Innovation Waves and Academic Bubbles

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Abstract

We study how a principal motivates innovation by contracting researchers to generate ideas that impact economic productivity. Because individual research contributions are unobservable, the principal must rely on accolades provided by peers, such as citations. As a result, researchers may inefficiently over-coordinate their research efforts and work in areas with a low likelihood of advancing society. This can give rise to "academic bubbles" in which researchers continue working in initially promising agendas after negative news about them has arrived. However, such incentives may be necessary to sustain participation, especially when researcher effort costs and risk aversion are high, and the likelihood that any agenda will advance society is low.

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Ideas are non-rival, but credit is not...

Societal progress and technological advancement depend on discovering and developing new ideas. Academic and industrial researchers play a primary role in this process, usually by publishing articles and obtaining patents (and citations to these works) throughout their careers. Academic institutions and private firms value such progress and thus reward researchers for these activities. These institutions, however, may not be able to evaluate the quality of research and patent activity. Possibly due to this difficulty, the broader scientific and academic community increasingly relies on publications and citations (i.e., google scholar, Web of Science, and USPTO Patent and Citation data) to assess impact. Metrics such as the h- and i-10-index have been developed to measure publication quality based on citations, and these metrics feature prominently during merit and promotion reviews.[1] Patent citations, for instance, are used to proxy not only for patent quality (e.g., Trajtenberg (1990), Hagedoorn and Cloodt (2003), Moser et al. (2018)), but also for knowledge spillovers (e.g., Jaffe et al. (1993)) and influence on future technological innovation (e.g., Corredoira and Banerjee (2015)).[2] Such reliance on these metrics makes a lot of sense to a first approximation—who better to evaluate the quality and significance of a researchers work than other researchers in that area?

In this paper, we evaluate the contracting problem of inducing research effort when the principal cannot directly observe research effort or the importance of the particular topic that a researcher chooses to pursue. Publications and citations, however, are observable. A researcher with career concerns (e.g., Holmström (1982a))[3] will then be motivated to pursue citations, which have been shown empirically to lead to better career outcomes by, among others, Ellison (2013), Jensen, Rouquier, and Croissant (2009), and Hilmer, Ransom, and Hilmer (2015), while Hager, Schwarz, and Waldinger (2024) shows that the

[1]The h-index measures the minimum number of publications with a minimum number of citations (i.e., an h-index of ten indicates a researcher has ten publications with at least ten citations), while the -10 index looks at the minimum number of citations among a researcher's top ten cited publications.

[2]See Jaffe and de Rassenfosse (2017) for a review of this literature.

[3]Hamermesh (2018) provides a review of the literature on citations in economics and shows how citations impact researcher salaries and non-monetary rewards.

introduction of a public citation record (the Science Citation Index, or SCI) significantly contributed to subsequent positive assortative matching between scientists and academic departments, in part by alleviating informational frictions. We take the view that such career incentives are necessary to facilitate research when research effort is unobservable and non-contractible, and the significance of the agendas are unknown to society until they mature. However, because researchers are rewarded for publications and citations, they may end up excessively researching more speculative topics that are less likely to be socially valuable.

We construct a continuous-time model of a population of N researchers who can exert costly effort to try to discover new research agendas or to produce new research within an existing active agenda. An active agenda can be either significant, that is, it raises economic output, or insignificant, that is, it destroys economic output. Whether an agenda is significant is only discovered after it matures. At inception, there is a noisy binary public signal about whether a new active agenda is significant. Agendas that receive high signals are considered promising, while those that receive a low signal are speculative. Although speculative agendas remain speculative until they mature, active agendas may also have an additional negative signal arrive before maturity that switches beliefs about that agenda to speculative. The discovery of a new agenda and the maturation of an active agenda are both driven by Poisson counting processes whose expected likelihood of an arrival is increasing in the number of active researchers in that agenda.

In our model, researchers are driven at least in part by career concerns. In addition to a wage that depends on current economic output, a researcher can also be rewarded for citations and with promotions or awards, which we refer to as prestige, when they participate in a significant agenda that matures. In contrast, if they participate in an insignificant agenda when it matures, they receive a penalty to their prestige. An important aspect that we wish to capture with our multi-researcher equilibrium model is that research is often done within networks and research communities. For instance, Zeng et al. (2019) show

that researchers tend to coordinate on specific topics in clear community structures of co-citing networks, and that staying within such communities leads to a higher number of published papers and higher average citations per paper. Jaffe et al. (1993) show that US (and specifically within state) inventors have a higher propensity of citing each other in patents. As we will see, collective career concerns in our equilibrium framework will be crucial in driving innovation by incentivizing researchers to coordinate their research activities. Researchers initially have an outside option to pursue a different occupation that does not require costly effort, which captures how such talented individuals may instead pursue non-research-intensive occupations, and consequently face a participation constraint when they begin their careers.

Researchers in our framework consequently engage in research not only to increase their wage by advancing society and increasing economic output, but also because they value citations and prestige to advance their careers. This latter motive not only introduces coordination incentives across researchers that may lead them to work inefficiently across different fields, but also gives rise to rich dynamics for how research impacts economic growth. This is because private incentives to research (i.e., career concerns) may at times be at variance with social incentives for research (i.e., growth). There may be too little experimentation not only because private risk aversion is higher than social risk aversion, but also because of coordination; a researcher has incentives to work in agendas in which there are already a lot of researchers so that he can acquire citations and participate in maturing agendas. This coordination mechanism can lead to over-researching of speculative agendas and under-exploration of new research agendas, and is a novel form of moral hazard in teams (e.g., Holmström (1982b)).

Our model is fully tractable and delivers several key insights. First, when career concerns are mild, researchers only research promising agendas, and always abandon speculative agendas. In contrast, when career concerns are severe, then they also research all speculative agendas to maturity before trying to discover a new agenda—researching

an active agenda garners citations while researching to discover a new agenda does not. Strong career incentives consequently make citations less informative about the quality of research and lead to more low productivity research effort, patterns supported by more recent evidence (e.g., Marco (2007), Kuhn et al. (2017), Bloom et al. (2020)). As a consequence, a promising active agenda that garners attention from researchers continues to be researched after negative news arrives and it becomes common knowledge that it is likely a speculative agenda with a low likelihood of being significant. We refer to this phenomenon as a "academic bubble". The result that measuring research quality imperfectly with citations leads to behavioral distortions among researchers is reminiscent of the insights of the multi-tasking framework of Holmström and Milgrom (1991).

But, providing such career incentives is necessary when researcher's participation constraints are particularly tight. This unfortunate situation occurs when researchers have high effort costs and/or high risk aversion, and the probability that an active agenda is significant is low. Consequently, a planner designing an incentive-compatible research contract may need to reward all research to incentivize good research, and this is particularly true in professions in which the stakes are low (i.e., the likelihood that an agenda is significant to society is low). Because of the strong coordination motive among researchers, not providing career incentives can lead to a Pareto inferior outcome in which no research is conducted.

From these baseline results, we consider several extensions of our framework. First, we consider a continuous learning framework in which signals about the significance of an active agenda arrive over time until the agenda matures. We show that there is a critical probability of being significant at which an active agenda is abandoned, and this probability is decreasing in the strength of career incentives. Consequently, the stronger the career incentives, the longer researchers are willing to continue researching a highly speculative agenda despite the arrival of negative information. Second, we examine heterogeneity among researchers. We show that a research contract that gives rewards based

on career incentives selects on researchers who have stronger career concerns relative to the value they put on social progress to foster economic growth. These researchers consequently are more willing to research speculative agendas. Finally, we study how research is conducted when the most senior researcher is able to prioritize a field of research by providing stronger career incentives to researchers who work in that field. Turnover in senior researchers can be socially harmful because it can pull other researchers out of active promising agendas, redirecting research efforts to the field chosen by the new influential senior researcher. On the other hand, it can be beneficial as a way of pulling researchers out of active speculative agendas through relaxing their participation constraints with higher lifetime career rewards. Such a mechanism is consistent with the findings of Azoulay, Graff Zivin, and Wang (2010) that research output among collaborators contracts significantly after the death of a superstar researcher in the life sciences, while allowing that research network to move onto another topic.

Our paper relates to the literature on knowledge diffusion and research. Aghion and Howitt (1992) construct a general equilibrium model in which growth stems from the research activities of monopolistic firms and, similar to our maturation of new agendas, the arrival rate of new innovations is increasing in the number of researchers. Klette and Kortum (2004) and Aghion et al. (2005) study how innovation interacts with competition to explain innovation dynamics within industries. Aghion, Dewatripont, and Stein (2008) study the complementarity of incentives between public and private research, while we focus on complementarity across researchers. Lucas and Moll (2022) study how knowledge diffuses over time from interactions among differentially informed individuals, while we focus on how knowledge is created through research networks. To our knowledge, we are among the first to provide a general equilibrium characterization of how research is conducted in the presence of strong coordination motives arising from the career concerns and risk aversion of researchers.

Our paper is also related to the literature on agency issues in innovation. Holmström

(1989) examines the agency conflict within a firm in which innovation competes with the scope of tasks that the firm must accomplish, which gives small firms a comparative advantage in innovation. Manso (2011) examines optimal contracting between a principal and a manager who can innovate, and concludes that providing insurance against the risks associated with innovation is essential to motivating it. Similarly, Aghion, Van Reenen, and Zingales (2013) argues that institutional ownership fosters innovation by reducing career risks for managers, for instance by reducing downside risk and firing them less after profit downturns. Similar to these frameworks, we emphasize that risk aversion impacts an agent's incentives to innovate, and insuring the agent increases innovation. However, our focus is on the insurance provided by career incentives through citations and prestige and the general equilibrium incentives to informally coordinate on innovation in teams.

In contrast to many papers on innovation incentives, which often focus on editorial boards at journals or operational management in private sector firms, we consider a general equilibrium setting in which researchers face agency frictions. Because researchers fully internalize the game, distortions to the social path of discovery are not driven by coordination failures but rather by deliberate coordination because of common career concerns. In contrast to much of the career concerns literature in which peers enter either through benchmarking or teamwork, we emphasize an externality in which the incentives of one researcher do not take into account its impact on the incentives of other researchers. As a result, the sub-optimal evaluation of researchers based on citations and awards/promotions fosters implicit coordination to advance their careers because such evaluation ignores that they all benefit from researching the same agendas regardless of the agenda's likelihood of success. Consequently, there are contract externalities in the implicit contract signed between a researcher and the academic community.

Our paper also relates to the literature on resource misallocation. For instance, Eisfeld and Rampini (2006) show how capital misallocation is countercyclical while reallocation

is procyclical, while Glode and Lowery (2017) show how resources may be needlessly consumed on zero-sum transfers in the financial industry. Other papers focus on the misallocation of attention because information is costly to acquire (e.g., Sims (2003)). In contrast to the focus in these papers on the misallocation of inputs to production or attention, we examine the consequences of misallocation of innovation effort.

1 Model

In our model, researchers engage in research in continuous time. They work on agendas that either turn out to be significant or insignificant. Research serves to accelerate the process through which agendas *mature*,meaning that they either are discovered to be useless or they begin to improve the output of the economy by increasing total factor productivity. The process of research generates projects which accelerate the maturation of the agenda/ These projects also garner citations and generate citations for other researchers. One can interpret projects as academic papers or patents. Researchers have a claim on the productivity of the economy but also may be compensated for citations to their research projects. These two goals may coincide, but they also may be in tension.

1.1 Fields and Agendas

We begin with the description of an agenda in a field. There are L fields in which $N \geq 2$ researchers can potentially research. Not all research fields will necessarily be active at any given time, and we take $L >> N$ to be very large. At some time t_j^l, a researcher publishes a seminal project j in field l that sets an agenda that is indexed by its inception time. This publication can be viewed as an academic journal publication or the granting of a patent. The arrival of this new agenda is determined by the arrival of a compound Poisson counting process dJ_t^l that has a compensator process $\lambda e_{lt} dt$, where $e_{lt} = \sum_{n=1}^{N} e_{lt}^n$ and $e_{lt}^n \in 0, 1$ is the effort a researcher devotes to investigating field l.

Once an agenda is developed, other researchers can begin working in that field, pursuing that agenda. Let $r_{lt}^n \in 0,1$ be the indicator that researcher n is working in active field l at time t. We assume a researcher can only work in one field or research a new field at a given instant. At each instant $t \geq t_j^l$, $r_{lt} = \sum_{n=1}^{N} r_{lt}^n$ researchers choose to produce a project in the current agenda of field l, and each research project cites the other research projects in that agenda. The agenda randomly matures at some stopping time $\tau_j^l > t_j^l$. This is determined by the arrival of a second Poisson jump dB_t^l that has compound compensator process $\lambda r_{lt} dt$, i.e., the more researchers working on the agenda, the faster it matures. This rate may be faster than the rate at which new agendas are discovered. The maturity of a field in academic research can be seen as the development of a conclusive academic article that provides a decisive answer to the overarching questions posed by the literature or a critique that illustrates the flaws or inability of the literature to answer its overarching questions. In the context of patents, the maturity of a field can be seen as a final patent of an invention upon which only modest future improvements in the area can be made or mounting evidence that such technology will have minimal application or industry impact.

When an agenda matures, it is either a significant discovery, and advances the profession, or an insignificant discovery, and does not. This significance or insignificance is indexed by $\pi_{lj} \in 0,1$, where $\pi_{lj} = 1$is a significant field, which is hidden and unknown to researchers until the agenda matures. At inception, all researchers observe a binary public signal, drawn randomly upon the inception of the agenda, of the likelihood that the agenda is significant, $S_{lj} \in 0,1$, where $\Pr\left(S_{lj} = 1 \mid \pi_{lj} = 1\right) = q_1$ and $\Pr\left(S_{lj} = 1 \mid \pi_{lj} = 0\right) = q_0 < q_1$. The prior probability a new agenda is significant is p. Consequently, by Bayes' Rule, upon observation of S_{lj}, the updated posterior of all re-

searchers about the agenda's significance is

$$\Pr\left(\pi_{lj}=1 \mid S_{lj}=1\right)=\frac{\Pr\left(S_{lj}=1 \mid \pi_{lj}=1\right)\Pr\left(\pi_{lj}=1\right)}{\Pr\left(S_{lj}=1 \mid \pi_{lj}=1\right)\Pr\left(\pi_{lj}=1\right)+\Pr\left(S_{lj}=1 \mid \pi_{lj}=0\right)\Pr\left(\pi_{lj}=0\right)},$$
$$\Pr\left(\pi_{lj}=1 \mid S_{lj}=0\right)=\frac{\Pr\left(S_{lj}=0 \mid \pi_{lj}=1\right)\Pr\left(\pi_{lj}=1\right)}{\Pr\left(S_{lj}=0 \mid \pi_{lj}=1\right)\Pr\left(\pi_{lj}=1\right)+\Pr\left(S_{lj}=0 \mid \pi_{lj}=0\right)\Pr\left(\pi_{lj}=0\right)},$$

from which it follows that

$$\Pr\left(\pi_{lj}=1 \mid S_{lj}=1\right)=\frac{pq_1}{pq_1+(1-p)\,q_0}=p_1,$$
$$\Pr\left(\pi_{lj}=1 \mid S_{lj}=0\right)=\frac{p\,(1-q_1)}{1-pq_1-(1-p)\,q_0}=p_0.$$

The consequences of a significant versus an insignificant agenda are discussed in the sequel. Note that the unconditional probabilities of each signal realization are $\Pr\left(S_{lj}=1\right)=pq_1+(1-p)\,q_0$ and $\Pr\left(S_{lj}=0\right)=1-pq_1-(1-p)\,q_0$.

After an agenda is discovered, additional news beyond the initial signal, S_{lj}, can arrive to update the beliefs of researchers about the agenda's significance. We capture this potential news by having a second signal that may arrive before an agenda matures. This signal arrives according to a Poisson process dL_t^l with compensator ξdt that updates the beliefs of researchers about the agenda. For simplicity, we assume that a second signal may arrive only if the initial signal was high, i.e., $S_{lj}=1$, and only if it is negative news, in which case it reduces the probability that the agenda is significant to p_0 (i.e., as if researchers had observed a low initial signal, $S_{lj}=0$). Such a signal can, in principle, improve economic efficiency by providing additional information to researchers about whether active agendas are worth researching, and this parsimonious structure will help highlight a key inefficiency that career concerns introduce.

We can then define the following pseudo-probability process $p_{lt}\in 0,p_0,p_1$ with the

law of motion

$$dp_{lt} = \left(\Pr\left(\pi_{lj} = 1 \mid S_{lj}\right) - p_{lt-}\right)\left(dJ_t^l - \lambda e_{lt}dt\right) + \left(p_0 - p_{lt-}\right)\left(dL_t^l - \xi dt\right) + \left(0 - p_{lt-}\right)\left(dB_t^l - \lambda r_{lt}dt\right), \tag{1}$$

where $dB_t^l - \lambda r_{lt}dt$, $dL_t^l - \xi dt$, and $dJ_t^l - \lambda e_{lt}$ are three martingale jump processes. The first process updates p_{lt} when a new agenda is discovered to the conditional probability that the agenda is significant, $\Pr\left(\pi_{lj} = 1 \mid S_{lj}\right)$. The second updates agendas with initially high signals if negative news arrives that the agenda is less likely to be significant. The third process resets p_{lt} to zero when the agenda matures. Because signals arrive quicker when more people work in the area, the economy exhibits social learning and experimentation akin to social bandit strategies.

The cumulative citations a researcher who works in the current agenda of field l from time s to t' receives is consequently $\int_s^{t'}(t-s)\, r_{lt}dt$ and the expected citations from the project at time t_j^n V_{jt_j} is

$$V_{jt_j} = \mathbb{E}\left[\int_{t_j^l}^{\tau_j^l}\left(\tau_j^n - t_j^n\right) r_{lt}dt \mid \mathcal{F}_{t_j}^c\right] = \mathbb{E}\left[\int_{t_j^n}^{\infty} e^{-\lambda t}\left(t - t_j^n\right) r_{lt}dt \mid \mathcal{F}_{t_j}^c\right], \tag{2}$$

according to the memory-less properties of Poisson counting processes, where $\mathcal{F}_t^c$ is the filtration based on common knowledge. Because there can only be at most one active agenda in a field at a given instant, we can omit the j subscript for the agenda in the researcher count.

1.2 Researchers

A researcher's goal is to complete research projects over the course of her career and to garner citations. Each researcher is born at some time t as with type $n \in 1, ..., N$. Because there is only one researcher of a given type at any time, we also refer to her as researcher

n. The researcher retires at some random time T_i^n according to a Poisson shock dQ_{nt} with compensator ηdt, and the researcher is replaced with a researcher in the same field.

At each instant, a researcher chooses which agenda to work on, selecting only one agenda at a time. Let $r_{lt}^n \in 0, 1$ be the indicator that the researcher is working in field l at time t. If instead they try to investigate and create a new agenda, a new agenda arrives according to the Poisson counting process described above. Let $e_{lt}^n \in 0, 1$ be the indicator that the researcher is investigating a new agenda in field l at time t. A researcher incurs a cost $\kappa > 0$ in certainty equivalent utility each instant to research an active agenda or investigate a new agenda. Investigating a new agenda consequently entails the additional cost that it is also uncertain and may not arrive.

We assume researcher n is risk-averse and has career concerns over his citation count, C_{nt}, and his prestige or esteem, β_{nt},which reflects promotions, awards, and accolades. To capture this, we assume his compensation as a researcher has two components: 1) a time-varying wage, c_{nt}, that will later be linked to current output; and 2) path-dependent high-powered incentive pay, $\phi_X \left(\log \beta_{nt} + C_{nt}\right)$, cumulated over his career. In addition, he incurs an effort cost to conduct research at each instant, $\kappa \sum_{l=1}^{L} \left(r_{lt}^n + e_{lt}^n\right)$. Let $\boldsymbol{r}_t^n = \left[r_{1t}^n, ..., r_{Lt}^n\right]$ be the vector of binary efforts that the current researcher of type n exerts to researching in active agendas. In addition, let $\boldsymbol{e}_t^n = \left[e_{1t}^n, ..., e_{Lt}^n\right]$ be the vector of binary efforts that the current researcher of type n exerts to discovering a new agenda, and ι_L be the $L \times 1$ vector of ones. Similar to Holmström (1989), the researcher has Constant Relative Risk Aversion (CARA) flow preferences over compensation and effort

$$u\left(c_{nt}, \beta_{nt}, C_{nt}, \boldsymbol{r}^n, \boldsymbol{e}^n\right) = -\beta_{nt}^{-\gamma\phi_X} e^{-\gamma(c_{nt}+\phi_X C_{nt})+\kappa(\boldsymbol{r}^n+\boldsymbol{e}^n)'\iota_L},$$

where γ is the coefficients of absolute risk aversion over wage.

If the researcher works in agenda j of field l, then his citation count evolves over time

according to the law of motion

$$dC_{nt} = \sum_l r_{lt} r^n_{lt} dt + (1 - C_{nt-})\, dQ_{nt}, \tag{3}$$

This law of motion reflects that researchers cite each other when working in an area. Consequently, researchers want to work in fields populated by other researchers. If they are working on an agenda that matures and is significant (i.e., $\pi_{lj} = 1$), then they receive accolades in the form of promotions, prizes, or awards, and β_{nt} increases according to

$$d\beta_{nt} = \beta_{nt-} \sum_l \pi_{lj} r^n_{lt-} dB^l_t + (1 - \beta_{nt-})\, dQ_{nt}, \tag{4}$$

as an additional benefit. The initial citation count is initialized to 0 and initial prestige is 1 when the researcher begins his career. We can then summarize the status of researcher n X_{nt} as $X_{nt} = \log \beta_{nt} + C_{nt}$, which has law of motion

$$dX_{nt} = \sum_l r_{lt} r^n_{lt} dt + \log\left(1 + \sum_{n'} \pi_{lj} r^n_{lt-}\right) dB^l_t - X_{nt-} dQ_{nt},$$

where $X_{n0} = 0$. Consequently, the preferences of researcher n can be expressed as $-e^{-\gamma c_{nt} - \gamma \phi_X X_{nt}}$. Note that career rewards are not modeled as having a fixed supply; for example, if everyone chose to start a new agenda and no one worked in existing agendas, the total rewards available would be low as no one would garner citations from other researchers.

The researcher has subjective discount rate $\rho > 0$, and we assume $\rho + \eta > \lambda N$ (i.e., discounting is faster than the maximum arrival rate of jumps). Let $\boldsymbol{r}^n_t = \left[r^n_{1t}, ..., r^n_{Lt}\right]$ be the vector of binary efforts that the current researcher of type n exerts to researching in active agendas, subject to the agenda being active. In addition, let $\boldsymbol{e}^n_t = \left[e^n_{1t}, ..., e^n_{Lt}\right]$ be the vector of binary efforts that the current researcher of type n exerts to discovering a new agenda, subject to the agenda being inactive.

Finally, we assume a researcher has an outside option when they are born at time T^n_{i-1}

to choose a different career that does not require any effort. For simplicity and to maintain stationarity, we assume it pays a constant flow of consumption $c_{nT^n_{i-1}}$. As such, the outside option delivers an expected value $U^o_{T^n_{i-1}}$ of

$$U^0_{T^n_{i-1}} = -\mathbb{E}\left[\int_{T^n_{i-1}}^{T^n_i} e^{-\rho\left(t-T^n_{i-1}\right)} e^{-\gamma c_{nT^n_{i-1}}} dt \mid \mathcal{F}_{T^n_{i-1}}\right] = -\frac{e^{-\gamma c_{nT^n_{i-1}}}}{\rho+\eta}.$$

Consequently, researcher n faces a participation constraint (PC)

$$U_{nT^n_{i-1}} \geq U^0_{T^n_{i-1}}. \ (PC). \tag{5}$$

Given that a researcher can be born at any instant, and the participation constraint is tightest when there is no active agenda, we consequently must verify that the participation constraint is satisfied when there is no active agenda.

Researcher i of type n born at time T^n_{i-1} (with $T^n_0 = 0$) consequently solves the following optimization problem:

$$\begin{aligned} U_{nT^n_{i-1}} &= \sup_{\boldsymbol{r}^n, \boldsymbol{e}^n, (\boldsymbol{r}^n_t + \boldsymbol{e}^n_t)' \iota_L \leq 1 \ \forall \ t} \mathbb{E}\left[\int_{T^n_{i-1}}^{T^n_i} e^{-\rho\left(t-T^n_{i-1}\right)} \left(-e^{-\gamma c_{nt} - \gamma \phi_X X_{nt} + \kappa(\boldsymbol{r}^n_t + \boldsymbol{e_t}^n)' \iota_L}\right) dt \mid \mathcal{F}_{T^n_{i-1}}\right] \\ &= \sup_{\boldsymbol{r}^n, \boldsymbol{e}^n, (\boldsymbol{r}^n_t + \boldsymbol{e}^n_t)' \iota_L \leq 1 \ \forall \ t} \mathbb{E}\left[\int_{T^n_{i-1}}^{\infty} e^{-(\rho+\eta)\left(t-T^n_{i-1}\right)} \left(-e^{-\gamma c_{nt} - \gamma \phi_X X_{nt} + \kappa(\boldsymbol{r}^n_t + \boldsymbol{e_t}^n)' \iota_L}\right) dt \mid \mathcal{F}_{T^n_{i-1}}\right], \end{aligned} \tag{6}$$

$$s.t. : (5).$$

by the memory-less properties of Poisson processes. An individual researcher fully internalizes how her behavior and those of other researchers impact her career. Researchers further understand how firms produce output, and consequently internalize the impact of their research on output. This could reflect, for instance, benefits that researchers who

develop patents capture from their firms and universities. It can also be interpreted as a direct preference by the researcher for producing useful research. In fact, this latter interpretation is most natural for cases where the value of the research comes from the production of public goods or better government policy. The special case where $\gamma\phi_X = 0$ represents the case where a researcher cares only about the impact of their research on the economy.[4]

1.3 Growth

While citations and prestige correspond to the private benefits of research, such research has the externality of promoting economic growth. This feature relates our model to the endogenous growth literature. Alternatively, one can think of output in our model as the profits of the firms at which the researchers are employed.

We capture this by assuming the aggregate productivity of the economy is given by A_t, where A_t evolves according to the law of motion[5]

$$dA_t = \sum_{l=1}^{L} \left(2\pi_{lj} - 1\right) dB_t^l. \tag{7}$$

This equation states that aggregate productivity increases when a significant field matures, and decreases when an insignificant field matures. That productivity falls when an insignificant agenda matures reflects that firms use active research to inform their decision-making and product development, and such investments can be speculative and wasteful if the agenda is less promising than first thought. This drop in productivity can be thought of as a revelation of previously wasted investment; formally model-

[4]In principle, we could introduce persistence into the success of research agendas by assuming the likelihood a new agenda is significant is positively correlated with the significance of the last agenda that matured in that field.

[5]We could allow the jump in productivity to depend on the number of researchers on that agenda r_{lt}. However, this would both bias researchers toward coordinating on agendas and maximize the social cost of coordinating on insignificant agendas. To mute these effects, we assume the jump in aggregate productivity is independent of how many researchers are working on the maturing agenda.

ing it in that fashion would add complexity without changing any of the implications of the model. Further, since their is already an opportunity cost of pursuing an ultimately failed agenda, it is not qualitatively important that this cost be nonzero, but allowing for nonzero costs of pursuing failed research does not complicate the model.

The representative firm has output given by

$$Y_t = A_t K, \tag{8}$$

where capital $K > 0$ is fixed in the economy.

We assume each researcher receives as part of their compensation a percentage of total output, i.e., $c_{nt} = \phi_A Y_t$, where $\phi_A < \frac{1}{N}$, because of perfect consumption insurance across researchers and researchers own firms in the economy (i.e., they are part of a Lucas household). Further, Y_0 is sufficiently large that the economy provide the high-power career incentives in compensation without violating feasibility that total compensation to all researchers, $N\phi_A Y_t + \phi_X \sum_{n=1}^{N} X_{nt}$ exceeds Y_t.

In what follows, we assume that $J \geq 2$ so that there is the option of investigating a new agenda and abandoning an active one. We also assume the probability that an active agenda will be significant conditional on observing a low signal $S_{lj} = 0$, p_0, is sufficiently small, specifically that $p_0 < \frac{1}{2}$. By L'Hospital's Rule, this further implies that $p_0 < \frac{1-e^{-\gamma\phi_A K}}{1-e^{-2\gamma\phi_A K}}$ for any $\phi_A > 0$ because $\frac{1-e^{-x}}{1-e^{-2x}}$ is increasing in x. In contrast, we assume that $p_1 \geq \frac{1-e^{-\frac{\gamma}{N}K}}{1-e^{-2\frac{\gamma}{N}K}}$.

1.4 Relationship Among Payoff Sources

Prestige and economic output play similar roles in motivating researchers, since they both increase only when a significant agenda matures. The difference between these two drivers of payoffs is that economic output is directly linked to the magnitude of the value of a successful research project, while prestige wins can be, for example, quite large even

if the contribution of a successful research project to economic output is quite small. For the baseline analysis this distinction is not particularly important, but the specification used allows for success on a significant agenda to enter the payoff function in a flexible way. When we introduce heterogeneous researchers, the distinction between pursuing prestige and pursuing citations plays a larger role.

In the main analysis, citations are the main focus. Unlike prestige or economic output, accruing citations may or may not be associated with doing useful research, but citations, unlike prestige and productivity boosts, are available continuously as a measure. Also, we impose risk aversion over citations to reflect the asymmetry between a failed career versus survival in academia compared to the difference between survival and academic stardom.

1.5 Equilibrium Definition

We consider a Markov Perfect Equilibrium in which each researcher fully internalizes his impact on his own career trajectory, those of others, and the aggregate economy. A strategy for a researcher in field n is a sequence of project efforts during her career $\vec{e}_t^n, \vec{r}_t^n{}_{t=T_{i-1}^n}^{T_i^n}$ that solves 6. An equilibrium is a fixed point between conjectured project intensities $\hat{e}_{lt}, \hat{r}_{ltl,t}$ and actual project intensities $e_{lt}, r_{ltl,t}$, i.e., all researchers have rational expectations of the dynamics of the game.

This is a mean-field game of a Nash Equilibrium, where the "mean fields" are the number of researchers in each field $e_{lt}, r_{ltl,t}$. A researcher's program will be Markov in $L + N + 1$ state variables: the L probabilities that the L agendas are significant, p_{lt}, which also indexes when it is not zero or one that the field is active, the N statuses of researchers across fields, X_{nt}, and aggregate productivity, A_t. However, as we will show, researchers need only to keep track of a much smaller state space for their optimal closed-loop research policies to be not only Markov, but recursive.

We initialize the economy with zero active agendas at $t = 0$.

2 Equilibrium

In this section, we construct the equilibrium of our research game. Our key proposition is the behavior of the N researchers. We appeal to the dynamic programming principle to characterize the researcher's optimal research policy. Because researchers have CARA preferences and status grows linearly over time, it will be the case in equilibrium that the statuses of the N researchers will not matter for their optimal research policies. As a result, they will follow identical research policies in equilibrium. In equilibrium, all that will matter is whether there is currently an active field, and whether it received a high or low signal, S_{lj}, about its significance. We refer to an active field that received a high signal ($S_{jl} = 1$) as a "promising" agenda because it has a high likelihood of being significant. In contrast, we refer to an active field that received a low signal ($S_{jl} = 0$) as a "speculative" agenda because it has a low likelihood of being significant.

We then have the following key proposition.

Proposition 1. *The optimal research policy for the N researchers has the following properties:*

- *if there is a promising active agenda, then all researchers research that agenda until it either negative news arrives or it matures;*
- *if there is no promising active agenda, then if career concerns are sufficiently strong (i.e., $\phi_X \geq \phi_X^*$), then all researchers research any speculative active agenda until it matures;*
- *if there is no active agenda, then all researchers investigate to try to discover a new agenda (and are indifferent between investigating in the same or different fields).*
- *this is an equilibrium if the effort cost, κ,is sufficiently small, i.e., $\kappa \leq \min \kappa_1^*, \kappa_1^{pc}$ if active speculative agendas are researched and $\kappa \leq \min \kappa_2^*, \kappa_2^{pc}$ if they are not, where κ_1^*, κ_1^{pc}, κ_2^*, and κ_2^{pc} are given, respectively, by equations (A.34), (A.37), (A.33), and (A.39).*

In contrast, in the absence of career concerns, all researchers instead try to discover a new agenda

if there is no active promising agenda. That is, they abandon speculative agendas that have a low likelihood of being significant.

Proposition 1 illustrates that the equilibrium in our mean-field research game is surprisingly simple. All researchers focus on researching any active promising agenda that has received a high signal ($S_{jl} = 1$) until it matures because it has the highest likelihood of being significant, which raises both output and each researcher's prestige in the economy. Further, by coordinating to research the same agenda, researchers maximize their citations during the research process. As a result, there is only one or zero active agendas with a high signal at any given instant.

The more interesting situation is one in which researchers have discovered an agenda that has received a low signal ($S_{lj} = 0$) or when negative news arrives about an agenda that initially received a high signal ($S_{jl} = 1$). In the absence of career concerns, researchers would abandon this speculative agenda in favor of trying to find a new, promising agenda; in this case all that matters is whether an agenda is significant when it matures, and the conditional probability of a speculative agenda of being significant, p_0, is sufficiently small that it is socially optimal to abandon it and continue investigating.

In the presence of career concerns, however, researches may instead focus on researching any speculative field to maturity instead of investigating new agendas. Such a policy benefits their careers for two reasons: 1) investigating a speculative agenda garners citations while investigating new agendas does not; and 2) speculative agendas yield prestige if they are significant, and do not harm status if not. As a result, researchers may continue to research agendas that were once promising, but over time have been shown to be unlikely to have a profound impact. Consequently, research in our economy with career concerns end up in "academic bubbles" or agendas that researchers agree are not worthwhile to research from an output perspective, but are desirable from a career perspective.

But, rewarding for citations and prestige relaxes a researcher's participation constraint (5) because it provides a higher payoff to researchers during their careers. This is partic-

ularly valuable when the participation constraint is tight, such as when the cost of effort, κ, and risk aversion, γ, are high, and when the likelihood that an active agenda is significant, p_0 and p_1, are low. Risk aversion over citations and prestige dampens incentives to innovate, which is similar to the mechanism in Jones (1995), where private risk aversion being lower than social risk aversion dampens the willingness of entrepreneurs to experiment on risky projects. Also, unsurprisingly, the lower the likelihood that research yields significant results, the more difficult it is to sustain such research. We summarize these observations in the following proposition.

Proposition 2. *A higher reward for career advancement, ϕ_X, and higher probabilities of agendas being significant, p_0 and p_1, relax a researcher's participation constraint, while a higher effort cost, κ, and risk aversion, γ, for γ sufficiently large tighten it.*

Our analysis has several important implications. First, is that it is difficult to interpret citations in the patent literature if citations reflect career concerns. Researchers may choose to research agendas that are likely to be insignificant because doing so garners citations compared to investigating new agendas, which is risky and does not add to their status. As such, citations need not reflect social impact or, if we think of economic growth as a longer horizon outcome, long-term impact.

Second, is that career concerns incentivize academic journals to publish articles from more speculative agendas because they will be cited. Rather than exclusively focusing on agendas that are more promising from a social perspective, journals that internalize researchers' career concerns recognize that a wide variety of topics will be cited regardless because researchers effectively coordinate their research activities to maximize each other's status.

Third, when career concerns are sufficiently strong, researchers may devote more research efforts to topics that ultimately die out or fade away than is socially optimal. Disciplines where the signals about whether a new agenda will be significant are quite strong (i.e., very high p_1 and very low p_0), like the natural sciences, are less likely to exhibit this

feature because career concerns have to be particularly salient (i.e., a much higher ϕ_X) to induce researchers to devote effort to speculative fields.

2.1 Career Concerns as a Contracting Outcome

In this section we microfound the implicit academic contract that rewards citations and publications as a solution to an agency problem. We extend our model to assume that not only is effort now costly for for researchers, but that from the principal's (i.e., society's) perspective, it is unobservable and non-contractible. Such an assumption is realistic because documenting new facts and discovering new ideas is very difficult, and a lot can go into the research process that is not reflected in the final output (whether it be a publication or a patent). In addition, the principal does not observe any signals about an agenda until it matures. Because researchers indirectly work together to discover new ideas and advance agendas, from a social perspective the industry is effectively a situation of moral hazard in teams (e.g., Holmström (1982b)).

We now express the flow utility of researcher n as

$$u\left(w_{nt}, \vec{e}_t^n, \vec{r}_t^n\right) = -e^{-\gamma w_{nt} + \kappa(\vec{e}_t^n + \vec{r}_t^n)' \iota_J},$$

where w_{nt} is now the researcher's compensation paid by the social planner, $\vec{r}_t^n$ and $\vec{e}_t^n$ are again the vectors of efforts that researcher n devotes to researching active agendas and investigating new agendas, respectively, and ι_J is the $J \times 1$ vector of ones. The researcher's budget constraint is still $(\vec{e}_t^n + \vec{r}_t^n)' \iota_J \leq 1$.

The first-best outcome would have the planner disperse all output at each instant. The maximum the planner can give to each researcher is $w_{nt} = \frac{1}{N} Y_{nt}$; by ex-ante symmetry among researchers, it will consequently choose $\frac{1}{N} Y_{nt}$. In addition, the planner would have all m^* active researchers, which may be less than N, research only promising active agendas. The number of active researchers is limited by the flow certainty equivalent cost of

effort, κ. This cost acts through the conditions for Pareto optimality; each active researcher must prefer to follow the planner's recommendation than to deviate, leaving only $m^* - 1$ active researchers. We summarize these observations in the following proposition.

Proposition 3. *In the first-best economy, which is Pareto efficient, it is socially optimal for there to be $m^* \leq N$ active researchers and:*

- *if there is a promising active agenda, then all active researchers research it until it matures;*
- *if there is no promising active agenda, then all researchers investigate to try to discover a new agenda (and are indifferent between investigating in the same or different fields);*
- *the number of active researchers, m^*, is the largest $m \leq N$ that satisfies condition (A.55). If $\kappa \leq \kappa^*$,where κ^* is given by equation (A.56),then all N researchers are active researchers.*
- *this is an equilibrium if $\kappa \leq \kappa^{pc}$, where κ^{pc} is given by (A.58).*

Proposition 3 also highlights the key coordination failure from a free-rider problem. The incentives for one researcher to research are highly dependent on how many other researchers are actively researching, and these incentives are particularly relaxed when there are relatively few researchers. Because effort is unobservable, researchers have incentive to shirk because the lack of arrival of a new agenda or the maturation of an active agenda can be a result of bad luck rather than the lack of effort. With asymmetric information, the first-best may not be achievable, which motivates the need for incentive-compatible contracting.

In what follows, we assume that $\kappa = \kappa^*$, where κ^* is defined in Proposition 3, so that it is just optimal for all N researchers to be active in the first-best economy. We now illustrate the key free-rider problem among researchers when effort is not observable. If N is not too large, then if all other active researchers deviate and do not research, then it is optimal for the last researcher to also deviate and not to research. This is because the

benefits of research accrue to everyone but the effort cost is borne privately by each researcher. Proposition 4 indeed establishes that zero active researchers constitutes a Nash Equilibrium.

Proposition 4. *Suppose $\kappa = \kappa^*$. Then, if*

$$N < \tilde{N} = \frac{(\rho + \eta)(\rho + \eta + \xi)}{\lambda^2 (pq_1 + (1-p) q_0) \left(1 - p_1 e^{-\frac{\gamma}{N}K} - (1 - p_1) e^{\frac{\gamma}{N}K}\right)}, \tag{9}$$

then zero active researchers constitutes a Nash Equilibrium. This equilibrium is Pareto inferior to that characterized in Proposition 3.

The potential for coordination failure introduces a role for the principal to offer researchers an incentive-compatible contract to try to achieve a second-best outcome. Since effort is unobservable, contracting can only be on output, which is observable to the principal. Because output is observable, the principal can also observe when a research agenda is successful. So, a contract can either reward agents for continuously revealed information in the form of citations, or it can reward agents only when a significant agenda matures. The latter approach requires either saving output to provide rewards or violating budget balance by paying more than is being produced at a given time. Thus, the higher powered incentives, so to speak, will create distortions away from first-best and may not be feasible. This failure opens up the possibility that the contracts that generate academic bubbles may be second-best, despite the fact that they generate wasteful research and distract researchers from potentially fruitful areas of research. The standard contract theory trade-off applies here–providing payment to researchers only when economic output increases provides strong incentives to research only agendas that have received promising signals, but with risk averse agents this policy requires very high total compensation. So, when agents dislike working and are highly risk averse, output changes are infrequent even under efficient research effort allocation (or, stepping somewhat outside of the model, hard to observe), contracts that generate career concerns by

rewarding citations will be optimal.

We conclude this section by characterizing the optimal contract, i.e., the loading of ϕ_A and ϕ_X, that a principal, i.e., society, would choose. We assume the principal is risk-neutral and can commit to a contract for researchers at time 0 to maximize discounted expected future output less the total compensation paid to researchers. The principal also has subjective discount rate ρ, and chooses the contract loadings subject to researchers' participation and incentive compatibility constraints. The principal consequently maximizes

$$U_P = \sup_{\phi_A, \phi_X} \mathbb{E}\left[\int_0^\infty e^{-\rho t}\left(Y_t - \sum_{n=1}^{N} \phi_{nt}\right) dt\right], \tag{10}$$

$$s.t. : (6).$$

We assume at time 0 that no researchers have status and that there is no active research agenda.

Proposition5 characterizes properties the optimal contract. In addition to the participation constraint binding, the optimal choice of contract loadings trades off the marginal decrease in net profit from providing higher compensation to researchers with the marginal relaxation of their participation constraints.

Proposition 5. *The principal chooses the research contract loadings such that:*

- *if each researcher's effort cost, κ, is sufficiently small, the principal setsϕ_A and $\phi_X$to satisfy equations* 5 *and A.66, and only rewards research in promising agendas;*
- *if each researcher's effort cost, κ, is sufficiently large, the principal setsϕ_A and $\phi_X$to satisfy equations* 5 *and A.67, and rewards research in all agendas.*

Proposition 5reveals that a researcher's optimal compensation contract depends on the cost of research effort. If the cost of effort is sufficiently small, then the principal chooses a socially optimal contract that does not reward researchers too strongly with

career incentives, i.e., ϕ_X sufficiently small, such that only promising agendas are researched. However, if a researcher's effort cost is sufficiently high, then the principal must reward all research to incentivize any research.

2.2 Discussion

The question of whether such contracts should be used thus depends on the preferences of the researcher. In reality, the contracts we observe may depend more on the perception of the preferences of the researcher by those designing implicit academic contracts. If researchers are perceived to be motivated by a desire to achieve significant results in their field, or if they are perceived to have an inherent desire to engage in research (i.e., low cost of effort), then low powered incentives that do not reward attention to career concerns are ideal; researchers should not be distracted from their inherent truth-seeking mission. If, on the other hand, researchers are more indolent and self-interested, the incentives become necessary, even at the cost of generating academic bubbles. If the people determining the contract are far enough removed from an academic setting to misunderstand the preferences of researchers, we may end up in a worst-case scenario where the perceived need to motivate indolent researchers shifts the outcome from one where researchers only pursue promising agendas to one where researchers, despite their own preferences, knowingly engage in academic bubbles to capture the (unnecessary) rewards offered for garnering citations and publications.

This possibility raises concerns about the professionalization of academic administration. Traditionally, university governance was something taken on by senior researchers as a matter of service. This period corresponded to relatively low powered incentives for research, and arguably greater productivity and less research dishonesty. The rise of a class of professional administrators who abandon research early in their career in favor of administrative jobs has corresponded with the rise in more mechanical compensation contracts which emphasize counting publications and citations. This change could be a

necessary outcome of divorcing authority at universities from ability to objectively evaluate the quality of research; if true experts in an area are evaluating research, then there is no need to rely on proxies like citation counts since the likelihood that a research agenda is significant is to some extent directly observable to the expert, while it is almost certainly not observable to a professional administrator. The change could also represent a shift in perceptions of researcher preferences. As administrators become more divorced from the research environment, or as nonresearchers become more influential in academic administration, administrators may become less sympathetic to researchers and come to believe that they need closer monitoring and motivation.

2.3 Prizes and Awards

Up until now, we have assumed that society is a risk-neutral principal that contracts with researchers and that the total resources in the economy from output, Y_t, are sufficiently large that it is unconstrained in providing incentives. In this subsection, we relax these two assumptions and show that they lead to a different incentive scheme that offers rewards and prizes for conducting research.

First, we consider how society would design research incentives if compensation came from a limited pot. For starkness, we impose budget-balance, i.e.,

$$N\phi_A Y_t + \phi_X \sum_{n=1}^{N} X_{nt} \leq Y_t,$$

at each date and state of the world. Because Y_t can decrease over time as a result of non-meaningful agendas maturing, compensating researchers with status can violate the budget constraint with positive probability. As such, it must be the case that $\phi_X \equiv 0$. However, offering a researcher compensation that does not depend on his effort, i.e., $\phi_A > 0$ and $\phi_X = 0$, tightens his incentive compatibility constraint and risks coordination failures because of research free-riding. Consequently, this motivates the use of

bonus pay that rewards researchers with a portion of output for researching an agenda to maturation, i.e., prizes and awards.

We next consider how society would design research incentives if it were risk-averse over research successes and failures. Such risk aversion is a motivation for incentivizing diversification in research activities across researchers because this lowers the volatility of research outcomes. While rewarding citations and prestige induces coordination on researching a common agenda, prizes and awards that are awarded to the researcher who discovered the agenda (or randomly if multiple researchers participate in investigating the agenda) instead incentivizes researchers to pursue independent agendas.

3 Extensions

In this section, we consider several extensions of our baseline analysis. First, we make the model more realistic by assuming that signals about the viability of an agenda constantly arrive over time. As an agenda is researched, researchers are likely to learn more about whether it will turn out to be significant. This change gives rise to a time-varying probability of the agenda being significant. In this setting, all researchers research an active agenda until the probability it is significant falls below some critical threshold, and this threshold is decreasing in the importance of career concerns, $\gamma\phi_X$. Second, we study heterogeneity in career concerns. Those with weak concerns will only research promising agendas, while those with strong career concerns will also research speculative agendas, and a research contract that emphasizes career concerns selects on this latter group of researchers. Third, we show that influential researchers who garner more citations for researchers in their agendas have more incentive to research speculative agendas, and they relax the participation constraints of other researchers by garnering them higher citation counts.

3.1 Learning about Agenda Significance

In this subsection, we consider how continually learning about an active agenda's significance over time impacts researcher behavior. Suppose now that there are no signals at inception about whether an agenda is likely significant. Instead, all agendas have an initial prior probability $p_0 = .5$ of being significant. As researchers work on the agenda, however, they receive signals about whether the agenda is likely to be significant. Specifically, at each instant, the new projects in agenda j of field n generate a signal S^n_{jt} about the agenda's significance π^n_j as long as it is active

$$dS^n_{jt} = \pi^n_j dt + \sigma dZ^n_{jt} + \left(\pi^n_j - S^n_{jt-}\right) dB^n_t, \tag{11}$$

where Z^n_{jt} is a standard Wiener process independent of other $Z^{n'}_{j't}$ and σ is the diffusion of the signal. It is immediate that the common knowledge posterior about the quality of the current agenda in field n given $S^n_{jk_{k\in[t_j,t]}} \in \mathcal{F}^c_t$ for $t \geq t_j$ is summarized by $p_{nt} = \mathbb{E}\left[\mathbf{1}_{\pi^n_j=1} \mid \mathcal{F}^c_t\right]$ and is given by the Wonham Filter

$$dp_{nt} = \frac{p_{nt}\left(1-p_{nt}\right)}{\sigma} d\hat{Z}^n_{jt} + \left(\pi^n_j - p_{nt-}\right)\left(dB^n_t - \lambda m^n_t dt\right), \tag{12}$$

where $d\hat{Z}^n_{jt} = dZ^n_{jt} + \frac{1}{\sigma}\left(\pi^n_j - p_{nt}\right) dt$ is a $\mathcal{F}^c_t$-standard Wiener process by Girsanov's Theorem, and $dB^n_t - \lambda \mu^n_t dt$ is a martingale jump process that reveals the true π^n_j once the agenda matures.

Based on our analysis in the baseline model, it is clear that if there is an active agenda, all researchers will focus on working on it. However, there is now the possibility that they may abandon an active agenda to investigate a new one if the likelihood that it is significant, p_{nt}, is sufficiently low. Because there will be at most one agenda on which researchers are working at a given instant, we drop the n subscript from p_{nt}, and just refer to the probability the current active agenda is significant as p_t. Our key result is that

the threshold probability p^* at which an agenda is abandoned is decreasing in the reward for career advancement, ϕ_X. This is summarized in the following proposition.

Proposition 6. *All researchers research any active field as long the probability it is significant, p_t, exceeds a threshold p^**

$$p^* = \frac{e^{\gamma\phi_A K} - \frac{1+\gamma\phi_X/\lambda-1/N}{\rho+\eta+\lambda}e^{\kappa} - \frac{\lambda}{\rho+\eta+\lambda}\frac{\rho+\eta+\gamma\phi_X N+\lambda N}{\rho+\eta+\gamma\phi_X N+2\lambda N}\left(1+\frac{1}{2}\left(2^{-\gamma\phi_X}e^{-\gamma\phi_A K}+e^{\gamma\phi_A K}\right)+\frac{\rho+\eta}{\lambda N}\right)}{e^{\gamma\phi_A K}-2^{-\gamma\phi_X}e^{-\gamma\phi_A K}}. \tag{13}$$

This threshold is decreasing in the reward for career advancement, $\gamma\phi_X$.

3.2 Heterogeneity in Career Concerns

In this subsection, we explore the role of heterogeneity in career concerns among researchers for research outcomes. Suppose we have two types of researchers. The first type, A researchers, care only about prestige (i.e., β_{nt}), while the second type, B researchers, also care about citations (i.e., C_{nt}). Both types value their status according to the utility coefficient, $\gamma\phi_X$. Because rewards to prestige are similar to those to economic growth, in that prestige only increases when a significant agenda matures, A researchers will only research active promising agendas. In contrast, B type researchers will also research active speculative agendas if the reward for citations, embedded in $\gamma\phi_X$, is sufficiently high. However, the presence of A type researchers dampens these incentives by reducing the overall number of researchers who research active speculative agendas.

In addition, if the planner cannot distinguish across researcher types, then a contract that rewards for both prestige and citations will be more attractive to B-type than to A-type researchers if $\gamma\phi_X$ is sufficiently large. We summarize these observations in the following proposition.

Proposition 7. *A-type researchers will only research active promising agendas, while if $\gamma\phi_X$ is sufficiently large, B-type researchers will also research active speculative agendas. The required*

$\gamma\phi_X$ is increasing in the number of A-type researchers because fewer researchers research active speculative agendas. Furthermore, if researchers' contracts reward status and $\gamma\phi_X$ is sufficiently large, the profession selects on B-type researchers.

3.3 Hegemony and Intellectual Dynamism

In this subsection, we extend our model to capture the potential for research to become dominated by certain topics when senior researchers act as agenda-setters. Such a phenomena is beneficial to researchers' careers by providing more status for working in a senior researcher's preferred agenda. However, although it can be beneficial for growth if it encourages researchers to abandon active speculative agendas, it is harmful if it also causes researchers to abandon active promising agendas.

Suppose that each researcher has a preferred field. Without loss, let researcher n's preferred field be field n, which is not exhaustive because there are $L >> N$ fields. The researcher with the most status, X_{nt}, is considered the senior researcher, and can set additional career incentives to researchers who work in his preferred field. Specifically, researchers receive a reward $\bar{\phi}_X$ for active agendas researched in field n, while the rewards for other fields are all set at ϕ_X. Because researchers retire randomly, the identity of this most senior researcher changes over time and is a source of risk for researchers.

The following proposition highlights the key features of how having a senior researcher alters the equilibrium characterized in Proposition 1.

Proposition 8. *Suppose $\bar{\phi}_X > \phi_X$. When the senior researcher retires, if there is no active agenda, then all researchers investigate in the new preferred field. Otherwise:*

- *if $\bar{\phi}_X$ is in an intermediate range, then all researchers abandon active speculative agendas to investigate an agenda in the new preferred field. The presence of senior researchers maximizes economic growth;*
- *if $\bar{\phi}_X$ is in sufficiently large, then all researchers abandon any active agenda to investigate*

an agenda in the new preferred field. The presence of senior researchers can be harmful for economic growth.

The presence of a senior researcher relaxes the participation constraints of all researchers.

This extension demonstrates that having senior researchers set the agendas for the profession has both benefits and costs for society. For researchers, the additional status acquired for working in a senior researcher's preferred agenda makes them better off and, by revealed preference, relaxes their participation constraints. Whether having senior researchers is good for growth depends on how much authority they wield over the profession. If their authority is not too modest but also not too great (i.e., $\bar{\phi_X} > \phi_X$ in an intermediate range), then turnover among senior researchers can cause the profession to abandon speculative active agendas, which are undesirable from a growth perspective because of the low likelihood of being significant (i.e., $p_0 < \frac{1-e^{-\gamma\phi_A K}}{1-e^{-2\gamma\phi_A K}}$). In contrast, if the incentives to research preferred fields are too strong (i.e., $\bar{\phi_X} > \phi_X$ sufficiently large), then turnover among senior researchers also pulls all researchers away from active promising agendas to investigate in the new preferred field. This harms growth because active promising agendas have the highest likelihood of being significant among any active agenda.

Consequently, we conclude that researchers and society benefit when the academic community is guided by senior researchers provided that their influence on researcher careers is not so strong as to sacrifice economic growth in favor of career growth.

4 Conclusion

Academia can produce work that benefits society, but the mechanisms for tapping into this value are poorly understood. We have formally modeled the process of academic inquiry and derived implications for how this process could go wrong. The nature of the incentives that are used, and perhaps have to be used, create the risk of academic bubbles,

where scarce, valuable resources may be poured into doomed research agendas simply because they are currently fashionable.

Our model suggests that academic incentives should face careful scrutiny. Large amounts of public and philanthropic resources pour into academic research every year without any natural disciplining market forces. Although it is difficult to derive specific policy implications from our stylized setting, we believe it does highlight the need to think carefully about aligning the incentives of researchers with the interests of society, and our model suggests that there may be room for improvement from the current state.

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Appendix

Proof of Proposition 1:

In what follows, let $\mathcal{A}_t$ be the set of active fields at time t, and $\mathcal{E}_t$ its complement (i.e., the set of inactive fields), $R_{-n,lt}$ the number of researchers working in active agenda l other than researcher n, and $\boldsymbol{X}_{-nt}$ the vector of statuses of other researchers. In addition, let $\boldsymbol{u_i}$ be $N \times 1$ Euclidian basis vector that is all zeros except for the i^{th} entry that is 1.

For simplicity, we first begin with the special case in which $\xi = 0$ and $\kappa = 0$, and no negative news ever arrives after an agenda has an initial high signal, $S_{lj} = 1$. We then consider the more general case in the sequel.

Step 1: Researcher n's Hamilton-Jacobi-Belman Equation

Recall that the state variable X_{nt} to be the status of researcher n with law of motion by Ito's Lemma

$$dX_{nt} = \sum_l r_{lt} r^n_{lt} dt + \log\left(1 + \sum_l \pi_{lj} r^n_{lt-}\right) dB^l_t - X_{nt-} dQ_{nt}. \tag{A.2}$$

A new researcher begins with a X_{nt} of $X_0 = 0$ because they have an initial citation of 0 and prestige of 1. In addition, we recognize his consumption is per capita output, i.e., $c_{nt} = \phi_A A_t K$.

To condense notation, let $\boldsymbol{p}_t = [p_{1t}, ..., p_{Lt}]'$ to be the vector of pseudo-probabilities of significance for each of the J fields (which also indexes which fields are active), and $\boldsymbol{X}_{-nt}$ to be the vector of other researchers' statuses $X_{n't}$. Let $\partial_y g$ denote the first partial derivative of the function g with respect to y, respectively, and $\nabla_z g$ the gradient of g with respect to the vector $\boldsymbol{z}$. Further, let $\boldsymbol{u_i}$ be $N \times 1$ Euclidian basis vector that is all zeros except for the i^{th} entry that is 1.

The value function of the researcher $V_{nT^n_{i-1}}(t, X_{nt}, \boldsymbol{p}_t, \boldsymbol{X}_{-nt}, A_t)$ for a researcher n born at time T^n_{i-1} then satisfies the Hamilton-Jacobi-Bellman (HJB) Equation according to the

Dynamic Programming Principle

$$0 \geq \sup_{\boldsymbol{r}^n, \boldsymbol{e}^n, (\boldsymbol{r}_t^n + \boldsymbol{e}_t^n)' \iota_L \leq 1 \ \forall \ t} e^{-(\rho+\eta)t} \left(-e^{-\gamma \phi_A A_t K - \gamma \phi_X X_{nt} + \kappa (\boldsymbol{r}_t^n + \boldsymbol{e}_t^n)' \iota_L} \right) dt + \mathbb{E} \left[dV_{nT_{i-1}^n} \left(t, X_{nt}, \boldsymbol{p}_t, \boldsymbol{X}_{-nt}, A_t \right) \right]. \tag{A.3}$$

The HJB equation remains valid for random optional stopping times, and consequently is equipped to handle researcher retirement.

Let us conjecture that researcher n's value function takes the form

$$V_{nT_{i-1}^n} \left(t, X_{nt}, \boldsymbol{p}_t, \boldsymbol{X}_{-nt}, A_t \right) = -e^{-(\rho+\eta)\left(t - T_{i-1}^n\right) - v_a A_t - v_n X_{nt}} f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right).$$

We can then expand this HJB Equation by Ito's Lemma and factor out the $e^{-(\rho+\eta)t - v_a A_t - v_n X_{nt}}$ terms to arrive at

$$\begin{aligned} 0 \geq \sup_{\boldsymbol{r}^n, \boldsymbol{e}^n, (\boldsymbol{r}_t^n + \boldsymbol{e}_t^n)' \iota_L \leq 1 \ \forall \ t} \Bigg\{ & - e^{v_a A_t + v_n X_{nt} - \gamma \phi_A A_t K - \gamma \phi_X X_{nt} + \kappa (\boldsymbol{r}_t^n + \boldsymbol{e}_t^n)' \iota_L} + v_n f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right) \sum_l \left(R_{-n,lt} + r_{lt}^n \right) r_{lt}^n \\ & - \lambda \sum_{l \in \mathcal{A}_t} \left(R_{-n,lt} + r_{lt}^n \right) \left(\left(\frac{p_{lt} e^{-v_a}}{\left(1 + r_{lt}^n\right)^{v_n}} + \left(1 - p_{lt}\right) e^{v_a} \right) f_n \left(\boldsymbol{p}_t - p_{lt} \boldsymbol{u_l}, \boldsymbol{X}_{-nt-} + \boldsymbol{\Delta X}_{-nt} \right) - f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right) \right) \\ & - \sum_{l \in \mathcal{E}_t} \lambda \left(E_{-n,lt} + e_{lt}^n \right) \left(\mathbb{E} \left[f_n \left(\boldsymbol{p}_t + p_{lj} \boldsymbol{u_l}, \boldsymbol{X}_{-nt} \right) \right] - f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right) \right) + \left(\rho + \eta \right) f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right) \\ & - \sum_{i,l} \left[\nabla_{\boldsymbol{X}_{-n}} f_n \right]_i \left(R_{-n,lt} + r_{lt}^n \right) r_{it}^l - \sum_{n' \neq n} \eta \left(f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} - X_{-n't} \boldsymbol{u_{n'}} \right) - f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right) \right) \Bigg\}, \end{aligned} \tag{A.4}$$

where $R_{-n,lt}$ and $E_{-n,lt}$ are the number of researchers researching and investigating in each agenda without researcher n, respectively. The second term reflects the marginal impact of an increase in citations on the researcher's status. The third is the jump in the researcher's value function that accumulates when an agenda matures. The fourth is the researcher's value function when a new agenda is discovered. The fifth is the flow discounting in value from subjective discounting and the instantaneous probability of the researcher's retirement. The sixth term reflects the growth in the status of other re-

searchers and the last term reflects the stochastic their retirement. The inequality becomes an equality under the optimal policy.

Matching coefficients on the A_t and X_{nt} terms, we find that

$$v_a = \gamma \phi_A K,$$

and

$$v_n = \gamma \phi_X,$$

which confirms the conjecture.

Step 2: Optimal Research Policies

Suppose researcher n chooses in which agenda to research only among active fields. We take the convention that $r_{lt} + 1$ represents the number of researchers in agenda l with researcher n, and r_{lt} the number without researcher n, and similarly with e_{lt}. Their optimal choice is then

$$\begin{aligned} v_{nt}^R = \sup_{l \in \mathcal{A}_t} \Big\{ & \gamma \phi_X f_n \left(r_{lt} + 1 \right) - \lambda p_{lt} e^{-\gamma \phi_A K} \left(\left(r_{lt} + 1 \right) 2^{-\gamma \phi_X} - r_{lt} \right) f_n \left(\boldsymbol{p}_t - p_{lt} \boldsymbol{u_l}, \boldsymbol{X}_{-nt-} + \boldsymbol{\Delta X}_{-nt} \right) \\ & - \lambda \left(\left(1 - p_{lt} \right) e^{\gamma \phi_A K} f_n \left(\boldsymbol{p}_t - p_{lt} \boldsymbol{u_l}, \boldsymbol{X}_{-nt-} + \boldsymbol{\Delta X}_{-nt} \right) - f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right) \right) - \sum_i \left[\nabla_{\boldsymbol{X}_{-n}} f_n \right]_i r_{lt}^i \Big\}, \end{aligned} \tag{A.5}$$

for fields in which $p_{lt} \in (0, 1)$. The $\sum_{i,n'} \left[\nabla_{\mathbf{X}_{-n}} f_n \right]_i r_{it}^{n'}$ reflects that researcher n internalizes that they can raise the status of other researchers by investigating in field l because $r_{lt} = \sum_{i=1}^N r_{it}^l$. The last two positive terms reflect that the researcher internalizes that their choice of field impacts the number of researchers working in that field, and consequently the citations of other researchers and variance of the signals about the quality of each agenda. It is immediate that the benefit of researching a given active agenda is increasing in the number of other researchers in the agenda (i.e., r_{lt}).

If the researcher instead tries to investigate their own agenda, then the payoff from this is risky endeavor is

$$v_{nt}^{E} = \sup_{l \in \mathcal{E}_t} -\lambda \left(\mathbb{E}\left[f_n \left(\boldsymbol{p}_t + p_{lj} \boldsymbol{u}_l, \boldsymbol{X}_{-nt} \right) \right] - f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right) \right). \tag{A.6}$$

The optimal choice for researcher n is to research an active agenda if $v_{nt}^{R} > v_{nt}^{E}$ and to research a new agenda if $v_{nt}^{R} \leq v_{nt}^{E}$.

Notice now that v_{nt}^{E} and v_{nt}^{R} are independent of X_{nt} for researcher n. By symmetry, then, $v_{n't}^{E}$ and $v_{n't}^{R}$ are independent of $X_{n't}$ for researcher n'. If no researcher's optimal research policy depends on his status, then by rational expectations, researcher n recognizes that researcher n''s research policy does not depend on his own status. Consequently, researcher n does not need to keep track of researcher n''s status, or that of any other researcher. Consequently, by this argument, it must be the case that $f_n \left(\boldsymbol{p}_t, \boldsymbol{X}_{-nt} \right) = f_n \left(\boldsymbol{p}_t \right)$, which is the same for all researchers, and equations (A.5) and (A.6) simplify to

$$\begin{aligned} v_{nt}^{R} = \sup_{l \in \mathcal{A}_t} \Bigg\{ & -\lambda \left(p_{lt} e^{-\gamma \phi_A K} \left(\left(R_{-n,lt} + 1 \right) 2^{-\gamma \phi_X} - R_{-n,lt} \right) + \left(1 - p_{lt} \right) e^{\gamma \phi_A K} \right) f_n \left(\boldsymbol{p}_t - p_{lt} \boldsymbol{u}_l \right) \\ & + \left(\lambda + \gamma \phi_X \left(R_{-n,lt} + 1 \right) \right) f_n \left(\boldsymbol{p}_t \right) \Bigg\}, \end{aligned} \tag{A.7}$$

and

$$v_{nt}^{E} = \sup_{l \in \mathcal{E}_t} -\lambda \left(\mathbb{E}\left[f_n \left(\boldsymbol{p}_t + p_{lj} \boldsymbol{u}_l \right) \right] - f_n \left(\boldsymbol{p}_t \right) \right). \tag{A.8}$$

where

$$\mathbb{E}\left[f_n \left(\boldsymbol{p}_t + p_{lj} \boldsymbol{u}_l \right) \right] = \Pr\left(S_{lj} = 1 \right) f_n \left(\boldsymbol{p}_t + p_1 \boldsymbol{u}_l \right) + \Pr\left(S_{lj} = 0 \right) f_n \left(\boldsymbol{p}_t + p_0 \boldsymbol{u}_l \right), \tag{A.9}$$

$\Pr\left(S_{lj} = 1 \right) = pq_1 + (1-p) q_0$, and $\Pr\left(S_{lj} = 0 \right) = 1 - pq_1 - (1-p) q_0$. Because the value of investigating a new agenda is always non-negative, a researcher will always prefer to

investigate than to not research at all. Consequently, the optimal choice of agenda is always a non-empty set surely for all time.

Step 3: Researcher n's Maximized Hamilton-Jacobi-Belman Equation

Let l_{nt}^* be the optimal agenda for researcher n to research at time t. From the researcher's Hamilton-Jacobi-Bellman Equation (A.4), the researcher's maximized Hamilton-Jacobi-Bellman equation can be expressed as

$$\begin{aligned} 0 = -1 &+ \left(\gamma\phi_X r_{l_{nt}^* t} r_{l_{nt}^* t}^n + \lambda \sum_l (r_{lt} + e_{lt}) + \rho + \eta\right) f_n(\boldsymbol{p}_t) - \sum_{l \in \mathcal{E}_t} \lambda e_{lt} \mathbb{E}\left[f_n\left(\boldsymbol{p}_t + p_{lj}\boldsymbol{u_l}\right)\right] \\ &- \lambda \sum_{l \in \mathcal{A}_t} r_{lt} \left(p_{lt}\left(1 + r_{lt}^n\right)^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1 - p_{lt}) e^{\gamma\phi_A K}\right) f_n\left(\boldsymbol{p}_t - p_{lt}\boldsymbol{u_l}\right), \end{aligned} \tag{A.10}$$

Because researchers will always either research an existing or a new agenda from Step 2, it follows that $\sum_l (r_{lt} + e_{lt}) = N$. Substituting this and the expectation (A.9) into equation (A.10), we arrive at

$$\begin{aligned} 0 = -1 &+ \left(\rho + \eta + \gamma\phi_X r_{l_{nt}^* t} r_{l_{nt}^* t}^n + \lambda N\right) f_n(\boldsymbol{p}_t) \\ &- \lambda \sum_{l \in \mathcal{E}_t} e_{lt} \left(\left(pq_1 + (1-p)q_0\right) f\left(\boldsymbol{p}_t + p_1\boldsymbol{u_l}\right) + \left(1 - pq_1 - (1-p)q_0\right) f_n\left(\boldsymbol{p}_t + p_0\boldsymbol{u_l}\right)\right) \\ &- \lambda \sum_{l \in \mathcal{A}_t} r_{lt} \left(p_{lt}\left(1 + r_{lt}^n\right)^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1 - p_{lt}) e^{\gamma\phi_A K}\right) f_n\left(\boldsymbol{p}_t - p_{lt}\boldsymbol{u_l}\right). \end{aligned} \tag{A.11}$$

Step 4: Incentives to Coordinate on Research Activities

We first consider the incentives to investigate different new agendas. Notice that all inactive research fields are ex ante identical, and therefore deliver equivalent value to all researchers. As such, $f_n\left(\boldsymbol{p}_t + p_{lj}\boldsymbol{u_l}\right) = f_n\left(\boldsymbol{p}_t + p_{l'j}\boldsymbol{u_{l'}}\right)$ if $l, l' \in \mathcal{E}_t$. Consequently, we have that for all $n \in 1, ..., N$

$$v_{nt}^E = \mathbb{E}\left[f_n\left(\boldsymbol{p}_t + p_{lj}\boldsymbol{u_l}\right)\right] - f_n(\boldsymbol{p}_t) = \mathbb{E}\left[f_n\left(\boldsymbol{p}_t + p_{l'j}\boldsymbol{u_{l'}}\right)\right] - f_n(\boldsymbol{p}_t) \;\forall\, l, l' \in \mathcal{E}_t.$$

Further, because the total value in the Hamilton-Jacobi-Bellman Equation (A.11) of investigating new research agendas for researcher n is

$$\sum_{l\in\mathcal{E}_t} \lambda e_{lt} \left(\left(pq_1 + (1-p)\, q_0 \right) f\left(\boldsymbol{p}_t + p_1 \boldsymbol{u}_{l'} \right) + \left(1 - pq_1 - (1-p)\, q_0 \right) f\left(\boldsymbol{p}_t + p_0 \boldsymbol{u}_{l'} \right) - f\left(\boldsymbol{p}_t \right) \right),$$

it follows that any combination of investigative efforts $e^{n\,N}_{lt\,n=1,l\in\mathcal{E}_t}$ will deliver the same expected value. To see this, suppose there are 2 researchers and there are two fields, 1 and 2, that are both inactive. Then, if both researchers only investigate field 1,each earns an expected value from investigating of

$$2\lambda \left(\left(pq_1 + (1-p)\, q_0 \right) f_n\left(p_1, 0 \right) + \left(1 - pq_1 - (1-p)\, q_0 \right) f_n\left(p_0, 0 \right) - f_n\left(0, 0 \right) \right),$$

while if one researcher investigates field 1 and one field 2, each earns an expected value from investigating of

$$\begin{aligned} &\lambda \left(\left(pq_1 + (1-p)\, q_0 \right) f_n\left(p_1, 0 \right) + \left(1 - pq_1 - (1-p)\, q_0 \right) f_n\left(p_0, 0 \right) - f_n\left(0, 0 \right) \right) \\ +&\lambda \left(\left(pq_1 + (1-p)\, q_0 \right) f_n\left(0, p_1 \right) + \left(1 - pq_1 - (1-p)\, q_0 \right) f_n\left(0, p_0 \right) - f_n\left(0, 0 \right) \right) \\ =&2\lambda \left(\left(pq_1 + (1-p)\, q_0 \right) f_n\left(p_1, 0 \right) + \left(1 - pq_1 - (1-p)\, q_0 \right) f_n\left(p_0, 0 \right) - f_n\left(0, 0 \right) \right), \end{aligned}$$

because both fields deliver the same conditional continuation value regardless of in which a new agenda is discovered. Consequently, any combination of efforts to investigate new agendas delivers the same value, and only the total effort is identified. Further, conditional continuation values are the same for all inactive agendas.

We now consider the incentives to investigate different active agendas. In contrast to the case of inactive agendas, researchers are not indifferent between researching one active agenda l versus another l' because each may garner different citation counts. Notice that in the absence of career concerns (i.e., $\gamma\phi_X = 0$), active researchers are indifferent to which active agenda they research with the same probability of being significant p_{lj} be-

cause any combination of research efforts $r^{n\,N}_{ltn=1,l\in\mathcal{A}_t}$ will deliver the same expected value. To see this, suppose there are again 2 researchers and there are two fields, 1 and 2, that are both active and likely significant (i.e., $p_{1j} = p_{2j} = p_1$). Then, if both researchers only research field 1,each earns an expected value from researching of

$$2\lambda\left(\left(p_1 e^{-\gamma\phi_A K} + (1-p_1)\, e^{\gamma\phi_A K}\right) f_n\left(0, p_1\right) - f_n\left(p_1, p_1\right)\right),$$

while if one researcher researchers field 1 and one field 2, each earns an expected value from researching of

$$\begin{aligned}
&\lambda\left(\left(p_1 e^{-\gamma\phi_A K} + (1-p_1)\, e^{\gamma\phi_A K}\right) f_n\left(0, p_1\right) - f_n\left(p_1, p_1\right)\right)\\
+&\lambda\left(\left(p_1 e^{-\gamma\phi_A K} + (1-p_1)\, e^{\gamma\phi_A K}\right) f_n\left(p_1, 0\right) - f_n\left(p_1, p_1\right)\right)\\
=&2\lambda\left(\left(p_1 e^{-\gamma\phi_A K} + (1-p_1)\, e^{\gamma\phi_A K}\right) f_n\left(0, p_1\right) - f_n\left(p_1, p_1\right)\right),
\end{aligned}$$

because both fields deliver the same conditional continuation value regardless of in which one matures. Consequently, any combination of efforts to investigate active agendas delivers the same value, and only the total effort is identified. Further, conditional continuation values are the same for all active agendas.

However, in the presence of career concerns (i.e., $\gamma\phi_X > 0$), researcher n is no longer indifferent toward which agenda he researches because of the flow benefit $\gamma\phi_X r_{lt} f_n\left(\boldsymbol{p}_t\right)$ from the r_{lt} additional citations and the $\left(1 + r^n_{lt}\right)^{-\gamma\phi_X}$ term in the $p_{lt}\left(1 + r^n_{lt}\right)^{-\gamma\phi_X} e^{-\gamma\phi_A K} f_n\left(\boldsymbol{p}_t - p_{lt}\boldsymbol{u_l}\right)$ $-f_n\left(\boldsymbol{p}_t\right)$ benefit from the field maturing. Both of these additional forces favor coordinating on the same agenda as other researchers.

Consequently, in the presence of career concerns, all researchers who research an active field coordinate on the same field with the highest likelihood of being significant, i.e., a field for which $p_{lj} = p_1$ before a field for which $p_{lj} = p_0$, although on which specific field they coordinate is indeterminate.

Because all researchers behave in a symmetric manner and do not distinguish between active agendas that received a high signal $S_{lj} = 1$ or between active agendas that received a low signal $S_{lj} = 0$, we can shrink the state space into the number of active fields that received a high signal $S_{lj} = 1$, L_1, and the number of active fields that received a low signal $S_{lj} = 0$,L_0. The number of inactive fields is then $L - L_1 - L_0$. It follows $f_n(\boldsymbol{p}_t) = f(L_1, L_0)$. Further, because all researchers prioritize researching an active agenda with a high signal over that with a low signal or investigating, we need only consider the case where $L_1 \in 0, 1$.

Step 5: Solving for the Maximized Hamilton-Jacobi-Belman Equation

Because all researchers face the same incentives to research, it follows that all researchers will either research an active agenda or all will investigate a new agenda. Suppose they all investigate a new agenda, in which case there is no active agenda with a high signal $S_{lj} = 1$, and consequently $L_1 = 0$ (otherwise they would research it instead). Then, because all new agendas deliver $f(1, L_0)$ with probability $pq_1 + (1-p)q_0$ and $f(0, L_0 + 1)$ with probability $1 - (pq_1 + (1-p)q_0)$, it follows that researcher n's value Hamilton-Jacobi-Bellman Equation in this case is

$$f(0, L_0) = \frac{1 + \lambda N (pq_1 + (1-p)q_0) f(1, L_0)}{\rho + \eta + \lambda N} + \frac{\lambda N (1 - pq_1 - (1-p)q_0) f(0, L_0 + 1)}{\rho + \eta + \lambda N}. \tag{A.12}$$

Similarly, if all researchers research an active agenda that received a high signal $S_{lj} = 1$ and $L_1 = 1$, then researcher n's value Hamilton-Jacobi-Bellman Equation in this case is instead

$$f(1, L_0) = \frac{1 + \lambda N \left(p_1 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1-p_1) e^{\gamma\phi_A K}\right) f(0, L_0)}{\rho + \eta + \gamma\phi_X N + \lambda N}. \tag{A.13}$$

Finally, if all research an active agenda that received a low signal $S_{lj} = 0$, which will only

occur if $L_1 = 0$ and there is no active agenda with a high signal $S_{lj} = 1$, then researcher n's value Hamilton-Jacobi-Bellman Equation in this case is

$$f(0, L_0) = \frac{1 + \lambda N \left(p_0 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_0) e^{\gamma \phi_A K} \right) f(0, L_0 - 1)}{\rho + \eta + \gamma \phi_X N + \lambda N}. \tag{A.14}$$

Because researchers will always research an active agenda that that received a high signal $S_{lj} = 1$, we can substitute equation (A.13) (shifting the L_1 index forward by 1) into (A.12) to find

$$\begin{aligned} f(0, L_0) = & \frac{1 + \lambda N \left(p q_1 + (1 - p) q_0 \right) \frac{1 + \lambda N \left(p_1 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_1) e^{\gamma \phi_A K} \right) f(0, L_0)}{\rho + \eta + \gamma \phi_X N + \lambda N}}{\rho + \eta + \lambda N} \\ & + \frac{\lambda N \left(1 - p q_1 - (1 - p) q_0 \right) f(0, L_0 + 1)}{\rho + \eta + \lambda N} \end{aligned}. \tag{A.15}$$

We now have two cases depending on whether it is preferable to research an active agenda that received a low signal $S_{lj} = 0$ or to continue investigating until researchers discover an agenda that received a high signal $S_{lj} = 1$.

Case 1: It is preferable to research agendas with low signals to investigating new agendas. In this case, we also have that $L_0 \in 0, 1$, and we can recover $f(0, 1)$ from equation (A.14) and substitute it (shifting the L_0 index forward by 1) into equation (A.15) to find

$$f(0, 0) = \frac{1 + \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N}}{\rho + \eta + \lambda N \left(1 - \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N} \delta \right)}, \tag{A.16}$$

where

$$\begin{aligned} \delta = & \left(1 - p q_1 - (1 - p) q_0 \right) \left(p_0 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_0) e^{\gamma \phi_A K} \right) \\ & + \left(p q_1 + (1 - p) q_0 \right) \left(p_1 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_1) e^{\gamma \phi_A K} \right) \\ & > 0. \end{aligned}$$

For the solution to be well-defined, we require that

$$\rho + \eta + \lambda N \left(1 - \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N} \delta\right) > 0.$$

Consequently, the optimal research policy for all researchers is to coordinate to research any active agenda, then investigate a new agenda once it has matured.

Case 2: It is preferable to investigate new agendas than to research agendas with low signals. In this case, we never use equation (A.14). Instead, we recognize that $f(0, L_0 + 1) = f(0, L_0) = f(0)$ (we can ignore the count of low signal agendas), i.e., the new agenda with a low signal is abandoned, and equation (A.15) reduces to

$$f(0) = \frac{1 + \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N} \left(p q_1 + (1 - p) q_0\right)}{\rho + \eta + \lambda N (1 - \chi)}, \tag{A.17}$$

where

$$\chi = 1 - \left(p q_1 + (1 - p) q_0\right) \left(1 - \frac{\lambda N \left(p_1 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_1) e^{\gamma \phi_A K}\right)}{\rho + \eta + \gamma \phi_X N + \lambda N}\right) > 0,$$

which is decreasing in $\gamma \phi_X$, and it follows that

$$f(1) = \frac{1 + \lambda N \left(p_1 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_1) e^{\gamma \phi_A K}\right) f(0)}{\rho + \eta + \gamma \phi_X N + \lambda N}. \tag{A.18}$$

For the solution to be well-defined, we require that

$$\rho + \eta + \lambda N (1 - \chi) > 0.$$

Consequently, the optimal research policy for all researchers is to coordinate to research only active agendas with high signals $S_{lj} = 1$, and to investigate a new agenda otherwise.[6]

[6]This characterization fails in the extreme case that all fields have active agendas with low signals, in

Step 6: Pecking Order for Research Activities

We have already identified that all researchers will prioritize researching agendas with high signals $S_{lj} = 1$. We now need to examine when an individual researcher has incentive to research an active agenda with a low signal. The marginal value of researching the active agenda, v_{nt}^R, from equation (A.7) in this case simplifies to

$$v_{nt|S_{lj}=0}^R = (\lambda + \gamma\phi_X r_{lt}) f(0,1) - \lambda \left(p_0 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1-p_0) e^{\gamma\phi_A K} \right) f(0,0), \quad \text{(A.19)}$$

while the marginal value of investigating from equation (A.6) is

$$v_{nt}^E = -\lambda \left((pq_1 + (1-p) q_0) f(1,1) + (1 - pq_1 - (1-p) q_0) f(0,2) - f(0,1) \right). \quad \text{(A.20)}$$

For it to be preferable to investigate new agendas and ignore active agendas with low signals, we require that $v_{nt}^E \geq v_{nt|S_{lj}=0}^R$, i.e.,

$$\begin{aligned} &\gamma\phi_X r_{lt} f(0,1) - \lambda \left(p_0 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1-p_0) e^{\gamma\phi_A K} \right) f(0,0) \\ \leq &-\lambda \left((pq_1 + (1-p) q_0) f(1,1) + (1 - pq_1 - (1-p) q_0) f(0,2) \right). \end{aligned} \quad \text{(A.21)}$$

Considering we are in Case 2 from Step 5, we recognize $f(0,2) = f(0,1) = f(0,0) = f(0)$, and substituting with equations (A.18) and (A.17), condition (A.21) when one researcher deviates to research the active agenda (i.e., $r_{lt} = 1$) (and assuming $\rho + \eta +$

which case there is a bottleneck and researchers are forced to complete one of these fields to then investigate to try to discover a high signal field. We consequently consider L to be sufficiently large that this happens with an arbitrarily low probability.

$\lambda N(1-\chi) > 0$) reduces to

$$0 \geq \gamma\phi_X + \lambda\left(1 - p_0 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} - (1-p_0)\, e^{\gamma\phi_A K}\right) - (p_1 - p_0)\left(e^{\gamma\phi_A K} - 2^{-\gamma\phi_X} e^{-\gamma\phi_A K}\right) \lambda N \frac{\lambda\left(pq_1 + (1-p)\, q_0\right)}{\rho + \eta + \gamma\phi_X N + \lambda N}. \tag{A.22}$$

This is a conservative incentive compatibility condition because if one researcher has incentive to deviate, then $m > 1$ researchers have stronger incentive to deviate through the higher citation count to deviating. This ensures there is no coordination failure in which all researchers may suddenly revert to not researching active speculative agendas.

Suppose there are no career incentives (i.e., $\phi_X = 0$), then the condition (A.22) reduces to

$$1 - p_0 e^{-\gamma\phi_A K} - (1-p_0)\, e^{\gamma\phi_A K} - (p_1 - p_0)\left(e^{\gamma\phi_A K} - e^{-\gamma\phi_A K}\right) \frac{\lambda N\left(pq_1 + (1-p)\, q_0\right)}{\rho + \eta + \lambda N} \leq 0. \tag{A.23}$$

Given that $p_1 > p_0$ by construction, and $e^{\gamma\phi_A K} > e^{-\gamma\phi_A K}$,it follows that the final term on the left-hand side of condition (A.23) is negative. Further, since $1 - p_0 e^{-\gamma\phi_A K} - (1-p_0)\, e^{\gamma\phi_A K}$ is increasing in p_0 and negative when $p_0 < \frac{1-e^{-\gamma\phi_A K}}{1-e^{-2\gamma\phi_A K}}$, we have that for $p_0 < \frac{1-e^{-\gamma\phi_A K}}{1-e^{-2\gamma\phi_A K}}$, condition (A.23) is satisfied and researchers will never research an active agenda with a low signal $S_{jl} = 0$.

In contrast, suppose researchers have career concerns (i.e., $\gamma\phi_X > 0$). Let LHS represent the left-hand side of condition (**??**). Then, it is immediate that

$$\frac{dLHS}{d\phi_X} = 1 + \lambda\left(p_0 - (p_1 - p_0)\frac{\lambda N\left(pq_1 + (1-p)\, q_0\right)}{\rho + \eta + \gamma\phi_X N + \lambda N}\right) 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} \log 2 + (p_1 - p_0)\left(e^{\gamma\phi_A K} - 2^{-\gamma\phi_X} e^{-\gamma\phi_A K}\right)\left(pq_1 + (1-p)\, q_0\right)\left(\frac{\lambda N}{\rho + \eta + \gamma\phi_X N + \lambda N}\right)^2$$

which is increasing in ϕ_X for ϕ_X sufficiently large. Consequently, there is a critical ϕ_X, ϕ_X^*, such that for $\phi_X \geq \gamma\phi_X^*$, condition (**??**) fails and researchers will instead research

active agendas that receive low signals. Further, if $p_0 \geq (p_1 - p_0) \frac{\lambda N(pq_1+(1-p)q_0)}{\rho+\eta+\gamma\phi_X N+\lambda N}$, then $\frac{dLHS}{d\phi_X} \geq 0$, and for $\phi_X < \phi_X^*$, condition (**??**) is satisfied.

Step 7: Transversality and Sufficiency

It is a necessary condition that the value function satisfy the transversality condition

$$\lim_{T\to\infty} \mathbb{E}\left[V_{nT_{i-1}^n}\left(T, X_{nT}, \boldsymbol{p}_T, \boldsymbol{X}_{-nT}, A_T\right)\right] = \lim_{T\to\infty} \mathbb{E}\left[-e^{-(\rho+\eta)\left(T-T_{i-1}^n\right)-\gamma\phi_A K A_T-\gamma\phi_X X_{nT}} f\left(L_0, L_1\right)\right] = 0. \tag{A.24}$$

It is immediate from Step 5 that $f\left(L_0, L_1\right) \geq 0$ is bounded. Because status X_{nt} is non-negative, $-e^{-\gamma\phi_X X_{nt}}$ is bounded from above by 0 and below by -1. In addition, $-e^{-(\rho+\eta)\left(T-T_{i-1}^n\right)-\gamma\phi_A K A_T}$ is bounded from above by 0 and, given the jumps in A_t are finite and (at maximum) arrive slower than the rate of discounting $\rho+\eta$, it follows that $-e^{-(\rho+\eta)\left(T-T_{i-1}^n\right)-\gamma\phi_A K A_T}$ is also bounded in expectation from below. Consequently, the transversality condition (A.24) is satisfied.

Standard arguments establish that it is sufficient that the value function $V_{nt}\left(X_{nT}, \boldsymbol{p}_T, \boldsymbol{X}_{-nT}, A_T\right)$ satisfies the Hamilton-Jacobi-Bellman Equation (A.11) and the transversality condition (A.24) for it to solved researcher n's problem and delivers value $U_{nT_{i-1}^n}$.

Consequently, we have solved the researcher n's problem and, as a consequence, the full equilibrium in the special case in which $\xi = 0$.

Step 8: The Case in which $\xi > 0$ and $\kappa > 0$

We can draw insights from the special case in which $\xi = 0$ to discern the equilibrium in which $\xi > 0$, and negative news about promising agendas can arrive. This is true regardless of effort cost κ.

It is immediate that the best situation for researchers still is that there is a promising agenda that received an initial signal of $S_{lj} = 1$. Amplified by career concerns, all researchers will research any active agenda with a high signal. However, there is now the possibility that agenda will receive a second, negative signal before it matures. Because researching an active promising agenda is preferable to researching a speculative agenda

or investigating a new agenda, researchers will research the agenda until either it matures or the negative signal arrives.

If a negative signal arrives, then by the memory-less property of Poisson processes, this is equivalent to the arrival of new speculative agenda. As such, our analysis for whether the researchers research the speculative agenda or abandon it remains valid.

The normalized value of an active promising agenda consequently now satisfies

$$f(1, L_0) = \frac{e^{\kappa} + \lambda N \left(p_1 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_1) e^{\gamma \phi_A K} \right) f(0, L_0) + \xi f(0, L_0 + 1)}{\rho + \eta + \xi + \gamma \phi_X N + \lambda N}, \quad \text{(A.25)}$$

We again have two cases depending on whether it is preferable to research an active agenda that received a low signal $S_{lj} = 0$ or to continue investigating until researchers discover an agenda that received a high signal $S_{lj} = 1$.

Case 1: It is preferable to research agendas with low signals to investigating new agendas. We can repeat our procedure in Step 5 in this case to find

$$f(0, 0) = \frac{1 + \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N}}{\rho + \eta + \lambda N \left(1 - \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N} \theta \right)} e^{\kappa}, \quad \text{(A.26)}$$

where

$$\theta = -(p_1 - p_0) \frac{\rho + \eta + \gamma \phi_X N + \lambda N}{\rho + \eta + \xi + \gamma \phi_X N + \lambda N} (p q_1 + (1 - p) q_0) \left(e^{\gamma \phi_A K} - 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} \right) \quad \text{(A.27)}$$

$$+ p_0 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_0) e^{\gamma \phi_A K}.$$

Notice because $\frac{\partial \theta}{\partial \phi_X} < 0$, we have that $\frac{\partial f(0,0)}{\partial \phi_X} < 0$.

For the solution to be well-defined, we require that

$$\rho + \eta + \lambda N \left(1 - \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N} \theta \right) > 0.$$

Case 2: It is preferable to investigate new agendas than to research agendas with low signals. We can repeat our procedure in Step 5 in this case to find

$$f(0) = \frac{1 + \frac{\lambda N(pq_1 + (1-p)q_0)}{\rho+\eta+\xi+\gamma\phi_X N+\lambda N}}{\rho + \eta + \lambda N(1-\omega)} e^{\kappa}, \tag{A.28}$$

where

$$\omega = 1 - (pq_1 + (1-p)q_0)\left(1 - \frac{\lambda N\left(p_1 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1-p_1)e^{\gamma\phi_A K}\right) + \xi}{\rho + \eta + \xi + \gamma\phi_X N + \lambda N}\right), \tag{A.29}$$

which is again decreasing in ϕ_X, and that

$$f(1) = \frac{e^{\kappa} + \lambda N\left(p_1 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1-p_1)e^{\gamma\phi_A K}\right) f(0) + \xi f(0)}{\rho + \eta + \xi + \gamma\phi_X N + \lambda N}. \tag{A.30}$$

Notice again that because $\frac{\partial\omega}{\partial\phi_X} < 0$, we have that $\frac{\partial f(0)}{\partial\phi_X} < 0$.

We can further derive the necessary and sufficient condition for a researcher not to deviate to research an active speculative agenda (i.e., $r_{lt} = 1$) instead of investigating a new one. Based on our derivation in Step 6, we can substitute equations (A.28) and (A.30) into condition (A.21), recognizing $f(0,2) = f(0,1) = f(0,0) = f(0)$ and assuming $\rho + \eta + \lambda N(1-\omega) > 0$, to arrive at

$$\begin{aligned} 0 \geq\ & \gamma\phi_X + \lambda\left(1 - p_0 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} - (1-p_0)e^{\gamma\phi_A K}\right) \\ & - (p_1 - p_0)\left(e^{\gamma\phi_A K} - 2^{-\gamma\phi_X} e^{-\gamma\phi_A K}\right)\lambda N \frac{\lambda(pq_1 + (1-p)q_0)}{\rho + \eta + \xi + \gamma\phi_X N + \lambda N}. \end{aligned} \tag{A.31}$$

Analogous arguments to those in Step 6 establish that for $p_0 < \frac{1-e^{-\gamma\phi_A K}}{1-e^{-2\gamma\phi_A K}}$, a researcher would never deviate to research a speculative agenda when there are no career incentives, i.e., $\gamma\phi_X = 0$. Similarly, there is a critical ϕ_X, ϕ_X^*, such that for $\phi_X \geq \phi_X^*$, condition (A.31) fails and researchers will instead research active agendas that receive low signals.

Noticeably, these results do not on the effort cost, κ.

The equilibrium strategies we characterized in the special case when $\xi = 0$ and $\kappa = 0$ therefore remain valid when $\xi > 0$ and $\kappa > 0$.

What remains to be shown is that a researcher has the benefits of research exceed the effort costs. Notice that researching an active agenda must yield (weakly) conditionally more value to a researcher than investigating to find a new agenda. Consequently, we need only show that a researcher wishes to investigate a new agenda despite the effort cost.

Substituting our verified solution, $V_{nt}\left(X_{nt}, \boldsymbol{p}_t, \boldsymbol{X}_{-nt}\right) = -e^{-(\rho+\eta)t - v_a A_t - v_n X_{nt}} f_n\left(L_1, L_0\right)$, the Hamilton-Jacobi-Bellman equation for a investigating a new agenda is given by

$$0 \geq \min 1, e^{\kappa} + \lambda N\left(\left(pq_1 + (1-p)\,q_0\right) f\left(1,0\right) + \left(1 - pq_1 - (1-p)\,q_0\right) f\left(0,1\right) - f\left(0,0\right)\right) - \left(\rho + \eta\right) f\left(0,0\right).$$

Consequently, we need only verify the one-shot deviation principle that

$$1 \geq e^{\kappa} + \lambda N\left(\left(pq_1 + (1-p)\,q_0\right) f\left(1,0\right) + \left(1 - pq_1 - (1-p)\,q_0\right) f\left(0,1\right) - f\left(0,0\right)\right), \tag{A.32}$$

for it to be optimal for a researcher always to engage in research.

In Case 2, when active speculative agendas are abandoned, $f\left(0,1\right) = f\left(0\right)$ and $f\left(1,0\right) = f\left(1\right)$, and condition (A.32) from equations (A.28) and (A.30) reduces to

$$\kappa \leq \kappa_1^* = -\log\left(\left(1 + \frac{\lambda N\left(pq_1 + (1-p)\,q_0\right)}{\rho + \eta + \xi + \gamma\phi_X N + \lambda N}\left(1 - \frac{\rho + \eta + \xi + \gamma\phi_X N + \lambda N + \lambda N\left(pq_1 + (1-p)\,q_0\right)}{\frac{(\rho+\eta)(\rho+\eta+\xi+\gamma\phi_X N+\lambda N)}{\rho+\eta+\gamma\phi_X N+\lambda N\left(1-p_1 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} - (1-p_1)e^{\gamma\phi_A K}\right)} + \lambda N\left(pq_1 + (1-p)\,q_0\right)}\right)\right)\right). \tag{A.33}$$

Similarly, for Case 1, when active speculative agendas are researched to maturity, con-

dition (A.32) from equation (A.26) reduces to

$$\kappa \leq \kappa_2^* = -\log\left(1+\left(\frac{\left(pq_1+(1-p)\,q_0\right)\xi}{\rho+\eta+\xi+\gamma\phi_X N+\lambda N}+1\right)\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}\right. \tag{A.34}$$
$$\left.+\frac{\lambda N\left(1+\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}\right)\chi}{\rho+\eta+\lambda N\left(1-\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}\theta\right)}\right).$$

where

$$\chi = \left(pq_1+(1-p)\,q_0\right)\frac{\lambda N\left(p_1-p_0\right)\left(2^{-\gamma\phi_X}e^{-\gamma\phi_A K}-e^{\gamma\phi_A K}\right)}{\rho+\eta+\xi+\gamma\phi_X N+\lambda N}$$
$$+\left(\frac{\left(pq_1+(1-p)\,q_0\right)\xi}{\rho+\eta+\xi+\gamma\phi_X N+\lambda N}+1\right)\frac{\lambda N\left(p_0 2^{-\gamma\phi_X}e^{-\gamma\phi_A K}+(1-p_0)\,e^{\gamma\phi_A K}\right)}{\rho+\eta+\gamma\phi_X N+\lambda N}-1. \tag{A.35}$$

Step 9: The Participation Constraint

Notice that the participation constraint (5) is tightest when there is no active agenda. Consequently, if it is satisfied in this case, then it will also be satisfied when there is an active agenda. We again have two cases depending on whether it is preferable to research an active agenda that received a low signal $S_{lj}=0$ or to continue investigating until researchers discover an agenda that received a high signal $S_{lj}=1$.

Case 1: It is preferable to research agendas with low signals to investigating new agendas. At inception when there is no active agenda, a researcher's value function because $X_{nT_{i-1}^n}=0$ and $c_{nT_{i-1}^n}=\phi_A A_{T_{i-1}^n}K$

$$V_{nT_{i-1}^n}\left(T_{i-1}^n, X_{nT_{i-1}^n}, A_{T_{i-1}^n}\right) = -e^{-\gamma c_{nT_{i-1}^n}} f\left(0,0\right) \geq -\frac{e^{-\gamma c_{nT_{i-1}^n}}}{\rho+\eta},$$

from which it follows that we require from equation (A.26)

$$\frac{1+\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}}{\rho+\eta+\lambda N\left(1-\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}\theta\right)}e^{\kappa} \leq \frac{1}{\rho+\eta}, \tag{A.36}$$

We can rewrite the participation constraint as

$$\kappa \leq \kappa_1^{pc} = \log\left(\frac{1}{\rho+\eta}\frac{\rho+\eta+\lambda N\left(1-\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}\theta\right)}{1+\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}}\right). \tag{A.37}$$

Case 2: It is preferable to investigate new agendas than to research agendas with low signals. At inception when there is no active agenda, a researcher's value function because $X_{nT_{i-1}^n}=0$ and $c_{nT_{i-1}^n}=\phi_A A_{T_{i-1}^n}K$

$$V_{nT_{i-1}^n}\left(T_{i-1}^n, X_{nT_{i-1}^n}, A_{T_{i-1}^n}\right) = -e^{-\gamma c_{nT_{i-1}^n}} f(0) \geq -\frac{e^{-\gamma c_{nT_{i-1}^n}}}{\rho+\eta},$$

from which it follows that we require from equation (A.26)

$$\frac{1+\frac{\lambda N(pq_1+(1-p)q_0)}{\rho+\eta+\tilde{\zeta}+\gamma\phi_X N+\lambda N}}{\rho+\eta+\lambda N(1-\omega)}e^{\kappa} \leq \frac{1}{\rho+\eta}, \tag{A.38}$$

and the left-hand-side is again decreasing in ϕ_X. We can rewrite the participation constraint as

$$\kappa \leq \kappa_1^{pc} = \log\left(\frac{1}{\rho+\eta}\frac{\rho+\eta+\lambda N(1-\omega)}{1+\frac{\lambda N(pq_1+(1-p)q_0)}{\rho+\eta+\tilde{\zeta}+\gamma\phi_X N+\lambda N}}\right). \tag{A.39}$$

Consequently, the participation constraint is relaxed the higher is the reward for citations, ϕ_X.

Proof of Proposition 2:

We consider both cases depending on whether it is preferable to research an active agenda that received a low signal $S_{lj}=0$ or to continue investigating until researchers discover an agenda that received a high signal $S_{lj}=1$.

Case 1: From Step 8 of the proof of Proposition **1,** $f(0,0)$ is decreasing in ϕ_X. It is also immediate that $f(0,0)$ is increasing in κ. In addition, we recognize from rewriting θ from

equation (A.27) as

$$\begin{aligned}\theta = &\left(1 - pq_1 + (1-p)\,q_0\right)\left(p_0 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1-p_0)\,e^{\gamma\phi_A K}\right) \\ &+ \left(pq_1 + (1-p)\,q_0\right)\frac{\rho+\eta+\gamma\phi_X N+\lambda N}{\rho+\eta+\xi+\gamma\phi_X N+\lambda N}\left(p_1 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1-p_1)\,e^{\gamma\phi_A K}\right) \\ &+ \frac{\xi\left(pq_1 + (1-p)\,q_0\right)}{\rho+\eta+\xi+\gamma\phi_X N+\lambda N}\left(p_0 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1-p_0)\,e^{\gamma\phi_A K}\right), \qquad \text{(A.40)}\end{aligned}$$

that θ is increasing in γ for γ sufficiently large, and therefore so is $f\,(0,0)$. It is also immediate that θ is decreasing in p_0 and p_1, and therefore so is $f\,(0,0)$.

Consequently, the left-hand-side of the participation constraint (A.36) is decreasing in ϕ_X, p_0, and p_1, relaxing the constraint, and increasing in κ and γ for γ sufficiently large, tightening the constraint.

Case 2: From Step 8 of the proof of Proposition **1,** $f\,(0)$ is decreasing in ϕ_X. It is further immediate that $f\,(0)$ is increasing in κ. In addition, we recognize that ω from equation (A.29) is increasing in γ for γ sufficiently large, and therefore so is $f\,(0)$, while it is decreasing in p_1, and therefore so is $f\,(0)$.

Consequently, the left-hand-side of the participation constraint (A.38) is decreasing in ϕ_X and p_1, relaxing the constraint, and increasing in κ and γ for γ sufficiently large, tightening the constraint.

Proof of Proposition 3:

Let the value function for researcher n in the first-best economy with costly effort be $e^{-(\rho+\eta)t} v_n\,(A_t, L_1, L_0)$, where L_0 is again the number of active speculative and L_1 is the number of active promising research agendas.

Researching Active Agendas: Because effort is contractible, for it to be optimal to have researcher n research an active speculative agenda if $m-1$ other researchers are actively researching it at time t, it must be the case by the Hamilton-Jacobi-Bellman Equa-

tion for researcher n that

$$-e^{-\frac{\gamma}{N}A_tK+\kappa}+\lambda m\left(p_0v_n\left(A_t+1,L_1,L_0-1\right)+\left(1-p_0\right)v_n\left(A_t-1,L_1,L_0-1\right)-v_n\left(A_t,L_1,L_0\right)\right)$$
$$-\rho v_n\left(A_t,L_1,L_0\right)\geq$$
$$-e^{-\frac{\gamma}{N}A_tK}-\lambda\left(m-1\right)\left(p_0v_n\left(A_t+1,L_1,L_0-1\right)+\left(1-p_0\right)v_n\left(A_t-1,L_1,L_0-1\right)-v_n\left(A_t,L_1,L_0\right)\right)$$
$$-\rho v_n\left(A_t,L_1,L_0\right). \tag{A.41}$$

We focus on the expected benefit for the M^{th} researcher to ensure that having M researchers actively researching represents a Pareto improvement. The remaining $N-M$ researchers who are not actively researching are clearly better off if those who are required to provide effort are better off.

Conjecturing that $v_n\left(A_t,L_1,L_0\right)=-e^{-\frac{\gamma}{N}A_tK}h_n\left(L_1,L_0\right)$,condition A.41 reduces to

$$e^{\kappa}+\lambda\left(\left(p_0e^{-\frac{\gamma}{N}K}+\left(1-p_0\right)e^{\frac{\gamma}{N}K}\right)h_n\left(L_1,L_0-1\right)-h_n\left(L_1,L_0\right)\right)\leq 1. \tag{A.42}$$

If having a speculative agenda is socially valuable, then it must be the case that $h_n\left(L_1,L_0\right)<h_n\left(L_1,L_0-1\right)$. In addition, because $p_0<\frac{1}{2}$, we have that$p_0<\frac{1-e^{-\frac{\gamma}{N}K}}{1-e^{-2\frac{\gamma}{N}K}}$ and consequently $p_0e^{-\frac{\gamma}{N}K}+\left(1-p_0\right)e^{\frac{\gamma}{N}K}>1$. These two observations imply that

$$\left(p_0e^{-\frac{\gamma}{N}K}+\left(1-p_0\right)e^{\frac{\gamma}{N}K}\right)h_n\left(L_1,L_0-1\right)-h_n\left(L_1,L_0\right)>h_n\left(L_1,L_0-1\right)-h_n\left(L_1,L_0\right)>0,$$

and because $\kappa>0$ that condition A.42 fails. Consequently, it is not socially optimal (for any m) to research a speculative agenda.

In contrast, for it to be optimal to have researcher n research an active promising agenda if $m-1$ other researchers are actively researching it at time t, it must be the case by the Hamilton-Jacobi-Bellman Equation for researcher n that

$$-e^{-\frac{\gamma}{N}A_tK+\kappa}+\lambda m\left(p_1 v_n\left(A_t+1,L_1-1,L_0\right)+\left(1-p_1\right)v_n\left(A_t-1,L_1-1,L_0\right)-v_n\left(A_t,L_1,L_0\right)\right)$$
$$-\rho v_n\left(A_t,L_1,L_0\right)+\xi\left(v_n\left(A_t,L_1-1,L_0+1\right)-v_n\left(A_t,L_1,L_0\right)\right)\geq$$
$$-e^{-\frac{\gamma}{N}A_tK}-\lambda\left(m-1\right)\left(p_1 v_n\left(A_t+1,L_1-1,L_0\right)+\left(1-p_1\right)v_n\left(A_t-1,L_1-1,L_0\right)-v_n\left(A_t,L_1,L_0\right)\right)$$
$$-\rho v_n\left(A_t,L_1,L_0\right)+\xi\left(v_n\left(A_t,L_1-1,L_0+1\right)-v_n\left(A_t,L_1,L_0\right)\right), \tag{A.43}$$

where the last term in each expression reflects the possibility that bad news arrives about the agenda. Because this arrival is independent of the number of active researchers in the agenda, it does not meaningfully impact the optimality condition.

Conjecturing that $v_n\left(A_t,L_1,L_0\right)=-e^{-\frac{\gamma}{N}A_tK}h_n\left(L_1\right)$ (where we drop the L_0 argument because it is never optimal to research a speculative agenda), condition A.43 reduces to

$$e^{\kappa}+\lambda\left(\left(p_1e^{-\frac{\gamma}{N}K}+\left(1-p_1\right)e^{\frac{\gamma}{N}K}\right)h_n\left(L_1-1\right)-h_n\left(L_1\right)\right)\leq 1. \tag{A.44}$$

This is the key condition we will evaluate after solving for researcher's value function.

Investigating a New Agenda: We assume for now that it is optimal for m researchers to to research an active promising agenda. In this case, in equilibrium, there will be either zero or one active promising agendas. In contrast, we have established that the planner would abandon any speculative active agenda.

For it to be optimal for $M\leq N$ researchers to investigate a new agenda, there cannot be an active promising agenda it must be the case by the Hamilton-Jacobi-Bellman Equation for researcher n's value function in the first-best economy with costly effort,

$e^{-(\rho+\eta)t} v_n(A_t, L_1)$,

$$\begin{aligned} -e^{-\frac{\gamma}{N}A_t K+\kappa} - \lambda M(pq_1 + (1-p)q_0)(v_n(A_t,1) - v_n(A_t,0)) \\ - (\rho+\eta) v_n(A_t,0) \geq \\ -e^{-\frac{\gamma}{N}A_t K} + \lambda(M-1)(pq_1 + (1-p)q_0)(v_n(A_t,1) - v_n(A_t,0)) \\ - (\rho+\eta) v_n(A_t,0), \end{aligned} \tag{A.45}$$

where $pq_1 + (1-p)q_0$ is the probability a new agenda is promising, and

$$(\rho+\eta+\lambda M) v_n(A_t,0) = -e^{-\frac{\gamma}{N}A_t K+\kappa} + \lambda M(pq_1 + (1-p)q_0)(v_n(A_t,1) - v_n(A_t,0)), \tag{A.46}$$

and

$$\begin{aligned} (\rho+\eta) v_n(A_t,1) = -e^{-\frac{\gamma}{N}A_t K+\kappa} + \lambda m(p_1 v_n(A_t+1,0) + (1-p_1) v_n(A_t-1,0) - v_n(A_t,1)), \\ + \xi(v_n(A_t,0) - v_n(A_t,1)) \end{aligned} \tag{A.47}$$

are the value functions conditional on having researcher n investigating and researching an active promising agenda, respectively. The last term in equation A.47 reflects the arrival of negative news.

Let us conjecture that $v_n(A_t, L_1) = -e^{-\frac{\gamma}{N}A_t K} h_n(L_1)$,from which follows that condition (A.45) reduces to

$$1 - e^{\kappa} + \lambda(pq_1 + (1-p)q_0)(h_n(0) - h_n(1)) \geq 0, \tag{A.48}$$

equation (A.46) reduces to

$$h_n(0) = \frac{e^{\kappa} + \lambda M(pq_1 + (1-p)q_0) h_n(1)}{\rho+\eta+\lambda M(pq_1 + (1-p)q_0)}, \tag{A.49}$$

and equation (A.47) reduces to

$$h_n(1) = \frac{e^{\kappa} + \lambda m\left(p_1 e^{-\frac{\gamma}{N}K} + (1-p_1)\, e^{\frac{\gamma}{N}K}\right) h_n(0) + \xi h_n(0)}{\rho + \eta + \xi + \lambda m}, \tag{A.50}$$

which confirms the conjecture. Notice that $p_1 \geq \frac{1-e^{-\frac{\gamma}{N}K}}{1-e^{-2\frac{\gamma}{N}K}}$ implies that $p_1 e^{-\frac{\gamma}{N}K} + (1-p_1)\, e^{\frac{\gamma}{N}K} \leq 1$. Combining equations $(A.49)$ and (A.50), we find

$$h_n(0) = \frac{e^{\kappa}}{\rho + \eta + \lambda m\left(1 - p_1 e^{-\frac{\gamma}{N}K} - (1-p_1)\, e^{\frac{\gamma}{N}K}\right) \frac{\lambda M(pq_1 + (1-p)q_0)}{\rho+\eta+\xi+\lambda m+\lambda M(pq_1+(1-p)q_0)}}, \tag{A.51}$$

and

$$h_n(0) - h_n(1) = \frac{e^{\kappa}}{\lambda M\left(pq_1 + (1-p)\, q_0\right) + (\rho+\eta)\, \frac{\rho+\eta+\xi+\lambda m+\lambda M(pq_1+(1-p)q_0)}{\lambda m\left(1-p_1 e^{-\frac{\gamma}{N}K}-(1-p_1)e^{\frac{\gamma}{N}K}\right)}} > 0. \tag{A.52}$$

Substituting equation $(A.52)$ into condition $(A.52)$, condition $(A.52)$ becomes

$$\frac{\lambda\left(pq_1 + (1-p)\, q_0\right)}{\lambda M\left(pq_1 + (1-p)\, q_0\right) + (\rho+\eta)\, \frac{\rho+\eta+\xi+\lambda m+\lambda M(pq_1+(1-p)q_0)}{\lambda m\left(1-p_1 e^{-\frac{\gamma}{N}K}-(1-p_1)e^{\frac{\gamma}{N}K}\right)}} \geq 1 - e^{-\kappa}. \tag{A.53}$$

The Two Optimality Conditions:

Substituting equations A.51 and A.52 into conditions $A.44$, we arrive at the optimality condition to research an active promising field (recognizing there is, at most, one active promising field at time t)

$$\frac{1}{m}\frac{\rho + \eta + \xi + \lambda M\left(pq_1 + (1-p)\, q_0\right)}{\lambda M\left(pq_1 + (1-p)\, q_0\right) + (\rho+\eta)\, \frac{\rho+\eta+\xi+\lambda m+\lambda M(pq_1+(1-p)q_0)}{\lambda m\left(1-p_1 e^{-\frac{\gamma}{N}K}-(1-p_1)e^{\frac{\gamma}{N}K}\right)}} \geq 1 - e^{-\kappa}. \tag{A.54}$$

Consequently, for it to be optimal to investigate to find new agendas and to research any active promising agendas, conditions $A.54$ and $A.53$ must be satisfied. The planner's

goal is to have both constraints be as tight as possible to maximize the number of active researchers. It is intuitive that having more researchers research active promising agendas (i.e., higher m) relaxes the constraint on M in condition $A.53$, while a higher M tightens it.

If $M \geq m$, then it is immediate that if condition $A.53$ is satisfied, then so is condition $A.54$. We focus on this case when m is as large as possible, i.e., $M = m$, as this slackens condition $A.53$ the most. Then, we can rewrite condition condition $A.53$ as

$$f(m) = \frac{\lambda\left(pq_1 + (1-p)\,q_0\right)}{\lambda m\left(pq_1 + (1-p)\,q_0\right) + (\rho+\eta)\,\frac{\rho+\eta+\xi+\lambda m(1+pq_1+(1-p)q_0)}{\lambda m\left(1-p_1 e^{-\frac{\gamma}{N}K}-(1-p_1)e^{\frac{\gamma}{N}K}\right)}} \geq 1 - e^{-\kappa}. \quad \text{(A.55)}$$

Notice that $f(m)$ is hump-shaped in m, equaling zero at $m \in 0, \infty$. There are consequently either zero solutions to condition $A.55$ or one value of m, m^*, for which $f(m^*) \geq 1 - e^{-\kappa}$ and $f(m^*+1) < 1 - e^{-\kappa}$, and this m^* is decreasing in κ (and always equal to N, the maximum value of m, when $\kappa = 0$). By feasibility, the active number of researchers is the largest $m \leq N$ that satisfies condition $A.55$. It may be the case that no feasible m satisfies condition $A.55$, in which case there is no solution.

Further, if $\kappa \leq \kappa^*$, where

$$\kappa^* = -\log\left(1 - \frac{\lambda\left(pq_1 + (1-p)\,q_0\right)}{\lambda N\left(pq_1 + (1-p)\,q_0\right) + (\rho+\eta)\,\frac{\rho+\eta+\xi+\lambda N(1+pq_1+(1-p)q_0)}{\lambda N\left(1-p_1 e^{-\frac{\gamma}{N}K}-(1-p_1)e^{\frac{\gamma}{N}K}\right)}}\right), \quad \text{(A.56)}$$

then it is optimal for all N researchers to actively research at all times.

The Participation Constraint:

Finally, the participation constraint (5) is given by

$$-e^{-\gamma c_{nT_{i-1}^n}} h_n(0) \geq -\frac{e^{-\gamma c_{nT_{i-1}^n}}}{\rho+\eta}, \quad \text{(A.57)}$$

which reduces from equation $(A.51)$ to

$$\kappa \leq \kappa^{pc} = \log\left(\frac{\rho+\eta+\lambda m\left(1-p_1 e^{-\frac{\gamma}{N}K}-(1-p_1)\,e^{\frac{\gamma}{N}K}\right)\frac{\lambda M(pq_1+(1-p)q_0)}{\rho+\eta+\xi+\lambda m+\lambda M(pq_1+(1-p)q_0)}}{\rho+\eta}\right). \tag{A.58}$$

Proof of Proposition 4:

We need only verify that condition $A.55$ fails when $m = 1$ and $\kappa = \kappa^*$. Substituting with κ^* from equation A.56 into condition $A.55$ when it fails, we require that

$$\begin{aligned} f(1) &= \frac{\lambda\left(pq_1+(1-p)\,q_0\right)}{\lambda\left(pq_1+(1-p)\,q_0\right)+(\rho+\eta)\,\frac{\rho+\eta+\xi+\lambda(1+pq_1+(1-p)q_0)}{\lambda\left(1-p_1e^{-\frac{\gamma}{N}K}-(1-p_1)e^{\frac{\gamma}{N}K}\right)}} \\ &\leq \frac{\lambda\left(pq_1+(1-p)\,q_0\right)}{\lambda N\left(pq_1+(1-p)\,q_0\right)+(\rho+\eta)\,\frac{\rho+\eta+\xi+\lambda N(1+pq_1+(1-p)q_0)}{\lambda N\left(1-p_1e^{-\frac{\gamma}{N}K}-(1-p_1)e^{\frac{\gamma}{N}K}\right)}}, \end{aligned} \tag{A.59}$$

which is satisfied if

$$N < \tilde{N} = \frac{(\rho+\eta)\,(\rho+\eta+\xi)}{\lambda\left(pq_1+(1-p)\,q_0\right)\lambda\left(1-p_1e^{-\frac{\gamma}{N}K}-(1-p_1)\,e^{\frac{\gamma}{N}K}\right)}, \tag{A.60}$$

and zero active researchers is a Nash Equilibrium.

That zero versus N active researchers constitutes a Pareto inferior equilibrium is immediate because, by revealed preference, the planner prefers to actively investigate and research promising agendas than to not.

Proof of Proposition 7:

Step 1: Principal's Indirect Utility Function

Given the linearity of the principal's objective in Y_t and X_{nt}, and that researchers are ex-ante identical up to their status, we can solve for the principal's problem researcher-by-researcher. Let $e^{-\rho t}U_{Pn}(A, X, S)$be the per capital value the principal derives from researcher n, where $S = \emptyset$ if there is no active agenda, $S = 1$ if there is an active promising

agenda, and $S = 0$ if there is an active speculative agenda. The Hamilton-Jacobi-Bellman Equation governing the principal's value when there is no active agenda is

$$0 = \lambda N \left(\left(pq_1 + (1-p) q_0 \right) U_{Pn}(A, X, 1) + \left(1 - pq_1 - (1-p) q_0 \right) U_{Pn}(A, X, 0) - U_{Pn}(A, X, \emptyset) \right) \tag{A.61}$$
$$+ \frac{1}{N} (1 - \phi_Y) AK - \phi_X X + \eta \left(U_{Pn}(A, 0, \emptyset) - U_{Pn}(A, X, \emptyset) \right) - \rho U_{Pn}(A, X, \emptyset).$$

Its value when there is an active promising agenda similarly has law of motion

$$\begin{aligned} 0 = {} & \lambda N \left(p_1 U_{Pn}(A+1, X + \log(1+N), \emptyset) + (1-p_1) U_{Pn}(A-1, X, \emptyset) - U_{Pn}(A, X, 1) \right) \\ & + \frac{1}{N} (1 - \phi_Y) AK - \phi_X X \\ & + \partial_X U_{Pn}(A, X, 1) N + \eta \left(U_{Pn}(A, 0, 1) - U_{Pn}(A, X, 1) \right) - \rho U_{Pn}(A, X, 1). \end{aligned} \tag{A.62}$$

If speculative agendas are not researched, we can conjecture that

$$0 = \lambda N \left(p_0 U_{Pn}(A+1, X + \log(1+N), \emptyset) + (1-p_0) U_{Pn}(A-1, X, \emptyset) - U_{Pn}(A, X, 0) \right) \tag{A.63}$$
$$+ \frac{1}{N} (1 - \phi_Y) AK - \phi_X X$$
$$+ \partial_X U_{Pn}(A, X, 0) N + \eta \left(U_{Pn}(A, 0, 0) - U_{Pn}(A, X, 0) \right) - \rho U_{Pn}(A, X, 0).$$

We now consider two cases depending on whether only promising or all agendas are researched. This is determined by each researcher's incentive compatibility constraint such that if career incentives, ϕ_X, are sufficiently high, then all agendas are researched, while if it is not, then only promising agendas are researched to maturity.

Case 1: Suppose researchers only pursue promising agendas, and prefer to investigate

a new agenda than to research a speculative agenda. Let us conjecture that

$$U_{Pn}(A, X, S) = u_0(S) + u_A(S) A + u_X(S) X,$$

and $U_{Pn}(A, X, 0) = U_{Pn}(A, X, \varnothing)$. Substituting these conjectures into equations $A.61$ and $A.62$, we find

$$u_A(\varnothing) = u_A(1) = \frac{1}{\rho N}(1 - \phi_Y) K,$$
$$u_X(\varnothing) = u_X(1) = -\frac{\phi_X}{\rho + \eta},$$

and

$$U_{Pn}(A, X, S) = -\frac{u(s)}{\rho}\left(\frac{\phi_X}{\rho + \eta} N + \frac{\phi_X}{\rho + \eta}\lambda N p_1 \log(1 + N) + \lambda N (1 - 2p_1)\frac{1}{\rho N}(1 - \phi_Y) K\right) + \frac{1}{\rho N}(1 - \phi_Y) AK - \frac{\phi_X}{\rho + \eta} X,$$

where

$$u(\varnothing) = \frac{\lambda N (p q_1 + (1 - p) q_0)}{\rho + \lambda N (1 + p q_1 + (1 - p) q_0)},$$
$$u(1) = \frac{\rho + \lambda N (p q_1 + (1 - p) q_0)}{\rho + \lambda N (1 + p q_1 + (1 - p) q_0)}.$$

If there is no active agenda and we initialize all statuses at zero, then the planner's indirect utility function is

$$U_{Pn}(A, 0, \varnothing) = -\frac{1}{\rho}\frac{\lambda N (p q_1 + (1 - p) q_0)}{\rho + \lambda N (1 + p q_1 + (1 - p) q_0)}\left(\frac{\phi_X}{\rho + \eta} N + \frac{\phi_X}{\rho + \eta}\lambda N p_1 \log(1 + N)\right) - \frac{1}{\rho}\frac{\lambda N (p q_1 + (1 - p) q_0)}{\rho + \lambda N (1 + p q_1 + (1 - p) q_0)}\lambda N (1 - 2p_1)\frac{1}{\rho N}(1 - \phi_Y) K + \frac{1}{\rho N}(1 - \phi_Y) AK,$$

Case 2: Suppose researchers pursue both promising and speculative agendas, and prefer to research them to investigating a new agenda. We again conjecture that

$$U_{Pn}(A, X, S) = u_0(S) + u_A(S) A + u_X(S) X,$$

and substitute this conjecture in equations $A.61$-$A.63$ to find

$$u_A(\varnothing) = u_A(1) = u_A(0) = \frac{1}{\rho N}(1 - \phi_Y) K,$$
$$u_X(\varnothing) = u_X(1) = u_A(0) = -\frac{\phi_X}{\rho + \eta},$$

and

$$U_{Pn}(A, X, S) = \frac{1}{\rho N}(1 - \phi_Y) AK - \frac{\phi_X}{\rho + \eta} X + u_0(s),$$

where

$$u_0(\varnothing) = -\frac{1}{\rho}\frac{\lambda N}{\rho + 2\lambda N}\left(\frac{\phi_X}{\rho + \eta} N + \lambda N \frac{\phi_X}{\rho + \eta} p \log(1 + N) + \lambda N (1 - 2p) \frac{1}{\rho N}(1 - \phi_Y) K\right),$$
$$u_0(1) = \frac{-\frac{\phi_X}{\rho+\eta}\lambda N p_1 \log(1 + N) - \lambda N (1 - 2p_1) \frac{1}{\rho N}(1 - \phi_Y) K - \frac{\phi_X}{\rho+\eta} N}{\rho + \lambda N} + \frac{\lambda N}{\rho + \lambda N} u_0(\varnothing)$$
$$u_0(0) = \frac{-\frac{\phi_X}{\rho+\eta}\lambda N p_0 \log(1 + N) - \lambda N (1 - 2p_0) \frac{1}{\rho N}(1 - \phi_Y) K - \frac{\phi_X}{\rho+\eta} N}{\rho + \lambda N} + \frac{\lambda N}{\rho + \lambda N} u_0(\varnothing).$$

If there is no active agenda and we initialize all statuses at zero, then the planner's indirect utility function is

$$U_{Pn}(A, 0, \varnothing) = -\frac{1}{\rho}\frac{\lambda N}{\rho + 2\lambda N}\left(\frac{\phi_X}{\rho + \eta} N + \lambda N \frac{\phi_X}{\rho + \eta} p \log(1 + N) + \lambda N (1 - 2p) \frac{1}{\rho N}(1 - \phi_Y) K\right)$$
$$+ \frac{1}{\rho N}(1 - \phi_Y) AK.$$

Step 2: Optimal Choice of Contract Loadings

The principal maximizes its objective subject to the participation constraint, equation

(5), which will bind in equilibrium. Let Ξ_n be the Lagrange multiplier on the participation constraint. Given the linearity of the planner's optimization program in ϕ_A, we can take the first-order necessary condition for the optimal choice of ϕ_A when only promising agendas are pursued, recognizing the participation constraint binds and substituting with it,

$$0 = -\frac{1}{\rho N} AK + \frac{1}{\rho N} \frac{\lambda N \left(pq_1 + (1-p)\, q_0\right)}{\rho + \lambda N \left(1 + pq_1 + (1-p)\, q_0\right)} \frac{\lambda N}{\rho} \left(1 - 2p_1\right) K + \Xi_n \frac{\frac{e^{-\gamma \phi_A A_t K}}{\rho + \eta} \lambda N \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N}}{\rho + \eta + \lambda N \left(1 - \frac{\lambda N}{\rho + \eta + \gamma \phi_X N + \lambda N} \theta\right)} \partial_{\phi_A} \theta, \tag{A.64}$$

where

$$\partial_{\phi_A} \theta = -\gamma K \left(p_1 - p_0\right) \frac{\rho + \eta + \gamma \phi_X N + \lambda N}{\rho + \eta + \xi + \gamma \phi_X N + \lambda N} \left(pq_1 + (1-p)\, q_0\right) \left(e^{\gamma \phi_A K} + 2^{-\gamma \phi_X} e^{-\gamma \phi_A K}\right) + \gamma K \left(1 - p_0\right) e^{\gamma \phi_A K},$$

and when all agendas are pursued

$$-\frac{1}{\rho N} AK + \frac{1}{\rho} \frac{\lambda N}{\rho + 2\lambda N} \lambda N \left(1 - 2p\right) \frac{1}{\rho N} K + \Xi_n \frac{\frac{e^{-\gamma \phi_A A_t K}}{\rho + \eta} \lambda N}{\rho + \eta + \lambda N \left(1 - \omega\right)} \partial_{\phi_A} \omega = 0, \tag{A.65}$$

where

$$\partial_{\phi_A} \omega = \gamma K \left(pq_1 + (1-p)\, q_0\right) \frac{\lambda N \left(-p_1 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + \left(1 - p_1\right) e^{\gamma \phi_A K}\right)}{\rho + \eta + \xi + \gamma \phi_X N + \lambda N}.$$

The optimal choice of $\phi_A$in both scenarios trades off the marginal present-value cost of rewarding researchers with additional output, which includes the expected growth in output from researching, with the relaxation of the participation constraint through raising researchers' expected lifetime utility.

Finally, we can take the first-order condition to find the optimal ϕ_X when only promis-

ing agendas are pursued, recognizing the participation constraint binds and substituting with it,

$$0 = -\frac{1}{\rho}\frac{\lambda N\left(pq_1+(1-p)\,q_0\right)}{\rho+\lambda N\left(1+pq_1+(1-p)\,q_0\right)}\left(\frac{1}{\rho+\eta}N+\frac{1}{\rho+\eta}\lambda N p_1\log\left(1+N\right)\right)$$
$$+\Xi_n\frac{\frac{e^{-\gamma\phi_A A_t K}}{\rho+\eta}\lambda N}{\rho+\eta+\lambda N\left(1-\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}\theta\right)}e^{\kappa}\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}\left(\partial_{\phi_X}\theta-\frac{\gamma N\theta}{\rho+\eta+\gamma\phi_X N+\lambda N}\right)$$
$$+\Xi_n\frac{\frac{e^{-\gamma\phi_A A_t K}}{\rho+\eta}\frac{\lambda N}{\left(\rho+\eta+\gamma\phi_X N+\lambda N\right)^2}\lambda N}{1+\frac{\lambda N}{\rho+\eta+\gamma\phi_X N+\lambda N}}, \tag{A.66}$$

where Ξ_n is given by equation A.64and

$$\partial_{\phi_X}\theta = -\left(p_1-p_0\right)\left(1+\frac{\gamma N\xi}{\left(\rho+\eta+\xi+\gamma\phi_X N+\lambda N\right)^2}\right)\left(pq_1+(1-p)\,q_0\right)\left(e^{\gamma\phi_A K}-2^{-\gamma\phi_X}e^{-\gamma\phi_A K}\right).$$

and when all agendas are pursued

$$0 = -\frac{1}{\rho}\frac{\lambda N}{\rho+2\lambda N}\left(\frac{1}{\rho+\eta}N+\lambda N\frac{1}{\rho+\eta}p\log\left(1+N\right)\right)$$
$$+\Xi_n\frac{e^{-\gamma\phi_A A_t K}}{\rho+\eta}\frac{\frac{\lambda N(pq_1+(1-p)q_0)}{\left(\rho+\eta+\xi+\gamma\phi_X N+\lambda N\right)^2}}{1+\frac{\lambda N(pq_1+(1-p)q_0)}{\rho+\eta+\xi+\gamma\phi_X N+\lambda N}}+\Xi_n\frac{\frac{e^{-\gamma\phi_A A_t K}}{\rho+\eta}\lambda N}{\rho+\eta+\lambda N\left(1-\omega\right)}e^{\kappa}\partial_{\phi_X}\omega, \tag{A.67}$$

where Ξ_n is given by equation A.65and

$$\partial_{\phi_X}\omega = -\gamma N\left(pq_1+(1-p)\,q_0\right)\frac{\lambda N\left(p_1 2^{-\gamma\phi_X}e^{-\gamma\phi_A K}+\left(1-p_1\right)e^{\gamma\phi_A K}\right)+\xi}{\left(\rho+\eta+\xi+\gamma\phi_X N+\lambda N\right)^2}.$$

Step 3: Minimizing Cost to the Principal

Step 2 provides the necessary conditions for the optimal contract loadings when the contract incentivizes researchers to research only promising agendas and all agendas, respectively. However, the question remains which equilibrium the principal would prefer.

For this, we recognize that given our parameter restrictions on $p_0$and p_1, the principal would not want to reward research in speculative agendas if it is not necessary because

such research has a negative net present value and the career incentives required to sustain it, i.e., a high ϕ_X, accrue a high cost in compensating researchers. Based on our results from Proposition 1, if researcher effort costs are sufficiently high, the principal must pay for all research; otherwise, it will restrict ϕ_X to be small enough as to not induce the researching of speculative agendas.

Proof of Proposition 7:

In what follows, we assume the effort cost, κ, is sufficiently small It is immediate from our analysis in Proposition 1 that researchers will all research an active field before they all investigate a new one provided that the probability it is significant is sufficiently high. Consequently, to prove our claim, we focus on the case in which there is one active agenda with current probability p_t of being significant, and researchers must choose whether to research it or investigate a new agenda.

Let us conjecture that researcher n's value function takes the form

$$V_{nT_{i-1}^n}\left(t, X_{nt}, A_t, p_t\right) = -e^{-(\rho+\eta)\left(t-T_{i-1}^n\right)-v_a A_t - v_n X_{nt}} f_n\left(p_t\right),$$

with the convention that $p_t = 0$ if there is no active agenda (i.e., $t = 0$) or the researchers abandon an active agenda.

Let r_t^n be the indicator whether researcher n researchers the active agenda and e_t^n the indicator whether he investigates a new agenda. Factoring out the $e^{-(\rho+\eta)\left(t-T_{i-1}^n\right)-v_a A_t - v_n X_{nt}}$ from the value function, the Hamilton-Jacobi-Bellman Equation for researcher n is then

$$\begin{aligned}
0 \geq \sup_{r^n, e^n, \left(r_t^n + e_t^n\right)' \iota_L \leq 1 \ \forall \ t} \Bigg\{ & - e^{v_a A_t + v_n X_{nt} - \gamma\phi_A A_t K - \gamma\phi_X X_{nt} + \kappa\left(r_t^n + e_t^n\right)'\iota_L} + v_n f_n\left(p_t\right) \sum_l \left(R_{-n,lt} + r_{lt}^n\right) r_{lt}^n \\
& - \lambda\left(R_{-n,t} + r_t^n\right)\left(\left(p_t\left(1 + r_t^n\right)^{-v_n} e^{-v_a} + \left(1 - p_t\right) e^{v_a}\right) f_n\left(0\right) - f_n\left(p_t\right)\right) - \frac{1}{2} f_n''\left(p_t\right)\left(\frac{p_{nt}\left(1 - p_{nt}\right)}{\sigma}\right)^2 \\
& - \sum_{l \in \mathcal{E}_t} \lambda\left(E_{-n,lt} + e_{lt}^n\right)\left(f_n\left(\frac{1}{2}\right) - f_n\left(p_t\right)\right) + \left(\rho + \eta\right) f_n\left(p_t\right) \Bigg\}. \qquad \text{(A.68)}
\end{aligned}$$

It is immediate that $v_n = \gamma\phi_X$ and $v_a = \gamma\phi_A K$, confirming the conjecture. The

Hamilton-Jacobi-Bellman Equation (A.68) consequently reduces to

$$0 \geq \sup_{r^n, e^n, (r_t^n + e_t^n)' \iota_L \leq 1 \ \forall \ t} \Bigg\{ - e^{\kappa (r_t^n + e_t^n)' \iota_L} + \gamma \phi_X f_n (p_t) \sum_l (R_{-n,lt} + r_{lt}^n) r_{lt}^n - \frac{1}{2} f_n'' (p_t) \left(\frac{p_{nt} (1 - p_{nt})}{\sigma} \right)^2$$
$$- \lambda (R_{-n,t} + r_t^n) \left(\left(p_t (1 + r_t^n)^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_t) e^{\gamma \phi_A K} \right) f_n (0) - f_n (p_t) \right)$$
$$- \sum_{l \in \mathcal{E}_t} \lambda (E_{-n,lt} + e_{lt}^n) \left(f_n \left(\frac{1}{2} \right) - f_n (p_t) \right) + (\rho + \eta) f_n (p_t) \Bigg\}. \tag{A.69}$$

We now compare the value to the researcher of investigating a current agenda along with the other $N - 1$ researchers versus abandoning it to research a new one by himself. Both choices incur the effort cost κ, and therefore it is irrelevant. Similarly, new information about the current agenda will arrive regardless, so it is irrelevant as well. As shown in the proof of Proposition 1, researchers are indifferent to investigating in the same or in different fields, and consequently we assume they all investigate in the same field without loss.

Researcher n will consequently pursue the active agenda if

$$(\gamma \phi_X N + \lambda (N - 1)) f_n (p_t) - \lambda N \left(p_t 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_t) e^{\gamma \phi_A K} \right) f_n (0) \geq -\lambda f \left(\frac{1}{2} \right). \tag{A.70}$$

It follows from equation (A.70) that there is a critical p_t, p^*, at which an active agenda will be abandoned if $p_t \leq p^*$.

Consequently, assuming conducting research to not is always optimal, we have two regions for the Hamilton-Jacobi-Bellman Equation. For $p_t \geq p^*$,the Hamilton-Jacobi-Bellman Equation from (A.69) in the research region is

$$(\rho + \eta + \gamma \phi_X N + \lambda N) f_n (p_t) = e^{\kappa} + \lambda N \left(p_t 2^{-\gamma \phi_X} e^{-\gamma \phi_A K} + (1 - p_t) e^{\gamma \phi_A K} \right) f_n (0)$$
$$+ \frac{1}{2} f_n'' (p_t) \left(\frac{p_{nt} (1 - p_{nt})}{\sigma} \right)^2, \tag{A.71}$$

and in the investigate region when $p_t < p^*$, which we designate as $p_t = 0$, is

$$f_n(0) = \frac{e^{\kappa} + \lambda N f_n\left(\frac{1}{2}\right)}{\rho + \eta + \lambda N}. \tag{A.72}$$

Substituting equation (A.72) into (A.71), we arrive at

$$\begin{aligned}(\rho + \eta + \gamma\phi_X N + \lambda N) f_n(p_t) = e^{\kappa} + \lambda N \left(p_t 2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + (1 - p_t) e^{\gamma\phi_A K}\right) \frac{e^{\kappa} + \lambda N f_n\left(\frac{1}{2}\right)}{\rho + \eta + \lambda N} \\ + \frac{1}{2} f_n''(p_t) \left(\frac{p_{nt}(1 - p_{nt})}{\sigma}\right)^2. \end{aligned} \tag{A.73}$$

Notice that $f_n\left(\frac{1}{2}\right)$ in equation is a constant in (A.73).

Let us conjecture that $f_n(p_t)$ is linear in p_t, or

$$f_n(p_t) = a + b p_t.$$

Substituting this conjecture into equation (A.73) for $p_t = \frac{1}{2}$, we have that

$$f_n\left(\frac{1}{2}\right) = \frac{1 + \frac{1}{2}\left(2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + e^{\gamma\phi_A K}\right) \frac{\lambda N}{\rho + \eta + \lambda N}}{\rho + \eta + \gamma\phi_X N + \lambda N - \frac{1}{2}\lambda N \left(2^{-\gamma\phi_X} e^{-\gamma\phi_A K} + e^{\gamma\phi_A K}\right) \frac{\lambda N}{\rho + \eta + \lambda N}} e^{\kappa},$$

and

$$\begin{aligned} a &= \frac{e^{\kappa} + \lambda N e^{\gamma\phi_A K}}{\rho + \eta + \gamma\phi_X N + \lambda N} \frac{e^{\kappa} + \lambda N f_n\left(\frac{1}{2}\right)}{\rho + \eta + \lambda N}, \\ b &= \frac{\lambda N \left(2^{-\gamma\phi_X} e^{-\gamma\phi_A K} - e^{\gamma\phi_A K}\right)}{\rho + \eta + \gamma\phi_X N + \lambda N} \frac{e^{\kappa} + \lambda N f_n\left(\frac{1}{2}\right)}{\rho + \eta + \lambda N}, \end{aligned}$$

confirming the conjecture. Consequently, we have for $p_t \geq p^*$ that

$$f_n(p_t) = \frac{1}{\rho+\eta+\gamma\phi_X N+\lambda N}\frac{e^{\kappa}+\lambda N f_n\left(\frac{1}{2}\right)}{\rho+\eta+\lambda N}\left(e^{\kappa}+\lambda N e^{\gamma\phi_A K}+\lambda N\left(2^{-\gamma\phi_X}e^{-\gamma\phi_A K}-e^{\gamma\phi_A K}\right)p_t\right) \tag{A.74}$$

Substituting our expression for $f_n(p_t)$ from equation (A.74) and (A.72) into condition (A.70) at the critical p^*, i.e., when it holds with equality, we find with some manipulation

$$(\rho+\eta+\lambda) f_n(p^*) = \lambda f\left(\frac{1}{2}\right)+\frac{e^{\kappa}+\lambda N f_n\left(\frac{1}{2}\right)}{\rho+\eta+\lambda N}e^{\kappa} \tag{A.75}$$

from which follows that

$$p^* = \frac{e^{\gamma\phi_A K}-\frac{1+\gamma\phi_X/\lambda-1/N}{\rho+\eta+\lambda}e^{\kappa}-\frac{\lambda}{\rho+\eta+\lambda}\frac{\rho+\eta+\gamma\phi_X N+\lambda N}{\rho+\eta+\gamma\phi_X N+2\lambda N}\left(1+\frac{1}{2}\left(2^{-\gamma\phi_X}e^{-\gamma\phi_A K}+e^{\gamma\phi_A K}\right)+\frac{\rho+\eta}{\lambda N}\right)}{e^{\gamma\phi_A K}-2^{-\gamma\phi_X}e^{-\gamma\phi_A K}}. \tag{A.76}$$

It is immediate from rewriting p^* from equation (A.76) as

$$p^* = \frac{e^{\gamma\phi_A K}-\frac{1+\gamma\phi_X/\lambda-1/N}{\rho+\eta+\lambda}e^{\kappa}-\frac{\lambda}{\rho+\eta+\lambda}\frac{\rho+\eta+\gamma\phi_X N+\lambda N}{\rho+\eta+\gamma\phi_X N+2\lambda N}\left(1+e^{\gamma\phi_A K}+\frac{\rho+\eta}{\lambda N}\right)}{e^{\gamma\phi_A K}-2^{-\gamma\phi_X}e^{-\gamma\phi_A K}},$$
$$+\frac{\lambda}{\rho+\eta+\lambda}\frac{\rho+\eta+\gamma\phi_X N+\lambda N}{\rho+\eta+\gamma\phi_X N+2\lambda N}$$

that p^* is decreasing in ϕ_X.

Proof of Proposition 7:

For the first part of the claim, it is immediate from Proposition 1 that when $\phi_X = 0$, condition (**??**) is satisfied and no researcher would deviate to research an active speculative agenda instead of investigating a new one. This corresponds to the case of an A-type researcher who cares only about prestige and not also citations.

Consequently, if ϕ_X is sufficiently large, B-type researchers who care about citations will research active speculative agendas, while those that care only about prestige will instead investigate a new agenda. The presence of researchers who care about prestige

raises the required ϕ_X because there are less overall researchers researching speculative agendas, lowering citation counts and the probability that such agendas mature.

For the second part of the claim, notice that if ϕ_X is sufficiently large, B-type researchers earn higher life-time expected utility that A-type researchers because, by revealed preference, they prefer to research both types of agendas (and not just promising active agendas). Consequently, the discipline selects on B-type researchers.

Proof of Proposition 8:

Since the identity of the most senior researcher changes over time, the field of the most senior researcher n^*, l_t^*, is now a payoff-relevant state variable. Because this state variable only changes when the most senior researcher retires, it jumps based on a Poisson point process with compensator ηdt, and has law of motion

$$dl_t^* = \sum_{n=1}^{N} \left(l\left(n\right) \mathbf{1}_{X_{nt}=max_{n\neq n^*} X_{1t},...,X_{Nt}} - l_t^* \right) dQ_{n^*t}, \tag{A.77}$$

where $l\left(n\right)$ is the mapping from researcher n to his preferred field.

Suppose researcher n^* has just become the new senior researcher. It is immediate because $\bar{\gamma}_c \geq \gamma\phi_X$ that active researchers will do one of two things: 1) continue researching any active agenda in field l; 2) immediately abandon the current active agenda in field l' and begin investigating a new agenda in field l_t^*. Because each researcher is associated with a distinct field, it will never be the case that $l' = l_t^*$.

Suppose $\gamma\bar{\phi}_X \leq \gamma\phi_X$, then it is immediate that the equilibrium is the same as in Proposition 1 because incentives to research an active or investigate a new agenda are unchanged. Because there are open fields without active agendas other than field l_t^* (i.e., $L >> N \geq 2$), and consequently field l_t^* can be ignored.

Consequently, we need only focus on the case in which $\bar{\phi_X} > \phi_X$. In this case, a change in senior researchers has two potential effects. First, is a direct effect. It may pull all researchers out of an active agenda to investigate a new agenda in field l_t^*. Second, is

an indirect effect. If there is a direct effect, then anticipation of a regime change in the future ex ante reduces incentives to investigate and research in active agendas that will be abandoned upon a change.

There are two sub-cases to consider $\bar{\phi_X} > \phi_X$: 1) $\bar{\phi_X}$ is sufficiently large to cause all researchers to abandon active speculative agendas, but not too large to also cause all researchers to abandon active promising agendas when there is a regime change; and 2) $\bar{\phi_X}$ is sufficiently large to cause all researchers to abandon active speculative and promising agendas when there is a regime change.

Such a $\bar{\gamma}_c$ must exist in sub-case 2 because if we set $\bar{\phi_X} \to \infty$ (as a thought experiment), then all researchers will have an arbitrarily large incentive to switch to the preferred agenda, regardless of how promising is the current active agenda. Because $\bar{\phi_X} = \phi_X$ induces no change in researcher behavior, by continuity and the observation that researchers have more incentive to abandon active speculative than promising agendas, there must also be an interval of $\bar{\phi_X}$ consistent with sub-case 1.

Further, by revealed preference, the presence of senior researchers and preferred agendas must further relax the participation constraint of all researchers because they could always choose to follow the equilibrium characterized in Proposition 1. That they do not reveals that they earn more discounted expected continuation career utility from the option to switch to preferred agendas based on the sub-case. Because value is higher in expectation during a researcher's career, it must be weakly higher ex ante when the researcher first begins his career, which relaxes the participation constraint.

Finally, growth is maximized when significant agendas mature. Consequently, if regime changes among senior researchers cause researchers to abandon both promising and speculative agendas (sub-case 2), then this is harmful to growth because it delays maturation of all agendas. However, if they only cause researchers to abandon speculative agendas, then it is beneficial because $p_0 < \frac{1-e^{-\gamma\phi_A K}}{1-e^{-2\gamma\phi_A K}}$ by assumption, and it is optimal from a growth perspective to abandon speculative agendas in favor of investigating new ones.