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ORIGINAL ARTICLE

Decision Theoretic Model of the Productivity Gap

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Abstract Using a decision theoretic model of scientists' time allocation between potential research projects I explain the fact that on average women scientists publish less research papers than men scientists. If scientists are incentivised to publish as many papers as possible, then it is necessary and sufficient for a productivity gap to arise that women scientists anticipate harsher treatment of their manuscripts than men scientists anticipate for their manuscripts. I present evidence that women do expect harsher treatment and that scientists' are incentivised to publish as many papers as possible, and discuss some epistemological consequences of this conjecture.

1 Introduction

Scientists who are women publish fewer research papers than scientists who are men (Erkowitz et al. 2008, pp. 409–410). This productivity gap has resisted explanation by science scholars (Cole and Cole 1973, pp. 136–137; Cole and Zuckerman 1987; Scott 1992; Fox 2005; van Arensbergen et al. 2012). Many theorists have attempted to identify factors which reduce the amount of time women have available to them to publish, and which, if controlled for, would eliminate a productivity gap between men and women scientists. Age, family status, and institutional affiliation (for instance teaching vs. research orientated institutions) are examples of factors which have been tried and have not yet been agreed to fully explain the productivity gap (Erkowitz et al. 2008, p. 410). Others have attempted to identify causes of the productivity gap. Causal explanations based upon the premise

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that women are on average less scientifically talented than men, or the premise that there is bias against women's submissions in gatekeeping or credit allocating processes have been tested. However, there is little-to-no evidence of any difference in aptitude between men and women (Cole and Cole 1973, p. 134; Xie and Shauman 2003, p. 55). And evidence suggests that when under anonymous review gender of author does not make a difference to a paper's acceptance rate (Lee 2016, pp. 3–4), and that, using citation count as a metric of peer recognition, on average women are as well cited as men per paper (Ceci et al. 2014, p. 125). Besides differences in talent, bias, and various lifestyle factors sociologists have accounted for, some suggest women are just inherently less productive scientific workers than men; see (Barres 2006, p. 133) for discussion of those who offer this hypothesis. Others suggest that something about the early socialisation of people who become scientists explains the productivity gap, e.g. (Cole and Cole 1973, p. 159–160). These explanations again rely on some facts about men and women, either relating to some inherent qualities or their socialisation, resulting in aggregate differences in talent which in turn results in producing different amounts of scientific research.

My goal in this paper is not to contradict or refute any of the above explanations of the productivity gap but rather to offer an as yet under explored alternative. Many of these previous attempted explanations have assumed at least one of: women are less talented than men, women have less time available to them than men, or gatekeepers are biased against women. The diversity of positions considered and alternately supported or rejected above is evidence that, at the least, explanations based on one or all of these assumptions have thus far failed to bring consensus to the literature on the productivity gap. In contrast, the explanation I focus on is based around the following ideas: women concentrate on producing high quality papers in response to an expectation that their work will receive greater scrutiny. Whether or not this expectation is accurate, producing such work is time consuming, so women then produce fewer papers overall. This explanation was first suggested in (Sonnert and Holton 1996, p. 68), and recently Carole Lee outlined institutional features of science that may result in women being systematically less likely to submit work for publication (Lee 2016, p. 3). The assumptions behind this explanation for the productivity gap have not before been explicitly modeled in any detail. By producing a formal model of this explanation type, I show that this explanation is strictly independent of the three aforementioned principles, by explicitly assuming that women and men are equally talented, have equal time available, and do not need to face gatekeepers. Being independent of those classes of explanation that have received the most attention in the literature to date, I hope it therefore offers a new way forward, and suggests new empirical inquiries to carry out, in a discussion that is at risk of becoming stagnated.

Further, using a model to be fully explicit about the behavioural assumptions underlying the conjecture under consideration has a surprising result. The aforementioned previous work on this conjecture by Lee, Sonnert, and Holton, all emphasises scientists' beliefs about how much time must be allocated to a project in order to produce a publishable unit. In the framework of the model, however, one sees that there is an additional factor playing an important causal role—scientists' beliefs about how the community rewards any additional effort put into papers beyond the point at which it is publishable. It is proven in the appendix that if scientists are incentivised to churn out as many minimally publishable units as they can, then we can give precise necessary and sufficient conditions for the existence of a productivity gap. These necessary and sufficient conditions are stated in terms of beliefs about how difficult it is to publish, and intuitively correspond to the explanation offered by Lee, Sonnert, and Holton. The model thus brings to the surface the role of the 'publish or perish' norm in producing and perpetuating a productivity gap between men and women. This allows me to discuss some of the epistemic consequences of this fact: I argue that the factors which produce a productivity gap are likely causing us to miss out on valuable sources of cognitive diversity, and offer some thoughts as to what policies may therefore be appropriate for closing the gap.

2 Three Key Claims

I will be considering an explanation of the productivity gap that relies upon claims about the relationship between men's goals in publishing, women's goals in publishing, and the length of time they believe is necessary to devote to a paper in order to get it published. As I will argue, the conjecture I develop is independent of previous work in not relying on posits about different talent or time available to men and women, or gatekeeping biases women or men must face. However, I also believe the premises this conjecture relies upon are, at the least, plausible in light of the evidence currently available about the social structure of science. To give the reader a feel for the conjecture, and to motivate it as plausible enough to be worthy of further investigation, I begin in this section by outlining and motivating three claims about gender and publication habits in science. In the next section I construct a model that allows me to draw inferences from these claims. As I show in Sect. 4 (formally in the "Appendix"), if my model of scientific publication sufficiently well represents the phenomena, these claims would suffice to explain the productivity gap, and would do so independently of those controversial premises incipient in previous work.

The first claim, which I shall refer to as 'claim (a)', concerns scientists' beliefs about the reward structure of science. Scientists believe that the credit system of science rewards more low effort papers over fewer high effort papers. That is to say, scientists believe they should churn out as many minimally publishable units as possible rather than invest more time than is necessary for publication into a paper. That claim (a) is true is supported by anecdotal data, by the policies scientific institutions adopt, by advice scientists give each other in published articles, and by survey data. Anecdotally, scientists complain of the fact that they are pushed to publish ever more papers at what they perceive to be ever lower quality. For instance, one published article bemoans the fact that "[t]he academic scientific enterprise rewards those with the longest CVs and the most publications" (Neil 2008, p. 2368). Likewise, Hamilton (1990) reports similar complaints from many scientists in response to evidence that most papers go uncited. Regarding policy, publishing as many articles as one can is often incentivised by tenure requirements in research departments—as is shown in the case of political science by Rothgeb and Burger (2009, p. 517). Qiu (2010) reports on evidence that cash prizes for publication incentivised Chinese academics to publish as much as possible. Such direct incentivisation of maximising publication is not unique to China; Australian universities receive extra funding based on their academic publication rates (McGrail et al. 2006). McGrail et al. go on to offer advice as to how to get academics to publish more. Likewise Hwang (2012) offers advice as to how to publish more papers in light of the fact that one is expected to publish or perish. There is also survey evidence that scientists "feel pressure to amass publications"; when asked why a certain sort of misconduct occurred 95 % of authors and 75 % of editors agreed with the quoted statement (Yank and Barnes 2003, p. 111). I hence take claim (a) to be borne out by empirical evidence concerning scientists' beliefs about how they will be rewarded for publications. Whether or not they are correct to believe as much (and see Cole and Cole 1967 for evidence that they are not), it seems scientists believe that the scientific reward structure favours publication maximisation.

The next claim, (b), is that the maximum number of papers women scientists think they can produce is less than the total number of potential projects they can envision working on. That is to say, women scientists do not think they have enough time to develop into a published paper all of the projects they could envision themselves working on. This claim is plausible in light of general familiarity with academic life: it is extremely rare for academics to feel they have enough time to successfully carry through all the projects they could envision. If this is true, then claim (b) will in almost all cases be true, because for all scientists of any gender an equivalent claim will almost always be true. However, as shall be seen, additional support for (b) comes from results in the model I produce when coupled with the observation that productivity gaps occur. I shall hence return to the justification of claim (b).

The final claim, (c), is that given how much time women think must be invested in a project to output a published paper, if they produce as many papers as they think possible they still would not produce as many papers as men would, given how much time men think must be invested in a project to output a published paper. Somewhat unwieldy though it is, (c) is the core claim of this explanation, and motivating it goes some way to motivating the explanation I wish to promote. It should be admitted at the outset that direct evidence for (c) is unavailable; I hope that interest in testing (c) is generated by the role I shall show it plays in this explanation for the productivity gap.

One way to argue for claim (c) is to show that it coheres well with what is known about the social structure of science. To this end I note two things. First, there is direct evidence that women are less confident in their own abilities in academia, which is plausibly linked to how much time one believes one must dedicate to a project before it becomes publishable. It was such evidence that prompted Sonnert and Holton to make their claim, for instance. Further, although it pertains to philosophy in particular, there is evidence that women come into academic study already less confident in their abilities (Dougherty et al. 2015b, p. 469). Relatedly, evidence suggests that beliefs that academics must have a certain brilliance to succeed has been shown to correlate with exclusion of some marginalised demographic groups, including women (Leslie et al. 2015). As Leslie et al. (2015) remark, female students may well internalise stereotypes of women as not being good at these disciplines in virtue of lacking this brilliance. That this could plausibly account for women being underrepresented in disciplines where belief in brilliance is widespread has been argued in (Dougherty et al. 2015a, p. 20). This same internalised stereotype could lead women who remain in the relevant disciplines to believe that, lacking the required brilliance their colleagues value so highly, they must work extra hard to 'make up the gap' between them and their peers. Note that this is not to invoke the assumption that men and women actually differ in talent, only to invoke the consequences of an internalised belief that such differences exist.

Second, evidence of a hostile workplace climate in science lends support to claim (c). Workplace climate refers to

> perceptions of the work environment, or perceptions of organizational policies, practices, and procedures, that can be formed through interactions and communication with others in the organization (Settles et al. 2007, p. 270).

There is ample evidence that women perceive the climate in science to be more hostile than men perceive it to be. Women scientists report perceiving the scientific workplace to often be sexist (Settles et al. 2007, p. 273). Similarly, a survey of successful women scientists found that, when asked what the biggest problems in laboratory climate were, 'the largest proportion of responses did suggest that, to some degree, their gender led to them being perceived as a problem, anomaly, or deviant in their laboratory or work environment' (Rosser and Lane 2002, p. 175). Although this response was not universal, it was a non-trivial number of women scientists (Rosser and Lane 2002, p. 178). Similar results were found when a larger pool of women scientists were polled (Rosser and Daniels 2004, p. 140). Whereas a far smaller number of men scientists report feeling discriminated against based on their sex (Sonnert and Holton 1996, p. 66). Second, differential (and greater) perceived hostility of climate features in sociologists' explanations of why women choose not to enter scientific fields (Glover 2002, p. 42). Third, direct evidence for the proposition is given in (Gunter and Stambach 2005), which reports survey evidence that

> [a] smaller percentage of women than men described their workplace environments in positive terms, and a larger percentage of women than men described uncomfortable, tense, or hostile interactions (Gunter and Stambach 2005, p. 97).

When it comes to climate to be perceived is to be; hence, the climate for women in science is more hostile for women than men.

Claim (c) is true if there is a sufficiently large difference between how difficult men think it is to get a paper published and how difficult women think it is to get a paper published. Available evidence does not presently allow us to determine the exact difference between men and women's beliefs about the difficulty of publication. However, evidence of a more hostile climate faced by women is arguably evidence that women will believe it is harder to produce publishable work than men believe it is. Women scientists may come to expect that gatekeepers are explicitly biased against them and are looking for reasons to reject one's work. Such expectations are not without reason, as in situations where peer review lacks anonymity women can find themselves discriminated against on the basis of their gender (Wenneras and Wold 2001). This may cause women to engage in a time consuming exercise of preempting biased evaluation by shoring up their work against hostile scrutiny (Lee 2016, p. 3). Alternately, women scientists may believe that poor treatment is a consequence of their poor work, and thereby think of themselves as someone who must check and double check their work before it is publishable. This is supported by the fact that a large number of surveyed women scientists report lower confidence in their ability than men (Fox and Firebaugh 1992). Further, this lack of self-confidence in scientific ability has been linked to experience of hostile climate in at least one study (Sonnert and Holton 1996, p. 67). Finally, when women are editors of scientific journals they have higher standards than when men are editors regarding what is publication worthy, suggesting that they have internalised harsh standards of critique (Lee 2016, Section 1). Both expectation of bias and internalised negative self-evaluation could explain women scientists self-reported tendencies towards 'perfectionism', and unwillingness to affirm their results until a higher standard of proof had been met when compared to men scientists (Sonnert and Holton 1996, p. 68; Osbeck et al. 2011, p. 185). The evidence that women experience a more hostile workplace climate in science than men could therefore be evidence that women will believe more effort is required to generate a publication worthy piece.

3 Scientific Time Allocation Models

In order to draw out predictions from claims (a)–(c) I construct a model of scientists' decision making about allocating time among research projects. Since the productivity gap arises out of the aggregate behaviour of a great many people some simplification of the phenomena are necessary for modelling purposes. Scientific time allocation models are simple yet none the less powerful enough to generate predictions from claims (a)–(c). Further, they are models of subjective decision making. This means that they further my aim of exploring a conjecture independent from previous empirical work, since they model the consequences of reasoning that occurs before any formal gatekeeping may introduce bias against women.

This section consists of an informal description of the model, with formal description and proof of results found in the "Appendix". In the model there are two agents, the Representative Man Scientist and the Representative Woman Scientist, facing a decision about how to allocate a fixed budget of time between different potential research projects. This represents the scenario, for instance, faced by a pre-tenure scientist trying to decide what to work on before the tenure clock runs out, or an academic deciding which projects to spend their time on during a sabbatical. The aforementioned efforts to explain the productivity gap by sociologists suggests that a productivity gap exists even for men and women scientists who work for the same amount of time. To represent their budget of time in the model, therefore, each agent in the model can allocate any real in the interval [0,1] to a project, and the sum of all their time allocations cannot exceed 1. Note that I have therefore assumed that the agents have the same amount of time available to them, ensuring the results of this model are independent from those explanations which posit a productivity gap arising from men and women having different amounts of time available to them. Each agent in the model is characterised by three things. First, how many potential projects they may allocate their time between, I call the set of such projects their idea set. Second, how much time they think it takes to turn a potential project into a published unit, I call this their *G* function. Third, how much credit they think the scientific community will award them for a piece of work given how much effort they have put into it, I call this their *C* function.

I make the following three assumptions:

1. [Analytic Egalitarianism] All agents have the same number of potential projects to decide between.
2. [Idea Homogeneity] Agents believe all potential projects have the same potential to be accepted for publication and generate credit if given equal attention.
3. [Credit Maximisation] Agents wish to accrue as much credit to themselves as possible.

These assumptions are compatible with a wide variety of *C* and *G* functions. Scientific time allocation models thus have the flexibility to represent a wide variety of attitudes to publication that scientists could hold.

Assumption (1) is an egalitarian assumption about the distribution of scientific talent between men and women. The cardinality of an agent's set of potential projects is the only part of the model that does represent scientific talent, in all other ways the structure of the model presupposes the agents equally well endowed with talent and time. Using the cardinality of ideas sets as a way of modelling talent is based upon Merton's work on cases where researchers working separately come to discover the same fact or achieve the same result at about the same time. Merton found that those recognised as geniuses in the history of science tend to be involved in more such incidents of multiple independent discovery; they tend to be involved in multiple multiples (Merton 1961). Merton's discovery suggests a connection between the number of projects one can envision working on and one's talent as a scientist. With this in the background, assumption (1) is explicitly an *a-priori* assumption of an egalitarian distribution of talent between the Representative Man and Representative Woman scientists. Hence if productivity gaps can be shown to arise in scientific time allocation models satisfying assumption (1) it will be evidence that productivity gaps are consistent with egalitarian presumptions about men and women's scientific capacities. It is worth noting that I have abstracted away from many sources of potential differences in talent between men and women. This itself is an additional egalitarian modelling presumption. The term "Analytic egalitarianism" is drawn from historical work on an egalitarian tradition in economics, wherein it was assumed that agents are homogenous and differences in outcome were explained by pointing to difference in incentives or institutional arrangement agents face, differences in luck, or differences in initial wealth endowment—see (Peart and Levy 2005, ch. 1) for details. Since I shall explain the productivity gap by appealing to differences in how men and women scientists experience the institutions of science, my explanation of the productivity gap in science is an instance of the analytic egalitarian explanatory strategy.

Assumption (2) is worth restating more formally. The agent's *C* and *G* functions take some amount of time which has been indexed to some particular project within their idea set, and output a value. Assumption (2) says that the value outputted by the agents *G* and *C* functions depends only on the amount of effort allocated and not on the index, i.e. not on which particular idea that effort is being spent on. Further, assumption (2) builds in a requirement that the value of *C* monotonically increases with the amount of effort allocated to a project. It is worth noting that assumption (2) does not require the agents to make comparative judgements concerning each other's work, nor does it specify any particular relationship between the agents' *C* functions or *G* functions. Rather, assumption (2) concerns something 'internal' to each agent; it says that the agent does not differentiate among their own projects in terms of how publishable or creditable they are.

Idea Homogeneity is retained throughout the paper, but the appendix ends by noting the interesting possibilities raised by modifying this assumption. I show that if agents can type their ideas into high effort/high reward versus low effort/ low reward then productivity gaps can arise under circumstances quite different from those which produce productivity gaps where Idea Homogeneity obtains.

Assumption (3) places this work in the broader tradition of studying the manner in which science or academia functions as a credit economy. Taking scientists to be concerned with how much credit (prestige, acclaim, recognition, etc) they can gain through scientific publication has shown its theoretical usefulness in previous work on the economics and social epistemology of science, e.g. (Kitcher 1990), (Dasgupta and David 1994), (Stephan 1996), (Strevens 2003). This assumption also meshes well with sociologists' and anthropologists' observations of scientists at work (Merton 1968; Latour and Woolgar 1986, ch. 5; Lamont 2006, p. 34). Assuming that scientists are credit maximisers therefore has the doubly beneficial effects of ensuring the model of scientists motivations has some empirical support, and that the explanation of the productivity gap here forms part of a unified, coherent, picture of the social epistemology of science currently under construction.

Further, not only does the Credit Maximisation assumption connect to previous empirical and theoretical work on the social structure of science, it is also directly justified by the purposes of this model. This is strictly a model of scientists attempts to generate publishable articles, rather than other aspects of scientific research. By assumption (3) the scientists are seeking to allocate their effort so as to generate the maximum amount of credit. However, *G* functions are step functions; defined so that scientists in the model will not expect to gain any credit from an idea that they do not think has had enough effort allocated to it to be publishable. Since agents in the model are rational credit maximisers they will therefore not allocate any amount of time below whatever threshold their *G* function sets for publishability—this is lemma 3 in the “Appendix”. The model therefore only represents scientists in so far as they are allocating some fixed (and equal) budget of time between potential publications. This strict focus on attempts to publish is an idealisation of scientific research activity; for instance, it does not represent attempt to win credit by informing the press of one’s results. This idealisation is justified by the fact that the target phenomenon is a gap in publications under the assumption that everyone has the same time to dedicate to research projects (Yap 2014).

I will illustrate the model at work with two examples. The agents’ *G* functions are represented by the lowest number *r* such that each agent respectively thinks that a project with *r* amount of time dedicated to it would be published. Note that this is an abuse of notation, since technically *G* is a function of time invested in a paper rather than a constant. I label the Representative Man Scientist’s functions with *m*, and Representative Woman Scientist’s functions with *w*. With their functions given in the top row, the amount of effort put until a project represented by *n*, and the number of papers they are spreading their effort between on the far left, the following table illustrates a scenario where the model predicts a productivity gap:

	$< G_m = 0.5 \,\&\, C_m(n) = 1 + n >$	$< G_w = 0.6 \,\&\, C_w = C_m >$
1 Paper	$EU_m = 2$	$EU_w = 2$
2 Papers	$EU_m = 3$	$EU_w = 1.6$

Each agent has two rows, representing the fact that they both have two potential projects they can allocate effort to. For each row, the agents attempt to invest into each potential project as near as they can to the minimal *r* that is the cutoff point for their G function. Note that if their $r > 0.5$ they will not be able to allocate minimal publishable effort to at least one project if they attempt to divide their time between two projects. Once the agents have allocated as near as they can to *r* to however many projects they are attempting to have published then lemma 2, proven in the “Appendix”, shows they will then distribute all their remaining effort amongst the papers. As mentioned, the *G* functions ensure that if agents do not allocate enough effort to an idea to get it published, they expect to receive no credit from that idea. There are multiple possible allocations of effort between projects corresponding to each row in the table, but the Idea Homogeneity assumption ensures that all allocations of effort corresponding to the same row of the table generate the same expected utility for the agent.

Given their *C* functions, both agents expect to be equally well rewarded for their investment in any project that does get published. Further, both would prefer to publish more papers rather than less. However, given their different *G* functions, the Representative Man Scientist thinks himself capable of converting both potential projects into published papers, whereas the Representative Woman Scientist thinks that if she spreads her efforts between both projects only one will result in a publication. Hence if the Representative Woman Scientist invested .6 into the first paper, earning herself an expected 1.6 credit from that paper, the .4 remaining credit she could devote to the second paper would simply be wasted according to her *G* function, and she would not expect to gain any reward from so investing it. The Representative Man Scientist thus opts to work on two projects, investing the minimum amount of effort into each that he thinks is required to get the relevant ideas published. The Representative Woman Scientist invests all her effort into just one project. A productivity gap arises between the Man and Woman scientists, even though both had the same number of potential projects and both expected to be equally rewarded for published work.

Contrasting this example with another, where the agents' *G* functions are identical, each thinking, unrealistically, that no effort at all is required to render a piece publishable. However, they have different *C* functions:

	$< G_m = 0 \,\&\, C_m(n) = 1 + n >$	$< G_w = 0 \,\&\, C_w(n) = n^2 >$
1 Paper	$EU_m = 2$	$EU_w = 1$
2 Papers	$EU_m = 3$	$EU_w = < 1$

Entries to the table are calculated in the same manner as with the previous table. The fact that the Representative Woman Scientist thinks herself able of publishing multiple papers, due to her *G* function, but would choose to allocate all her time to just one paper makes clear the formal distinction between credit maximisation and paper maximisation, although the conjecture I develop involves collapsing the two. Assumption (3) says that agents want to maximise their credit; but I have not presupposed that agents will seek to do this by producing as many papers as possible. The comparison between this example and the last highlights the following consequence of this model: there are multiple ways a productivity gap can arise consistent with the model.

Before moving on, I note that Theorem 1 proven in the "Appendix" suggests that one will be able to use scientific time allocation models to determine whether a productivity gap is predicted whenever one can calculate the agents' preference orderings over potential allocations of effort. This should be possible once one has specified the cardinality of their idea set, how much time must be allocated to a project to render it publishable given their *G* function, and how much credit they believe shall be received per project given time invested per their *C* function. The characterisation theorem shows that, while I am focussing on a particular conjecture based around claims (a)–(c), scientific time allocation models are not inherently tied to this particular conjecture. For instance, while assumption (a) will turn out to entail that scientists seek to maximise paper production, it is possible to construct a scientific time allocation model of a productivity gap arising where scientists instead credit maximise with some alternate strategy.

4 Formalising the Conjecture

It is now time to return to claims (a)–(c) as outlined in Sect. 2.

Conjecture 1 *A productivity gap occurs in a field if and only if a scientific time allocation model of that field would satisfy*

a. *Both agents' C functions are such that they think spreading some fixed amount of effort among papers will always result in more credit than concentrating the same amount of effort among fewer papers.*
b. *Given her G function, the maximum number of papers the Representative Woman Scientist thinks she can produce is less than than the cardinality of her idea set.*
c. *Suppose the Representative Woman Scientist were to publish as many papers as she possibly could given the value of her G function and the cardinality of her idea set. Call the number of papers she publishes W. Given his G function, the Representative Man Scientist thinks that if he were to invest the minimal time necessary to render projects publishable into W papers, he could still publish at least one more paper at minimal effort.*

In plainer English, this conjecture states that everybody wants to produce more papers rather than less, and given how difficult women think it is to get published they do not believe they could spread their time among as many projects as men believe they can given how difficult they think it is to get published. These are claims (a)–(c) discussed in the previous section, phrased in the language of scientific time allocation models.

Theorem (2) in the "Appendix" makes this conjecture stand out as worthy of further investigation. First, theorem (2) shows that in the context of scientific time allocation models satisfaction of conditions (a) through (c) entails the existence of a productivity gap. Hence the right hand side of the biconditional states sufficient conditions for the model to predict the occurrence of a productivity gap. Since assumptions (1)–(3) were sufficient in the model to generate theorem (2) this shows that, as was desired, the conjecture based on (a)–(c) is independent of assumptions concerning gatekeeping bias, men and women's respective degrees of scientific talent, or women and men having different amounts of time available to them. Second, conditional on (a) being true, theorem (2) also shows that (b) and (c) are necessary for a productivity gap to arise. Hence given theorem (2), and if one grants that scientists want to publish as many papers as they can, conjecture 2 represents necessary and sufficient conditions for a productivity gap to occur in a scientific time allocation model. Note that in so far as one accepts that scientific time allocation models capture the relevant features of scientific decision making, then it follows from theorem (2) that accepting there is a publication gap in a field and that claim (a) holds in that field together entail that (b) holds. This, then, is an additional argument for premise (b) beyond the general consideration offered in Sect. 2. If one accepts scientific time allocation models as capturing the target phenomenon and accepts the argument for (a), which itself had significant empirical support, one is thereby committed to (b).

What is more, there are empirical tests of this conjecture that could be carried out. First, and most directly, if the assumptions of this model hold, then if one controlled for expectation of difficulty of publication one should not see a gendered productivity gap within the similarity classes this induces. Or, on the plausible assumption that multiple factors contribute to the productivity gap, one should at least expect to see the productivity gap reduced within such similarity classes. Second, survey evidence could be gathered to (dis)confirm my hypothesis that scientists believe they are rewarded for sheer volume of minimally adequate publishable units rather than producing fewer papers they worked harder on. Finally, one could test whether interventions that improve workplace climate for women scientists also result in women scientists publishing more papers. Having outlined the model, and via theorem (2) shown that within this model claims (a)–(c) suffice to explain the productivity gap while offering a testable predictions, I will now consider the epistemic consequences of the conjecture, taking the conjecture to be now plausible enough to merit such consideration.

5 Against Publication Maximisation

Harding (1995), Longino (1987) each argue that because of the diverse opinions, values, and preferred research methodologies brought in by demographically diverse researchers, demographically diverse research teams are most likely to uncover and challenge false beliefs which may otherwise have been accepted. This is in line with work elsewhere in social epistemology showing that cognitive diversity can help groups of inquirers reach more accurate outcomes (Bohman 2006, p. 175). For instance, Kevin (2010) shows that a diversity in opinions or a diversity in willingness to give up on an idea in the face of discomfirming evidence is beneficial for communal truth seeking, so long as people are not so extremely diverse in their opinions as to never be able to reach agreement. Kurtzberg (2005) shows that different strategies for approaching work is beneficial for increasing creativity of a research group by various objective measures, and creativity is beneficial to scientific research (Simonton 2004). Similarly, Hong and Page (2004) provides a formal argument that diverse groups of low skill reasoners can outperform homogenous high skill researchers on cognitive tasks. Finally, Dahlin et al. (2005) shows that diversity of educational background increases range and depth of information use.

Conversely, demographic homogeneity can lead to poor epistemic performance. For instance, Du Bois (1935, ch. 7) is an extended argument that the predominance of white southerners in the study of the American Civil War led to a seriously distorted picture of the Civil War. More recently, in her study of research on the female orgasm Lloyd (2009) argued that the male dominated field resulted in systematically biased science. These are not isolated incidents, and the discovery and documentation of such bias resulting from demographic homogeneity has been an active research programme in feminist science scholarship.

This evidence in favour of the epistemic benefits of cognitive diversity suggests the productivity gap does the following epistemic harm. If the model is capturing the publication decisions of scientists, the simultaneous truth of claims (a)–(c) can create a situation where there is a demographic skew in whose ideas are entered into the public domain of science, and therefore available to be taken up by others. We have historical evidence that, at least for some fields, demographic diversity can correlate with cognitive diversity. Ideas more likely to be produced by the class of persons who publish more would gain an advantage in the market place of ideas, since competitor ideas are not being submitted to the commons for evaluation and uptake by peers. The aforementioned evidence of the benefits of cognitive diversity tells us we should expect our market of place of ideas to do better at selecting superior beliefs where there are not arbitrary demographic skews in who contributes ideas. The productivity gap can function as just such a skew. Hence we should expect the market place of ideas to do better at selecting superior beliefs without the productivity gap.

Since the productivity gap is potentially epistemically harmful, it is worth considering how to intervene so as to falsify at least one of claims (a), (b), or (c) respectively. I will focus below on claim (a), but first I will briefly set aside claims (b) and (c) here. Claim (b) states that women scientists can envision more projects than they actually believe themselves publishing papers on. This, alas, is likely a part of the human condition, at least in so far as the human in question is a scientist, and is unlikely to be ameliorable by policy intervention. The condition described in claim (c), it was argued, is likely caused, or at least exacerbated, by the relatively hostile climate women face in science. There is independent reason to want to improve workplace climate, I simply note that in virtue of the previous arguments such improvement can be expected to have epistemically desirable consequences in addition to the more immediate ethical or social gains.

I turn, now, to policy interventions for reducing or eliminating the productivity gap that focus on eliminating people's sense that publishing more papers is always desirable. That is to say, intervening on the social structure of science in a way that falsifies claim (a). If one holds (a) fixed, there may be a temptation to reduce the productivity gap by inducing women to publish more. However, feminist scholars have long warned against the 'deficit model', where men's behaviour is treated as a normative standard and women's differences treated as problems to be overcome by helping the women become more like men—c.f. (Bebbington 2002). The argument produced above suggests that the harm done by the productivity gap is the difference in proportion of papers published by men and women, and plausibly papers are presently over produced (Forman 2002, pp. 112–115). If women are publishing less because they are expending more effort per paper than men it is far from obvious that the policy goal should be to get women to publish more rather than men to publish less. Hostile climates can and should be rectified. But worthy questions for future research are whether a policy should be implemented to engender higher scientific standards in men, and if so how this could be done. Women self-describe as 'perfectionist' (Sonnert and Holton 1996, p. 68), but perhaps they need not. The pressure to publish as many minimally publishable units rather than produce papers that have had more time than necessary invested in them can play a role in bringing about productivity gaps. To say that women are perfectionist pathologises women, when in fact it may be a better characterisation of the situation that men scientists are on average more slap-dash than women in their attitudes to what is required for producing publication worthy research. At the least, without further investigation there is no reason to prefer the characterisation of women as perfectionist rather than men as slap-dash.

6 Conclusion

I have highlighted the role in bringing about productivity gaps played by an incentive system that pressures scientists to publish minimally publishable units. By building in explicitly egalitarian assumptions, I hope my model will be of interest to those interested in feminist science scholarship: if validated it would represent an explanatory victory on a puzzle that may not have seemed promising.

The discussion in this paper has focussed on comparisons between the publication rates of men and women. However, nothing in the formal structure of scientific time allocation models requires that the agents be representations of men and women respectively. The conditions which characterise a productivity gap could arise for agents representing other demographic or socially significant groupings, for instance racial or ethnic groups. Further work expanding the domain of application for scientific time allocation models would therefore be of interest. An especially promising site of possible generalisation concerns scientific time allocation models of people publishing in their first language versus people publishing in a second language. The empirical evidence surveyed in (Ayala 2015, Section 1) suggests that very similar climate issues could arise for scientists publishing in their second language as arises for women scientists. Suggestive initial work along these lines is found in Fernandez et al. (2012). Further work is necessary to know whether any analogue to the conjecture explored in this piece would be viable and interesting in these cases.

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Appendix: Proofs

To explain the formal model underlying the above claims, it is necessary to introduce some terminology. An *agent* p is a pair of two functions $<G_p, C_p>$, G: [0,1] $\rightarrow \{0, 1\}$ and C: [0,1] $\rightarrow [0, \infty]$. G_p tracks the minimal amount of effort p thinks they have to put into a project to get it published, and C_p specifies how much credit they expect to receive from a project given how much effort they have put into it, conditional on it being published. Each agent is faced with the following choice scenario. They have a fixed budget of time to allocate as effort spent on projects, and may distribute this effort between k options $\{\mathcal{I}_1 \ldots \mathcal{I}_k\}$. The set of options is called their associated *idea set*. Once chosen how to allocate their efforts a vector of length k is formed $<x_1 \ldots x_k>$ where x_j is the element of [0,1] allocated to $\mathcal{I}_j$, with the researcher's time budget to allocate being 1. I call this vector the agent's *research profile* (henceforth abbreviated to RP). The function #(RP) outputs the set of all $x \in$ RP s.t. $G_p(x) = 1$. This is the set of projects the researcher believes will result in published papers. I refer to the numbers which are elements of RP by the variables x, y, z, and the index of the ideas they are allocated to by the variables i, j, k. For any $x \in$RP it accrues the credit generated by the composite function $G_p(x)C_p(x)$; which is to say however much credit C_p gives x providing $G_p(x)$ is 1, and no credit otherwise. Let $\cup_p(RP) = \sum_1^k G_p(x_k)C_p(x_k)$. If $\cup_p(RP) > \cup_p(RP')$ then say that $RP > RP'$. A *parameterisation* of the model consists of specifying the number of agents, the cardinality of their associated idea sets, and each agent's G and C functions.

The three assumptions from Sect. 3 can now be stated formally.

Axiom 1 (*Analytic Egalitarianism*) In any parameterisation of the model, all agents are associated with the same cardinality idea sets.

Axiom 2 (*Idea Homogeneity*) All ideas have the same potential to generate credit. This can be broken into two parts

a. Agents believe all ideas require the same amount of time allocated to them in order to be published. I.e. For all agents $\exists x \in [0.1]$ *s.t.* $\forall i \in [\mathcal{I}_1 \ldots \mathcal{I}_k]$, $\forall y \in [0,1]$ $((y \geq x \rightarrow G(y_i) = 1)$ & $(y < x \rightarrow G(y_i) = 0))$
b. For any two ideas with differing amount of effort allocated to them, the idea that has more time allocated to it generates more credit. $\forall i \forall j \in [\mathcal{I}_1 \ldots \mathcal{I}_k] \forall y \in [0,1]$ $(x > y \rightarrow C(x_i) > C(y_j))$

Axiom 3 (*Credit Maximisation*) Agents which to accrue as much credit to themselves as possible. I.e. Agents select an RP so as to maximise the value of ∪(RP).

Let RP^+ be the set of all top ranked elements of the agent's choice set according to the preference ranking induced by Axiom 3. Let $\#^{max}$ be the set of highest cardinality sets generated by # when applied to all members of RP^+. That is to say, it is the set of all sets of papers published in agents' most preferred research papers that have the most publications. Call the set elements of RP^+ that generate members of $\#^{max}$ RP^{max}. Let $\#^+$ be the set of all sets generated by # when applied to all members of RP^+. I now characterise a *productivity gap* between agents m and w as occurring when one of the following sentence is made true by the parameterised model:

- Productivity Gap: $\exists x \in \#_w^{max} \forall y \in \#_m^+ (|x| < |y|)$

In English, this says that a publication gap occurs when agent w's top ranked research profiles with the most papers published contain less publications than any of the agent m's top ranked research profiles.

Lemma 1 *No agent would choose a research profile RP such that* $\#(RP) = \emptyset$, *i.e. an agent will never choose to distribute their effort in a way that leaves them with no publications.*

Proof Suppose agent p chose a research profile RP which induced no publications, i.e. $\neg\exists$x $\in$ RP s.t. $G_p(\mathrm{x}) = 1$. Consider the research profile RP′ such that an element of p's associated idea set, i, was allocated all their effort. Note that if RP is in p's choice set then RP′ will be and that it follows from axiom 2a that $G_p(1_i) = 1$. Note that $\cup_p(\mathrm{RP}) = 0$, whereas it follows from axiom 2b and the fact that C_p is bounded above 0 by definition that $C_p(1_i) > 0$, and therefore that that $\cup_p(\mathrm{RP'}) > 0$. Hence by axiom 3 p would never choose RP over RP′, and #(RP′) is not empty. □

Lemma 2 *No agent would choose a research profile RP that did not satisfy* $\sum_{i=0}^{k} x_k \in RP = 1$, *i.e. an agent would never leave some effort unallocated.*

Proof Note that the nature of the choice scenario ensures that $\sum_i^k \mathrm{x} \in \mathrm{RP} \not> 1$. Hence either $\sum_i^k \mathrm{x} \in \mathrm{RP} < 1$ or $\sum_i^k \mathrm{x} \in \mathrm{RP} = 1$. Suppose $\sum_i^k \mathrm{x} \in \mathrm{RP} < 1$. Let $\sum_i^k \mathrm{x} \in \mathrm{RP} = \mathrm{y}$ and $1 - \mathrm{y} = \mathrm{z}$. Note that by lemma 1 $\#(\mathrm{RP}) \neq \emptyset$. Now consider the alternate profile RP′ which is identical to RP except idea i has x + z effort allocated to it. Note that by axiom 2b $C(\mathrm{x} + \mathrm{z}) > C(\mathrm{x})$ for any positive number z. By construction z is a positive number, hence $\cup(\mathrm{RP'}) > \cup(\mathrm{RP})$. Hence by axiom 3 the agent would never choose RP over RP′. Hence $\sum_i^k \mathrm{x} \in \mathrm{RP} = 1$. □

Lemma 3 *No agent would choose a research profile RP such that* $\exists x \in RP(x > 0 \& G(x) = 0)$, *i.e. an agent would never allocate effort to a project if they did not think that level of effort will result in a publication.*

Proof Note that since credit is allocated by the function $G_p(\mathrm{x})C_p(\mathrm{x})$ if $G_p(\mathrm{x}_i) = 0$ then the agent gains no credit from idea i. Suppose $\exists \mathrm{x} \in \mathrm{RP}(\mathrm{x} > 0 \& G(\mathrm{x}_i) = 0)$. By lemma 1 there exists an idea j in RP that has some amount of effort y_j allocated to it such that $G(\mathrm{y}_j) = 1$. Consider the alternate profile RP′ which is identical to RP except that j has y + x effort allocated to it. Note that by axiom 2b $C(y + x) > C(y)$ where x is a positive number. Hence if $x > 0$ then $\cup(\mathrm{RP'}) > \cup(\mathrm{RP})$. Hence by axiom 3 an agent would never choose RP over RP′. □

Lemma 4 *If* $RP > RP'$ *and* $RP^{\star}$ *is a permutation of the elements of RP, then* $RP^{\star} > RP'$, *i.e. if research profile A is preferred to research profile B, then research profile C that results from permuting the elements of A will also be preferred to B.*

Proof Note that the preference ordering over research profiles is formed by summing the credit generated by each element of the research profile. Note further that, since the credit function takes as input just a number representing the time allocated to an idea rather than that number indexed to a particular idea, the same amount of effort allocated to any two ideas will result in the same amount of credit allocated. Hence simply relabelling the ideas the effort is allocated to could never generate a change in the preference ordering. □

Theorem 1 (Characterisation Theorem) $\exists x \in \#_w^{max} \forall y \in \#_m^{+}(|x| < |y|) \iff \exists RP_w^{max} \exists RP^{\star} \in RP_m^{+} \exists x_i \forall y \in RP\ [(y_j \neq x_i \rightarrow (y_j > 0 \rightarrow u_j^{\star} > 0)) \quad \& \quad (x_i = 0 \& z_i^{\star} > 0)]$, *i.e. a productivity gap occurs if and only if one of the women's most preferred* *research profiles which generates an element of* $\#_w^{max}$ *has more ideas allocated 0 effort in it than one of the man's most preferred research profiles.*

A consequence of this characterisation theorem is that it suffices to tell whether a productivity gap will occur to simply count the number of 0s in an element of RP_w^{max} and RP_m^+ respectively. The significance of this is that it shows that preference orderings in the model suffice to capture the occurrence of productivity gaps, and, as mentioned in Sect. 3, gives the model a greater generality than just representing my conjecture, since so long as one can calculate preference orderings over research profiles, there is a simple procedure for telling whether or not a productivity gap is predicted by a scientific time allocation model.

Proof From Left to Right: Informally the proof strategy will go as follows. An element of w's most preferred research profiles which generates an element of $\#_w^{max}$ that satisfies productivity gap (i.e. the antecedent) will be selected. It will then be shown that one can take an arbitrary element of m's most preferred research profiles and, by means of permuting its elements, construct a research profile which demonstrably has at least one more non-0 element than the previously selected member of w's most preferred research profiles. This, then, satisfies the consequent.

In formal detail, let W be a member of RP_w^+ that generates some element of $\#_w^{max}$, and let this be the witness for the existentially quantified statement in the antecedent. Take an arbitrary element element of RP_m^+ and call it M. Generate $M^\star$ as follows. For each $i^W \in W$, if i^W is allocated some $x > 0$ and i^M is also allocated $x > 0$ then $i^{M^\star}$ is allocated the same amount of effort as i^M. Whereas if i^W is allocated some $x > 0$ and i^M is allocated 0 effort then find a j^M such that j^M is allocated some $x > 0$, j^W is allocated 0, and j^M has not been used in a previous iteration of this process. Let $i^{M^\star} = j^M$, and $j^{M^\star} = 0$. Lemma 3 entails that if an element i of M or W has non 0 effort allocated then $G(y_i) = 1$; hence, since by the antecedent $|\#(W)| < |\#(M)|$, one will never run out of such j's necessary for this constructive process. If i^W is allocated 0 effort then $i^{M^\star} = i^M$. Note that by construction $M^\star$ is such that it is non-0 wherever W is non-0, and contains at least one element which is non-0 where W is 0. Now I need to show that $M^\star \in RP_m^+$, which is to say that $M^\star$ is amongst m's top ranked research profiles. It follows from lemma 4 and the method of constructing $M^\star$ that $h^\star$ must be preferred to every RP that M was preferred to. Hence the relationship between $M^\star$ and W witnesses the consequent.

Proof From Right to Left: Call the $RP \in RP_w^{max}$ which witnesses the antecedent W, and the call the $RP \in RP_m^+$ which witnesses the antecedent M. Want to show that $|\#(W)| < |\#(M)|$. Note that by construction M has at least one more non-0 element than W. By lemma 3 if an element i of M or W has non 0 effort allocated then $G(y_i) = 1$. Hence #(M) has at least one more element than #(W).

Suppose the minimum amount of effort necessary to render a paper publishable according to the representative woman scientist's G function is g. Let w be the largest integer such that $wg \leq 1$. I use m to represent the equivalent integer for the representative man scientist's possible publications given their G function. Such integer's are the representative scientists' *max*. I refer to the cardinality of the idea sets the agents are working with by "n".

Lemma 5 *If an agent's credit function is subadditive then for any $RP^\bigstar \in RP^+$ the cardinality of $\#(RP^\bigstar)$ is whichever is lower out of n or the agents max, i.e. an agent with a subadditive credit function will publish as many papers as they can.*

Proof A subadditive credit function satisfies $C(x+y)<C(x)+C(y)$. This can be interpreted as the agent expecting to be better rewarded for producing two minimally publishable units than producing one paper with twice as much effort put in. Let RP be a research profile such that a rational agent with G function equal to g has allocated k papers effort, which given lemma 3 is to say that there are k papers allocated at least g effort. By lemma 1 $k > 0$. By lemma 2 the agent has distributed all their effort between these projects. I will show that RP is an element of RP^+, only if the cardinality of #(RP) is equal to n or the agents max. If $|\#(RP)| = k = n$ then there does not exist a research profile with more papers published. Any candidate RP^* that might be preferred to RP will therefore either have less than k papers allocated effort or will also have k papers allocated effort. I need only consider cases where the number of papers allocated effort in RP^* is less than k. Consider a research profile RP^* such that $|\#(RP^*)| = |\#(RP)|-1$. Given lemma 2, the agent would have to have redistributed effort from one element of RP among the $k-1$ non-0 elements of RP^*. Due to the nature of their credit function and given axiom 3, the agent would prefer to distribute the same amount of effort allocated to j papers among k papers, for any $j<k$, assuming that their G function permits them all to be published. By hypothesis the agent can allocate k papers at least g effort. Hence they prefer to publish k papers to $k-1$ papers. Hence the agent prefers RP to RP^*. The same reasoning would result in any paper with less publications than RP always being preferred to a paper with at least one more, hence for any RP^{**} with less papers allocated effort than RP will always be dispreferred to RP by the transitivity of preference.

Suppose that $|\#(RP)| = k<n$. Note that k cannot be greater than the agent's max, since the agent cannot allocate at least g to more papers than their max since they only have 1 effort to distribute. Hence k must either be less than or equal to the agent's max. If it is equal they cannot produce any more papers, and by the same reasoning as in the previous paragraph will prefer RP to any RP^* with less papers allocated effort. If k is less then their max then by the definition of the max there exists an $RP^!$ such that $RP^!$ has more papers allocated g effort than RP. Once again the same reasoning as in the previous paragraph would show that the agent prefers $RP^!$ to RP. This did not depend on the value of k in particular, hence this generalises to any research profile that induces a slam dunk set with a cardinality less than the max or n. This covers all cases, and hence $RP \in RP^+$ only if $|\#(RP)|$ is equal to the least of the agent's max or n.

Lemma 6 $m > w$ *if and only if* $wG_m + G_m \leq 1$, *i.e. the representative man scientist's max is greater than the representative woman scientist's max if and only if the representative man scientist could allocate G_m between w papers and still have at least G_m effort left to allocate.*

Proof Recall that the definition of the max for agent J is defined as the largest integer, j, such that $jG_j \leq 1$. From left to right, note that if $m > w$ then given the definition of maxes $w\mathrm{G}_m < \mathrm{mG}_m \leq 1$. Given that both agents' maxes must be integers, $m = w + k$ where $k \geq 1$. From these facts it follows that. $w\mathrm{G}_m + \mathrm{G}_m \leq 1$. From right to left, suppose $m \leq w$. Suppose $m = w$. Note that from this and the definition of maxes it follows that $w\mathrm{G}_m + \mathrm{G}_m = \mathrm{mG}_m + \mathrm{G}_m > 1$. But this contradicts the initial assumption that $w\mathrm{G}_m + \mathrm{G}_m \leq 1$. Suppose $m < w$. From this and the definition of maxes it would follow that $1 < m\mathrm{G}_m + \mathrm{G}_m < w\mathrm{G}_m + \mathrm{G}_m$. But $w\mathrm{G}_m + \mathrm{G}_m \leq 1$. This exhausts the cases, hence $m > w$. □

Theorem 2 *Let the cardinality of both agents' idea sets be n and suppose that both agents have subadditive credit functions. Then* $\exists x \in \#_w^{max}\ \forall y \in \#_m^{+}(|x| < |y|) \iff wG_m + G_m \leq 1$ *and the representative woman scientist's max is less than n, i.e. if both agents have subadditive credit functions then a productivity gap between the man and the woman representative scientists occurs when the man thinks they could produce to the woman's max and then produce at least one more paper, and the woman does not think it possible for her to allocate her time in a way that will result in all of the ideas in her idea set being published.*

Proof of Theorem 2 From right to left. By lemma 5 any element of RP_m^+ will have the least of either m or n papers assigned at least G_m effort. Likewise RP_w^+'s elements will have the least of w or n elements assigned at least G_w effort. By the antecedent we hence know that any element $\mathrm{RP}_w \in \mathrm{RP}_w^+$ will be such that $|\#(\mathrm{RP}_w)| = w$. If RP_m^+ has n papers assigned at least G_m effort then it will have a greater number of non-zero elements than RP_w^+. Suppose $\mathrm{RP}_m \in \mathrm{RP}_m^+$ has $m < n$ elements allocated non-zero effort. By the antecedent and lemma 6 we have $m > w$. Hence RP_m^+ has m papers assigned at least g_m effort and hence has a greater number of non-zero elements than any element of RP_w^+. This covers all cases, and hence we know that any element of RP_m^+ has more non zero elements than any element of RP_w^+. Hence $\exists \mathrm{x} \in \#_w^{max}\ \forall \mathrm{y} \in \#_m^{+}(|\mathrm{x}| < |\mathrm{y}|)$.

Going from left to right, suppose a productivity gap has occurred. By lemma 5 we know that if she could have produced n papers the representative woman scientist would have, but if she had done so then, given axiom 1, no strong productivity gap could have occurred by definition of a productivity gap. Hence the representative woman scientists' max (w) is less than n. Want to show that $w\mathrm{G}_m + \mathrm{G}_m \leq 1$. Suppose the representative man scientist had produced n papers. This would entail that largest integer m such that $\mathrm{mG}_m \leq 1$ is greater than or equal to n. Whereas we already know that the representative woman scientist's max is less than n. Hence $m > w$, and by lemma 6 $w\mathrm{G}_m + \mathrm{G}_m \leq 1$. Suppose the representative man scientist had produced $m < n$ papers. By the antecedent we know that there is a productivity gap between both agents, hence $\exists \mathrm{x} \in \#_w^{max}\ \forall \mathrm{y} \in \#_m^{+}(|\mathrm{x}| < |y|)$. By lemma 5 all of the representative woman scientist's most preferred research profiles will have w elements assigned non-zero effort, hence every element in $\#_w^{max}$ will have the same cardinality and hence every element of $\#_w^{max}$ will be such that it has a lower cardinality than every element of $\#_m^{max}$. By lemma 5 again the cardinality of any element of $\#_w^{max}$ is w and the cardinality of any element of SD_m^{max} is m. Hence $m > w$, and by lemma 6$w\mathrm{G}_m + \mathrm{G}_m \leq 1$. By lemma 5 this exhausts the possible cases, therefore $w\mathrm{G}_m + \mathrm{G}_m$.

Before concluding, as mentioned in Sect. 3 I consider an example of relaxing Idea Homogeneity, particularly axiom 2a, and modifying the manner in which C and G functions work. Two agents M and W idea sets are divided into high and low type ideas: $\mathcal{I}_a = \mathcal{I}_h \cup \mathcal{I}_l$, where $\mathcal{I}_h \cap \mathcal{I}_l = \emptyset$. The difference in effort/reward status of those subsets can be represented by typed C and G functions, with separate functions for elements of $\mathcal{I}_h$ and $\mathcal{I}_l$ respectively. Let both agents have identical C and G functions, as follows: $\mathrm{C}_h(\mathrm{x}) = \mathrm{x}^2 + 2, \mathrm{C}_l(\mathrm{x}) = \mathrm{x} + 0.2$, $\mathrm{G}_h = 0.5$, $\mathrm{G}_l(\mathrm{x}) = \epsilon$. The respective G and C functions are applied according to whether the index of the element of the research profile is of a high or low type idea. Now suppose, finally, that both agents are associated with idea sets $\mathcal{I}_a$, $|\mathcal{I}_a| = 4$. But agent M has $|\mathcal{I}_{Mh}| = 1$, $|\mathcal{I}_{Ml}| = 3$, whereas agent W has $|\mathcal{I}_{Wh}| = 2$, $|\mathcal{I}_{Wl}| = 2$. M maximises by investing .5 into the high type idea, earning them 2.25 credit, and distributing the rest of their time among low type ideas, earning them 1.1 credit. This earns M credit of 3.35 with 4 papers published. W maximises by investing all their effort into high type ideas, earning credit of 4.5 with 2 papers published. This modified model hence predicts a productivity gap between M and W in this scenario, even though axioms 1, 2b, and 3 are all satisfied, and the agents have identical C and G functions. This suggests that future research may fruitfully focus on relaxations of Idea Homogeneity.

References

Ayala, S. (2015). Philosophy and the non-native speaker condition. *The American Philosophical Association Newsletter on Feminism and Philosophy*, *14*(2), 2–9.

Barres, B. A. (2006). Does gender matter? *Nature*, *442*(1), 133–136.

Bebbington, D. (2002). Women in science, engineering, and technology: A review of the issues. *Higher Education Quarterly*, *56*(4), 360–372.

Bohman, J. (2006). Deliberative democracy and the epistemic benefits of diversity. *Episteme*, *3*(3), 175–191.

Ceci, S. J., Ginther, D. K., Kahn, S., & Williams, W. M. (2014). Women in academic science: A changing landscape. *Psychological Science in the Public Interest*, *15*(3), 75–141.

Cole, J. R., & Cole, S. (1973). *Social stratification in science*. Chicago: The University of Chicago Press.

Cole, J. R., & Zuckerman, H. (1987). Marriage, motherhood, and research performance in science. *Scientific American*, *256*(2), 119–125.

Cole, S., & Cole, J. R. (1967). Scientific output and recognition: A study in the operation of the reward system in science. *American Sociological Review*, *32*(3), 377–390.

Dahlin, K. B., Weingart, L. R., & Hinds, P. J. (2005). Team diversity and information use. *Academy of Management Journal*, *48*(6), 1107–1123.

Dasgupta, P., & David, P. A. (1994). Towards a new economics of science. *Policy Research*, *23*(5), 487–521.

Dougherty, T., Baron, S., & Miller, K. (2015a). Female under-representation among philosophy majors: A map of the hypotheses and a survey of female under-representation among philosophy majors: A map of the hypotheses and a survey of the evidence. *Feminist Philosophical Quarterly*, *1*(1), 1–30.

Dougherty, T., Baron, S., & Miller, K. (2015b). Why do female students leave philosophy? The story from sydney. *Hypatia*, *30*(2), 467–474.

Du Bois, W. E. B. (1935). *Black reconstruction in America, 1860–1880*. New York: The Free Press.

Erkowitz, H., Fuchs, S., Gupta, N., Kemelgor, C., & Ranga, M. (2008). The coming gender revolution in science. In E. J. Hackett, O. Amsterdamska, M. Lynch & J. Wajcman (Eds.), *The handbook of science and technology studies* (3rd ed.). Cambridge, MA: MIT Press.

Fernandez, A. I. M., Rocha, J. R., Burgess, S., Navarro, I. L., & Sachdev, I. (2012). Spanish researchers' perceived difficulty writing research articles for english-medium journals: The impact of proficiency

in english versus publication experience. *Ibérica: Revista de la Asociación Europea de Lenguas para Fines Específicos (AELFE)*, *24*(1), 157–183.
Forman, P. (2002). Recent science: Late-modern and postmodern. In P. Mirowski & E.-M. Sent (Eds.), *Science brought and sold*. Chicago: University of Chicago Press.
Fox, M. F. (2005). Gender, family characteristics, and publication productivity among scientists. *Social Studies of Science*, *35*(1), 131–150.
Fox, M. F., & Firebaugh, G. (1992). Confidence in science: The gender gap. *Social Science Quarterly*, *73* (1), 101–113.
Glover, J. (2002). Women and scientific employment: Current perspectives from the UK. *Science Studies*, *15*(1), 29–45.
Gunter, R., & Stambach, A. (2005). Differences in men and women scientists' perceptions of workplace climate. *Journal of Women and Minorities in Science and Engineering*, *11*(1), 97–116.
Hamilton, D. P. (1990). Publishing by-and for-the numbers. *Science*, *250*, 1331–1332.
Harding, S. (1995). "Strong objectivity": A response to the new objectivity question. *Synthese*, *104*(3), 331–349.
Hong, L., & Page, S. E. (2004). Groups of diverse problem solvers can outperform groups of high-ability problem solvers. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(46), 16385–16389.
Hwang, K. (2012). How to write a scientific paper: Three tips to remember. *Archives of Plastic Surgery*, *39*(1), 77.
Kitcher, P. (1990). The division of cognitive labour. *The Journal of Philosophy*, *87*(1), 5–22.
Kurtzberg, T. R. (2005). Feeling creative, being creative. An empirical study of diversity and creativity in teams. *Creativity Research Journal*, *17*(1), 51–65.
Lamont, M. (2006). *How professors think*. Cambridge: Harvard University Press.
Latour, B., & Woolgar, S. (1986). *Laboratory life*. Princeton: Princeton University Press.
Lee, C. (2016). Revisiting current causes of women's underrepresentation in science. In J. Saul & M. Brownstein (Eds.), *Implicit bias and philosophy: Metaphysics and epistemology* (Vol. 1). Oxford: Oxford Univeristy Press.
Leslie, S. J., Cimpian, A., Meyer, M., & Freeland, E. (2015). Expectations of brilliance underlie gender distributions across academic disciplines. *Science*, *347*(6219), 262–265.
Lloyd, E. A. (2009). *The case of the female orgasm: Bias in the science of evolution*. Cambridge: Harvard University Press.
Long, J. S. (1992). Measures of sex differences in scientific productivity. *Social Forces*, *71*(1), 159–178.
Longino, H. E. (1987). Can there be a feminist science? *Hypatia*, *2*(3), 51–64.
McGrail, M. R., Rickard, C. M., & Jones, R. (2006). Publish or perish: A systematic review of interventions to increase academic publication rates. *Higher Education Research and Development*, *25*(1), 19–35.
Merton, R. K. (1961). Singletons and multiples in scientific discovery: A chapter in the sociology of science. *Proceedings of the American Philosophical Society*, *10*(5), 470–486.
Merton, R. K. (1968). Behavior patterns of scientists. *American Scientist*, *57*(1), 1–23.
Neil, U. S. (2008). Publish or perish, but at what cost? *The Journal of Clinical Investigation*, *118*(7), 2368.
Osbeck, L. M., Nersessian, N. J., Malone, K. R., & Newstetter, W. C. (2011). *Science as psychology*. New York, NY: Cambridge University Press.
Peart, S. J., & Levy, D. M. (2005). *The "vanity of the philosopher"*. Michigan: University of Michigan Press.
Qiu, J. (2010). Publish or perish in China. *Nature*, *463*, 142–143.
Rosser, S. V., & Daniels, J. Z. (2004). Widening paths to success, improving the environment, and moving toward lessons learned from the experiences of POWRE and CBL awardees. *Journal of Women and Minorities in Science and Engineering*, *10*(1), 131–148.
Rosser, S. V., & Lane, E. O. N. (2002). Key barriers for academic institutions seeking to retain female scientists and engineers: Family-unfriendly policies, low numbers, stereotypes, and harassment. *Journal of Women and Minorities in Science and Engineering*, *8*(2), 161–189.
Rothgeb, J. M., & Burger, B. (2009). Tenure standards in political science departments: Results from a survey of department chairs. *Political Science and Politics*, *42*(3), 513–519.
Settles, I. H., Cortina, L. M., Stewart, A. J., & Mallet, J. (2007). Voice matters: Buffering the impact of a negative climate for women in science. *Psychology of Women Quarterly*, *31*(3), 270–281.
Simonton, D. K. (2004). *Creativity in science: Chance, logic, genius, and zeitgeist*. Cambridge: Cambridge University Press.

Sonnert, G., & Holton, G. (1996). Career patterns of women and men in the sciences. *American Scientist*, *84*(1), 63–71.

Stephan, P. E. (1996). The economics of science. *Journal of Economic Literature*, *34*(3), 1199–1235.

Strevens, M. (2003). The role of the priority rule in science. *The Journal of Philosophy*, *100*(2), 55–79.

van Arensbergen, P., van der Weijden, I., & van den Besselaar, P. (2012). Gender differences in scientific productivity: A persisting phenomenon? *Scientometrics*, *93*(3), 857–868.

Wenneras, C., & Wold, A. (2001). Nepotism and sexism in peer review. In M. Wyer & D. Giesman (Eds.), *Women, science, and technology* (pp 46–52). Routledge.

Xie, Y., & Shauman, K. A. (2003). *Women in science*. Cambridge: Harvard University Press.

Yank, V., & Barnes, D. (2003). Consensus and contention regarding redundant publications in clinical research: Cross-sectional survey of editors and authors. *Journal of Medical Ethics*, *29*(2), 109–114.

Yap, A. (2014). Idealization, epistemic logic, and epistemology. *Synthese*, *191*(14), 3351–3366.

Zollman, J. S. K. (2010). The epistemic benefits of transient diversity. *Erkenntnis*, *72*(1), 17–35.