Reward Schemes, Competition, and Output within Scientific Teams

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Abstract: Scientists often perform their work organized in laboratories. As lab teams become increasingly large, research management grows in its capacity to make science more useful and efficient. Generally, management choices influence output by modifying workplace conditions, and thereby the skill, effort, and time workers devote to production. Managers may choose team members' reward scheme, and one option is to introduce within-team competition for incentives. In science, *inter*-lab competition is well-documented, while *intra*-lab competition is understudied. This field preliminary paper reviews prior work from economics, sociology, and labor studies relevant to individualistic and competitive reward schemes and output, and considers how findings in non-science settings might apply to scientific production. A survey and interview study is proposed to address the lack of theoretical clarity on how research management choices shape intra-lab competition and output at the lab and individual levels.

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1 Introduction

The scientific research production function includes land and building space, physical capital in the forms of equipment and materials, and—the primary subject of this study—the labor of scientists. A scientist's work takes numerous forms depending on the organizations they are embedded in, their organizational role, and their career stage. They perform creative work when they generate hypotheses and design studies; communicative work when they synthesize existing literature and present their own research; administrative work when they manage paperwork and personnel; and manual or execution work when they collect, process, and analyze data from the outside world. Science is fundamentally a material labor process, combining physical and human resources to produce new knowledge.

Policy aimed at making scientific production more efficient is relatively new. In the U.S., the origin of science and technology public policy can be traced to Vannevar Bush's 1945 report to President Roosevelt (Bush 1945). Government has since been the primary source of science funding (Stephan 2012). Although research administration existed prior to the 1940s, research management became a more central concern as scientists struggled to comply with increasing regulations (Monahan, Shaklee, and Zornes 2023). How the choices of research managers relate to scientific output is an active area of study. There is a vast literature on how policies and practices that modify workers' conditions affect the output of individual workers and teams. However, whether findings from other settings translate to science remains an open question due to particular features of scientific work.

One aspect of the workplace that management can exogenously control is competition among team members. Commonly competition is induced through contests for pecuniary and non-pecuniary incentives, although competition may take on other forms. Competition is a regularity of scientific work, well-documented between individual scientists and labs (Anderson et al. 2007; Evans 2010; Hill and Stein 2021a). However, modern science is produced in increasingly large social organizations, where laboratories or research teams are the basic unit. Literature addressing the effects of competition within teams on individual and team output is more sparse, and there is almost no relevant work in the scientific setting. Research managers and policymakers seeking to influence the rate and direction of science would benefit from an understanding of how their decisions affect scientific output through intra-lab competition.

1.1 Project Description and Scoping Considerations

This field preliminary paper reviews prior work from economics, sociology, and labor studies relevant to reward schemes, competition, and output. Findings from non-science settings are considered in relation to particular features of scientific work—discussed in the following section—to generate theoretically informed hypotheses. Then, if studies of scientific work were found, they are reviewed to see whether such hypotheses are empirically supported. Several scoping considerations help to narrow the focus of this review and make it more manageable. Empirical work in this review consists mainly of statistical analyses with an emphasis on the strength of causal evidence. Empirical studies of science prior to 1995 are excluded to ensure that findings are applicable to contemporary science. Scientific institutions vary globally; studies were not excluded based on geography, but comparisons are mostly made to the U.S. context.

Scientific production takes place broadly in either public or private institutions, although public-private collaboration is not uncommon. This review focuses on the academic lab, the primary site of public science production, for three reasons. First, common measures of productivity in public and private science differ. Published research articles are the main metric in academic science, whereas patents are more commonly observed in industrial science. Academics are increasingly filing for patents (Azoulay, Ding, and Stuart 2009), and many scientists in industry publish research (Stern 2004). However, private institutions also seek to gain competitive advantages by having their scientists generate trade secrets, which are more difficult to observe by design. Second, industrial scientists likely share similarities with other corporate professionals, such that general research on reward schemes and output may be more applicable to them than those in academia. Third, academic labs operate differently from industrial labs. They are more often training labs, and the effects of competition may be more pronounced among trainees (i.e., students and postdocs) than among members of industrial labs. Academic labs are also more typically aimed at basic research that is far from commercialization, while industrial labs are typically focused on applied research, although this dichotomy is not strict.

Much work has been done on the topic of management, working conditions, and output in general. To further narrow the scope of this review, I define here each of the specific constructs investigated. Figure 1 summarizes the causal relationship this paper addresses, where managers' exogenous effect on output is mediated through reward scheme policy.

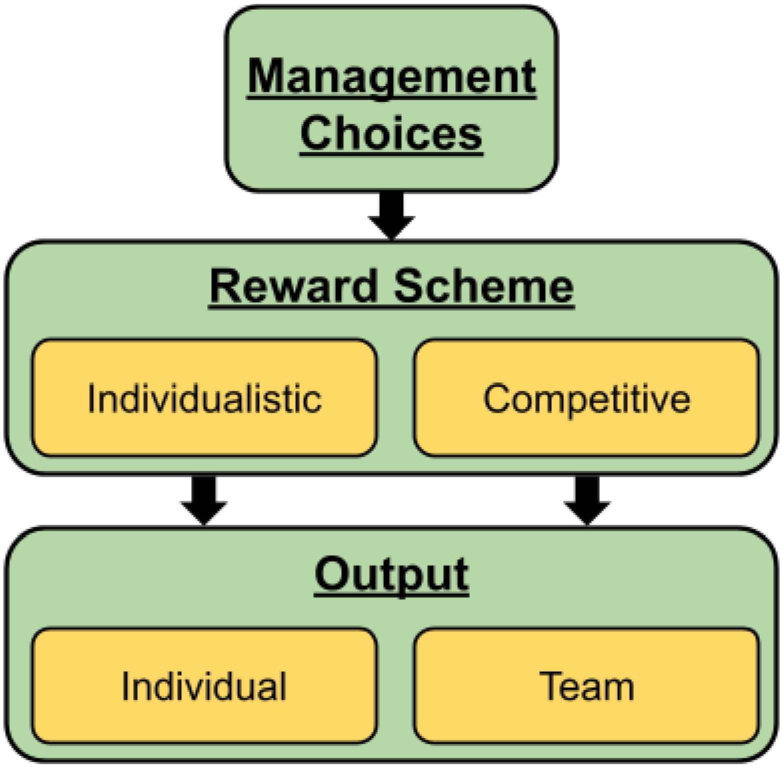

Figure 1: Managers choose reward schemes to affect output

Competition can be between organizations, across teams within an organization, and within teams. The focus of this review is on competition within teams. While competition between organizations can constrain management choices (e.g., "best practices"), within-team competition is arguably controlled exogenously through managers' decisions. Managers may use a wide array of policies and practices to control workplace competition. Competitive working conditions may be categorized as material, structural, and/or cultural depending on how they manifest in day-to-day operations. To give an example for each category, first, reward schemes such as pay for productivity or tournaments with cash prizes create *material* incentives to produce and can induce competition between team members. In a lab, this might look like a monthly cash prize for the member deemed to contribute most to project progress. Second, task allocation refers to how the team is organizationally *structured*, whether that be hierarchical—with a clear division between management and labor—or flat where all team members contribute to both planning and execution. A competitive task allocation in the research setting might manifest as lab members being allocated to the same task or project where only one will be selected to continue with that responsibility and receive authorship credit. This aspect is perhaps even more important in academic training labs, where continued responsibility is crucial to professional development. Last, workplace *culture* generally refers to norms and expectations held by team members and leadership. Competitive workplace culture can be instantiated if, for example, a lab manager chooses to select members who signal more competitive—rather than cooperative—work styles. Norms about productivity (e.g., work devotion) and collaboration (e.g., information sharing) could be altered by competition.

I limit the focus of this review to one specific form of competition, competitive reward schemes, because the literature on the effects of incentives on workers' output is formidable in its own right. This is true of both competitive and individualistic reward structures, in which incentives do or do not depend on the output of fellow workers, respectively. However, I maintain that task allocation competition and competitive workplace culture are important phenomena to understand in the scientific context. The proposed study in the final section motions to explore the various presentations of competitive working conditions in labs.

Additionally, most work in bibliometrics and science studies takes individual authors as the basic unit of analysis. This review recognizes the social organization of scientific production, that there are relationships and dynamics between members of a lab or research team. The effects of reward schemes on output are thus considered at the lab level and at the individual level, with attention paid to how individuals are situated within the structure of the organization (e.g., lab head vs. trainee). At the individual level, output can be thought of as the result of one's skill, effort, and time, each of which may be modified by the conditions of their work. For example, if skill is operationalized as the rate or quality of one's output, working with high-quality colleagues or equipment may be skill-enhancing. At the lab level, output may be represented by a more traditional production function combining labor and capital inputs. Probing how working conditions shape individual performance and how this relates to team performance is a major contribution of this review toward understanding research management.

Lastly, output can be measured in terms of quantity, quality, and topic. Since this review focuses on academic science, output is primarily operationalized as published research articles and sometimes patents. Research products could also include infrastructure like code and data or communications like podcasts and newspaper op-eds. These products are less often rewarded by scientific institutions and are not typically the subject of metaresearch. Altogether, the research question of this review is: ***How does intra-lab competition over rewards affect the quantity, quality, and topic of published research outputs for academic lab heads and members?***

The remainder of this paper is organized as follows. Section 2 briefly discusses particular features of scientific work that guide analyses of how general findings might apply to the science setting. Section 3 focuses on how individualistic (non-competitive) reward schemes motivate output. Section 4 examines how competitive rewards schemes affect output. Lastly, Section 5 proposes a study to begin addressing the gap of how intra-lab competition is managed and its effects on lab- and member-level output.

2 Features of Scientific Work

There are several features of academic scientific work that, in combination, differentiate it from other types of work. Elucidating these features will help motivate hypotheses about how findings from other work settings on competitive working conditions and output will translate into academic science, whether they are dampened, amplified, or otherwise distorted. The three features discussed here are the primacy of non-pecuniary compensation, the intensity of academic training, and the partial observability of effort and productivity.

First, academic science has many forms and sources of non-pecuniary compensation. The economic theory of equalizing differentials states that jobs hiring similarly skilled workers offer similar levels of compensation through a combination of pecuniary and non-pecuniary incentives (Lucas 1977). Non-pecuniary incentives, sometimes referred to as psychic wages, may be further categorized into consumption and investment benefits of a job (Rosen 1986). The former refers to job characteristics related to workers' health, flexibility, and control over where and when one works, and other non-monetary substitutes for wages; the latter refers to a job's ability to offer opportunities for professional development. The wage gap between workers in for-profit and nonprofit organizations is a common object of inquiry in studies of equalizing differentials (Hallock 2000; Hamann and Ren 2013). In science, non-pecuniary compensation can take the form of reputational and social rewards from being credited with a discovery or adhering to norms (Merton 1973, Chs. 13 & 14). Additionally, where what is produced (i.e., output topic) is predetermined in many work settings, academic science is mostly self-directed. This academic freedom is another potential source of satisfaction in scientific work. Scientists are also often intrinsically motivated to solve puzzles or contribute to public knowledge (Stephan 2012, Ch. 2).

Together, non-pecuniary compensation may outweigh pecuniary compensation in academic science, complicating how prior findings on competition over material rewards might apply.

Second, scientific training is especially long and necessary for full participation in the profession. In general, professional careers are differentiated from jobs in that promises of future increases in compensation and performance are exchanged in addition to the exchange of wages and labor (Bar-Isaac and Lévy 2022; Zussman 1985). Indeed, managers of technical professionals have identified access to professional development opportunities as a lever of control (Meiksins and Whalley 2001). Taking into account undergraduate and graduate studies, as well as increasingly common post-doctoral training, a gestation period of roughly a decade is necessary but not sufficient for continued career progression in academia. While in training, students and post-docs who make up the majority of academic lab members are more often responsible for manual execution. Through their execution work, they might develop expertise in working with highly specialized equipment and materials (i.e., physical capital), making themselves indispensable to the production process. However, other skills are necessary to fulfill the responsibilities of a lab head or principal investigator (PI). It is generally expected trainees will move toward the planning and communication of research as they progress. However, prospects of achieving PI status grow more unlikely for the average trainee over time:

> The hope is to move on and have a lab of one's own—to be the one who sets the research agenda and shares in the intellectual property rights of the research coming out of the lab. But… a smaller and smaller percentage of scientists are able to make this transition. This means that, if they choose to continue doing research, scientists are likely to play supporting roles for life, and the intellectual property rights that proved so motivating may become farther from their reach. (Stephan 2012, p. 81)

As labs continue to increase in size, access to professional development opportunities may become a source of fierce competition among lab members, making the academic lab a particularly interesting site to study the effects of within-team competition.

Third, scientific productivity is only partially measurable and the ease of observation varies at different points in the production process (Merton 1973, Ch. 14). Output in a work context sits on a spectrum from fully observable and measurable, as it is in manufacturing, or unobservable and difficult to measure, as it can be for certain administrative roles. In academia, output quantity can be measured in terms of publications. Quality is arguably proxied through citations. However, these discrete measures only apply to finished products, which is more useful for comparisons across labs. On the other hand, science-in-the-making (Latour 1987) can be non-linear and exploratory, especially in academic labs doing basic science. Productivity at this level, which is more useful for comparisons among members within labs, is only partially observed and more difficult to measure, although lab members and heads may have a sense of others' effort and productivity.

3 Individualistic Reward Schemes and Output

The theory of equalizing differentials considers compensation as the combination of pecuniary and non-pecuniary rewards. While both kinds of rewards are partial substitutes for each other, most studies focus on pay since that reward is most easily measured. An understanding of how reward scheme policies in the absence of competition is helpful before examining the effects of within-team competition. Here, I review prior work on the connection between pay and output by outlining a core debate in labor economics regarding the efficiency of paying for productivity versus effort.

3.1 Pay for Productivity (Skill)

For the last forty years, economists have given attention to whether organizations are most efficient when paying workers for their output versus their working time. Lazear (1986) introduced this debate and considers factors under which pay for productivity, or "piece-rate wages," are preferable to fixed salaries. The primary factor is monitoring cost, which refers to the employer's ability to measure and observe the productivity of the worker. Lazear predicted that, as long as information about a worker's skill is not fully visible to the employer, some salary-paying firms will exist and contain the lowest-skill workers. Thus, organizations seeking the most productive workers should somehow tie pay to output, although they may wish to provide some baseline salary to mitigate issues for the workers like risk.

Lazear (2000) later supported this theory using data on manufacturing workers in an automotive glass company. He found that a shift from salaries to piece rates was associated with 44 percent higher output per worker and an increased variance in output across workers. Together, this suggests that piece rates incentivize all workers to produce more and higher-quality workers to differentiate themselves from lower-quality workers. However, Lazear notes that this finding is expected of the manufacturing setting, since "output is easily measured, quality problems are readily detected, and blame is assignable" (p. 1358), warning that these results may not generalize to professional settings such as science.

Although piece rates are rare in professional settings, a closely related way to tie pay to productivity is through performance reviews. Performance reviews involve a combination of subjective and objective measures of productivity. Where piece rates are most effective when output is observable and measurable, merit pay—increased compensation for positive reviews—makes payment for productivity possible in work where output is not perfectly observed. There is robust evidence that merit pay is associated with increased output quantity across various populations and settings, including experiments in the lab and the field (Jenkins et al. 1998; Rynes, Gerhart, and Parks 2005). The relationship between pay for positive performance evaluations and output quality is less established.

Together, the findings on piece rates and merit pay in non-science settings suggest that tying material compensation to productivity can increase output quantity. Pay based solely on objective measures—as is the case under a piece-rate scheme—may be more fitting for lab heads, who can be judged based on the finished products of their labs, namely published research articles. Samaniego and colleagues (2023) found evidence that output quantity and quality, measured by academics' h-index, were associated with higher pay. This suggests some universities already institute an implicit piece-rate scheme. However, performance evaluations may be more appropriate for measuring productivity among lab members, since output at this stage of production is more difficult to observe and measure objectively. While merit pay might boost the performance of lab members, it may also have an unintended consequence. As members of academic labs are often trainees, explicit policy relating pay to performance could disincentivize exploration and the development of new skills and stunt output in the long term. This could be described as a "training-output tradeoff."

3.2 Fixed Pay (Effort)

Lazear (1986) defines salaries as wages based on an input of effort in a given period. While the mainstream debate about whether piece rates or salaries yield greater output from workers generally favors the former, there is at least one way in which paying a higher salary can result in output gains. There are often many aspects of a job not explicitly specified in the labor contract, including the level of effort a worker must provide to receive their salary (Akerlof 1982; Fehr, Goette, and Zehnder 2009). Akerlof (1982) introduced the notion that the labor contract is a partial gift exchange, drawing theory for social psychology and sociology on norms of reciprocity. When a worker's output is a function of their effort, and effort is a function of wages, they may respond to a firm offering a wage higher than the market by exchanging greater effort. This motivates the efficiency wage hypothesis, which states that, when effort is variable and not perfectly observed, there exists a wage higher than the competitive labor market equilibrium wage that maximizes profit by incentivizing higher productivity from each worker. Efficiency wage theory explains the stylized fact that many industries feature wages higher than what is expected from the market and maintain a level of structural involuntary unemployment (Akerlof and Yellen 1990).

Empirical evidence of this sociological basis for wage setting, that "fair" wages can induce greater output in workers, is enhanced by more recent developments in behavioral economics. Experimental games in the lab and data from the field have found that reciprocity norms play a small but consistent role in labor contracts (Fehr et al. 2009). For example, Fehr and colleagues (1998) ran a series of simulated labor markets in a reciprocal setting comparing employers' and workers' choices when 1) effort was fixed, 2) effort was variable and there was no excess labor supply, and 3) effort was variable, but an excess labor supply could be exploited to minimize cost. When given the option to choose effort levels, workers chose to invest more effort in response to higher wage offers. This reciprocal behavior was present even with excess labor supply, suggesting that norms of reciprocity can overpower market forces. However, these experimental games only involved small payouts and simulated short-term employment relationships. Cohn et al. (2015) conducted a study combining data from a field and lab experiment to understand how efficiency wages and reciprocity operate in higher-stakes, real-world labor markets. Their field setting—workers selling newspapers on the street during a sales promotion—is opportune because pay was not dependent on workers' sales, nor was there a high likelihood of repeated employment. Even under these conditions, some workers input more effort when offered higher hourly wages. Specifically, only those who felt the base pay was unfair and demonstrated sensitivity to reciprocity norms in the lab experiment participated in the gift exchange of effort for pay. The authors concluded that efficiency wages operate through the removal of negative reciprocity, where feelings of unfairness are a barrier to full effort.

Moving toward a setting more similar to science, Hamman and Ren (2013) studied the role of fairness and inequality among workers in for-profit and nonprofit nursing homes. The authors put in conversation two lines of theory: efficiency wages and tournament theory—the latter is introduced in the following section. They predicted that workers in the nonprofit sector would be more responsive to efficiency wages than inequality and competition because they are more sensitive to social rewards and punishments compared to those working in for-profit organizations. Their data supported this hypothesis, as they found a negative correlation between wage inequality and output quality (measured in resident review positivity) in the nonprofit workers. Although the evidence is not enough to be conclusive about causal mechanisms, the narrative they proposed—that workers were sorted based on their preference for economic or social rewards—is plausible.

Although no causal studies were found on salary increases and output in science, findings from other settings suggest that paying efficiency wages may be effective for improving output under certain conditions. The previous discussion on the primacy of non-pecuniary incentives in science is most relevant here. Findings from Hamman and Ren's (2013) study may apply similarly to scientists sorting into industry and academia, where those working in the latter are more similar to the nonprofit nursing home workers. Social rewards and punishment are common in academic science. For example, service to the community through peer review or conference organizing is often expected without pecuniary compensation. However, Cohn and colleagues' (2015) findings suggest that sensitivity to reciprocity norms is a necessary but not sufficient condition; dissatisfaction with current pay is also required for higher wages to induce greater output. To my knowledge, no study has determined what scientists think is a "fair" wage. Well-established scientists may feel their pecuniary compensation is fair, given their level of intrinsic motivation and academic freedom. Alternatively, there has been a recent surge in union militancy among graduate students and postdocs (Bartusek et al. 2023; Langin 2023). Union activity could be caused by feelings that material conditions should improve. Unions could also stoke dissatisfaction among its members. In either case, trainees may be the most fitting target for salary increases aimed at boosting output.

3.3 Pay and Hours (Time)

Under both pay schemes, increases in pay may increase output by incentivizing workers to devote more hours to work. It is theorized that workers have some underlying shadow price for their labor, and that, as wages meet or exceed the value of their leisure time, they will choose to invest more hours into work (Heckman 1974). For workers paid hourly, their leisure time has the opportunity cost of their rate, whereas the opportunity cost of leisure for piece-rate workers is what they might produce in each hour of work. A field experiment of messengers who were paid piece rate found that workers who were free to choose their hours and effort responded to higher pay with increased hours (Fehr and Goette 2007). Workers who displayed loss aversion decreased their daily effort somewhat, but overall labor supply increased with higher wages. Whether paid for output or effort, though, it is not necessarily true that working more hours translates to greater productivity in professional and managerial work. Golden (2011) synthesized recent research related to working time schedules, workers' level of control over their schedule, total productivity, productivity per hour, and profit across multiple countries and work contexts. Overwork and fatigue are concepts central to linking working hours and output. Empirically, longer working hours were not associated with greater output quantity and quality in both manufacturing and professional settings. Also, giving workers the flexibility to choose their own schedule reduced barriers to maintaining their optimal productivity, such as spillovers from life into working time. However, much of the work synthesized was correlational and did not rule out reverse causal explanations.

No empirical studies on this topic were found in science, and it remains unclear whether the general findings on pay and working hours would be applicable. It is that rates of pay would have no effect on scientists' working hours, since non-pecuniary incentives and cultural conditions might already encourage maximum investment of time into research. Ackers (2007) reviewed the literature on working hours and scientific career progression through the lens of labor policy. She also surveyed and interviewed a stratified sample that included parent and caring scientists. Scientists did indeed work long hours that could harm their social relationships outside of work. However, long working hours were most often voluntary and invested into publications and networking, which are key to career progression. Parents and caregivers, often women, had less ability to invest those long hours. Ackers concluded that working time legislation would be largely ineffective as long as overwork culture remained. Family and caregiving leave policies aimed at promoting gender equity among professionals have also proven ineffective because of gendered expectations of family care after returning from leave (Cheng 2020; Fox and Gaughan 2021). These three studies examined how reduced working hours selects for scientists without care responsibilities and provide evidence that fewer hours results in lower productivity. None describe how exogenous shifts in working time would change what science could get done in terms of quality or topic. It is widely accepted—although untested—that making meaningful contributions requires a devotion of one's time and attention.

4 Competitive Reward Schemes and Output

In the previous section, the pay schemes discussed only depended on individual workers' output or input. However, many workers are paid not just piece rates or salaries, but also some amount determined through competition. Even in the absence of an explicit contest or tournament, promotions that come with significant pay increases or large bonuses for above-average sales are examples of competitive pay schemes because they depend on some others either not getting the promotion or selling below the average (Lazear and Rosen 1981; Nalebuff and Stiglitz 1983). This section introduces tournament theory and the effects of competitive reward schemes on workers' output.

4.1 Material Tournaments and Contests in General

Lazear and Rosen (1981) theorized that a tournament offering different prizes (i.e., wages) based on workers' ordinal rank can optimally incentivize productivity. Instead of rewarding each measure of output, workers invest their effort for a chance to win the higher prize, and it is in their self-interest to do so rather than shirk. They showed that tournaments are preferable to piece rates in settings where directly monitoring output would be costlier than ranking workers. Thus, rank-order tournaments may be an appealing pay scheme for incentivizing lab members because, while internal output is difficult to measure, lab heads likely have a sense of members' productivity in relation to each other.

On the whole, competitive pay schemes have both desirous and deleterious implications in contrast to individualistic pay schemes. Tournament theorists have found that competitive pay can incentivize riskier, more profitable production in workers who would otherwise be risk-averse under an individualistic scheme, which "is especially great in fields like research and development where prizes (in the form of patents) encourage risk-taking that can dramatically shorten the time to discovery" (Nalebuff and Stiglitz 1983). All workers would receive lower piece-rate wages in the case of a negative shock to output in general, so they might prefer tournament pay which would pay the same regardless of total output. However, it is also noted that competition for pay may decrease worker satisfaction (likely important for intra-organizational production but often excluded from traditional economic models) and disincentivizes cooperative behavior.

Empirical studies in non-science settings test some of the predictions from tournament theory. Brouwer and colleagues' (2016) study of gamification in professional teams supported the hypothesis that competition can have an overall positive correlation with team output quality and quantity. However, this main association was mediated by a strong positive relationship on individual engagement with tasks outweighing the negative relationships of increased conflict and decreased psychological safety. These findings leave unclear whether worker satisfaction increases or decreases with competition and at least suggest that competition can discourage risk-taking since these are associated with a sense of psychological safety within the group.

Cooperative behaviors within a work team can include sharing information or giving truthful feedback. He et al. (2014) measured "collectivism" in Taiwanese IT teams and found a distinction between the "hypercompetition" of individualistic teams, where each team member is looking to further their own interests over others, and the "development competition" of collectivistic teams, where members strive to make the largest contributions to the team's success. These types of competition had opposite effects on information sharing, showing that competition can reduce this form of cooperation in some cases. Riedl et al. (2024) provide causal evidence of widespread strategic behavior among designers in royalties contests given the opportunity to evaluate one's own submissions and those of direct competitors. Highly skilled contestants were more likely to engage in and be targeted with sabotage, whereas less successful contestants employed a self-promotion strategy.

There is evidence for both reduced cooperation and negative psychological effects of competition in science as well. Knowledge sharing or communalism is a social norm that encourages cumulative knowledge production (Merton 1973, Ch. 13). In practice, however, competition to be the first to make a discovery creates an incentive to withhold information. Evans (2010) documented researchers of the plant model *Arabidopsis thaliana* hindering competitors by restricting information through delay, omission, lying, and embargo. Another study with focus groups involving 51 early- and mid-career health scientists uncovered strategic behaviors among academic competitors including reduced information sharing and sabotage through biased peer review and communicating research in an unreproducible way (Anderson et al. 2007). Lastly, anecdotes in recent years attest to the negative psychological effects intra-lab competition can have on trainees seeking to form bonds with cohort mates (Quinn 2021).

4.2 Scientific Contests and the Partial Observability of Science-in-the-Making

Non-pecuniary contests over credit for priority are canonically the primary mechanism ensuring adequate production of knowledge, a public good, by scientists who are private actors (Merton 1973, Ch. 14). Pecuniary contests are also commonly employed to incentivize research, taking the form of grants, awards or bounties, patent contests, and tenure promotions (and their accompanying pay raise). Kolmar and Wagener (2012) use academic tenure as an example in their discussion of using contests to incentivize the private production of public goods. They formally model a contest where a contestant's chance of winning the prize is proportional to the size of their investment in producing the public good. This is akin to a lottery where the funds raised by purchasing tickets contribute to a prize pool and some public good like education through taxes. Kolmar and Wagener find that a contest will optimally allocate public goods investment if the prize incentivizes high-ability contributors to invest full-time but not so high that it attracts low-ability contributors. Additionally, even with proper sorting of high-ability contributors, the contest must be decisive. That is, the separation of individuals' contributions must be sufficiently visible.

While the authors explain optimal research output across labs, this conclusion troubles the prospect of using competition to increase output within academic labs for two reasons. Suppose the public goods within a lab are its portfolio of works in progress. Let lab members be in competition for some form of compensation based on their contributions to a work like a travel grant to present at a conference (pecuniary) or first authorship (non-pecuniary). First, if within-lab output is not perfectly observable as it is across labs with published articles, then the model suggests that lab members will be inefficiently sorted into contests, and thus there will be an overinvestment of labor into some projects. Second, even if only the lab members best suited for a project are in competition for that project, it may not be possible to decisively determine the proportion each team member contributed to the project, and therefore maximum effort will not be achieved. Thus, intra-lab competition may not have the same theoretical appeal as competition among scientists generally.

4.3 Could Competition Demotivate Scientists? Notes from Self-Determination Theory

Most of the work in the tournament theory literature takes workers as economic agents and does not consider non-pecuniary compensation. As discussed in the previous section, academic scientists receive non-pecuniary compensation for working on problems that are intrinsically motivated and self-chosen. These sources of motivation are well-studied in self-determination theory. A classic debate in this literature is whether extrinsic rewards undermine the motivation of workers seeking control over their work.

It is clear self-determination is a motivator of academic scientists. Scientists in the private sector are often restricted from publication, unlike those in the academic or other non-private sectors, because their research provides competitive advantages for their employer (e.g., trade secrets). Stern (2004) considered whether researchers in industry substitute higher wages for the ability to publish their findings publicly. Stern overcame an empirical concern that higher quality scientists—who may be more productive for a company in continuing to engage in science—may also have a higher preference for publishing by exploiting the fact that researchers often have multiple job offers and using researcher fixed effects to control for researcher quality. Analyzing survey data capturing 164 job offers among 66 postdoctoral biologists, he found that PhDs in industry who have the ability to publish their work are paid an estimated $14,000 less than those who cannot publish. This supports the argument that the incentive structure for participation in public research relies greatly on researchers' intrinsic motivation and preference for control. Aghion and colleagues (2008) formally modeled how creative control optimally allocates researcher attention across basic and applied problems. Academia may hire scientists at a lower wage because it allows for self-direction and publication. This allows more scientists to work on a diffuse set of problems that are far from commercialization. However, problems close to commercialization require focus to bring economic returns as soon as possible. This is when it is optimal for higher wages from the private sector to control the direction of scientists' effort. What remains unknown is how competition might modify the intrinsic motivation and creative control of academic scientists.

Early work in the self-determination literature proposes the undermining hypothesis, which states that extrinsic motivators and competition can crowd out intrinsic motivation and harm performance. In 1971, Deci introduced the undermining hypothesis to behavioral psychology with a seminal experiment showing participants were less likely to continue engaging in a puzzle task after monetary rewards were introduced (Deci, Koestner, and Ryan 1999). In a meta-analysis of 128 experimental effects nearly three decades later, Deci and colleagues (1999) found consistent evidence confirming the undermining effect of extrinsic rewards on intrinsic motivation. They did find that this undermining was stronger for young children than for college students, positing that older participants were more able to differentiate between rewards that were informative—based on ability or performance—versus controlling—meant to induce particular behaviors for someone else's benefit. The understanding of rewards as informative or controlling is a central mediating factor in the undermining hypothesis literature. However, findings from lab experiments may not generalize to settings where intrinsically motivated agents are engaging in labor relations or organized into teams.

Some work in applied settings similar to science supports the undermining hypothesis. A pair of studies by Besley and Ghatak (2005, 2014) in the nonprofit labor context theorize intrinsic motivation from psychological and economic perspectives. Sources of intrinsic motivation include competence, autonomy, social approval, cultural influence, and alignment with one's own values. They develop a model of public bureaucracies and private non-profits (i.e., mission-oriented organizations) showing that workers' level of intrinsic motivation is a dimension of heterogeneity in the workforce, and firms that select for more intrinsically motivated workers will be more productive, all else being equal. Under the assumption that incentive pay is meant to motivate workers otherwise unmotivated, Besley and Ghatak argue that such reward schemes are less effective in contexts where workers are intrinsically motivated. The authors only address competition across organizations rather than within organizations, stating that market competition decreases a firm's ability to pursue non-economic missions, which may lead to a degradation of intrinsic motivation among its workers. Another context similar to academia is the arts, as both institutions are often publicly funded and have principles of creative (academic) freedom. Eikhof and Haunschild's (2007) qualitative research examining artists in German theatre points out "a central paradox of creative production: when the artistic logic of practice is economically utilized, economic logic tends to crowd out the artistic logic and, thus, erodes the very resources upon which creative production depends" (p. 524). In other words, professionals in the arts can undermine their own intrinsic motivation in attempts to reconcile their creative drives with employability.

However, empirical evidence across multiple other contexts points to either a positive or no relationship between extrinsic rewards and intrinsic motivation or creativity. Dallmeyer et al. (2024) observed an increase in the hours supplied and indicators of recruitment and retention among volunteer coaches in German sports clubs. Although they used propensity score matching to rule out selection bias, the authors acknowledge that a crowding-in explanation (rather than crowding-out) is plausible. The increase in recruitment may have made coaching more enjoyable, and this might be an alternative cause of the positive effects. Intrinsic motivation among athletes is well documented, and a review of recent studies in this context echoes Deci et al.'s suggestion that the perceived meaning of extrinsic rewards—informational versus controlling—moderates whether they complement or substitute for intrinsic motivation (Schüler, Wolff, and Duda 2023). Aligned with the studies in that review, Readdy and colleagues' (2014) survey of college football players who underwent an off-season training program that included extrinsic rewards found a statistically significant decrease in amotivation and an increase in intrinsic motivation with no effect on the athletes' feeling of fulfillment. However, qualitative analysis of interviews contradicted the previous findings, as some athletes revealed a belief that the extrinsic rewards were not related to their actual football skills and did not find the extrinsic rewards motivating. They conclude that undermining effects may be idiosyncratic. Among private sector employees, survey analyses found that pay for performance at the individual and group levels had positive results on intrinsic motivation (Cabanas, Proença, and Carozzo-Todaro 2020) and creativity, measured as innovations (Curran and Walsworth 2014), respectively.

It is crucial to recognize that most of the studies reviewed in this subsection fail to provide even moderate evidence of a causal relationship between extrinsic and intrinsic motivators. Only Deci et al.'s meta-analysis featured well-controlled experiments, and this research lacked the context of an employment relation. Most likely, how competitive pay is framed when introduced to workers determines how it will affect their output. An information framing—that competition is being used to reward workers based on their output—will likely leave intrinsic motivation intact, while a control framing—that competition is being used to induce greater effort or time from workers—will diminish intrinsic motivation. A causal study of how intra-lab competition affects lab members' experience of intrinsic motivation and creative control would contribute to this general debate.

4.4 Prior Work on Inter-lab Competition and Output

A substantial body of work has examined the effects of competition in science, mostly concerned with individual scientists in separate teams and labs. While competition seems to increase output quantity and influence topic choice, there is mixed evidence with regard to its effect on output quality.

A number of studies find positive effects of competition on scientific output. Jin et al. (2021) used a differences-in-difference design to compare scientific topics that had similar growth in terms of scientists' attention and output prior to the introduction of an award in some topics and not others. They found that the introduction of an award was associated with 40 percent more papers published and 33 percent more citations in the first five to ten years after the first prize. This is likely related to the increased retention and recruitment of scientists' interest in the topic, including an influx of 47 percent more star scientists on average. In particular, these growth indicators were positively related to awards with a cash prize. The implication is that increased competition in a topic for both reputational and material rewards associated with awards boosted output quantity and quality (as proxied by citations) overall, although awards were not randomly assigned to topics, and the authors did not claim causality.

Besides awards, patents also act as competitions whose winners receive pecuniary rewards in the form of royalties. Academic scientists are increasingly engaging with industry sponsors and privatizing their intellectual property through patents. Azoulay and colleagues (2009) measured how the rise of academic patenting affected the quantity and quality of public research. Previous studies on the same topic were confounded by self-selection into patenting, so the authors applied Inverted Probabilities of Treatment Weights (IPTW) estimation to their data from a 31-year panel of 3,862 academic life scientists. They found that academics who patented more also published more and in slightly higher quality journals, focusing on "patentable" or commercial problems. In addition, patenting scientists were more likely to collaborate with private-sector researchers and publish in journals that publish private-sector research. Considering Aghion et al.'s (2008) model mentioned previously, this result might be concerning with respect to the optimal allocation of scientific labor across academia and industry. A key takeaway is that the privatization of intellectual property does not necessarily distract from the production of public research, and can actually promote academic output.

The prior two studies examine output after a prize is established and won, but how does competition affect losers' output? Ayoubi et al. (2019) looked into this question in the context of grant competitions. They used a combination of propensity score matching and instrumental variables approaches to identify similar scientists who did and did not apply to a Swiss funding program. Those who applied published 43 percent more papers and increased the average impact factor of their publication venues by seven percent in the five years after submitting their proposal, leading the authors to conclude that simply preparing to compete benefits scientists' output. Interestingly, grant recipients did not outperform other applicants after receiving the funds, but were more likely to coauthor with them.

Other work reveals the downsides of competition with respect to research output. Previously mentioned qualitative work documented how competition over credit for being first to make a discovery led scientists to withhold or give false information, sabotage competitors, and even partake in research misconduct (Anderson et al. 2007; Evans 2010), ostensibly making those research communities collectively worse off. However, competition may have deleterious effects even on good-faith actors if they are inclined to rush their work or are less productive after the contest is over. Hill and Stein (2021a) quantitatively examined what effect races for priority had on research quality in structural biology. They used data from the large macromolecule structure repository Protein Data Bank, which is advantageous because discoveries are discrete, comparable, and timestamped. Structures identified as more impactful contributions attracted more competition. While discoveries were made faster, those studies were of lower quality, suggesting that competitors invested less in improving their work. Crucially, scientists whose careers were less dependent on establishing priority through publication, such as tenured faculty, did not publish lower-quality work with haste. Borjas and Duran (2015) considered the output of successful competitors in science using the Fields Medal in mathematics as their setting. They employed a differences-in-differences strategy using multiple methods to construct a control group and demonstrate that Fields Medal recipients and their peers published at similar rates prior to the award year. Prizewinners experienced a reduction in output quantity, possibly because they took on fewer students after their award. Their students' output also declined in terms of both the number of publications and citations. Borjas and Duran attributed this to a shift in research focus to a more diffuse set of topics rather than demotivation.

Despite much work focusing on the finished products of academic labs, a gap exists in our understanding of how intra-lab competition for pecuniary or non-pecuniary rewards shapes individual and lab output. However, if findings from non-scientific teams and between scientific labs translate to the intra-lab context, I hypothesize competition among lab members will boost quantity, possibly at the expense of quality, pro-social behavior, and members' well-being.

5 Empirical Gap and Study Proposal

5.1 Beliefs, Choices, Experiences, and Effects of Intra-lab Competition and Output

To my knowledge, no study has considered how intra-lab competition might enhance or stifle the scientific productivity of each lab member or the lab as a whole, despite increasing anecdotal acknowledgment. There are several roadblocks that may explain the continued existence of this gap. First, laboratories are socioculturally privileged spaces as black boxes of knowledge production (Latour 1983). Research on the topic of intra-lab competition and lab management practices, broadly, as well as policies attempting to regulate laboratories are disincentivized if they attract pushback from the scientific community. Second, the dynamics of competition within any team are likely complex and hard to measure. This is especially true for scientific teams, which are hyperspecialized and operate under winner-take-all incentive structures. The lack of theoretical clarity or validated measures remains a challenge in designing rigorous research on the subject. Last, the conventional methods of different disciplines often either privilege the internal states or observable behaviors of subjects. However, competition likely has effects on both experiences and behavior. In this case, disciplinary boundaries may act as a barrier to achieving further understanding of this phenomenon. An initial step to begin filling this gap is to generate a substantial description of lab heads' productivity-related beliefs and management choices, as well as the experiences of and behavioral effects on lab members related to intra-lab competition.

Lab heads can play an active role in selecting reward schemes or influencing the organizational environment (e.g., task allocation, workplace culture) to encourage or discourage competition among lab members. It may be in their interest to promote competition at the cost of trainees' wellbeing as suggested in the prior literature on competition and team performance (Brouwer 2016; He et al. 2014). A study is needed to confirm whether academic PIs hold such *beliefs* and what policies and practices they *choose* to influence intra-lab competition.

Studying the promotion of competition among lab members opens discussions of labor exploitation in science and offers insights into the material, structural, and cultural dynamics operating within labs. Exploitation in labs may appear when competition boosts overall lab output—and PI output—without benefiting, and even harming, individual lab members. One practice that might promote competition is the hiring of as many students as possible without regard for one's capacity to adequately compensate or train them, which could induce a race to the bottom in terms of acceptable working conditions (e.g., longer hours, more safety risks). In order to understand how management choices affect output through competitive conditions, it would be helpful to examine how lab members *experience* the policies and practices aimed at influencing competition—both internally and interpersonally—and what *effect* competition has on their behavior in the workplace.

5.2 Study Proposal

Since little is formally known about the effect of intra-lab competition and member- and lab-level output, I propose a study involving a pair of surveys followed by a series of interviews. This study will produce descriptive and correlational findings on the lab managers' productivity-related beliefs regarding competition, the levers they use to control competition, and the range of experiences with competition and behavioral responses among labmates.

Chemistry is a discipline in which labs tend to have many members and hazardous materials or equipment are common (Ménard and Trant 2020), making it an appealing setting for this research. Survey sampling will take place at the level of the lab head. I will identify a universe of lab heads in American Chemistry using professional society membership, conference attendance, and online search with authorship order as a guide. The first survey will target PIs, asking them to elucidate the material, structural, and cultural policies and practices they use to encourage or discourage competition in their labs. Measures of their attitudes and beliefs about competition and productivity will be included. The second survey will target non-head lab members, asking them to describe their regular tasks and interactions with other lab members, including measures of their working hours and tolerance for risk at work. Crucially, measures of attitudes and perceptions of intra-lab competition in their lab, and in other labs generally, will be included. Later, I will use self-reports or bibliometric proxies of productivity to examine how competition relates to motivation and well-being, hours, safety, and productivity.

The operations and culture within each lab may vary substantially such that random sampling might not produce results generalizable to the population. Interviews are useful for understanding the various lab contexts and gathering data more in-depth. Interview subjects will be identified in large part through responses from the two surveys. Interviews with PIs will include questions about experiences with competition in previous labs in which they were trained. Interviews with lab members will include questions about how they responded to particular policies and practices exercised in their lab, as well as experiences with other labs.

Responses to open-ended questions from the surveys will be grouped in a data-driven manner, with unsupervised machine learning models for example. This is useful for creating initial taxonomies of beliefs about competition and output, policies and practices that control competition, or experiences and behaviors responding to those levers of control. These categories will then guide the qualitative coding of interview data, which will possibly be performed in collaboration with research assistants or coauthors. This may be described as a quantitative to qualitative mixed methods approach (Creswell 2009). Ideally, this will result in a holistic understanding of intra-lab competition, leading the way for future empirical work that is theoretically rich.

The proposed study overcomes the roadblocks described previously. First, this study opens up the black box of the lab and spotlights the employment relations and power dynamics present in knowledge production. Second, where intra-lab competition is currently undertheorized and operationalization would lack validity, the taxonomies and theory produced in this study would make progress toward future observational and experimental work. Last, in processing data on both behaviors and internal states, this interdisciplinary, mixed methods approach avoids the limitations of disciplinary boundaries and their epistemic cultures. In addition, this study design could easily be expanded to explore other poorly understood aspects of lab management, such as the level of control over a trainee's research direction. Furthermore, following this research agenda could lead to a contribution of causal evidence to general literatures on within-team competition and output. Results will inform policymakers in better managing scientific industrial relations to attend to exploitation, balance the training-output tradeoff, reduce safety risks, and promote collaboration and data sharing among lab members.

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