Job Insecurity in Academic Research Employment: An Agent-Based Model

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Abstract

This paper presents an agent-based model of fixed-term academic employment in a competitive research funding environment based on UK academia. The goal of the model is to investigate the effects of job insecurity on research productivity. Agents may be either established academics who may apply for grants, or postdoctoral researchers who are unable to apply for grants and experience hardship when reaching the end of their fixed-term contracts. Model results show that in general adding fixed-term postdocs to the system produces less total research output than adding half as many permanent academics. An in-depth sensitivity analysis is performed across postdoc scenarios, and indicates that promoting more postdocs into permanent positions produces significant increases in research output.

Introduction

In recent decades the career landscape for academics has changed markedly. Upon graduating with a PhD, many aspiring academics enter a series of fixed-term postdoctoral research fellowships. Permanent positions are increasingly difficult to come by – in the UK, for example, only 3.5% of PhD graduates will succeed in getting an academic position (Powell, 2015). Intense competition for academic posts coupled with ever-increasing numbers of PhD graduates means that the academic workforce in the UK has shifted substantially toward fixed-term contracts – currently 68% of researchers in the UK are on fixed-term contracts (University and College Union, 2015).

Much has been written about the impact insecure academic working conditions can have on the individual. According to the University and College Union report *Making Ends Meet – The Human Costs of Casualisation in Higher Education* some 21% of UK academics on fixed-term or zero-hour contracts have trouble putting food on their dinner tables, despite many of these individuals having higher degrees and substantial experience. In the United States, adjunct professor positions – casualised positions in which teaching staff are paid per course or by the hour at very low rates, often without health insurance – now make up the overwhelming majority of academic positions on offer. Some 75% of US academics are now 'contingent teaching faculty', or adjuncts, a ten-fold increase since 1975 (Hoeller, 2014).

In the case of funding, evidence suggests that the current trajectory of academia – toward larger grants targeted at 'research leaders', which tend to bring more fixed-term postdocs with them – is not necessarily a productive one. A study of the projects funded by the National Sciences and Engineering Council of Canada found that scientific impact was a decreasing function of funding – bigger projects produced less impact per dollar than smaller ones (Fortin and Currie, 2013). Similarly, a recent study of 398 project PIs in the UK found that while productivity – number of publications – was positively correlated with funding, the relationship with impact factor and citation number was far weaker, and diminishing returns set in as funding levels rise (Cook et al., 2015).

While there have been modelling studies examining competitive research funding systems and illuminating some of these shortcomings (Geard and Noble, 2010), currently we are unaware of any attempts to model the structure of academic careers. This seems a significant oversight given the prevalence of stress and job dissatisfaction reported by postdocs worldwide (Van der Weijden et al., 2015). In such circumstances, could the stress and uncertainty of postdoc employment lead to substantial impact on research productivity in academia?

Given that the majority of postdocs are hired with grant funding, we suggest that understanding the impact of the trend towards fixed-term contracts will require an examination of both competitive research funding structures and insecure postdoctoral employment. This paper presents a first attempt at modelling a simple academic system which incorporates both of these key elements. We propose that modelling techniques drawn from complex systems science are highly appropriate for this kind of meta-research, as we need to explicitly represent the complex and inter-related nature of sector-wide constructs like research funding councils and academic career paths.

Utilising previous work on modelling research funding

(Geard and Noble, 2010), we have constructed an agent-based model in which established academics compete for grants while postdocs compete for tenure. By examining the impact of these interrelated systems on overall research productivity we seek a deeper understanding of how the trend toward fixed-term contracts in academic employment may have affected the academic community. Performing a detailed sensitivity analysis allows us to examine the impact of key model parameters on overall research output.

The Simulation Model

The simulation model used here is based substantially on previous work by Geard and Noble (2010). The same code base was used as a starting point, and the postdoc employment mechanisms were added on top of this core functionality. Model parameters and postdoc behaviour were inspired by the characteristics of UK academia. A brief summary of the funding model will be provided here; for further details, please see the original paper.

Core Research Funding Model

The model represents research funding as a competitive bidding process, in which academic agents submit proposals each semester in the hope of obtaining a grant. Here we assume that 30% of research proposals are funded, so agents attempt to get their research funded by investing time into bid preparation. The grant evaluation process in the model evaluates proposals based on the research quality of the submitting agent and the amount of time spent preparing the bid – we also assume diminishing returns on time spent.

Agents each have an individual research quality, which is a figure ranging between 0 and 1. Each semester, agents produce research output based on their research quality and modified according to their time allocation strategy for bid preparation. The final output numbers are conceptualised as ‘units of research’, i.e., scientific publications.

Agents who are funded benefit from an increase to their research quality, which is intended to represent the material benefits of research funding: increased resources, time bought out from teaching obligations, and so forth. However, getting proposals funded requires bid preparation time, which in turn reduces research productivity. Agents make these decisions by looking at their history of successful applications in the recent past and altering their time allocations to attempt to optimise their success rates – the ‘Memory A’ strategy in Geard and Noble (2010). Here we defined the recent past as the previous ten semesters, as shorter memories produced more chaotic application behaviour due to the volatility introduced by the regular influxes of new agents in the baseline and postdoc scenarios.

Baseline Model: Simple Growing Population

The core funding model begins with an initial population of 100 established academics which stays static as the simulation runs for 100 semesters. For this paper we first developed a basic extension of the model which assumes that some portion of the disbursed grant funding is used to fund additional permanent academic positions. This allows us to provide a simple baseline case to compare with the postdoc scenarios.

Every semester, a number of additional academics are added to the system equal to half the number of disbursed grants, rounded up. These academics are given a random level of individual research quality, which is reduced slightly for the first two semesters to represent their acclimatisation process as they join the ranks of tenured faculty. Otherwise these new academics behave identically to the established academics.

Postdoc Model

Postdocs were added to the simulation through the implementation of some additional mechanisms. While the core funding model remains the same, as does the behaviour of the established academics, in the postdoc case additional agents with unique properties are added to the simulation each semester.

When a grant is successfully funded, the agent who submitted the grant receives the same beneficial increase to their research quality as in the baseline case. In addition, every grant funds a new postdoc who is then added to the simulation. Postdocs differ from established academics in several key aspects:

1. Postdocs spend 100% of their time doing research
2. Postdocs are unable to apply for grants
3. Postdocs are on fixed-term contracts, ranging from 4 to 10 semesters in length
4. New postdocs experience the same small reduction in research quality as new academics in the baseline scenario
5. At the end of their contract postdocs experience a reduction in research quality for their final two semesters

Note that the inability of postdocs to apply for grants is not true everywhere – postdocs in the UK are unable to apply for grants, but can do so in Australia, for example. In some countries this varies between funding agencies, as in the United States.

At the end of a contract, some postdocs will be fortunate enough to get promoted into a permanent position. Promoted postdocs are converted into established academics, will become able to apply for grants, and must devote some portion of their research time to bid preparation. The likelihood of being promoted is determined by a parameter, the *promotion chance*, which will be examined in detail later in this paper. The default promotion chance is 15%, a rate which was thought to be reasonable after comparing the

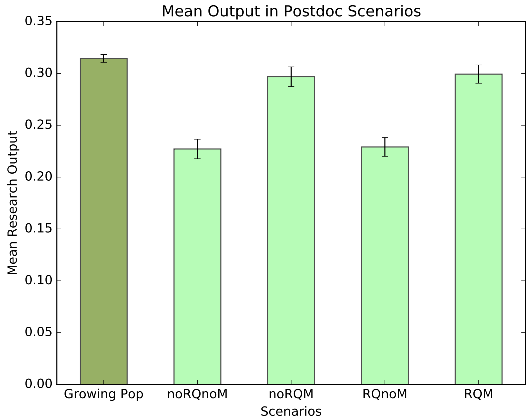

Figure 1: Mean research output per academic across five different scenarios. The Growing Population scenario does not include postdocs.

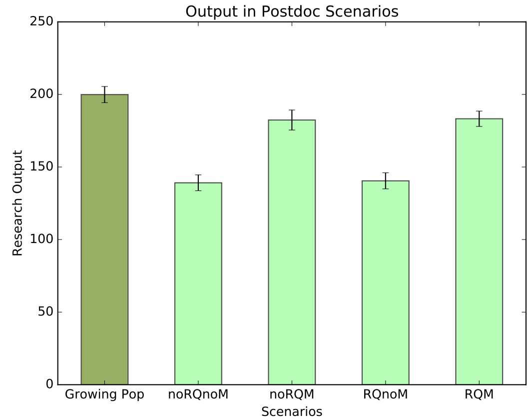

Figure 2: Total research output for the entire system across five different scenarios. The Growing Population scenario does not include postdocs.

widely variable statistics between different UK higher education organisations.

In the real world, promotion is not always a direct result of performance – timing, luck, geographical location, connections, and even nepotism can play a role. In order to examine the role of merit-based promotion in this model, we allow the promotion process to be set to either take into account an agent's research quality, or to promote a random selection of agents. In the former case, agents are ranked by research quality and a percentage of the top-ranked agents corresponding to the promotion chance will be advanced into permanent positions. In the latter case, a random sample of equivalent size is selected to be promoted. These two cases are referred to as *RQ* and *noRQ* scenarios in the Results section. Agents who are not promoted are removed from the system and may no longer contribute to research output.

In order to model the notion that postdocs provide useful experience and thus increase the quality of new permanent academics, we included an option for a *mentoring bonus* for newly-promoted agents. In the mentoring scenario, newly-promoted agents gain a significant bonus to research quality to represent the proposed benefit of this intensive research experience. The mentoring and no-mentoring scenarios are referred to later as *M* and *noM*, respectively. In the default scenario, the mentoring bonus adds an additional 0.5 to an agent's research quality.

Results

In order to examine the impact of fixed-term contracts on academic research productivity, we analysed the research output of a number of different scenarios. The first set of scenarios compares a variety of postdoc settings with the baseline growing population case. The second and third sets of scenarios investigate the postdoc model more deeply, looking at the impact of varying the promotion chances of postdocs and the levels of job-hunting stress they experience at the end of a contract, respectively. All three of these sets of scenarios used default settings of the key parameters as follows: postdoc promotion chance at 15%; mentoring bonus to research quality at 0.5; new postdoc stress and end-of-contract stress at 0.3. The mentoring bonus was turned off in certain scenarios.

Following these analyses, we recorded the results of 8,000 runs of the simulation across a comprehensive range of parameter settings and then performed a detailed sensitivity analysis. These techniques will be described in more detail in the Sensitivity Analysis subsection below.

Scenario Set 1: Postdocs vs Permanent Academics

The first set of scenarios compares four different postdoc scenarios to the baseline scenario in which the population consists entirely of permanent academics. These four scenarios correspond to the four possible combinations of the *RQ* and *M* parameter settings described above:

Table 1: Postdoc Scenarios – Set 1

Scenario Name	*Settings*
noRQnoM	Random promotions, no mentoring
noRQM	Random promotions, mentoring
RQnoM	Non-random promotions, no mentoring
RQM	Non-random promotions, mentoring

Figure 1 provides a comparison of mean research output per academic across these five scenarios. The results are averaged across fifty runs of the simulation for each scenario, and the error bars indicate the standard deviation. The basic growing population scenario outperforms all four postdoc

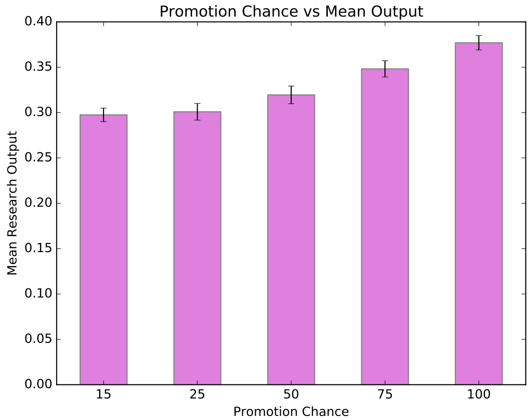

Figure 3: Mean research output per academic for five different values of the promotion chance parameter.

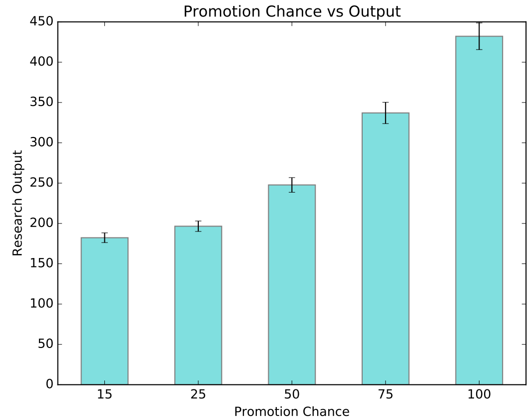

Figure 4: Total research output across the system for five different values of the promotion chance parameter.

scenarios on this measure; in the postdoc scenarios, mentoring appears to be the most important driver of increased research output. Perhaps surprisingly, promoting postdocs randomly or non-randomly seems to make little difference to the final outcome. Results suggest that the drop in research output in the postdoc scenarios may derive from the instability introduced by a constant influx of postdocs with unpredictable research quality; the fact that agents require a longer memory in the postdoc scenario in order to settle on stable time allocation strategies supports this interpretation. Postdocs are also ineligible for grant-related research bonuses, which negatively affects research output levels.

Figure 2 shows another comparison between the five scenarios, this time for total research output across the whole academic system. The figures displayed here are the mean final research outputs averaged across fifty simulation runs for each scenario. Again we see that the basic growing population case outperforms every postdoc scenario, even though only half as many permanent academics are hired in that scenario. Mentoring again takes precedence in the postdoc scenarios, as the mechanics of promotion seem to make little difference to the final outcome.

Scenario Set 2: Promotion Chance

In this second set of scenarios we compared the final outputs of simulation runs using five different values of the promotion chance parameter. This parameter sets the likelihood of a given postdoc being promoted into a permanent position. In this set of scenarios we used parameter settings for the *RQM* scenarios from Set 1, as these seemed to provide the most favourable results among the possible postdoc scenarios. All other parameters were kept at the default values indicated in the model description above.

Figure 3 shows a comparison of the mean research output per academic at the end of the simulation. Again each scenario was run fifty times and the error bars indicate the standard deviation. In this set of scenarios the 100% promotion scenario was the most successful; these runs gave us the highest values for mean research output out of any postdoc scenarios we ran.

In Figure 4 we provide a comparison of total research output across the entire system using the same five values for promotion chance. Here we see a marked increase in overall research productivity when 100% of postdocs are promoted – the mean total output is significantly more than double what we see at 15%. However, this clearly would be the most expensive option in a postdoc-employing academic world – in a later subsection we will examine the cost issue in more detail.

Scenario Set 3: Job-Hunting and Stress

In the third set of scenarios, we investigate the impact of job insecurity on research output. As described in the introduction, a number of studies of postdocs and fixed-term academics have revealed the difficult consequences of insecure and low-paid academic work on individuals. In order to represent the potential negative impact of these stressors, we have implemented a small research quality penalty, set to 0.3 by default, which represents the impact of postdocs needing to spend time searching for academic jobs, many of which require lengthy and detailed application processes to be completed, and the stress caused caused by impending redundancy.

For these analyses we again collected data from sets of 50 simulation runs for five different values of the key parameter, in this case the job-hunting/stress penalty applied to postdocs reaching the end of their contracts. We decided to set the upper bound for job stress at 0.7, as we felt it reasonable to assume that most postdoc positions, while potentially stressful, would likely not take up more than 70% of

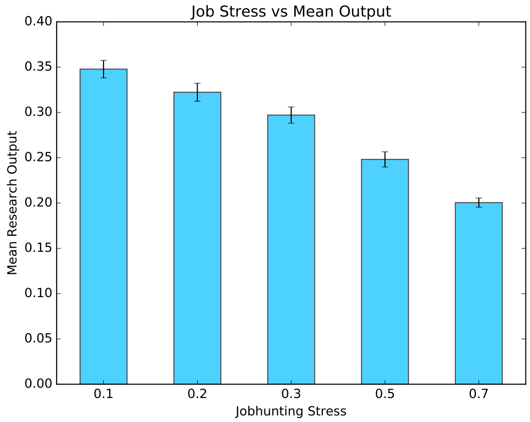

Figure 5: Mean research output per academic for five different values of the job-hunting stress parameter.

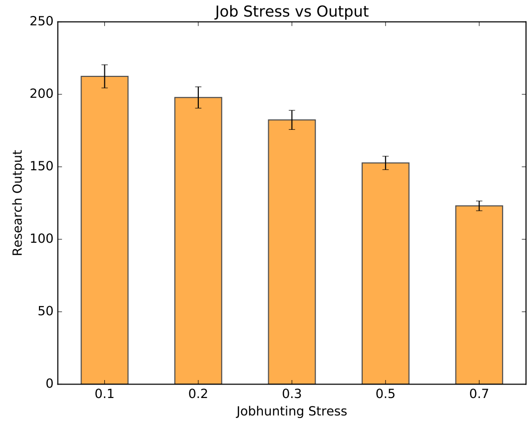

Figure 6: Total research output across the system for five different values of the job-hunting stress parameter.

researchers' time due to that stress.

Figure 5 shows a clear downward trend in mean research output for individual academics as the level of job stress increases, and Figure 6 shows a near-identical result for total research output across the entire system. We note that in all of these scenarios postdocs only represent approximately 10-15% of the total academic population at the end of a normal simulation run, and yet the impact of this stress parameter is very significant.

This result indicates the prominent role that even this small population of postdocs has in the research landscape. Established academics must divide their time between research and bid preparation, and failed bids often lead researchers to put enormous amounts of time into the next round of preparations. As a consequence, established academics tend to enter periods of 'feast or famine' in which they either spend all their time writing bids and failing to produce any research, or they succeed with several applications in a row and feel safe in reducing their bid preparation time in order to increase their research output – which is then further increased by the research bonus added by the grant itself.

In contrast, postdocs devote 100% of their available time to research, and since they cannot apply for grants they are not distracted from their work by the grant-funding lottery. During the average simulation run postdocs frequently average nearly double the research output of established academics, with only top-achieving grant-holders able to exceed their productivity. Postdocs thus take up the slack in the research community while everyone else fights to win grants. As a result, postdocs account for a significant fraction of the overall research output, and thus reductions to their productivity have a strong impact on the overall research output of the academic population.

Sensitivity Analysis

Despite the relative simplicity of the agent behaviours in this model, the system does incorporate a number of elements which may interact in unexpected ways. In order to further understand the dynamics of the model we looked to uncertainty quantification methods, which can allow us to delve deeper into the effects of each model parameter on research outcomes.

Our chosen method was inspired by a previous UK research project known as Managing Uncertainty in Complex Models, or MUCM (`http://www.mucm.ac.uk/`). The MUCM team developed some specialised software specifically for use in the analysis of complex computational models. One of these pieces of software, GEM-SA, implements a Gaussian process emulator, which allows us to perform an in-depth sensitivity analysis of complex computational models with multiple input parameters (O'Hagan, 2006), including agent-based models (Silverman et al., 2013).

Detailing the construction of Gaussian process emulators is beyond the scope of the current paper, so we recommend reading Kennedy and O'Hagan (2001) for further details. To summarise briefly, Gaussian process emulators provide a measure of the influence of each individual input parameter on the total output variance of the simulation. The emulator works on the assumption that the single output variable specified – total research output at the end of the simulation, in this case – can be understood as a composition of a series of main effects driven by the input parameters, interaction effects for all combinations of those parameters, and a constant term. In the current implementation, additional uncertainty introduced by the computer code itself is also taken into account. In essence, the emulator builds a statistical model of the computer model based on an input training set.

For this sensitivity analysis we chose four key input pa-

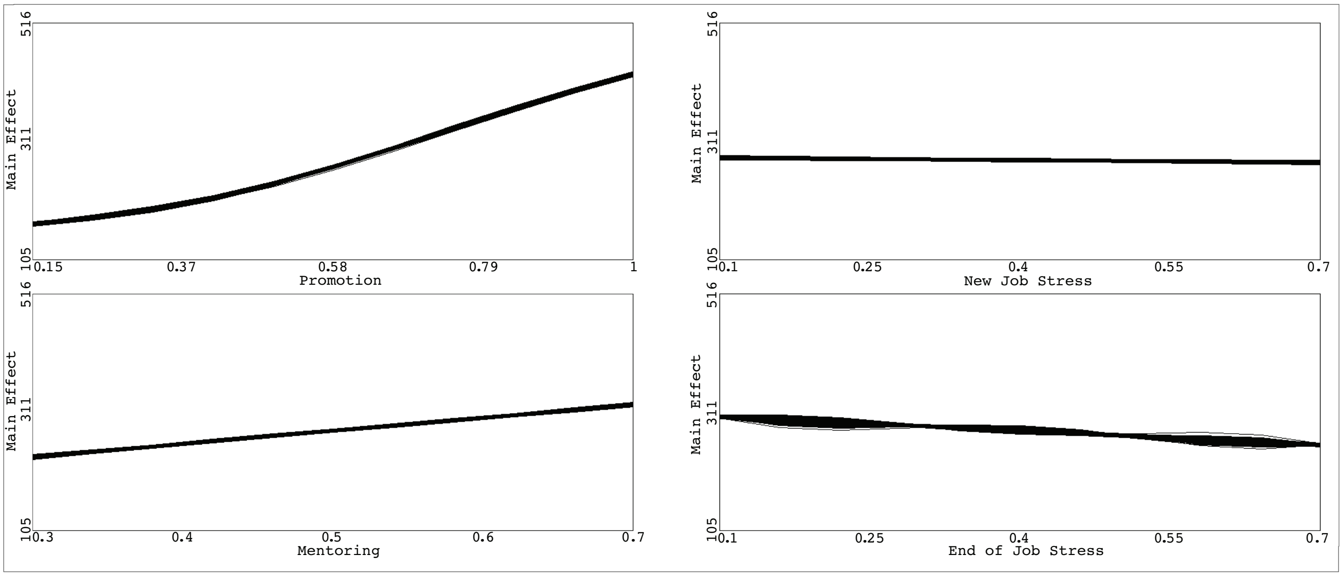

Figure 7: Results of Gaussian Process Emulator demonstrating the impact of four input parameters on final research output values for the whole system. The emulator was run with 400 different parameter combinations; each combination was run 20 times and the outputs averaged. Source: GEM-SA software (own calculations).

rameters – postdoc promotion chance, mentoring bonus for just-promoted postdocs, and the stress caused by entering a new position and by leaving a position. The final output of interest was the total research output across the system at the end state of the simulation.

GEM-SA requires a large training set in order to produce good results, so we generated a set of 400 possible parameter combinations for these four inputs – the maximum allowable in the GEM-SA software. Promotion chance values ranged between 0.15 – 1.0, mentoring bonus between 0.3 – 0.7, and job stress for both entering and leaving positions between 0.1 – 0.7. We then ran each one of those 400 settings 20 times, resulting in 8,000 total simulation runs, and took the mean of the total research output for each setting, then passed those results to GEM-SA.

Table 2 provides a summary of the GEM-SA output after 41,000 runs of the emulator. We can clearly see that the single largest driver of research output in these postdoc scenarios is the likelihood of postdoc promotion, which accounts for 86.43% of the final output variance. The mentoring bonus provided to newly-minted academics is the second largest contributor, accounting for 8.87% of the output variance. Job-hunting stress at the end of a contract plays a small role in the final results, but interestingly stress due to entering a new position is largely inconsequential – this could be due to the tendency for new academics to struggle to achieve consistent outcomes regardless of their stress levels, at least until they settle into a more stable pattern of bid preparation.

In Figure 7 we provide the graphs generated by the GEM-SA software, which show the effects of each input parameter on total research output. The graph demonstrates that as the postdoc promotion chance increases, the total research output increases as well – and once again the effect on the final output is significant despite the relatively small size of the postdoc population. Similarly, the size of the mentoring bonus applied to newly-promoted postdocs has a positive impact on total research output, although significantly less pronounced than the effect of promotion chance. Both starting a new job and reaching the end of a contract appear to impact negatively on research output, though the influence from the latter is somewhat variable. This makes intuitive sense, given that the amount of postdocs eligible for redundancy in each simulation will vary significantly depending on random factors in the simulation, in contrast to new-job stress which every postdoc is guaranteed to experience.

Table 2: Effect on output variance from input parameters

Parameter	*Variance* (%)
Promotion Chance	86.43
Mentoring Bonus	8.87
New Postdoc Stress	0.08
Job-Hunting Stress	2.57
Promotion x Mentoring	1.31
Promotion x New Stress	0.01
Promotion x Job-Hunt Stress	0.69
Other Interactions	0.02

Return on Investment

While the results to this point reinforce the interpretation that higher rates of postdoc promotion lead to greater research output, in the real world this would have substantial cost implications. Postdocs are welcomed by universities as employees given that their salaries are paid for by external funding in most cases – taking those employees on as permanent academics requires a significant investment from the university's point of view.

In order to better judge the cost-effectiveness of these scenarios, we implemented a very simple return on investment (ROI) calculation as a rough indicator of relative performance between scenarios. The simulation compares its total research output in a given time step to a funding-free scenario in which we calculate the research output of the current agent population if they were able to spend 100% of their time doing research only. Research outputs linked to funding – grant-related research quality bonuses and all postdoc research output – are removed. The ROI is then defined as the difference between the funded research output and the funding-free output, divided by the amount of funding disbursed. This gives us a measure of the amount of additional research purchased with each unit of funding.

Figure 8 shows a comparison of ROI for five promotion chance scenarios. Note that all results are in the negative – in other tests we also found that postdoc scenarios produced less research despite the increase in investment compared to the base case. Perhaps surprisingly, ROI becomes less poor in the higher promotion chance scenarios – so despite the additional cost, in a world with postdocs promoting more of them seems to produce dividends in terms of increased research output for the money spent.

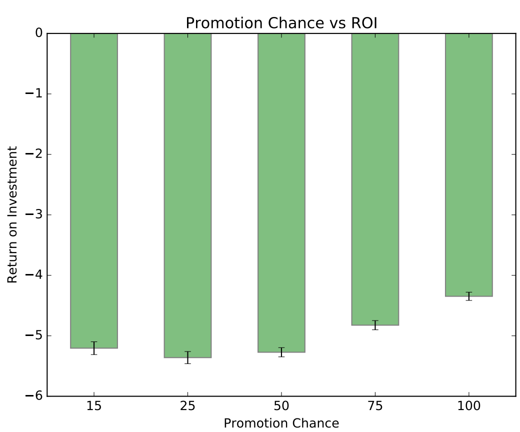

Figure 8: Results of ROI calculations for five postdoc promotion scenarios.

Discussion

While the core functionality of this simulation is relatively simple, understanding the complex agent behaviour and its consequences requires in-depth analysis. The multiple sets of scenarios presented here are intended to provide a relatively complete picture of the simulation outcomes across a range of parameter settings, and to give a comparison between the postdoc and non-postdoc scenarios.

In Scenario Set 1 we compared the postdoc scenarios with a growing population in which half as many permanent academics were hired. Notably, in every case the non-postdoc scenarios produced higher individual research productivity and higher total productivity. In Scenario Set 2 and 3 we examined two unique properties of the postdoc agents: their chance for promotion, and the job-hunting stress they feel toward the end of their contracts. We found that higher promotion chances lead to significantly higher research output, both individually and for the whole population. Unsurprisingly we found that higher stress leads to lower output – but the effects were surprisingly strong given the small size of the postdoc populations. The sensitivity analysis reinforces the results of Scenario Set 2, showing that postdoc promotion chance is driving the majority of the output variance in the postdoc scenarios.

These results lead us to conclude that in this simple model of postdoc careers in a competitive funding environment, the career path of postdocs has a significant impact on research productivity across the academic system. Postdocs end up accounting for a large fraction of the overall research output in the simulation while established academics get caught up in competing for grant funding, so the impact of job-related stress and poor mentoring is also felt across the population.

Unfortunately this does not bode well for real-world academia, as studies repeatedly confirm the poor mentoring and career development offered to postdocs around the world (Felisberti and Sear, 2014; Åkerlind, 2005). Postdocs regularly report significant anxiety about their career prospects, problems making ends meet financially, and a lack of career guidance and institutional support. The simulation shows that leaving postdocs to shoulder these burdens unsupported may have unexpectedly severe impact on our research productivity.

There are indications that this careers guidance aspect is being taken more seriously. In the UK institutions have signed up in large numbers to the Concordat to Support the Development of Researchers (Vitae, 2008), an agreement which calls on institutions and funders to develop strong frameworks for researchers' career development. However, this simulation suggests that offering supportive work environments and career advice may not be sufficient – maximising the sector's research potential would involve a more substantive rethink of the current state of academic careers and funding.

This simulation is only an abstract representation of the funding and careers situation in academia, and should not be taken as a recipe for policy at this early stage. However, these results do give us a sense of the dynamics at work between competitive funding systems and postdoctoral researchers. In a system which highly incentivises senior academics to spend significant time on grant applications, postdocs are intended to fill the research gaps – but when those same postdocs' careers are tied to insecure short-term funding, research funders end up actually getting fewer outputs for their money.

Future work will need to examine these systems in more detail. At the moment, grants are represented very simply: one grant is much like another; and any single grant only attracts one postdoc. Further differentiation between types of research funding may help us develop some new methods of research funding disbursement that could alleviate some of these issues. Future versions of the model would also benefit from additional detail on the postdoc life course – postdocs in this simulation only have one contract and one attempt to achieve promotion, whereas in the real world postdocs often work on a succession of fixed-term contracts.

Similarly, the treatment and experience of postdocs varies significantly between countries, disciplines, and even between individual institutions – this model is based on the postdoc situation at research-intensive universities in the UK. In the real world postdocs may face a wide variety of obstacles depending on where they may be employed, which could substantially change their coping strategies. Understanding the lived experience of postdocs through quantitative and qualitative studies and incorporating this data into a more sophisticated decision-making model would allow for a more detailed representation of the varied postdoc career landscape.

While these results look dire for the postdoc scenarios, we do not believe this is due to unjust assumptions on our part. This model is relatively optimistic: more postdocs get promoted in the simulation than in many real-world academic systems; ROI calculations do not include costs like redundancy payments or training costs for new postdocs; and 30% of all grants are funded regardless of the number of applicants. Even in this relatively positive environment, postdoc scenarios still underperform compared to non-postdoc scenarios, and our return on investment is quite poor. While we reiterate that the model is too early to serve as a driver for substantive policy, we suggest that it provides food for thought when the academic community wishes to evaluate its performance, both as researchers and as employers.

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