Forum

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The academic jungle: ecosystem modelling reveals why women are driven out of research

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The number of women studying science and engineering at undergraduate and postgraduate levels has increased markedly in recent decades. However females have lower retention rates than males in these fields, and perform worse on average than men in terms of promotion and common research metrics. Two key differences between men and women are the larger role that women play in childcare and house work in most families, and the narrower window for female fertility. Here we explore how these two factors affect research output by applying a common ecological model to research performance, incorporating part-time work and the duration of career prior to the onset of part-time work. The model parameterizes the positive feedback between historical research output (i.e. track record) and current output, and the minimum threshold below which research output declines. We use the model to provide insight into how women (and men) can pursue a career in academia while working part-time and devoting substantial time to their family. The model suggests that researchers entering a tenure track (teaching and research) role part-time without an established track record in research will spend longer in the early career phase compared to full-time academics, researchers without teaching commitments, and those who were beyond the early career phase prior to working part-time. The results explain some of the mechanisms behind the observed difference between male and female performance in common metrics and the higher participation of women in teaching-focussed roles. Based on this analysis, we provide strategies for researchers (particularly women) who want to devote substantial time to raising their families while still remaining engaged with their profession. We also identify how university leaders can enable part-time academics to flourish rather than flounder. In particular, we demonstrate that careless application of metrics is likely to further reduce female participation in research, and so reduce the pool of talent available.

The opportunities available for women to study and work in non-traditional fields such as engineering, maths and science have greatly increased in recent decades. Female undergraduate enrolments in engineering have increased from 5% in 1983 to a plateau of approximately 15% by 2007, and enrolments in science have now reached 40% women (Bell 2009).

However women continue to leave the science and engineering fields at a greater rate than men (APESMA 2007, Mills et al. 2008, Bell 2009, Hunt 2010, Fouad and Singh 2011, Robinson 2011). The exit of women from this sector is primarily due to family responsibilities such as caring for children and/or moving to follow a partner's job (Herman and Webster 2010, Hunt 2010, Robinson 2011), and dissatisfaction with work culture and career advancement (Hunt 2010, Fouad and Singh 2011). In academia, these factors are strongly connected; women are more likely to work part-time, and as a group remain at the bottom of the academic hierarchy, with lower salaries, more substantial teaching and service duties and less research productivity than men (Dever et al. 2008, Misra et al. 2011). Hence there is a need to further investigate the challenges of balancing a career in academia or industry with primary care responsibilities for children, which is still quite a recent phenomenon.

The accepted paradigm is full-time work, for which there exists plenty of encouragement. For women who choose to return to work full-time after a year or less of maternity leave, there are many role models for successful careers in industry, research and academia, along with a wealth of published experiences and advice (Marincola 2002, Kim 2003, Anon. 2006, Schiebinger et al. 2008, Royal Society 2009, Lahav 2010, Mejia 2010).

In contrast there are far fewer sources of career advice available for part-time professional women (Marincola 2002, Hosey 2007, Monosson 2008), despite the fact that many women take substantial career interruptions and/or work part-time for up to a decade or more to care for their children (Baxter et al. 2007, Herman and Webster 2010). Part-time roles remain uncommon in both industry and academia. For instance, in Australia only 12% of engineers and 16.5% of scientists have part-time positions (APESMA

2007). Thus women who work part-time do so in a system designed for full-time employees, in the absence of comparable role models, which may explain why career progression problems for part-time engineers are still common (Mills et al. 2008).

While the university sector is frequently perceived as a flexible family-friendly working environment, the competitive nature of research funding based on a typical career path (Bell 2009) and the increasing use of metrics developed for and by people with full-time continuous careers, actually produce substantial barriers to successful part-time careers, and the re-entry of people to academia after a break to raise children (Marincola 2002, Sax et al. 2002, Bell 2009, Lawrence and Garwood 2011).

Given that recent studies in western Europe, USA and Australia indicate that most mothers wish to work less than current full-time hours (Baxter et al. 2007, Corral and Isusi 2007), career interruptions and part-time work are likely to be a key feature of workplaces in the future. Hence increasing female representation in senior academic roles will require an increase in the availability and feasibility of long-term part-time roles, and the facilitation of re-entry to workforce after career interruptions.

This paper analyses the challenges currently faced by academics in the science-engineering sector working part-time or re-entering the workforce after career interruptions to care for their families. Through modelling and an analysis of the characteristics of research and teaching duties, we identify the structural mechanisms which drive women away from research and towards teaching. We use this analysis to provides suggestions for how managers can support their part-time staff, and how administrators can increase the feasibility of working part-time within their organisation. These issues are framed throughout this paper in terms of women, because they represent the majority of family primary care-givers and part-time workers and because optimal child-bearing years for women coincide with the critical time for establishing a career. However many of the same issues will apply to men who wish to work part-time or re-enter academia after career interruptions to care for families.

Research dynamics

Teaching and research (T&R) are the two key responsibilities of most academic positions. Research output, as measured by impact, publications, student supervision and funding, operates in a strong reinforcing feedback loop in which success is rewarded with further success: funding is required to perform research, and funding is awarded on the basis of track record, i.e. research success to date. Similarly high quality graduate students, postdoctoral fellows and collaborators are attracted to individuals with a history of strong research performance.

Research output is frequently assumed to be linear with time, i.e. half-time academics are expected assumed to publish half as many papers as a full-time academic. However a linear model fails to account for the feedbacks outlined above. We propose an alternative model: high research output builds research expertise and track record, which subsequently allows future output to be generated more rapidly, until some maximum (sustainable) output is reached.

These dynamics are analogous to population growth, where population growth rate increases with population until some 'carrying capacity', or maximum population is reached. A typical population dynamics model (Scheffer 2009) may thus provide a suitable model for the growth of research output over time for an individual:

$$\frac{dR}{dt} = rR\left(1 - \frac{R}{R_{max}}\right) \quad (1)$$

where R is research output as measured by a research quantity metric, R_{max} is research potential, i.e. the maximum sustainable research output achievable by a particular individual in given circumstances and r is the research generation rate (year^{-1}), i.e. the rate at which existing research output generates further research outputs. The maximum sustainable output R_{max}, is assumed to be affected by time available for research, as well as other factors including individual abilities in generating research output, resources available, effectiveness of collaborations, ability to attract good students and funding. The rate at which research output generates further output (through attracting funding and collaborators), as represented by the research generation parameter r is assumed to vary between individuals and institutions, and to be unaffected by time available.

Equation 1 is plotted over time in Fig. 1 for a range of parameters R_{max} which reflect the different time available to academics for research, depending on their teaching load and part-time status, assuming that research generation rate r is not affected by time available. This figure could be seen as comparing the output of individuals of similar capability, with access to comparable resources working in the same field, but with different time allocated to research. The well-known 'research start-up' phase is clearly illustrated in Fig. 1; the time at the start of a career where research output is low (Trifunac 2006, Kelly and Jennions 2006). What is also illustrated in Fig. 1 is that the research potential R_{max} impacts the the duration of this start-up phase in a non-linear manner; the start-up phase for the

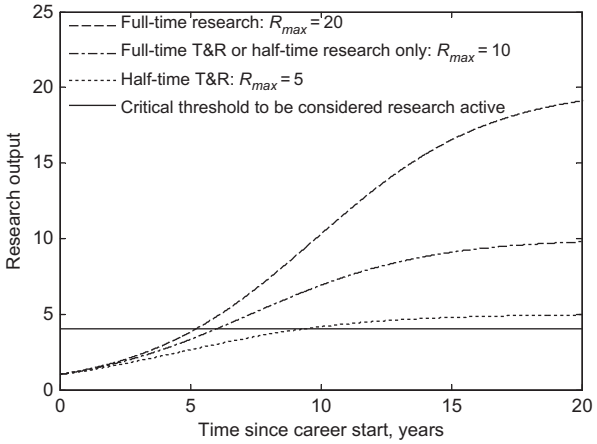

Figure 1. Impact of part-time work and teaching responsibilities on time taken to exceed critical threshold to be considered research active at start of career: Eq. 1 plotted for maximum research potential R_{max} corresponding to 100%, 50% and 25% full-time equivalent research respectively, with research generation rate $r = 0.3$ year^{-1} is constant.

half-time teaching and research academic (25% research full-time equivalent) is substantially longer, and the start-up duration for the 50% full-time equivalent research case is much more similar to the 100% than the 25% case. If the ability to generate future research output from current output were also scaled with time available, the difference between the three cases would be even more marked.

While the model is simplistic, and does not account for major break-throughs, career interruptions, funding cycles, publication lags or inter-annual variability, Fig. 1 does capture the essential feature of research output; that research output is not linear with time, there is a 'lag' in research output in the early stages of the research 'start up curve', and that success generates success.

Minimum critical mass

The concept of a minimum 'critical mass' often used to describe the minimum output or size required for a successful research centre (Kenna and Berche 2011) or the point at which research output becomes self-sustaining. In population dynamics, this is referred to as the 'Allee effect', whereby the birth-rate for a species will decline if the population falls below a critical level (Scheffer 2009). Equation 1 can be extended to include this phenomenon by introducing R_c, the minimum critical output required to generate further research (cf. Scheffer 2009):

$$\frac{dR}{dt} = rR\left(1-\frac{R}{R_{max}}\right)\left(\frac{R-R_c}{R_{max}}\right) \quad (2)$$

If research output is less than R_c, Eq. 2 indicates that dR/dt becomes negative, i.e. research output declines (Fig. 2). In academia, when track record remains below the critical threshold (R_c in Eq. 2) beyond the expected early career stage, the individual is likely to be labelled 'Research inactive', i.e. will be uncompetitive in most funding schemes, and will experience difficulty in attracting high quality students and collaborators. The minimum threshold also reflects a minimum amount of expertise and knowledge ('research capital') required for productivity.

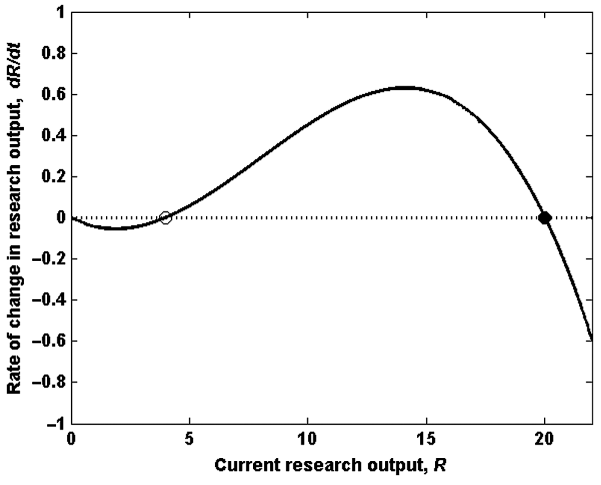

Figure 2. Impacts of current research output on future research output, as predicted by Eq. 2 for $r = 0.3$ year^{-1}. The closed circle marks the stable equilibrium at maximum research output ($R_{max} = 20$). The open circle marks the unstable equilibrium at maximum research output ($R_c = 4$): research output declines for $R < R_c$, increases for $R > R_c$.

While Eq. 1–2 can be plotted for various different parameter values, the implications of Fig. 1–2 are clear: it will be very difficult for part-time T&R staff to compete for funds with full-time staff, or even part-time research-only staff. Part-time academics will need very effective collaborative arrangements to survive in this environment. A particularly effective model would be to have part-time researchers filling a very specific role within an existing research group, for example modelling, whereby they can contribute to the team, while maintaining and developing their expertise and connections, without needing to lead funding applications or have a complete knowledge of current literature at this stage of their career. However it may be difficult to develop this arrangement after having children, because once research output falls below a minimum critical value, it becomes difficult to find high quality collaborators.

Competing timescales

Two critical aspects of research dynamics are demonstrated in Fig. 1–2; that a minimum track record is required to generate further research, and that it takes time to move beyond that minimum threshold (Trifunac 2006). Since the majority of PhD completions occur around the age of 30 (Dever et al. 2008), most researcher will spend a significant part of their thirties in the research start-up phase depicted in Fig. 1.

Here lies the challenge for women who wish to work in academia but take substantial time out to have their family. If they delay having children, they can get their research output above the critical threshold where it becomes sustainable. Thus their track record would enable them to attract effective collaborators, and continue to remain research active, even with much less time on the job: it is easier to maintain than to develop track record in research, and this is reflected in the model applied here.

Spending five years developing a track record prior to having a family would typically leave women in their mid to late thirties at the time of their first child, at time at which fertility drops off markedly (Khatamee 1988). In contrast, having children when younger has many advantages, but women who do so will find it very hard to obtain or maintain a teaching and research position unless they either work full-time, or choose between teaching and research.

Competitive exclusion: death by metrics

Quantitative metrics such the h-index, number of publications and/or citations, journal impact factors etc are now commonly used to assess research performance even though their flaws are well known (Amin and Mabe 2000, Kelly and Jennions 2006, Symonds et al. 2006, Trifunac 2006, Lane 2010). These measures reinforce the 'success to the successful' system archetype (cf. Meadows 2009) which characterises research in academia, and women are known to perform worse than men in these metrics (Symonds et al. 2006).

Metrics are used by managers to encourage behaviour towards a particular organisational objective. In the case of

research, these metrics are used by universities and scientific organisations to promote research productivity, with an emphasis on publishing research in well-regarded journals, and having that research cited by others. However no single metric can capture all of an organization's priorities. Focussing too strongly on a single objective can damage resilience, by reducing diversity in both how the organisation functions, and how it responds to change (Walker and Salt 2006).

In this case, while application of research metrics by managers may increase the research performance of their organizations, it will also provide dis-incentives for employing part-time academics, or academics returning from an extended career break (e.g. after having children), because their position on the research start-up curve will adversely affect the overall performance of their department or faculty as defined by the metrics. As a result, high achieving women are often excluded from science and engineering research simply because they have followed a non-traditional career path. Furthermore the nature of this 'success to the successful' paradigm, reinforced by metrics, can be very demoralising to capable women working hard in a system in which they are unlikely to ever succeed because they cannot obtain the critical mass. To compare their performance against full-time research-only staff using a metric which does not account for either part-time status or teaching load is unfair and destructive.

To address this problem, managers need to ensure that metrics are applied in the context of each researcher's position in their career, especially part-time status and teaching load. Furthermore, universities should identify where metrics may undermine other key organisational objectives (e.g. higher representation of women), and put in place systems which restore balance (e.g. scholarships, research grants and seed funding which target women whose research careers are affected by family responsibilities).

Lecturing: the ideal part-time role, or a female ghetto?

The models introduced in Eq. 1–2 demonstrate the mechanisms of research dynamics which pose challenges to part-time academics, or those returning from a career interruption. From this it is possible to define characteristics of a role in which it would be possible for women to succeed while working part-time or following a career interruption to raise children:

- skills and qualifications required for the job can readily be obtained before having children, i.e. by the age of about 30;
- success depends on performance in the role, rather than accumulated historical performance;
- success depends on the performance of the individual in the role, rather than competition with others (analogous to assessing student performance based on outcomes rather than a bell curve);
- tasks of clear size can undertaken in discrete pieces, with some flexibility in timing;
- performance does not require a minimum critical participation rate; i.e. 20% of the job could be completed in approximately 20% of the time.

All of these criteria are satisfied to a large degree by university lecturing; while expertise is certainly developed over time, the qualifications and basic skills can readily be acquired by the age of 30. A person can teach one component of a course extremely well, with a relatively small time commitment. The timing is predictable, and while the lecture times are fixed, preparation can be done with very flexible timing.

The contrast with research is stark, and explains the observed 'gender intensification' (Bell 2009) or 'female ghetto' effect, where women are over-represented in teaching roles, and then find if difficult to be promoted because they do not meet research performance metrics (Bell 2009).

There are also pressures on managers which may lead them to encourage their part-time or career-break staff into teaching-focussed roles. These people are likely to perform poorly under most research metrics, and so reduce the overall performance of their department or faculty. Furthermore in areas such as maths and engineering where the male: female ratio is proportionally much lower for staff than students, female lecturers are frequently allocated substantial teaching loads and associated pastoral roles to provide an obvious female presence for students (Bell 2009).

Conclusions

Getting female students in the doors of university is the easy part. A real measure of success of female participation in engineering and science is their position in the workforce one, two and three decades later, which ultimately must account for women's role as primary care givers in most families.

Because of the inherent 'success to the successful' structure of research, there are many barriers to initiating a research program while working part-time in a teaching and research role, or returning from an extended break out of the workforce. This is due in part to the inherent nature of research, the non-linear relationship between time and output, and the need for uninterrupted time which are extremely difficult to create when working part-time, teaching, and being the primary care-giver for children. However it is also reinforced by metrics and assessment of track record which do not adequately account for part-time status, career interruptions and teaching commitments. Since the rapid research output development phase coincides with the final decade of childbearing for women, many women simply don't get past the critical threshold, and are unable to participate.

In contrast, university teaching provides many of the features of a successful part-time role, in that success depends on the individual's current performance rather than historical accumulated performance. Telling the students you gave good lectures last year would not count for much this year! Finally, and perhaps most importantly, the skills and qualifications required for teaching can readily obtained by the age of thirty, the job can be readily re-entered after a prolonged absence, and there is a low threshold for participation; a person may give ten or one hundred excellent lectures in a year.

As a result, women working part-time while caring for their families or returning from extended maternity leave

tend to cluster in teaching. This 'female ghetto' provides women with the opportunity to participate in the workforce while still having retaining substantial time and energy for their family. However the accumulation of women in teaching does reduce their opportunities for promotion and job security and removes a substantial pool of very intelligent, capable people from active research.

Without direct action, this trend is set to continue; increasing assessment of university performance using research quality metrics developed for full-time uninterrupted employment is likely to reduce gender diversity within the research workforce, and so reduce the pool of talent from which researchers are drawn.

Recommendations

For women working in part-time roles in academia: *how to survive*

Focusing on either research or teaching is currently the best model for part-time academics. Working in a research-only role as part of an established research team will enable you to maintain your expertise and track-record, and move into teaching at a later date. A teaching-only role will enable you to maintain networks, expertise and confidence while caring for young children; however moving back into research after a prolonged absence will be very difficult.

The current paradigm means that working part-time in a Teaching and Research (T&R) role is very challenging. Since current expectations and systems cater primarily for full-time continuous employment, you will need to:

- *Be cunning*. Ideally find a position as part of a strong, effective, collaborative research team where your expertise is valued, your part-time status is accepted, and you can work with established researchers. This may require compromise and strategically concentrating on one key research area. Identify opportunities to build expertise and connections with minimal time input, find useful mentors and compartmentalise your time very effectively (see Lahav 2010 for useful tips).
- *Be wise*. You will be in the minority and you need to recognise that your worth is unlikely to be reflected in metrics which have been developed for, and by, people who have followed a more typical career path.
- *Be brave*. You may rate poorly on the ubiquitous metrics and may fail to meet various measures of success. You will need courage to choose a different path from the vast majority of your colleagues, a path that may not be recognised or rewarded in the obvious ways, and may be judged by many as a failure. Maintaining confidence in your abilities will be difficult under these conditions. Meeting with other part-time academics may help you navigate a system which was designed for and by full-time academics.
- *Be patient*. With yourself as you balance the demands of working to a high level in a competitive environmental and caring for a young family; with your managers and collaborators as they adapt to work with someone following a non-traditional career path, and with your children, who will grow up all too soon.

For women after a career break: *how to re-enter academia*

Landing a teaching and academic position after a substantial career break is both unlikely and unappealing, because the research start-up (or re-start) phase is quite punishing. Some universities and schools have re-entry schemes, however these will be competitive and so are likely to favour applications whose careers were well-established before they had children, and those with shorter career interruptions.

The best way to re-enter academia is via a part-time research only position, although this is currently rare. Re-entry through casual research or teaching contracts provides an alternative path, which may enable you to build up expertise, track record and contacts and so be in a position to find a permanent role at a later time. Good tutors and capable part-time post-docs/research assistants are valuable and hard to find: use this to your advantage.

For research group managers: *how to seize an opportunity*

Many very smart, capable women wish to re-enter research on a part-time basis as their families grow. If you can find innovative solutions to employ these researchers, you will have access to a relatively untapped pool containing some very talented individuals. These people are often secondary income earners in their families, in which case they may be less likely than other post-docs to move on after a few years, and may have the flexibility to adapt to workloads which vary with the cycle of grant success.

For university managers: *how to help part-time staff thrive*

Part-time staff will need good guidance to enable them to survive in the 'success to the successful' regime dominated by continuous full-time workers. Some strategies you can employ to assist them include:

- *Target time for research*. Allow part-time staff to load their teaching into a single semester so that they can have one semester with the continuous time required for effective research;
- *Fair teaching loads*. Ensure that part-time teaching and administration loads are fairly allocated compared to full-time loads;
- *Teaching relief during start-up phase*. allow time to develop a strategic plan and get the research started is critical for any starting academic (Hapgood and Hardin 2008).
- *Effective mentoring*. Ensure that part-time staff have good guidance, and assist them develop effective collaborations with other senior researchers.
- *Committee representation*. Women are often requested to serve on many committees for gender equity reasons, even when they are part-time. Whilst these initiatives are positive, there is a point where it unfairly reduces the time available to work on careers. If there are 20% women in the department, then only 20–30% of the departmental committees should have a female representative. Make sure that these committees are the important ones where their contribution has the most value.

For university administrators: *how to encourage a productive, diverse workforce*

The need to increase female participation in senior roles at university is a long-standing issue (Dever et al. 2008, Bell 2009) and will require reducing barriers to part-time work and to re-entering the work-force after a career break. We recommend considering:

- *Judicious use of metrics*. Aggressive application of metrics which do not account for part-time status, teaching duties or position on the research start-up curve will discourage female participation in academic roles.
- *'Return to Research' seed funding*. The competitive nature of research funding means that women who take extended time off to care for their family before establishing their research career will struggle to win even operating funds against those without career interruptions. Hence there is a need for specific funding schemes targeting those returning to research. Alternatively, support for part-time research-only positions may often be a worthwhile investment.
- *Under-writing post doc positions for 'return to research'*. A scheme to underwrite a post doctoral salary would enable 'return to research' staff to attract post docs, and work with the post doc to apply for competitive funding and so shift beyond the minimum critical research output required to be self-sustaining.
- *Short-list female applications*. A policy requiring at least one male and one female applicant be short-listed for all jobs would increase the opportunities available for academics who have worked part-time or had career interruptions to present their case at an interview when normally their CV would be overlooked.
- *Remove bureaucratic barriers*. Identify and remove institutional bias against part-time staff; e.g. ensure part-time staff are able to supervise PhD students, and apply for funding, and that performance metrics at least attempt to account for career stage, employment status, research only status etc.
- *Parental leave policy*. Generous maternity leave is only one half of the story. Without equally generous paternity/partner leave, it will institutionally enforce career disadvantage to women, as well as a family disadvantage to men.

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