SOCIAL SCIENCES

Labor advantages drive the greater productivity of faculty at elite universities

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Faculty at prestigious institutions dominate scientific discourse, producing a disproportionate share of all research publications. Environmental prestige can drive such epistemic disparity, but the mechanisms by which it causes increased faculty productivity remain unknown. Here, we combine employment, publication, and federal survey data for 78,802 tenure-track faculty at 262 PhD-granting institutions in the American university system to show through multiple lines of evidence that the greater availability of funded graduate and postdoctoral labor at more prestigious institutions drives the environmental effect of prestige on productivity. In particular, greater environmental prestige leads to larger faculty-led research groups, which drive higher faculty productivity, primarily in disciplines with group collaboration norms. In contrast, productivity does not increase substantially with prestige for faculty publications without group members or for group members themselves. The disproportionate scientific productivity of elite researchers can be largely explained by their substantial labor advantage rather than inherent differences in talent.

INTRODUCTION

Scientific productivity, crudely quantified by counts of scientific publications, is a basic measure of scientific progress, and its accumulation creates our collective record of scientific knowledge. However, researchers at more elite universities tend to dominate scientific discourse, via greater scientific productivity (*1*, *2*), as well as by greater attention in the form of scientific citations (*3*–*5*), more scientific awards (*6*), and more trainees that go on to become researchers themselves (*6*, *7*). These epistemic inequalities in who shapes the scientific literature are ubiquitous, appear early in scientific careers, and tend to persist over time (*1*, *2*, *6*). Understanding the mechanisms that underlie this prestige-productivity pattern would shed new light on the factors that govern scientific progress and inform efforts to accelerate and diversify technological, biomedical, and scientific discovery.

Epistemic inequalities in scientific productivity and impact raise complicated questions about their causes and effects. Do these inequalities facilitate or impede scientific progress? Do they reflect sorting by meritocratic characteristics, such as an individual's skill, effort, or potential? Are they driven by biases tied to non-meritocratic characteristics such as age and gender or by non-meritocratic structural factors such as working environment, social connections, or privilege (*2*, *5*)? Endogenous dynamics like cumulative advantage (*8*) make it difficult to answer these questions for scientific impact without first understanding scientific productivity, which is our focus here. Among early-career researchers, the greater productivity of elite researchers appears to be caused not by their academic pedigree but rather by their working environment: More elite institutions tend to provide more productive environments to their researchers (*2*). However, the precise mechanisms by which prestigious environments drive greater productivity remain unknown.

Prior studies have argued that prestigious working environments can induce greater productivity directly or indirectly through a number of factors. Prestigious work environments could increase an individual's available research time and, hence, also productivity by lowering researcher teaching load, e.g., by hiring non–research-track faculty such as adjuncts or teaching professors, or by limiting course or degree enrollments (*9*, *10*). Similarly, they could lower researcher service load by employing more administrative staff. Prestigious universities may incentivize individual productivity via greater compensation (*11*, *12*), may increase research efficiency via better technological support, or may promote more within-institution collaborations via larger departments (*2*), or as we study here, prestigious universities may have more productive or simply more available scientific labor, increasing faculty productivity via collaborations with non-faculty junior researchers.

In the sciences, it is common for a faculty researcher to head a group of non-faculty junior collaborators composed of graduate students, postdocs, and, in some cases, staff scientists and undergraduate students (*13*, *14*). By publishing together, all collaborators' publication counts increase with each scientific contribution, and past work has shown that increased collaboration is strongly associated with overall productivity (*15*). In these disciplines, collaboration leading to coauthorship is a basic aspect of successful mentorship of graduate students and postdoctoral researchers (*13*, *16*, *17*). However, in practice, collaboration and group norms vary substantially across disciplines and over time, which complicates efforts to estimate scientific labor's effect on scientific productivity (*18*–*24*). Past studies have found correlations between academic labor and faculty productivity but have tended to be cross-sectional, based on small sample sizes, or focused on either individual disciplines or only certain types of labor (*25*–*27*) [but see (*20*)]. No studies have examined the role of funded scientific labor on faculty group sizes. Hence, the extent to which the availability of scientific labor drives disparities in scientific productivity and how or why such an effect varies across disciplines is unknown.

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Through multiple lines of evidence, we show that differences in scientific labor drive substantial prestige-productivity inequalities, and the scientific dominance of elite universities can be explained by their substantial labor advantage over researchers at less prestigious institutions, primarily in disciplines where faculty lead and collaborate with a research group. Our analysis leverages cross-disciplinary, longitudinal data on the education, employment, and publications of 78,802 tenured or tenure-track faculty spanning 4492 departments across 25 disciplines in science, engineering, and the social sciences at 262 PhD-granting U.S.-based universities, which we combine with researcher-level productivity data encompassing 1.6 million publications from the Web of Science. We complement these data with institution-discipline–level counts of graduate and postgraduate (non-faculty) researchers (*28*), institutional covariates (*29*), and discipline-specific measures of prestige (*7*).

First, we show that faculty's annual productivity, measured crudely as their mean publications per year, increases substantially with environmental prestige, with elite researchers being roughly twice as productive as researchers at the least prestigious institutions. We isolate the component of total productivity that could be driven by differences in labor by partitioning each faculty's total productivity into two sources: (i) group productivity (publications coauthored with non-faculty research group members) and (ii) individual productivity (all other publications). In disciplines with group collaboration norms, a larger group will tend to drive greater group productivity. We show that in such disciplines, group productivity is substantial and grows with prestige, even as individual group members are no more or less productive. Last, we show that research labor is highly concentrated within prestigious environments, indicating that elite researchers tend to have larger research groups.

We then test this "labor advantage" hypothesis using a series of predictive models, showing that funded labor consistently plays a significant role in predicting productivity and group sizes in disciplines with research group collaboration norms but not in disciplines that lack these norms. Last, using a matching experiment on mid-career changes of institution, we show that faculty who move to an environment with more available funded labor tend to have groups that are significantly larger after the move than those who move to environments with less labor. Together, these results identify an environmental mechanism by which prestige drives greater scientific productivity (*2*, *3*) and show that a profound labor advantage of elite working environments allows their scientists to dominate scientific discourse.

DATA AND PRELIMINARIES

Isolating the mechanisms by which prestigious environments shape researcher productivity is complicated by mediating effects and substantial variability in publishing patterns and rates across disciplines, institutions, researchers, and even years within a career (*30*). To span these sources of variability and facilitate the isolation of causal effects, we construct a comprehensive longitudinal dataset of individual researcher productivity, encompassing 1.6 million publications by 78,802 tenured or tenure-track faculty in 4492 PhD-granting departments in the United States, across 25 scientific disciplines (see the Supplementary Materials). Faculty doctoral training and employment information were drawn from a dataset of researchers with tenure-track faculty positions from 2008 to 2017, provided by the Academic Analytics Research Center (AARC) under a Data Use Agreement, which we algorithmically matched to full scholarly records as indexed by the Web of Science. Through these publication data, we extracted and associated all coauthors along with their affiliations with each faculty researcher in our dataset. We then classify each scientific discipline according to whether it exhibits a research group norm, in which faculty lead a research group and coauthor publications with its members, or not (see the Supplementary Materials), allowing us to compare productivity patterns across disciplines.

We complement these researcher-level data with institution-level information on academic departments, providing within-discipline estimates of an institution's available scientific labor and environmental prestige. For each institution and discipline, we record departmental counts of graduate and postgraduate researchers by funding source from the 2008–2017 National Science Foundation (NSF) Survey of Graduate Students and Postdoctorates in Science and Engineering (*28*) and define "funded researchers" as graduate students on research assistantships, fellowships, or traineeships and all postdocs (unfunded researchers are self-funded graduate students and graduate students on teaching assistantships). Environmental prestige scores are derived from discipline-level faculty hiring networks, in which prestige quantifies the ability of an institution to "place" its graduates within a given discipline as faculty at other institutions (*7*, *31*). Specifically, when an institution v hires a faculty member who received their PhD from institution u, v signals an endorsement of the quality of the PhDs trained at u. The set of these endorsements can be represented as a weighted directed network that quantitatively organizes a discipline's collective endorsements of doctoral training programs (*32*–*34*). From this network, we can directly infer a "prestige" ranking of institutions that best explains the observed pattern of faculty hiring, without reference to productivity, prominence, or departmental statistics. These prestige ranks provide an independent predictor in our analysis (*7*, *35*). This measure of prestige correlates with authoritative rankings such as the U.S. News & World Report and the National Research Council rankings (*7*) but is more predictive of faculty placements. To facilitate cross-disciplinary comparisons, we then divide each discipline's institutions into prestige deciles, such that each decile contains roughly equal numbers of within-discipline faculty but potentially variable numbers of institutions.

Last, using the coauthors and affiliations extracted from each faculty researcher's publications, we identify each professor's research group, which allows us to partition faculty publications into group productivity and individual (non-group) productivity, as well as measure group sizes for each professor. In particular, we use our individual-level data on faculty to identify same-address non-faculty collaborators as likely group members (see the Supplementary Materials). This division allows us to compare individual and group productivities between disciplines with different collaboration norms, estimate the individual productivity of group members, and use propensity-score matching and Poisson regression to evaluate the predictiveness of environmental characteristics, including available scientific labor, on total productivity, group productivity, and group size (see Materials and Methods). We define group member productivity as the average number of publications by each non-faculty group member each year. Because our dataset only consists of papers with at least one faculty coauthor, group member productivity does not include papers by group members without faculty coauthors.

RESULTS

We examine four main lines of evidence for the central role of scientific labor in driving greater scientific productivity at more prestigious institutions. We begin by establishing a set of empirical prestige-productivity patterns that any explanation of the effect must be consistent with. In particular, we decompose faculty total productivity into its group and individual components and evaluate how these covary with prestige and across disciplines with and without group collaboration norms. We then quantify the systematic growth of funded scientific labor with prestige, a necessary condition for mean group size to grow with prestige. To establish a causal link between available labor and faculty group sizes, we use (i) a set of models to predict group size from departmental covariates and (ii) a matched-pair analysis of faculty who move mid-career to environments with more, or less, available labor. Last, we complete the argument by showing a systematic relationship between larger faculty group sizes and greater group productivity.

Decomposing the productivity-prestige effect

First, we decompose the total productivity of faculty, which grows substantially with environmental prestige (Fig. 1A), into publications coauthored with research group members (group productivity) and publications without group member coauthors (individual productivity) and then compare these patterns across disciplines with different coauthorship norms. If labor drives productivity, then we expect to see both greater total productivity and greater group productivity for faculty working in disciplines where it is normal to lead a research group and share coauthorship with its members. That is, we expect greater researcher productivity in disciplines with more scientific labor. If group member productivity is independent of prestige, then overall group productivity can increase only if group size increases with prestige. Second, we examine the empirical distribution of funded labor across the prestige hierarchy, where we expect to see more funded researchers per faculty at more elite institutions.

The 25 disciplines in our data can be divided into those with (12) and without (13) group-based coauthorship norms. Aggregating researchers within each group of disciplines, we find that researchers in the group-norm disciplines publish an average of 1.92 papers per year compared to 1.05 in the non–group-norm disciplines (t test, $P < 0.001$; Fig. 1). However, group member productivity in these disciplinary groups is nearly identical (0.74 versus 0.78 papers each year, respectively; t test, $P < 0.001$). Hence, the greater productivity of researchers in the group-norm disciplines derives from the excess publications that they coauthor with group members (Fig. 1B).

Within both groups of disciplines, individual productivity increases modestly with environmental prestige by only 0.04 additional annual individual publications per prestige decile (t test, $P < 0.001$). In contrast, group productivity is 1.27 times greater, on average, than individual productivity and grows slightly faster by 0.06 additional annual group publications per prestige decile (t test, $P < 0.001$). Hence, in disciplines with research group collaboration norms, researcher productivity is predominantly driven by papers coauthored with group members, and group productivity correlates strongly with environmental prestige (Fig. 1B).

The strong correlation between group productivity and prestige could be caused by (i) individual group members becoming more productive, i.e., research group sizes do not covary with environmental prestige, but each member's individual productivity is higher in more prestigious environments; (ii) research groups becoming larger, i.e., the individual group members are no more or less productive, but group sizes grow with environmental prestige; or (iii) a mixture thereof. Across disciplines, we find that group member productivity does not increase substantially with prestige, whether we consider disciplines as a group (Fig. 1A) or separately, e.g., chemical sciences, engineering, biological sciences, and sociology (fig. S9). On average, an increase by one prestige decile is associated with a significant but negligible increase of 0.0075 papers per year for non-faculty (t test, $P < 0.001$).

Labor advantages at prestigious institutions

A necessary condition for the average research group to be larger in a more prestigious environment is that a department's per-faculty available labor must tend to increase with departmental prestige. Holding a funded researcher position typically implies being formally advised by a faculty researcher in the same department and collaborating with them on research, depending on the discipline's norm. Hence, a department's per-faculty number of funded researchers provides an estimate of faculty group sizes in disciplines where faculty lead such groups.

Institution-level counts of funded graduate students and postdoctoral researchers, by discipline (*28*), show that access to funded scientific labor grows with institutional prestige, and some disciplines employ substantially more labor than others. With each additional prestige decile, institutions gain, on average, 0.05 to 1.37 funded graduate and postdoctoral researchers per tenure-track faculty, depending on discipline (Fig. 1, C and D, and fig. S6). This systematic pattern reflects an uneven distribution of labor across prestige (average Gini coefficient $G = 0.27$ across disciplines, ranging from 0.11 to 0.36), and this advantage in available labor at elite institutions appears in all disciplines, not only those with group collaboration norms.

Of the 12 disciplines in our data with group collaboration norms, 9 exhibit a statistically significant increase with prestige in per-faculty funded labor ($P < 0.05$, Bonferroni corrected). The top prestige decile of institutions holds, on average, 20.2% of all such funded labor, ranging from 13.2% (computer science) to a high of 31.6% (biological sciences). As a result of this labor concentration, the ratio of funded researchers to faculty in the top decile of institutions is 4.2 times larger, on average, than the ratio in the bottom decile, with the magnitude of this inequality varying substantially by discipline, from a low of 1.4 (psychology) to 8.2 (biology) (fig. S6).

Labor availability drives group productivity

These patterns are consistent with a causal relationship in which prestigious environments drive greater faculty productivity by providing more scientific labor to individual faculty, via larger research groups. To test this relationship more directly, we first establish that funded labor availability drives research group size through two complementary analyses: (i) We show that funded labor availability significantly explains group size variation in a statistical model of faculty productivity, and (ii) we use a matched-pair analysis to show that individual faculty who move to a new environment with more available funded labor tend to form larger groups there

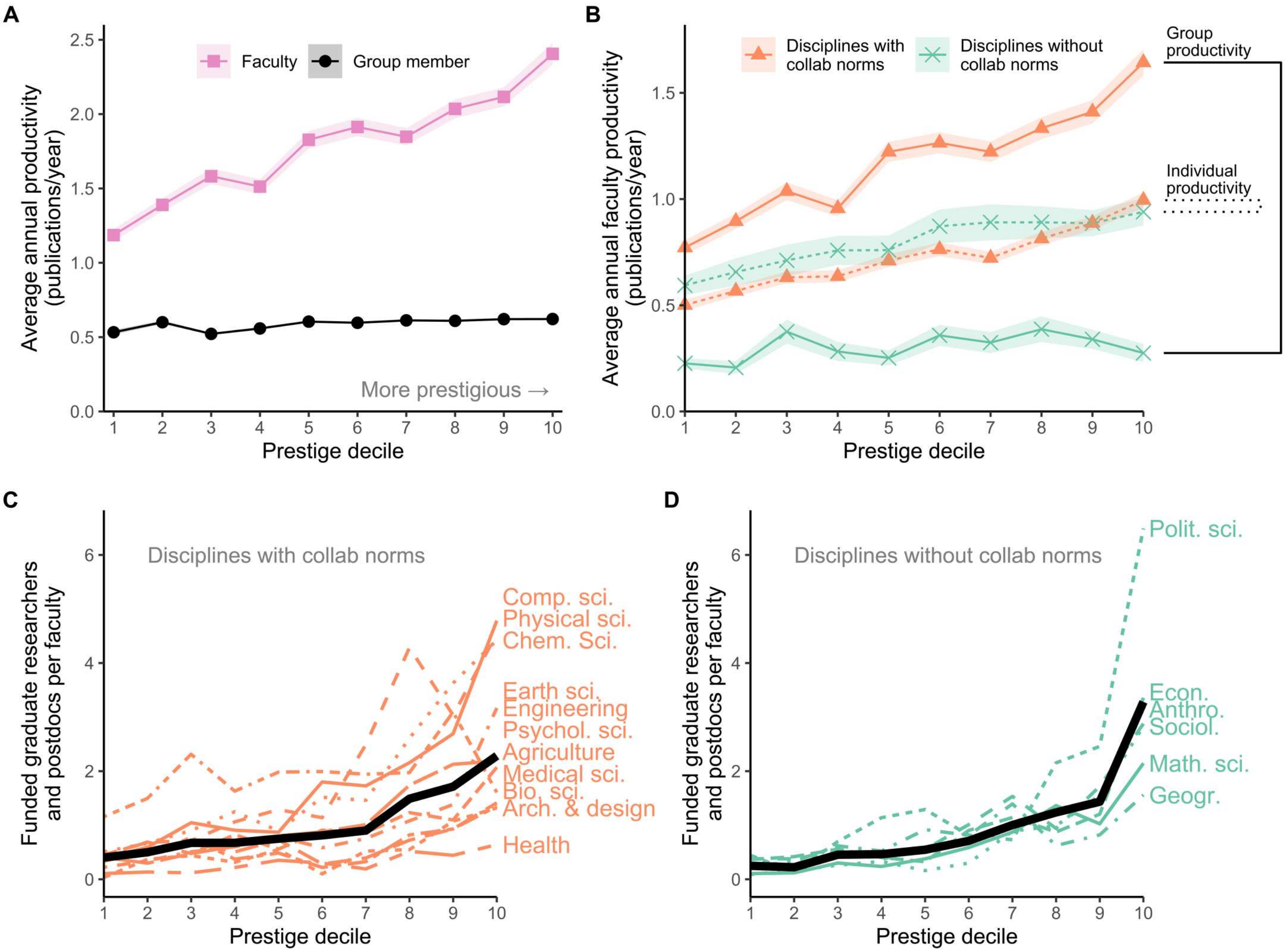

Fig. 1. Scientific productivity and scientific labor as a function of environmental prestige. (**A**) Across all disciplines, average faculty productivity tends to increase with prestige, while average group member productivity does not; higher deciles are more prestigious, and shaded intervals denote 95% confidence intervals. Group member productivity is the total number of papers coauthored by non-faculty group members with faculty, normalized by the length of their collaboration in years (see the Supplementary Materials). (**B**) A decomposition of faculty total productivity first by group productivity versus individual productivity and then grouped by disciplines with and without research group coauthorship norms (orange and green, respectively), showing that individual productivity is similar regardless of collaboration norms, but group productivity is substantially higher in disciplines with collaboration norms. (**C** and **D**) Funded scientific labor per faculty, as a function of prestige for disciplines with and without group collaboration norms, showing a systematic labor advantage for the highest prestige institutions regardless of norms; the cross-disciplinary mean is shown as a thick black line.

than faculty who move to environments with less available funded labor. Last, we quantify a systematic relationship between larger research group sizes and greater group productivity, independent of environmental prestige.

Modeling faculty productivity

We fit a series of regression models to predict the average individual productivity, group productivity, and productive group size in a department from available funded and unfunded labor, prestige, and other departmental and institutional covariates (see Materials and Methods). Supporting the labor advantage hypothesis, each model shows that available funded labor is significant and highly predictive of greater total productivity, group productivity, and group sizes in disciplines with collaboration norms (all $P < 0.001$; Fig. 2A and table S1). On the other hand, in disciplines without collaboration norms, greater funded labor availability does not predict total or group productivity and is only significantly associated with group size (Fig. 2A), a pattern that reinforces the mediating role of collaboration norms on the causal relationship between labor and productivity.

In our modeling, we aggregate individuals into departments because the variation in labor availability and productivity that we seek to explain occurs between departments, and the main variables are all measured at the department level. Nevertheless, our results are robust to alternative model specifications. In particular, we obtain similar results using an individual-level Poisson regression with discipline fixed effects and SEs adjusted for departmental clustering (fig. S7 and tables S4 and S5), as well as hierarchical Poisson and linear models of individual faculty, with departments and

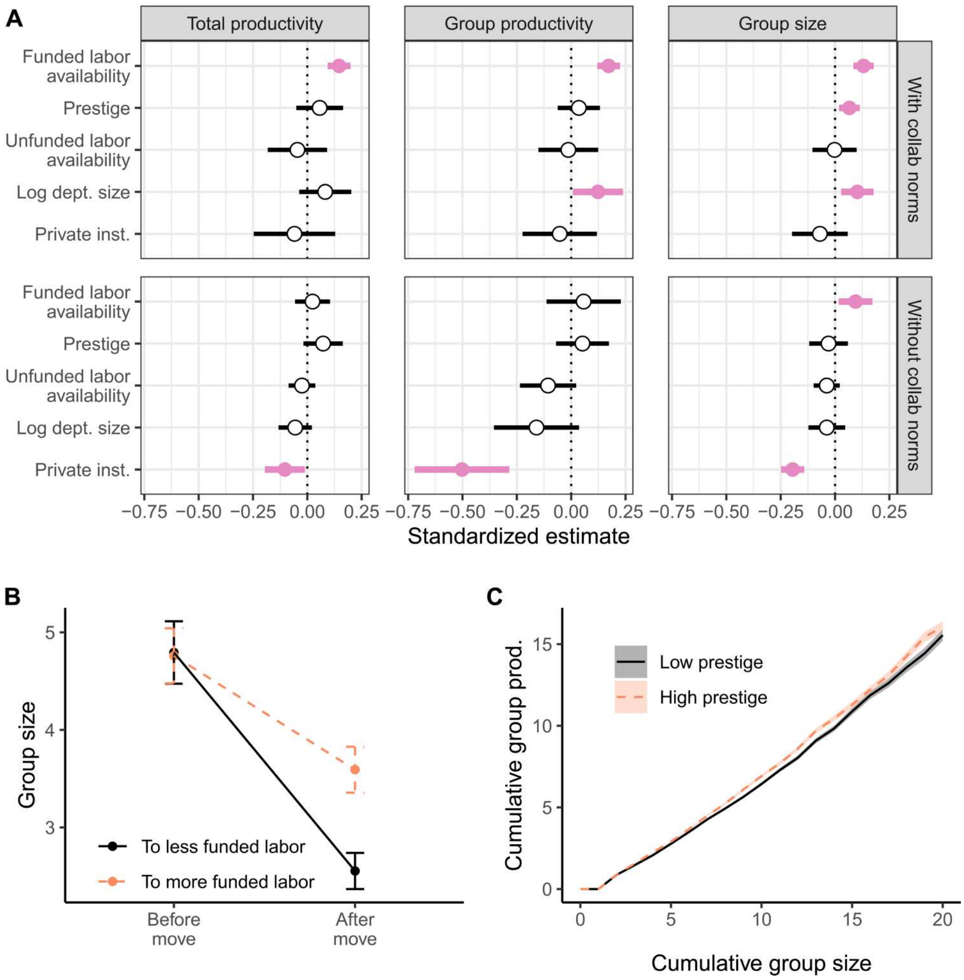

Fig. 2. Impact of available labor on group size and group productivity. (**A**) Coefficients of standardized departmental covariates for predicting annual average total productivity, group productivity, and group size, divided into groups of disciplines with and without collaboration norms (see the Supplementary Materials). Bars indicate 95% confidence intervals, and filled-in circles indicate statistically significant coefficients at the 0.05 level. Funded labor is significant and highly predictive of all dependent variables, even after controlling for prestige, in disciplines with collaboration norms. (**B**) For matched pairs of faculty, mean group size in the 3 years before and after moving to a location with more (dashed orange) or less (solid black) available funded labor than their pre-move location. Error bars indicate 1 SE. (**C**) Mean cumulative number of group members over a faculty career as a function of cumulative group productivity, for faculty at the least prestigious (solid black) or most prestigious (dashed orange) half of institutions in their discipline, showing a nearly identical size-productivity relationship. Envelopes indicate 95% confidence intervals around the means.

disciplines as hierarchical model levels (fig. S8 and tables S6, S7, S9, and S10). The latter models indicate a significant role for gender, with men exhibiting both larger productivities and larger groups. Moreover, we find that funded labor availability predicts increased productivity as the last author, but not as the first author, and only in disciplines with collaboration norms (table S8).

Matching on relocations

If greater funded labor availability causes increased faculty productivity, then faculty in disciplines with group collaboration norms who relocate from one working environment to another should exhibit a larger productive research group size if the new environment has a larger labor advantage. Mid-career moves thus represent a quasi-natural experiment by which to untangle the underlying causal effects of working environment on group sizes and hence productivity. We exploit this property using a matched-pair design, in which one mid-career researcher in the pair moves to a working environment with more available labor, while the other moves to an environment with less.

Matching faculty exactly by discipline and then by full propensity scores derived from other covariates (see Materials and Methods), we find that faculty who moved to locations with more funded labor developed groups with 0.9 ± 0.4 more members, on average, during the third and fourth years after moving than did faculty who moved to locations with less funded labor, which supports the labor advantage hypothesis (n = 778 faculty; t test, P = 0.028; Fig. 2B). Notably, this effect size is averaged across academic disciplines with different mean group sizes. Hence, we can expect larger effects in fields where research groups are larger, e.g., engineering, chemistry, and computer science. In addition, both cohorts of faculty who moved experienced an average decrease in subsequent group size during the post-move time period, including those who moved to a location with more available funded labor.

We attribute this effect to the universal difficulties of restarting a research group at a new institution.

Group size and group productivity

Although individual group members are not substantially more or less productive in high- or low-prestige environments (Fig. 1A), it remains possible that group members at more elite institutions tend to work with faculty for longer spans of time, which may confound the apparent prestige independence of group member productivity. We find that group members at more elite institutions tend to have slightly longer productive time spans with faculty (fig. S1A). However, independent of the number of years used to compute group member productivity, the difference across prestige deciles is negligible (Fig. 1A and fig. S1B).

If prestige drives group productivity in some way beyond setting the typical research group size, then we should expect the cumulative group productivity over a faculty career at a prestigious location to increase faster as a function of the cumulative number of group members than for faculty at less prestigious locations. Dividing faculty into those at the most and least prestigious halves of all departments in their discipline, we find nearly identical cumulative size-productivity curves, indicating essentially no effect for prestige beyond setting group sizes (Fig. 2C). We find that faculty at more elite institutions do not coauthor more papers with the same set of group members to any meaningful extent: The maximum difference in cumulative group productivity for any given cumulative group size is 1.03 publications at a group size of 19, meaning that faculty in the top half of prestige produce roughly one additional with-group paper for every 19 group members on average, compared to faculty in the bottom half of prestige.

DISCUSSION

A persistent puzzle in understanding the drivers of scientific productivity (*22*, *23*, *36*) is identifying why faculty at elite institutions so dominate scientific discourse (*2*), producing far more publications than faculty at less prestigious institutions. Past work (*1*, *2*) has shown evidence that prestigious environments cause greater productivity, at least for early-career faculty researchers in computer science, but the mechanism for the effect has remained unknown. Using detailed productivity data for more than 78,000 faculty across 25 scientific disciplines, we show through multiple lines of evidence that the greater productivity of elite faculty can be attributed to a substantial labor advantage that they hold over faculty at less prestigious institutions (Fig. 3), which translates into increased faculty productivity in disciplines where faculty lead and coauthor with a group of junior researchers. Hence, the productivity dominance of researchers at elite institutions is not due to inherent characteristics such as greater skill or insight or to their academic pedigree (*2*) but rather can be explained by the greater labor resources accorded to them by their prestigious location within the academic system.

By studying faculty who change institutions, we show that the positive effect on productivity of a researcher′s working environment is not limited to the beginning of their career and also holds for mid-career researchers. The generality of the effect is likely due to the simplicity of its mechanism: The creation of scientific knowledge is a collective effort, and increasing the number of researchers will reliably increase the amount of research being produced. Its simplicity suggests that sustained increases in available scientific labor for any reason, to an individual research group or to an entire institution, can be expected to proportionally increase scientific productivity. This prediction is supported by recent work on the effects of grant funding on faculty, graduate, and postdoctoral hiring and productivity (*37*). Our results enrich that understanding by uncovering the role of prestige: Prestigious institutions receive far more funding, which equates to more available research labor, and, in disciplines with collaboration norms, that labor advantage drives greater faculty productivity via coauthorship (Fig. 1, C and D, and fig. S6).

This unequal distribution of scientific labor likely reinforces existing prestige hierarchies (*7*). Larger research groups at elite institutions imply more scientific trainees who may themselves aspire to become faculty researchers. Hence, the labor advantage may partly explain the dominance of elite institutions in faculty hiring (*7*, *31*), with all the corresponding implications for influencing research agendas (*5*), departmental and disciplinary norms, and more, simply because there are many more elite trainees seeking faculty positions than trainees from less elite institutions in any particular faculty search.

The pivotal role of funded labor in explaining the scientific dominance of elite institutions also sheds new light on the historical dynamics of the American research ecosystem over the 20th century. U.S. federal funding for basic and applied research emerged and expanded markedly over the post–World War 2 era (*12*, *38*), and historically, elite institutions have received a disproportionate share of those funds (*39*). Our results linking funded labor, scientific productivity, and prestige suggest that the postwar funding environment may have enabled a fundamental change in the competitive dynamics of prestige among American universities. Specifically, external funding enables and encourages faculty-student coauthorship (*18*), and the influx of federal funding enabled a coupling between prestige and productivity, allowing institutions to now compete for status by producing a larger number of scientific contributions. The unequal concentration of funded labor among elite institutions then largely reinforced the existing prestige hierarchy despite this new dimension of competition. However, data on research expenditures and federal funding show a gradual decline in

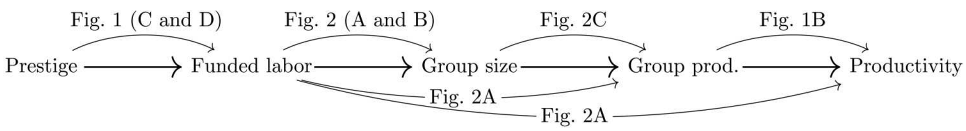

Fig. 3. Diagram of causal arguments. The association of environmental prestige with greater scientific productivity (Fig. 1A) is explained by greater available funded labor at elite institutions (Fig. 1, C and D), which drives larger faculty group sizes, even accounting for prestige (Fig. 2, A and B) and predicts both group productivity and total productivity. Faculty group size itself has a natural and tight relationship with group productivity, independent of prestige (Fig. 2C) because group member productivity itself is essentially independent of prestige (Fig. 1A). Last, increased group productivity can explain most of the prestige-productivity effect in disciplines with collaboration norms (Fig. 1B). A full causal diagram with confounders is provided in the Supplementary Materials (fig. S5).

the concentration of resources among elite institutions (*40*, *41*), suggesting that their "first-mover advantage" in the productivity competition may be eroding (*31*), as less prestigious institutions increase their share of resources and hence their own scientific productivity.

The lines of evidence described here are derived from observational data and hence cannot establish causality in the same way a randomized trial might. Hence, the possibility remains that unmeasured variables could account for some of the patterns that we observe.

Our analyses establish that available funded labor operates as a mediator for the effect of prestige on productivity. However, precisely quantifying the effect of other mechanisms by which prestige shapes productivity, after controlling for funded labor, remains an important direction of future research. In addition, the decomposition analysis (Fig. 1) is not causal and instead presents basic observational patterns that any theory of scientific productivity must explain. The similarity in the average individual productivity by prestige across the two types of disciplines, taken in conjunction with the lack of a relationship between group member productivity and prestige (Fig. 1A), suggests fairly general limitations on individual capacities for scholarly productivity, but some room for variation remains. We provide an extensive discussion of possible confounders and threats to causal identification, such as the potential role of faculty hiring committees, in the Supplementary Materials.

Similarly, labor and productivity interact over the course of an academic career and are often linked by changes in external funding in the sciences. Our analysis does not include data on the timing and effect of such funding. Furthermore, our analyses focus only on publication counts, which are a crude but quantifiable measure of scientific contributions. As a result, our analysis lacks the capacity to compare individual publications or otherwise assess their intellectual merit or broader impacts. Moreover, our analysis does not extend straightforwardly to analyze the role of research labor on proxies of impact such as citation counts, due to the endogenous dynamics of prestige on citations. Although we find that the productivity of group members does not vary with prestige, other aspects of their scholarship may. Elite researchers may tend to work more collaboratively, and we did not directly quantify the effect of these collaborations. However, we showed that last author publications increased with available funded labor in disciplines with collaboration norms, and there can be, at most, one last author per paper, suggesting that our results cannot be explained by collaboration effects (table S8). However, past work suggests that many departmental covariates including doctoral student representation, teaching loads, salaries, and geographic location do not significantly correlate with productivity or in-department collaboration rates (*2*).

In many disciplines, elite research environments exhibit a labor advantage in knowledge production because of the substantially unequal distribution of scientific labor across the prestige hierarchy, which drives faculty at more elite institutions to form larger research groups that they then collaborate with on papers. A more prestige-equitable distribution of scientific labor is likely to increase the diversity and innovativeness of scientific ideas being explored (*42*–*44*), partly because what topics are studied varies itself with institutional prestige (*5*, *45*). That is, increasing the availability of scientific labor at less prestigious institutions may change not only who makes discoveries but also which discoveries are made. It may also change the relative balance of work on ideas that require large teams and work that is best done by smaller teams (*46*).

More broadly, our findings have substantial implications for research on the science of science and, in particular, for theories of scientific knowledge production that assume meritocratic principles or mechanisms, as these tend to privilege individual characteristics in their explanations and omit environmental or structural mechanisms. In contrast, our findings on the importance of scientific labor and its concentration in elite research environments suggest that individual characteristics and pedigree may play a relatively limited role in certain aspects of knowledge production. It also suggests relatively simple interventions for both increasing scientific productivity and increasing the diversity of scientific advances. Accounting for the non-meritocratic effects of research environments will be an important component in developing predictive theories of knowledge production.

MATERIALS AND METHODS

We measure an individual's productivity as the number of publications that they produce per year indexed by the Web of Science, excluding letters, retractions, and corrections. This definition includes journal articles, edited anthologies, books, and other media indexed by the Web of Science such as book reviews (see the Supplementary Materials). The group size for each professor at year t was measured by counting unique same-address non-faculty coauthors on their papers for a 3-year period ending in year t. This window size captures 94% of productive same-address group members, which minimizes the extent to which our measure of productive group size is confounded by productivity (see the Supplementary Materials). Note that the group size is always measured from the publication record and used as an outcome variable, as in the matching, and is distinct from "available funded labor," which is a departmental covariable formed by dividing counts of available funded labor from the NSF surveys into the number of tenure-track faculty.

To analyze mid-career movements, the 806 faculty in disciplines with group collaboration norms in our dataset who made mid-career moves were divided into those who moved to an environment with more available labor (51.9%; treatment) and those who moved to an environment with less available labor (control), relative to their starting environment. Matching was then performed using full propensity scores derived from pre-move covariates of productivity, group productivity, within-discipline prestige, department-funded labor-to-faculty ratio, group size, faculty rank, gender, and exact matching on discipline. The 28 (3.5%) faculty whose propensity scores were outside the shared region of support between treatment and control groups were dropped, and propensity scores for the remaining faculty were recomputed. Group size in the after-move period was measured as the average size between 3 and 4 years after the move, ensuring comparability with the same measurement in the pre-move period.

The full propensity score matching isolates the effect of environmental funded labor on group size and mitigates the confounding effects of differences in academic discipline, faculty rank (assistant, associate, or full), pre-move institutional prestige, pre-move institutional available funded labor, pre-move annual productivity for the 4 years before the move, pre-move inferred group size for the 4 years before the move, and confounders correlated with the controlled variables. The impact of a change in environment on each faculty's productive group size was then measured. Further details are given in the Supplementary Materials.

A Poisson regression was used to predict the averaged departmental productivity using the departmental and institutional covariates given in table S1, with additional robustness tests using hierarchical linear and hierarchical Poisson models in the Supplementary Materials. The selection of within-discipline institutions as the unit of regression reflects the fact that both the covariates of interest and the likely policy interventions are environmental rather than individual. In particular, within-department variation of individual productivity is irrelevant to understanding the environmental role of labor on average departmental productivity. One motivation for switching to an individual-level analysis would be to incorporate individual group size directly as a covariate for modeling productivity. However, it is difficult to find a measure of group size that could be used as a covariate for predicting productivity (rather than outcome variable) at the individual level that would not introduce endogeneity between group size and productivity. On the other hand, departmental variables related to available funded labor can be measured independently of productivity by combining NSF survey data with AARC employment records (see the Supplementary Materials). Despite these difficulties with an individual analysis, we report fixed-effect and hierarchical models that demonstrate qualitatively similar results in the Supplementary Materials.

We report robust SEs, clustered by academic discipline. Coefficients in the regression are scaled to have zero mean and unit variance. Funded labor availability is the base-2 logarithm of the ratio of funded researchers (including faculty) to faculty in an institution-discipline. Unfunded labor availability is the base-2 logarithm of the ratio of unfunded graduate students to faculty in an institution-discipline, and 72 within-discipline institutions (9.74%) that had no unfunded graduate students in any years were omitted. All variables were averaged over faculty within institution-discipline and then averaged across years. Details about covariates and preprocessing are explained in full in the Supplementary Materials.

Supplementary Materials

This PDF file includes:
Data Preprocessing
Tables S1 to S14
Figs. S1 to S11
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