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RECOGNIZING OPPORTUNITIES FOR S&T WORKFORCE DEVELOPMENT AND PRODUCTIVITY

The gendered resource

Connie L. McNeely and Laurie A. Schintler

Introduction

In countries around the world, concerns about deficits in the science and technology (S&T) workforce have come to occupy places of prominence on policy agendas. Indeed, human capital development in fields associated with science, technology, engineering, and mathematics generally has been recognized as crucial to progress and growth in today’s innovation-driven knowledge economy. Human capital is at the centre of innovative activity and can be addressed either as a constraint or as an opportunity for innovation policy (Zimmerman 2012). Persons with S&T training and skills play an important role in channelling investments in knowledge into productivity and growth and, accordingly, achieving technological advancement requires human capital development as an investment in research and innovation. This situation has brought increasing attention to questions about educational access and workforce opportunities for populations who have been especially underrepresented in S&T fields, referring particularly to women (and, also, to some underprivileged minorities). Indeed, their underrepresentation has emerged as a major political, economic, and social issue for workforce development and growth. Recognizing women as a rich, yet under-utilized and often untapped resource in the S&T research enterprise (Pearson et al. 2015), gender dynamics and relations are a critical consideration in matters associated with politics and technology and the development of the future S&T workforce.

Arguably, depressing the potential, participation, and contribution of women and other groups in society is actually harmful to efforts for S&T supported economic advancement. While some progress has been made, female participation and, more, female professional advancement in S&T fields have, at best, been uneven (Hill et al. 2010; Ceci and Williams 2011; EC 2013; OECD 2013a). This situation speaks particularly to the demand for university-trained labour across academic, public and private sectors and to the need for a more realistic and fully informed assessment of S&T education and workforce conditions. Academia is a crucial consideration in this regard.
given that it is, in fact, the training ground for the S&T workforce. This point is especially relevant to the issue at hand since expanded and increased networks constituted by various (academic, public and private sector) researchers suggest a greater demand for academic labour – a demand that could be met by females if more favourable conditions existed for their recruitment, retention and general participation (McNeely and Vlaicu 2010).

To that end, gender mainstreamed and inclusive analytical perspectives and metrics are needed as policy inputs and determinants for related investments in human capital (Leggon et al. 2015). While there is a rich and burgeoning literature addressing women in S&T fields, a great deal of work remains to be done in delineating related processes and linking key indicators of scientific productivity and workforce development to broader contexts and concrete outcomes (Pearson et al. 2015). Thus, major theoretical and methodological issues are identified and examined here to provide insights for furthering research on scientific and technological knowledge creation, diffusion and application relative to gender relations and dynamics. The principal aim is to consider the situation of women in S&T, particularly as reflected in their relatively low participation and status in related careers.

The underpinning notion for this work is pragmatically straightforward: a broader pool of academics and researchers will provide a better means to S&T productivity and innovation. Thus, increased numbers and inclusion of qualified women will strengthen the potential for S&T workforce and expand possibilities for advancement and growth. As such, gender is a central analytical point for addressing resources for S&T workforce development across sectors at individual, national and international levels of analysis.

**Background**

Although there have been gains in advanced degree attainment by women in S&T fields, they still tend to be underrepresented and to occupy less than favourable positions in general (Bell 2010; Hill et al. 2010). Also, various studies have pointed to women in S&T as having lower levels of productivity than men, referring to the tendency for women to publish at lesser rates (Duch et al. 2012; West et al. 2013). This ‘productivity puzzle’, as it was framed by Cole and Zuckerman back in 1984, has been a fundamental concern for S&T workforce capacity and development.

- These interrelated gender issues – underrepresentation and lower productivity – signify important analytical and policy considerations in the face of calls for building the S&T workforce.

However, the conventional operationalization of scientific productivity principally as publication levels neglects the dynamic and interactive ways in which research is conducted, disseminated and evaluated. Indeed, scientific productivity might be more aptly framed as a process rather than an outcome (McNeely and Schintler 2010a, 2010b). Moreover, ‘given the complexity attending the conduct of science and innovation today, the life of an idea – from its “eureka” moment through its growth, development, and diffusion – is rarely the product of a single individual’ (Schintler and McNeely 2012: 125). Rather, innovation results from the influence of collections of people, i.e. of networks and collaborations (cf. Rycroft and Kash 1999; Gladwell 2002). As such, the underrepresentation and lower productivity of women also must be considered largely in terms of collaboration and participation in scientific networks as gendered aspects of the creation and transfer of scientific knowledge and of innovation.

Still, in practice, publications again are used to indicate networks and collaborations among scientists. Co-authored publications have been the chief means for measuring scientific
collaboration and productivity. Indeed, co-authorship has been treated as synonymous with collaboration and network positioning.\(^2\) However, accounting for less than 30 per cent of co-authored publications globally, women are less likely to participate in collaborations that lead to publication and, when they do, are much less likely to be listed as lead author in national and international contexts (Larivière et al. 2013; West et al. 2013). As suggested by recent studies showing that gender differences in spatial and other outcomes can be largely attributed to nurture and education (Hoffman et al. 2011), the process from which the puzzling outcomes result must be taken seriously relative to productivity levels. Accordingly, the productivity puzzle is examined here in terms of collaboration and networks as a policy concern and central issue for understanding female contributions, participation, and roles in S&T workforce and innovation processes.

**Collaborative networks**

Fostering the development of both formal and informal networks of women with other researchers, including partnerships within and across academia, government and industry, has been identified not only as an important step for advancing women in S&T careers, as it is for men, but also as crucial for technological progress (OECD 2006, 2012a). Increased productivity can be explained relative to participation and status in the S&T community, and increased participation in research networks and collaborative relationships can enhance the scientific intellectual, social and cultural capital that support human capital development.

Networks are central to the generation and dissemination of research, thus contributing to innovation and technological developments. Related connections arguably can contribute to interpersonal influence (Brass 1984) and career opportunities (Burt 1992), and the structure of collaborative networks and relative positions within them influence access to resources (Lin 2002). Also, network composition is a crucial feature relative to the range of colleagues and collaborators and the density of their connections. Accordingly, sensitivity to network boundaries and awareness of bias incorporated in network positions might reflect gender as a differentiating factor. While network structure, role and position are key determinants of collaboration possibilities (Hill 2008; Welch and Melkers 2008; Lin 2002), moving beyond or expanding such boundaries and overcoming bias could mean creating opportunities for participation and research for technological advancement.

Related workforce development largely depends on such networks that, in the literature, have been identified and operationalized through analyses of collaboration patterns and participation. These networks are defined through spatial, cultural and political links, affecting participation and the size, specialization, centrality, reach and autarky of broader networks that enable or constrain collaboration and productivity (cf. Schott 1993; Centola 2010). Also, collaborative relationships can be marked, to varying degrees, by a division of labour and hierarchical positions, often evincing considerable difference between women and men in co-authorship tendencies (Cronin et al. 2004; Newman 2004). While S&T research embodies a culture that encourages collaboration, it is not necessarily equal collaboration; collaborative partners may not receive equal recognition and value for their role and contributions in the relationship (Wray 2006; Zucker et al. 2007; Heinze and Kuhlmann 2008). That is, co-authorship as a measure of scientific interaction can be an incomplete and inaccurate characterization of collaboration and network participation. For example, it does not reflect the degree or way in which an individual author might actually contribute to a publication. In fact, authors may be listed on an article, not for their contribution to the research, but rather for social or political reasons (Katz and Martin 1997), which also can reflect preferential attachment considerations.
Moreover, listed authors (or even acknowledgements) do not necessarily reflect all of the individuals involved at various steps in the research process (Sonnenwald et al. 2009).

Collaboration and network construction are iterative processes reflecting various activities, stages, and contextual conditions (Sargent and Waters 2004; Sonnenwald 2007). They are dependent on the ways in which research is organized, conducted and located, i.e. on the culture and organization of S&T and on the contexts in which research is conducted, whether academic, public or private. The social and organizational features of work influence research performance and, as such, represent important areas for investigating scientists’ productivity (Drori et al. 2003; Fox and Mohapatra 2007; Wagner 2008). Thus, for example, several studies reveal that the pervasive culture of high-technology organizations reflects a decided gender gap in which women typically are excluded from professional networks and leadership positions (Tai and Sims 2005; Cross and Linehan 2006; NRC 2012).

**Cross-sector dimensions**

Female educational attainment is a fundamental consideration in framing workforce capacity issues, and recognizing disparities in higher education is critical to understanding related challenges to innovation. Generally speaking, while women lag behind men in advanced research degree attainment, they have reached parity in some countries and fields. As an example, general and female doctoral degree attainment in mathematics and in statistics can be quite variable across countries, as illustrated in Figure 4.1 showing selected countries that reported gender disaggregated data on degree awards in 2011. (These are arrayed by a relative number of the advanced research degrees and then, within the size groupings, percentage of women earning advanced research degrees in mathematics and statistics. Following OECD reporting conventions, advanced research degrees refer to doctoral or the highest level degree awarded in a country.)

![Figure 4.1](image-url)  
*Figure 4.1* Example: Mathematics and statistics advanced research degrees (bars) and per cent women (diamonds) among recipients, 2011.  
For the most part, although not across the board, the number of women earning advanced research degrees has grown, as illustrated in Figure 4.2 again using mathematics and statistics as examples showing change in female degree attainment in selected countries between 1998 and 2011. Overall, such changes indicate expanded opportunities for S&T workforce development.

Increased educational attainment arguably has accounted for half of the economic growth in ‘developed’ countries in the past 50 years, owing in large part to females reaching higher levels of education and making gains in gender equality in number of years spent in education (OECD 2012a). However, this situation has not necessarily translated into workplace equality and, even with expanded degree attainment, gaps in workforce representation remain significant. Even in the developed world, the overall number of women attaining degrees in S&T fields is much higher than the number of women actually employed in research and related positions (OECD 2006, 2013a; NRC 2010; EC 2013). In other words,

- **In terms of S&T workforce needs, a large part of the societal and individual investment in human capital is lost.**

For example, on average in European countries, 1.75 per cent of the total workforce are women scientists or engineers, compared to 3.65 per cent of men. This, then, is an unexplored workforce resource and basis of creativity that undergirds technology and innovative activity. Of course, this representation varies by country, as observed in the United Kingdom with 1.22 per cent women, compared to 4.48 per cent men, scientists in the total workforce, ranking behind such countries as Iceland, Belgium and Ireland that report parity in representation.3

![Figure 4.2 Example: Per cent women among recipients of mathematics and statistics advanced research degrees, 1998 and 2011.](source: Frehill (2014).)
Looking more specifically at female researchers across sectors, the European average is 33 per cent (EC 2013). Similar to educational attainment patterns, the largest regional differences in female employment overall have been found in Italy, Spain, Turkey, the United States (US) and the Slovak Republic (OECD 2013a). Generally speaking, regions with relatively low gross domestic product and income levels reflect the largest differences in female and male labour force participation rates overall.4

Both internal and external social, economic and political factors influence decision makers regarding mobilizing and supporting S&T research (Callon et al. 1986; Latour and Woolgar 1986; Katz and Martin 1997). Such factors include, among others, societal, organizational and disciplinary cultures, funding, research team size, institutional support and structure, and location (Bukvova 2010). Thus, national and institutional politics can affect researcher behaviour, and S&T productivity often results from collaboration among researchers in different organizations and countries. Network participation and collaboration among researchers from both developed and developing countries provide access to knowledge and expertise, to the extent that international collaboration has been framed as a means for capacity building, as reflected in increased international co-authorships that have characterized globalization processes (Chung 2002; Glänzel and Schubert 2004; Oldham 2005; Wagner and Leydesdorff 2005).5 These co-authorships have been enabled by technological and communications advances (Stokols et al. 2008). The internet and email have lowered communication costs, thereby facilitating collaboration and network participation, with recent evidence suggesting disproportionately positive effects on female co-authorship rates relative to those of males (cf. Butler and Butler 2011). Accordingly,

- A gender dimension is indicated in the extent to which productivity is reliant upon spatial correspondence and the potential for workforce development.

Growing involvement in collaborative relationships and S&T networks across sectors, organizations or countries demands a continually increasing workforce. The more prevalent such involvement, the more possibilities and opportunities exist for innovation and research activities. Thus, particularly pertaining to highly-skilled S&T trained women, the development of collaborative researcher capabilities is critical for innovation and for network building and participation.

Also, various factors, such as policy motivations, including government fostering and support of research, historical considerations and S&T globalization, compel not only individual researchers but broader scientific networks and communities to respond to social and political mobilizations for collaborative relationships (cf. Drori et al. 2003; Hwang 2008), with cultural differences in gender relations and participation providing relative advantages and disadvantages for S&T workforce development and productivity.

Unexplored potential

Female publication productivity is also strongly influenced by both structural and individual factors (cf. Prpić 2002). Of these, situational issues, such as female underrepresentation itself in some S&T fields, are arguably crucial considerations for understanding the observed unequal outcomes. Furthermore, broader disciplinary cultures represent another factor that must be considered, given that some fields have been referenced as relatively more ‘female friendly’. Accordingly, some research suggests that the male-dominated disciplinary cultures and organization of some fields contribute largely to low expectations and performance by women (Murphy et al. 2007),
explaining productivity differences. Women tend to be concentrated in fields and industries such as the biological sciences, agriculture and pharmaceuticals, but to have little presence in physics, computing and engineering (which typically are considered higher remunerative fields), thus contributing to disciplinary and occupational segregation and stereotypes and providing a clear example of uneven participation (OECD 2006, 2012a, 2013a; Roos and Gatta 2009). Also, reflecting the growing complexity of S&T disciplines, research specialization may be an important intervening variable that negatively affects productivity. Evidence suggests that women specialize more often than men, but the most productive scholars tend to be those with more broadly diversified research programs (cf. Leahey 2005).

Additionally, scientific research typically involves working with others to pool resources, and collaborative projects can provide researchers with expertise in associated disciplines, collegial vetting and support networks, a sense of community, and opportunities to relate to others (Rhoten and Pfirman 2007). This combining of resources is an especially relevant issue for female researchers given the explicit and implicit challenges and barriers to professional advancement and productivity that they often face — e.g. exclusion from information networks, exclusion from grant writing opportunities, marginalization of their research areas, smaller and less well-equipped offices and laboratories, and general denial of voice in institutional decision making (Roos and Gatta 2006; Hwang 2008; Ceci and Williams 2011; Duch et al. 2012). Such gender imbalances constitute a circular pattern in which gender disparities lead to gender disparities. More to the point,

• Gender disparities are detrimental to S&T capacity; they hinder creativity and innovation.

Women also tend to be concentrated in lower-level positions in their professional lives (Cross and Linehan 2006; Symonds 2007; Ceci and Williams 2011); female career trajectories generally are somewhat hampered compared to those of males. Even in academia in fields in which women have reached parity in advanced degree attainment, they are still grossly underrepresented in full time senior faculty positions (e.g. 30 per cent in the life sciences). For example, in Europe, men advance at three times the rate of women; women rarely reach more than 20 per cent of the top ranks in academia (OECD 2006). In both the US and European countries, large declines in female representation occur at each rung of the professional ladder, indicating a bottleneck in human capital development and, thus, lost opportunities and resources for ideas and creativity. These outcomes reflect various determinant conditions. In particular,

• Lower rates of female advancement are linked to gaps and differences in employment conditions, career management, evaluation standards, and research and productivity incentives and opportunities.

Women tend to have fewer opportunities for attaining positions at research universities where the availability of related resources and support facilitates increased faculty productivity (OECD 2006; Murphy et al. 2007; Hill et al. 2010; Moss-Racusin 2012).

Gender differences in publishing productivity have been attributed to the greater likelihood for women to work in non-tenure track and contingent positions, to work at teaching (rather than research) institutions; to lack access to institutional support, resources, and time; to participate in service activities that detract from research; to be excluded from broader professional networks; and to have family responsibilities that encroach on time for research (Bentley 2003; Xie and Schaumann 2003; Francl 2005; Robinson 2006; Fox and Mohapatra 2007; NAS 2007; Symonds 2007; Ceci and Williams 2011). In general, lower female productivity reflects the increased unpredictability of their careers (Symonds 2007).
Given technology and innovation defined workforce needs, related organizational and cultural determinants must be addressed to determine means for exploring opportunities represented by the participation of women in support of the S&T endeavour. In this sense, inclusion, along with credible and improved conditions for productivity and advancement, will allow women to contribute (through, e.g. findings, patents, products, etc.) to a more dynamic economy. Of course, related factors can vary dramatically, especially in the face of divergent sociocultural and political conditions, with fundamental implications for technology and innovation. Societies in which female educational attainment is more highly accepted and supported will ultimately benefit from greater S&T productivity and development; i.e. higher female productivity means greater contributions to knowledge, technology and innovation.

As Susan Windham-Bannister once remarked, ‘What is the story of women in science? It is the story of the few and the fewer’. Facing discriminatory practices from the very start of their careers, women have held only 27 per cent of S&T jobs (NRC 2012). Even with progress in educational attainment in some countries, ‘the glass is still only half full: women continue to earn less than men and are less likely to make it to the top of the career ladder’ (OECD 2012a: 13). That is, while females outnumber males in degree attainment in many countries (OECD 2012b), gender disparities remain rife in, for example, hiring, earnings, funding, patents, advancement and satisfaction (Holden 2001; Ding et al. 2006; Ley and Hamilton 2008; Moss-Racusin et al. 2012; Shen 2013). Having said that, increased demands for qualified S&T researchers have raised questions regarding policies and interventions that might better provide access and advancement opportunities for women and other underrepresented groups in related fields, which could result in improved network positioning and collaborations and, thus, in technology development and innovation.

The analytical nexus of representation and productivity processes

Network and collaborative relations in general are highly complex processes and, when gender is explicitly recognized and engaged as a critical influence on observed outcomes, it adds another layer of complexity to those processes to the extent that further study is needed in order to gain insight and understanding of the interrelated institutional, cultural, political and economic dynamics and structures that shape today’s S&T workforce. In other words, gender identity alone hardly explains or is responsible for S&T pipeline issues or related disparities in productivity and workforce development. Rather, as shown in Figure 4.3,

- Gender must be recognized as a critical determinant at each step within a complex web of relational dynamics and processes.

Only by capturing related interactive dynamics can the kind of understanding be developed on which to formulate effective policies and interventions for building an inclusive and diversified – and ultimately world-class and strengthened – S&T workforce. The issue here is how to effectively introduce gender into a model as either a contextual factor or, perhaps more importantly, as an intervening factor affecting productivity and workforce development.

Also, although, as discussed above, the operationalization of productivity as publications and of collaboration as number of co-authored publications is widely accepted, publication counts do not indicate quality or relevance. Indeed, using publication counts to study knowledge creation and dissemination does not require that they effectively convey knowledge; it is enough that the processes that transfer knowledge also tend to produce the publication (Hicks and Narin 2001). This type of measure says little about actual quality or whether they encompass new
insights, applications, or significant discoveries. To some extent, attempts to address such issues have been made by considering number of citations. Employing citation rates to examine co-authorship relative to productivity, some research considers the value of collaborations for further productivity in national and international contexts, using citations to indicate collaboration importance (e.g.; Moed 2005; Leydesdorff and Wagner 2008). This concern is especially notable given another side of the productivity puzzle: the ‘impact enigma’ in which, in some fields (e.g. biochemistry and biology), women’s publications, although fewer, have been found to be more frequently cited than those of their male counterparts – even when the women occupy more ‘marginal’ professional positions (Long 1992; Symonds 2007; Duch et al. 2012).

However, other recent work suggests that articles with women as lead authors in general receive fewer citations (Larivière et al. 2013). ‘Given that citations now play a central part in the evaluation of researchers, this situation can only worsen gender disparities’ (Larivière et al. 2013: 212), constituting a circular process that operates to retrench existing imbalances, as previously mentioned. Citations are the conventional metric for determining impact, but they too might occur for a variety of (positive or negative) reasons and still do not necessarily indicate substantive quality or relevance. The ‘citation disadvantage’ accentuates the fact that there is a problem and, while conflicting findings have yet to be explained, they lead to challenges and questions about analytical reliance on numbers of publications as the primary indicator of productivity (Francl 2005). In general, there are potential contributions and human capital that are essentially wasted; opportunities are left unexplored due to systemic disadvantages incurred

Figure 4.3 Collaborative processes for productivity and workforce development.
Source: author.
by females in S&T. By redressing such disadvantages that result in underrepresentation and lower productivity, gains could be made for societal and innovative progress and development. Accordingly, in this regard, innovation is fundamentally a gender issue.

Conclusion

Opportunities for growing the S&T workforce – based on increasing the participation and status of women – means more university trained labour comprising a larger pool of academic, government and private researchers. However, related problems will not take care of themselves; policy action is needed to address the issue of women’s participation in S&T careers across sectors (OECD 2006). Moreover, positive outcomes rely on the existence of credible opportunities and conditions for their effective participation and position in S&T professional networks and communities, which are further dependent upon political, economic, and cultural contexts.

As a policy issue, effecting change means meeting the challenge of mobilizing political will and resources for developing and implementing commitments to gender equality and equity across levels of analysis. Policies for prioritizing gender equity must be integrated as central concerns in broader political agendas. Especially given pressures for higher value-added technologies and products in academia, government and industry (NRC 2012), innovation as a goal demands increasing the university trained S&T workforce rather than increasing competition for already existing positions. To that end, the issue of gender mainstreaming is critical for addressing related needs. Effecting gender mainstreaming requires a wide variety of actions (cf. OECD 2013b): strengthening analytical tools and frameworks to incorporate gender considerations and ensure appropriate skills for related analysis; building evidence-based gender sensitive policy and programmatic approaches; enhancing support and accountability and monitoring mechanisms for gender equity activities; using international platforms and networks to support national and local change; identifying and addressing gaps in organizational capacities and skills to ensure access and influence in policy decisions; and fostering local and national organizational linkages and networks to ensure access to support and decision-making resources.

Overall, a range of policies and programmes have been proposed in many countries to attract and retain women in S&T careers in different sectors (Leggon et al. 2015). In addition to gender mainstreaming research initiatives and data collection and evaluation programmes, awareness raising measures, efforts aimed at promoting female S&T workforce participation and advancement in academic, public and private sectors have included, for example, coaching and mentoring activities, work returnee support, targeted awards, and comprehensive multi-dimensional policy strategies (OECD 2006, 2012a).

The discussion here has been an initiating step in noting important issues that remain to be explored as analytical approaches, calling for a more politically and culturally informed approach to engaging gender as a dynamic and vital issue in the pursuit of innovation and technological advancement. This task will require a multidimensional approach (cf. OECD 2013b):

• developing a highly nuanced and contextualized understanding of related conditions;
• employing diverse strategies to seize short and long term opportunities and direct and indirect approaches;
• supporting female empowerment across sectors and purposes;
• engaging a wide range of institutions and actors to facilitate identification of common interests and collaborative relationships to promote gender equality; and
• developing and using political opportunities and leadership influence and commitment to related goals.
Taking these points together means framing gender inequality as an integral concern in the complex causal relations reflected in network and collaboration processes. Doing so is a crucial step in delineating the gendered dynamics attending S&T workforce participation, development and productivity.

Gender is one of those issues that so permeates social interaction that its effects cannot be rightly captured by characterizing it simply as a separate factor in related analyses. Growing attention to research on networks and collaboration as key aspects of S&T productivity – not only as outcome, but as process – reveals that it must be understood within the context of larger social, cultural, political and economic conditions that have determined the underrepresentation of women, and of other disadvantaged groups as well, which ultimately translates into lost opportunities for future progress. The complex character of the embedded gender dynamics requires the explicit recognition of its critical interactive nature and influence. Moreover, in-depth analyses of societal relations and changing network patterns over time and place are needed in order to better understand the role of gender relative to other determinant factors affecting the development of the S&T workforce and to meet the needs and challenges of today’s innovation-driven knowledge society.

Notes
1 E.g. see references in Larivière (2013); Hill et al. (2010); NAS (2007); Turner and Mairesse (2003).
2 Smith (1958) was one of the first advocates for the use of co-authored papers to measure scientific collaborations, and de Solla Price (1963) was one of the first to produce and establish direct bibliometrics measurement as the standard for that purpose.
4 Note that, worldwide, approximately 17 per cent of countries have relatively equal numbers of men and women scientists (UNESCO 2007).
5 However, some analysts argue that political gains of formal collaborations may have been lessened by globalization dynamics that have made international collaboration more commonplace (Skolnikoff 2001).
6 Regarding arguments crediting increased family responsibilities for women as the cause of lower publication rates, this is the general perception, but empirical evidence is mixed (Sax et al. 2002). It is also the case that this situation may be due to specification issues.
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