In order to attract more women into research and encourage their careers, gender mainstreaming policies are being implemented by European governments and companies (EC, 2008). This includes targets, quotas, mentoring programmes and a focus on reconciling work and family duties. Yet in most EU member states, these measures have not yielded a breakthrough, as the under-representation of women in (natural) sciences and industrial research is an ongoing concern and needs to be critically assessed.

2 Gender and innovation

Widely known fictional characters such as Gyro Gearloose with his outrageous inventive productivity reflect the male driven image of engineering and innovation and carry the implicit assumption that inventive activities are largely the preserve of men. Such implicit assumptions and gendered images are critically assessed by social constructivism theories that focus on the development of social phenomena. Within constructionist thought, this paper is based on the assumption that the development and production of (technological) knowledge and innovation are socially constructed processes which are embedded in a wide field of institutional, structural and cultural realities (Blättel-Mink, 2005).

Science, technology development and knowledge creation are closely related to questions of gender, influence, control mechanisms and power (MacKenzie and Wajcman, 1985). It is a specificity of science and technology that "understanding and making science provides scientists with a certain power over the rest of the population" (EC, 2008). In this regard, it is a matter of gender equality and a political issue to investigate who participates in knowledge creation and inventions in Europe.

The historically close relationship between technology and masculinity is well expressed in the metaphor of "…Man the Maker (homo faber) [which] was a powerful intellectual construct that also had the power of neglecting the material practices that did not fit the relation implied by the metaphor" (Oldenziel, 1999). For a long time, science was regarded as a 'masculinised form of knowledge, both in form of content, what is reached and what is conceived, and its practices adopted for researching and generating knowledge' (Maynard, 1997). This close relationship is challenged by modern gender, science and technology studies, which elucidate the co-construction of technology and gender (Wajcman, 1994) and focus on the culture of knowledge, e.g. how gender structures knowledge and power (Schiebinger, 2008).

3 Benchmarking innovation and research productivity with patent data

The number and proportion of researchers as well as the amount of expenditure on research and development (R&D) are used by the European Commission as indicators for innovation processes and research productivity (EC, 2006b). Both indicators – human resources and financial resources – are counted as inputs into the research system of a country.

In contrast, output indicators are limited as outputs are more difficult to measure. Research institutions and universities use scientific publications, the amount of granted public research funding per professor, as well as Nobel- and other scientific prizes as output indicators, e.g. for ranking purposes. Industry depends strongly on the innovative productivity of its personnel and patents are needed to protect new inventions.

This research is based on the assumption that there is a strong dependence between science, research and technology development on the one side and inventions and patents on the other side. Patent applications are a high quality indicator for innovativeness and economic success in the global knowledge-based society (OECD, 2002). They can be used to indicate the potential of scientific activity in different countries and scientific fields. Furthermore, patents reflect the capacity to exploit knowledge and transform it into economic value during the innovation process. Patent documents offer a rich source of information on applicants and inventors. Data on patents can be broken down by geographical location, technology field and industrial sector and can be employed for comparative analysis at country level.

Indicators that are based on patent statistics can not only be used to assess the inventive success of countries, but also to assess the inventive performance of researchers and the measurement of their productivity (EC, 2003). Benchmarking of individual research productivity is typically conducted by analysis of bibliometrics, specifically publication counts and citation rates (EC, 2004). Similar to bibliometric counts, the analysis of patents provides a unique basis for benchmarking research productivity for individuals or aggregated levels of sub-groups. Patent applications reflect the successful inventive achievement of individual researchers in science and technology and can be used as a proxy for their scientific excellence and contribution to the production of technical knowledge. Nonetheless, evaluation methods that investigate gender differences in the research productivity should be related to other studies in order not to convey gender-bias or stereotypes.

Legally, patents are registered intellectual property rights (IPR) that document "a specific legal form of novel codified technological knowledge" (Troy and Werle, 2008). The owner of a patent (individual, company or other entity) has the right to produce and use his/her invention for a limited period of time, usually up to 20 years, given the document being disclosed to others. While real property has material parameters, one of the features of knowledge is that it is ‘intangible’. In this regard, patent documents can be regarded as material manifestations of immaterial or intangible knowledge, which was created by individual actors. As carriers of explicit technical knowledge, organisations can exploit patent documents which can be transferred into marketable products during the innovation process (Behrmann, 1998).

4 Methodology of the study

In the context of the Lisbon Strategy, it has become evident that data should be examined within a conceptual framework that relates input data to output data. Although, the European Commission continuously monitors the percentage of female researchers, the quantitative knowledge base on the participation of female inventors in Europe was fragmentary before the European Studies on Gender Aspects of Inventions (ESGI). Patent documents and databases do not register the gender of the inventors at the time of patent application. Due to this lack of gendered output data, it was not possible to compare the inventive achievement of researchers with their proportion in the corresponding institutional, technical and economic sectors from a gender perspective. By conducting an innovation input-output comparison by gender, this study enhances the development of gender indicators for industrial research.

According to earlier research findings (Greif, 2005; Naldi and Parenti, 2002), our results show a remaining under-representation of women inventors in all European member states. Moreover, the percentage of female inventors (related to the total number of inventors of an EU member state) is even lower than the percentage of female researchers in all EU member states.

This raised two questions: Why is there a gap between the percentage of female inventors and female researchers (i.e., between output and input)? Why is the percentage of female researchers and inventors low and stagnating throughout the EU? Eurostat statistics also show proportionally higher rates of women researchers in Eastern European countries (EC, 2006a), whereas the total number of researchers is quite low in these countries. These findings led to questions regarding the gender input-output relationship by country and the hypothesis that there would be a higher proportion of women inventors in Eastern European countries.

This study is based on a European comparative secondary database analysis of patent applications to the European Patent Office in the priority years 2001–2003. The patent database contained 157,646 patent applications and the names of 388,531 inventors of which 93% had a European residence address and thus were included in our analysis. The average inventor patent ratio in the database was 2.5, which indicates that on average two and a half inventors participate in one patent application.

As a precondition for gendered analysis, we assigned the names of European inventors to male and female gender by a comprehensive, multi-stage first name assignment procedure. This included a matching procedure with a first name database and the name assignment by native speakers. As a result, altogether 93% of all European names were classified as male or female with country variations between 81% and 100%.

For the input-output comparison, all inventors were assigned to institutional sectors by an elaborate assignment procedure (Van Loody et al., 2006). Consequently all inventors were counted by gender and country, which is the most appropriate measure for the comparison of the proportion of female inventors with the proportion of female researchers. For data comparison purposes, all data on researchers is based on the indicator 'head counts', which is preferably used by Eurostat for national comparisons.

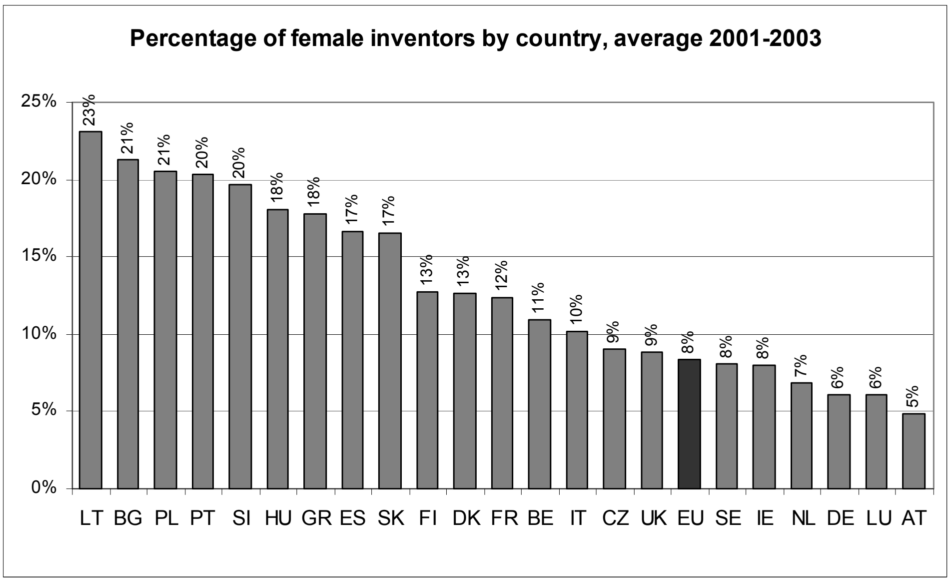
Per definition researchers are knowledge workers; they are defined as "professionals who are engaged in the conception or creation of new knowledge, products, processes, methods and systems and are simultaneously involved in the management of the projects concerned." (OECD, 2002)

5 Main empirical findings of the study

The research documented that women are considerably underrepresented among inventors in Europe. In Figure 1, one can see that 8% of all European inventors are female and 92% are male, which indicates that approximately one in twelve inventors is a woman. Yet, we find pronounced differences between the various countries for this indicator, ranging between 23% and 5%.

The analysis shows that approximately one half of all patents are applied by German applicants and inventors. Germany, producing the highest number of EPO patents per million inhabitants in the European Union is leading in regard to general patenting activities. In contrast, it has only a share of 6% women inventors and thus lowers the European average. Lithuania, Bulgaria, Poland, Portugal and Slovenia show the highest proportion of women inventors at between 23% and 20%. The highest shares of female inventors are thus found in the Eastern European member states. In contrast, the absolute number of patents and inventors of these countries is extremely low.

Figure 1 Proportion of female inventors of EPO patent applications by country, average 2001–2003

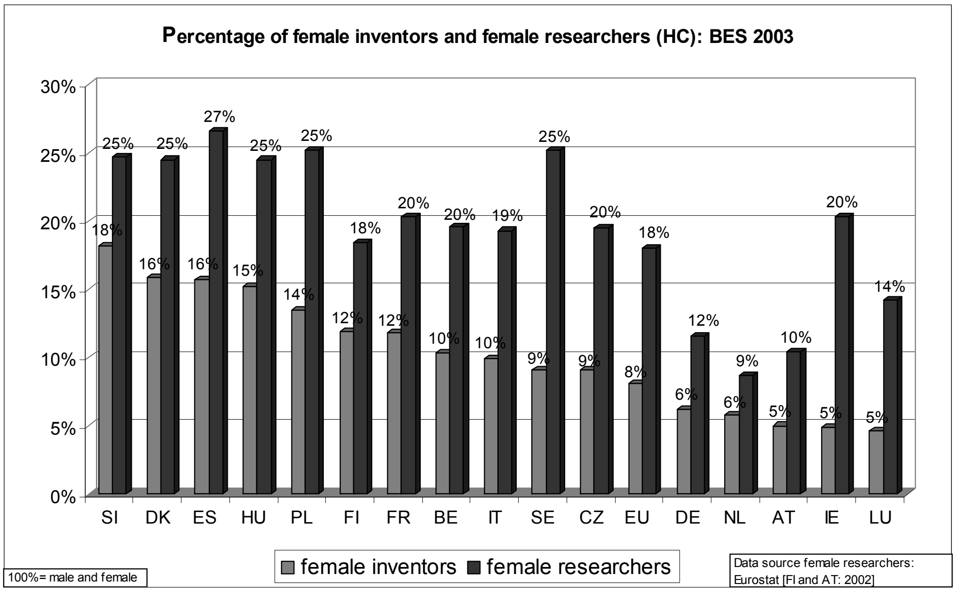


Note: The male share can be calculated by the difference between the female share and 100%.

Approximately 90% of patents are filed in the business enterprise sector (BES) which is the most important sector regarding technical knowledge creation in Europe. A detailed comparison of institutional sectors shows that woman inventors are more underrepresented in private sector research than in public research. While the share of women inventors in industry is only 8%, the share in public research (government, public non profit, higher education) reaches 16%.

Figure 2 correlates the proportion of female researchers and the proportion of female inventors by country in the business enterprise sector. There is an under-representation of women inventors in all European Union countries as shown by a disparity between women's participation in research and their success in patenting. Statistical regression analysis shows a positive correlation between the proportion of women researchers and the proportion of women inventors with $r = 0.79$, $r^2=0.62$ at 5% level.

Figure 2 Proportion of women inventors compared to women researchers (HC), BES, 2003



Focusing on the input-output relation, we find the European average to be 8% women inventors relative to a share of 18% female researchers. Statistical analysis shows that the low percentage of female researchers (input indicator) within the EU-member states is accompanied by an even lower percentage of female inventors (output indicator). As a consequence we see that women are significantly under-represented as inventors.

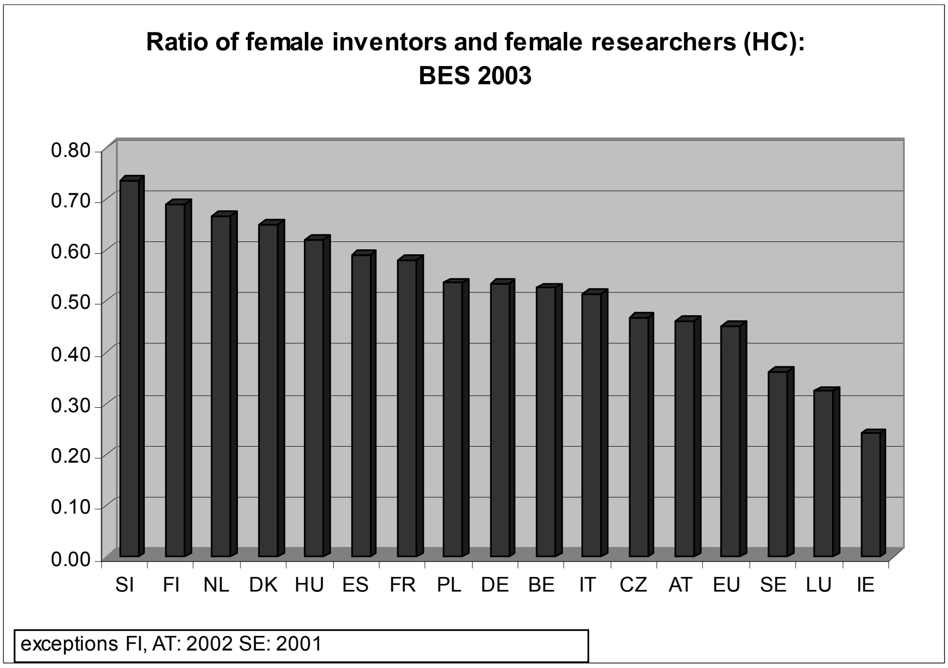
All European countries are failing to realise women's potential for technical knowledge creation and innovation. Moreover, the comparison shows pronounced differences by country. Slovenia, Denmark, Spain and Hungary are leading and show a proportion of women inventors of over 15%. By contrast, Germany, the Netherlands, Austria, Ireland and Luxembourg are below the EU-27 average. (Methodological note: All countries with less than 100 inventors in industry in the year 2003 are not included in these figures.).

For additional information, we calculated the ratio between the proportion of female inventors and female researchers (Figure 3).

$$\text{output} - \text{input} \quad \text{ratio} = \frac{\text{percentage} \quad \text{female} \quad \text{inventors} \quad (\text{HC})}{\text{percentage} \quad \text{female} \quad \text{researchers} \quad (\text{HC})}$$

One has to keep in mind that this calculation is limited since it does not provide any information on the basic values which lie behind the ratio. A value of 1.0 indicates no gap at all; high values indicate a narrow gap between the shares of female inventors and female researchers, meaning a country profits more from the existing potential of available women researchers. By contrast, low values indicate large gaps and lower profit from the available women's research and inventive potential. In sum, the best achieving countries which show smaller gender innovation gaps are Slovenia, Finland, the Netherlands, and Denmark, whereas Sweden, Luxembourg and Ireland show extremely large input-output gaps.

Figure 3 Output-input ratio, BES 2003



6 Explaining the gender innovation and research productivity gap

Gender research has analysed the gendered character of innovation and knowledge creation. Consequently, we can assume that inventions and patent creation are affected by a range of structural, cultural and institutional mechanisms as well as individual factors, which systematically vary between countries and gender. Until today, in most European countries women have not acquired parity with men in opportunities for undertaking research. These would include equal access to research instrumentation like funding, laboratory space and time allowance. Working in research and development means to compete with others not only for money but also for influence and power. But even if the number of female scientists increases, women have to compete in a historically male dominated domain which is controlled by a number of social mechanisms like the access to power, authority, influence, reward systems and networks. Thus, women often remain in 'the outer circle' of the scientific community (Zuckerman et al., 1991).

The aim of this part of the research is to answer the questions above by adopting the viewpoint of the economy as well as of the employers. A simple model is used to investigate the consequences of the relation between the gender gap and the percentage of female researchers for the economy and the employers.

The model ignores the above-mentioned single causes, which hinder women to become a researcher or inventor, but instead combines all causes, resulting in one single parameter. The advantage of this simple model is its universality in taking into account the given differences of the EU-member states regarding:

- different percentages of female researchers and inventors
- different measures to increase the named percentages
- different political approaches to solve the problems
- variations in economic performance.

Producing inventions or patents is viewed as a creative part of the work of researchers, stimulated by the employer by different measures, e.g. free time, training, group meetings, incentives, etc. There are two major categories of resources, which are relevant to the number of outputs (i.e. patents, publications, presentations):

1 free time, i.e. high quality time (T) for the researcher to stimulate ideas, discussions etc.

2 other resources (R) for the researcher - research money, laboratory space, training, equipment, co-workers.

There is evidence in all EU-member states that female researchers often face a lack of professional high-quality time compared to men. This is caused by maternity leave, parental leave, part-time work, home-office work and possible differences in work duties, motivation and obligations, salary differences, etc. Female researchers might also be confronted with a lack of other resources compared to their male colleagues, e.g. project money, laboratory space, equipment (hardware and software, computing time), number and quality of co-workers, secretaries, etc.

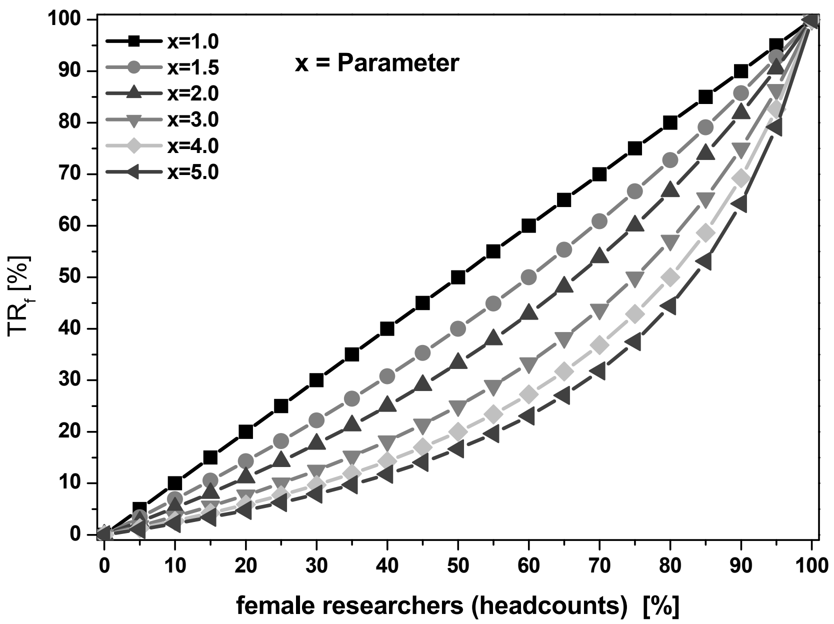
The main assumption of the model is that the output productivity of a researcher is directly determined by the resources (T, R), which are available to the researcher. This means that any gender productivity gap is caused by a gender resource gap of the same relative size. Other assumptions are that on average:

1 all patents are equal regarding their value

2 creation of an invention requires the same work time and the amount of other resources

3 male and female researchers have an equal inventive potential.

Figure 4 Percentage of resources (TR_f) that female researchers have related to resources men and women do have together (= 100%)



Notes: The modelling parameter x is running from 1 to 5; i.e. from total equality = 1 (black squares) to 5-fold more total resources for male researchers (lowest curve).

Reading example: If we assume 40% female researchers and total equality (x = 1) TR_f is 40%. 3-fold more resources for male researchers in a given country lead in this case to a TR_f of about 18%

The product of T and R includes all resources. If the resources (T, R) determine the productivity of a researcher (in this case: inventive activity), then the relative share of the resources should correspond to the relative percentage of inventors. The model function is:

$$\text{share } TR_f = \frac{fh \cdot T_f \cdot R_f \cdot 100}{fh \cdot T_f \cdot R_f + mh \cdot T_m \cdot R_m} = \frac{fh \cdot 100}{fh + mh \cdot \frac{T_m \cdot R_m}{T_f \cdot R_f}} = \frac{100}{1 + \frac{mh}{fh} \cdot x}$$

fh headcounts female researchers [%]

mh headcounts male researchers [%]

TR share of all resources [%]

$$\frac{T_m \cdot R_m}{T_f \cdot R_f} = x$$

x modelling parameter (goes from 1 to 5; i.e. from total equality = 1 to 5-fold more resources for male researchers). The parameter x is the proportion between the resources available for men and the ones available for women. How the parameter x is composed in a certain EU-member state is up to detailed analyses including all given influences. The exact composition of the parameter x is not important for the model. The model is therefore independent from socio-economic factors.

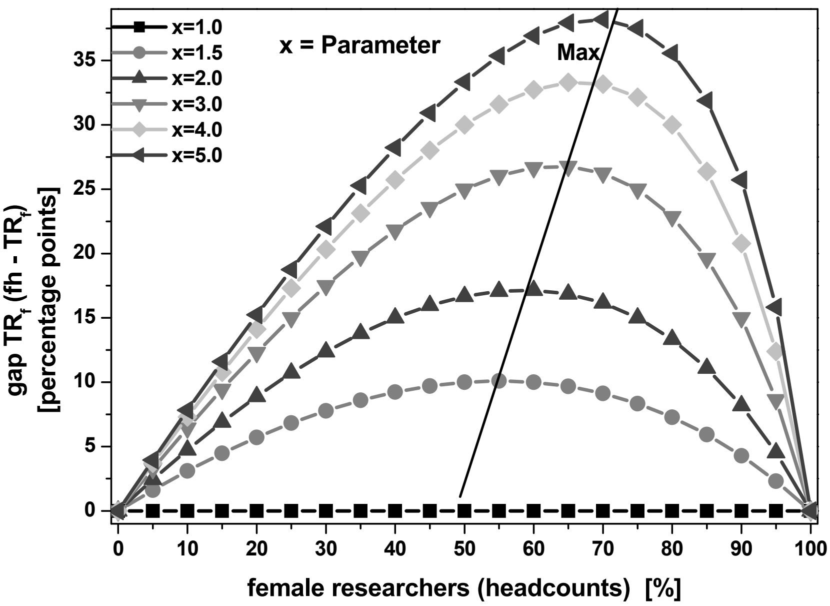
TR_f indicates the percentage of all resources (T_f and R_f) that female researchers have related to all resources men and women do have together (= 100%). TR_f in a given EU-member state is dependent on the percentage of female researchers (headcounts) in this EU-member state.

To model the gap it is necessary to calculate the deviation of TR_f from the percentage of female researchers, which enables us to build the ratio of output to input. Adopting the viewpoint of the economy or the employers, it is useful to consider the difference between the female researchers (fh) and their output, which is according to the assumptions above given by the resources (TR_f) that are available to the female researchers:

$$\text{gap} \quad TR_f = fh - TR_f$$

This difference provides an impression of how the absolute productivity gap will evolve with an increasing percentage of female researchers.

Figure 5 gap-TR_f , i.e. the difference between the female researchers and TR_f (in percentage points)



Notes: The modelling parameter x runs from 1 to 5; i.e. from total equality = 1 (black squares) to 5-fold more resources for male researchers (top curve). The straight line indicates the maximum of all curves, which is obviously shifted to the right side with increasing parameter x.

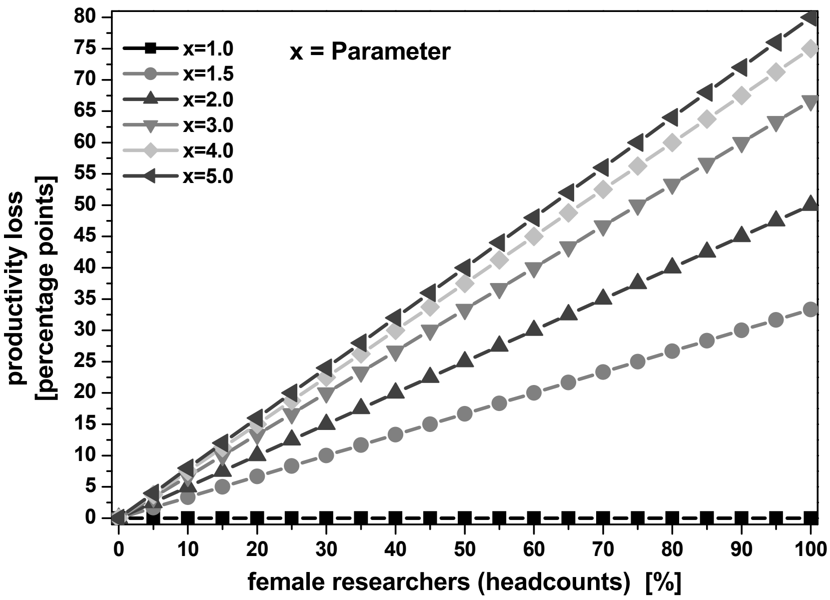
Reading example: If in an EU-member state the percentage of female researchers is 30% and the resources for male researchers are 2-fold better (x=2.0) the gap-TR_f amounts to about 12 percentage points.

Interestingly, the modelling curves have a maximum (and therefore the gap has a maximum) while increasing the percentage of female researchers up to 50%–70%. This means that if the working conditions (resources) within an EU-member state for male and female researchers are kept strictly constant (i.e. x is constant), an increase in the percentage of female researchers will result in a higher output productivity gap if x > 1.0.

Therefore, it would be detrimental to increase only the share of female researchers as the absolute output-gap will increase. It is necessary that the working conditions (resources) for female researchers (T_f and R_f) are improved at the same time. If the modelling parameter x is assumed to be constant (i.e. a constant gender distribution of resources) in a certain EU-member state and the percentage of female researchers increases, we expect a growing output productivity loss (PL):

$$PL = 100 - \left(mh + fh \cdot \frac{1}{x} \right)$$

Figure 6 Productivity loss is to be expected by increasing the percentage of female researchers if the working conditions (resources) for male and female researcher are kept constant, i.e. the parameter x is constant



The model assumes a productivity of 100% (i.e. a productivity loss of 0) if all researchers are male (100%), i.e. the percentage of female researchers is 0%. Using male productivity as a norm is a necessary reference point since in all EU-member states, the group of male researchers has a higher productivity regarding their inventive activity.

If the percentage of female researchers is increased while the working conditions (resources) for male and female researcher are kept constant, (i.e. the parameter x is constant) we expect a productivity loss. Possible solutions for this situation are:

- The productivity loss is accepted. This is unlikely for achievement-oriented economies.
- The working conditions (resources) of female researchers are improved.

Furthermore, it is to be expected that more achievement-oriented economies will be less willing to accept productivity losses compared to less achievement-oriented economies. The model explains why more achievement-oriented economies tend to keep the percentage of female researchers lower. This result fully corresponds to the findings of the EC report on benchmarking policy measures for gender equality in science (EC, 2008): “The statistical analyses of the size of the different R&D sectors in relation to the proportion of women researchers suggest that the main determinant of the proportion of female researchers in a country is the relative size of its business enterprise R&D sector”. This means that the bigger the BES R&D sector of a country, the less likely it is that this country will have higher proportions of women researchers. The proportion of women in R&D can therefore be considered as a negative index of the level of development of a country’s national innovation system. This suggests that more advanced national systems of innovation tend to involve proportionally fewer women as researchers (EC, 2008).

7 Conclusions

Although the outcomes of this study reveal that women are contributing significantly to European patents, our results show a high female potential which is not fully utilised. Similar to publication productivity, patent productivity is connected to intellectual recognition, advantages in accumulation of professional opportunities and visibility as well as contributions to technical knowledge creation. In light of the development of the European knowledge society, the under-representation of women in research and patenting implies an unacceptable loss of an intellectual resource.

Statistical analysis of EU patent data shows an under-representation of women inventors in all European member states. Moreover, the percentage of female inventors (relative to the total number of inventors) is even lower than the percentage of female researchers in all EU member states. Considering that economic growth relies on innovation, women’s under-representation in science and technology in the European Union is of special concern.

Our simple mathematical model predicts that the research productivity gap (the gap between input and output) will increase if the percentage of female researchers is increased without improving their output productivity by providing more resources and better working conditions at the same time. In the short term, it is not sufficient to only increase the number of women in research without improving their working conditions as the model predicts a severe productivity loss.

The discrepancy between the high achievement of women in the education system and their lower contribution to scientific knowledge creation and the innovation process is symptomatic of a lack of economic efficiency and societal development. Given the importance of knowledge creation in the European economy which increasingly focuses on the sustainable use of economic, human and ecological resources, it is of utmost importance to fully realise women’s innovation potential for the sustainable development and well-being of European societies.

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