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Postdoctoral training, departmental prestige and scientists' research productivity

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Abstract An implicit assumption prevailing in the science community is that scientists with postdoctoral training demonstrate a higher rate of productivity than their peers without such experience (Folger et al. in Human resources and higher education. Russell Sage, New York, 1970; NRC in Postdoctoral training in the biomedical sciences. National Academy of Science, Washington DC, 1974; NRC in Research training and career patterns of bioscientists: The training programs of the National Institutes of Health. National Academy of Science, Washington DC, 1976; Reskin in Am Sociol Rev 41(4):597–612, 1976), and especially so if postdocs are employed in research intensive settings (McGinnis et al. in Soc Force 60(3):701–722, 1982; Zumeta in Extending the educational ladder: The changing roles of postdoctoral education in the United States. National Technical Information Service, Springfield, Va, 1985). In contrast, by exploring the reward structure of the science system, sociologists contend that departments where scientists obtain positions play a substantial role in shaping their research productivity (Long in Am Sociol Rev 43(6):889–908, 1978; Long and McGinnis in Am Sociol Rev, 46(4):422–442, 1981; Allison and Long in Am Sociol Rev, 55(4):469–478, 1990). This study investigates both theories in an attempt to unfold how these factors impact scientists' research productivity over time. Using curriculum vitae (CV) from a nationally representative sample of academic scientists and engineers, the findings suggest that postdoc training indeed boosts individual research productivity during scientists' early career periods (the first 3 years after the doctoral degrees), however, the effect fades quickly. While departmental prestige plays a role in scientists' research productivity, further investigation indicates that only scientists placed in highly prestigious departments demonstrate a consistently higher productivity level than their peers in other departments. Given that postdoc training contributes significantly to the higher likelihood of being placed in highly prestigious departments, postdoctoral training and the subsequent placement in highly prestigious departments together are conducive to the presence of the accumulative advantage effect.

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1 Introduction

From its inception, postdoctoral training has been closely tied to one core mission: advancement of research productivity (National Research Council 1969). One implicit assumption prevailing in the science community is that scientists with postdoc training demonstrate a higher rate of productivity than their peers without such experience. The assumption has such power that it is taken for granted by the academic community as well as by outsiders. However, does it conform to reality over time in scientists' careers?

The question gains more significance due in a large part to the fact that postdoctoral training has been deeply entrenched in the science enterprise during the past few decades. As of 2006, there were approximately 34,757 science and engineering (hereafter S&E) postdocs working in doctorate-granting institutions (NSB 2006). The proportion of U.S. S&E doctorate holders heading for postdoc positions has been rising from roughly 30% in 1970s to 46% for the most recent graduation cohort (2002–2005) (NSB 2008). In fields such as life sciences and physical sciences, the proportion has even reached 60% (NSB 2008), making postdoc training a virtual prerequisite for further career development. Behind the large number of postdoctoral appointments lies the heavy individual and societal investment. Previous studies indicated that postdoc training is rarely a successful financial investment on the individual level since the salary gap between postdocs and non-postdocs may not close over a decade (Zumeta 1985). While individuals may take postdoc training for a wide variety of reasons, one shared outcome they expect to have is increased productivity. It has also been pointed out that the number of postdoc appointments closely follows the trend of research funds (NRC 1969; Davis 2006). As millions of dollars have been spent on postdoc programs in the hope of advancing scientific excellence for the United States, research productivity could be a best success measure of the societal investment in the postdoc enterprise.

Though postdoc training has been institutionalized on campuses for over a century in the United States, scholarly attention on how postdoc training affects scientists' career trajectories traces primarily back to the 1960s and 1970s, when postdoc appointments experienced a huge boom (NRC 1974, 1976; Reskin 1976; Long 1978; Coggeshall et al. 1978; Long et al. 1979). A large part of the literature addressed postdoc training within the notable framework of Robert Merton (1973) to explore the social stratification of the science system, leaving the topic of postdoc training and research productivity incompletely touched. The research samples were principally confined to U.S. S&E scientists who were awarded doctorate degrees before the early of 1980s (Reskin 1976; Long 1978; Coggeshall et al. 1978; Long et al. 1979; Long and McGinnis 1981; McGinnis et al. 1982; Zumeta 1984, 1985; Allison and Long 1990). Noteworthy is the fact that the following three decades witnessed a quick proliferation of postdoc training in almost every science and engineering field; however, the scholarship on postdoc training and research productivity waned. As such, it is important to examine how postdoc training relates to research productivity in this newly developed situation.

The topic requires a longitudinal design in that the effect postdoc training has on individual productivity may last for a while. More importantly, as suggested by the literature on social stratification of the science system, research productivity is subjected to the heavy influences of social factors and organizational contexts. For instance, those who were employed in research universities tended to demonstrate higher rates of productivity than their peers in teaching colleges and industrial companies where publication may not be encouraged but was tolerated (Long and McGinnis 1981). Therefore, it seems well-justified to combine individual level factors—postdoc training is a highly visible one—with factors related to organizational contexts to reveal the determinants of scientists' research productivity over their careers.

A national survey pointed out that a tenure track position has been the dream job of most postdoc aspirants, and around two-thirds of postdocs working in research universities expect to obtain such a position (AAU 1998, 2005). This study targets only tenure track/tenured scientists and engineers working in research extensive universities (Carnegie Classification 2000). Given its high homogeneity, the contextual factors are further narrowed down to departmental prestige, which previous studies proved its substantial impact on shaping scientists' productivity (Long 1978; Allison and Long 1990), but did not address whether and how it works with postdoc training. The central research question is how postdoc training and departmental prestige—individually and collectively—shape scientists' research productivity over time.

The research design differs from previous studies in the sense that the study uses curriculum vitae (CV) from a nationally representative sample of scientists and engineers to reveal their career events: educational background, postdoc training, job history, and research productivity. The CVs prove to be an innovative and very useful instrument to examine scientists' career trajectories, and its use has started to gain popularity recently (Dietz et al. 2000; Corley et al. 2003; Dietz and Bozeman 2005; Lin and Bozeman 2006; Gaughan and Ponomariov 2008). This study represents one more testament to its usefulness. The paper is organized as follows: Sect. 2 focuses on relevant studies and presents research hypotheses. In Sect. 3 of the paper, data collection methods used to complete this analysis are described as well as the constructed variables and model specifications. The results of statistical analyses and the relationship of the findings to the previously discussed research hypotheses are presented in Sect. 4. The paper ends with some general conclusions and implications for science and technology policy.

2 Relevant studies and research hypotheses

2.1 Postdoc training and research productivity

As a matter of fact, across all S&E fields and cohorts, 53–56% of former postdocs said that their postdoc experience greatly helped their careers, and an additional 33–38% claimed "somewhat helped" in 2006 (NSB 2008). A common belief is that postdoc training pays off the individual and societal investment in the form of higher levels of research productivity. Folger et al. (1970) found that former postdocs were considerably more productive than nonpostodcs, a conclusion echoed by numerous other studies (Reskin 1976; NRC 1974, 1976). However, few studies used longitudinal designs to examine the relationship; even fewer distinguished the effect of postdoc training from other factors highly relevant to individual productivity.

Zumeta (1985) provided one of the fundamental studies regarding the impact of postdoc training on scientists' research productivity, suggesting that for the faculty group, the training seemingly showed a large and highly significant effect within scientists' early career periods (the first 3 years after the receipt of doctoral degrees). However, caution is warranted in that his study sample was only confined to mobile faculty members in both doctorate and baccalaureate-and-higher degree granting institutions, which differ significantly from a representative sample of academic scientists at research extensive universities.

One study particularly relevant to the present one examined a sample of male biochemists with doctorate degrees awarded in 1957–1958 and 1962–1963, demonstrating that postdoc training per se does not necessarily result in better research performance, at least during the interval between 8 and 10 years after the receipt of their doctorate degrees, and that higher productivity of former postdocs may at large derive from the fact that they are more predisposed to be employed in research intensive settings (McGinnis et al. 1982). The findings were echoed by Long and McGinnis (1981, p. 441), who pointed out that "the major determinants of productivity a decade into the career are not direct effects of education and training, but largely the effects of past productivity and organizational context of employment". Noticeable is that organizational contexts in the two previously mentioned studies refer to multiple sectors, including but not limited to academia. It remains unknown whether the finding holds its validity for research extensive universities. With all relevant findings, it seems plausible that postdoc training, while possibly be beneficial to scientists' productivity in their early career periods, may have no long-term impact on productivity.

Hypothesis 1 Scientists working at research extensive universities who had postdoc training are more productive than their colleagues without such training during the first 3 years after the receipt of their doctoral degrees.

2.2 Departmental prestige and research productivity

As past studies pointed out, where scientists are employed makes a huge difference regarding their subsequent research productivity (Long and McGinnis 1981; McGinnis et al. 1982). The statement receives favorable support in academia. By working with the same sample as in the McGinnis et al. (1982) study, Long (1978) showed that the prestige of departments with which biochemists were affiliated demonstrates significant impact on their later research productivity and that the departmental effect works independent of other factors such as early research productivity, prestige of doctorate programs, and the number of collaborators. For biochemists who switched academic departments during their careers ($n = 47$), their productivity levels tended to be in accord with the prestige of new departments after a short period of time. Moreover, the departmental effect grows stronger over time regardless of job switching status.

Along the same research line, Allison and Long (1990) investigated how academic job changes impact scientists' subsequent research productivity. Using a more diverse sample of scientists who obtained their doctorate degrees during 1961–1975, their study showed that scientists who moved upward demonstrated a substantial increase in their productivity levels after the move, while the productivity levels decreased a great deal for scientists moving down on the scale of departmental prestige. The gap further widened with time.

The renewed interest in departmental prestige and research productivity largely comes from the concern that during the past three decades, the academic world has undergone drastic changes so that the previous findings are in need of reexamination. With regard to this study, the prevalence of postdoc training raises the question whether and how postdoc experience can be incorporated into this topic. Past studies suggested that postdoc training contributes significantly to the higher likelihood of being placed in prestigious departments

(Su 2009), as does the prestige of doctorate departments and mentors (Long et al. 1979). Therefore, it seems plausible that the initial effect of departmental prestige on scientists' productivity may reflect to some extent the impact of various selection factors, among which postdoc training could be a salient one, and that the departmental effect increases over time due to the subsequent socialization processes. There is no solid evidence in favor of the argument that postdoc training could overwhelm departmental prestige with respect to the impact on scientists' productivity.

Hypothesis 2 Departmental prestige has a strong effect on scientists' research productivity and the effect increases over time, regardless of postdoc training.

2.3 Accumulative advantage effect in research productivity

It is well documented in the existing literature that there is enormous inequity in scientists' research productivity (Allison 1980) and that the inequity increases over time as scientists' careers unfold (Allison and Stewart 1974). This phenomenon has been closely tied to the accumulative advantage effect. In the strictest sense, the dynamics for the accumulative advantage effect rest on the positive feedback loops in which recognition and resources are intervening variables (Cole and Cole 1973; Allison and Stewart 1974). More specifically, prolific scientists are more likely to be recognized, which further motivates scientists to maintain or increase their recognition by publishing more; highly productive scientists with good recognition usually have increased access to various resources, including but not limited to more funding, more students and more collaborators, which facilitate more publications. The central assumption underneath the accumulative advantage effect has its roots in the normative structure of the science system, within which the rewards—recognition and resources—should be allocated on the basis of individual contribution to the body of scientific knowledge. By this token, the loops between research productivity and recognition and resources are well fostered.

However, the reward expectations in the normative structure of the science system are not well supported by empirical evidence. Taking departmental prestige as a symbol of academic recognition and resources access, studies suggested that productivity has no significant effects on either the prestige of initial academic employment or on the outcomes of later institutional changes (Long 1978). Methodologically, though studies demonstrated the presence of the enormous inequity in scientific productivity, no longitudinal design has ever been performed to test the presence of any kinds of feedback loops, let alone sorting out the potential causal mechanisms. By adopting a broad, outcome-oriented interpretation of the accumulative advantage effect, with a special emphasis on the nature of "self-reinforcing" among different factors, this study is hoped to map the paths via which scientists accumulate their career advantages and advance the understanding of the enormous inequity in scientists' research productivity.

While much scholarly attention has been cast on the stratification both of the science system as a whole and within academic sectors, little is known regarding the stratification within academic departments. Using a quarter ranking system on academic departments, studies showed that those being placed in prestigious departments[1] publish more than their counterparts in the unrated departments (McGinnis et al. 1982). Working with the same sample scientists as in the present study (Su 2009), one study provided empirical evidence

[1] Prestigious departments are departments that rank as highly prestigious, strong and marginal according to the report published by Roose and Anderson (1970). More details about the quarter ranking system can be found in Sect. 3 of the paper.

that postdoc training contributes significantly to scientists being placed in both highly prestigious and marginal departments, with unrated departments as the reference group. It is reasonable to expect that highly prestigious departments would exercise a strong effect on scientist' research productivity, and the effect increases over time; therefore postdoc training and its effect on obtaining a position in highly prestigious departments would lead to the presence of the accumulative advantage effect in scientists' productivity. However, it remains to be known whether the marginal departments show positive effects on individual productivity, and if so, whether the effect increases over time.

Hypothesis 3 Postdoc training and placement in highly prestigious departments together are conducive to the presence of the accumulative advantage effect in scientists' research productivity.

3 Data, variables and model specifications

The target population for this study was tenure track/tenured scientists and engineers working at research extensive universities ($N = 150$) that produced at least one PhD in 2000 in at least one of 13 science and engineering disciplines. From each discipline, 200 male and female scientists were randomly drawn.[2] The questionnaire was administered by mail, soliciting information about the attitudes and the transitions of scientists' career development.[3] For more detailed information, see Bozeman and Gaughan (2007).

The CV data were collected concomitantly with the survey instrument. The survey respondents were requested to provide their professional CVs or indicate their availability. In addition, researchers searched scientists' websites, university departments' websites and other public venues to maximize the incidence of CVs. All of the 1,053 collected CVs were then coded into a database, with particular emphasis on the following variables: educational background, the timing and the transitions of career development, and the number of peer-reviewed articles per year over their life cycles. Further tests (Table 1) show no significant differences between scientists with CVs and those without regarding their demographic composition and the timing of major career events.

CVs vary widely in both the content and format. It is not uncommon for some scientists to skip the whole section of their research productivity or the employment history, making their CVs of little use for the purpose of the study; however, no systematic patterns were detected regarding why they dismissed part of the information in their CVs. More importantly, CV dataset represents a synthesis of different academic cohorts. As scientific

[2] The research extensive universities award at least 50 doctoral degrees each year. In this sample, we excluded Teachers' College of Columbia Universities since it did not award doctorates in science or engineering fields in 2000. The university list is revealed by Carnegie Classification (2000). The list of S&E fields is defined by National Science Foundation (2000). We excluded health science and economics to develop 13 sampling disciplines. In cases where disciplines had fewer female faculty members than 200, the census of women in disciplines was conducted. Here were the fields with less than 200 female faculty members: chemical engineering, civil engineering, material engineering and mechanical engineering.

[3] Multiple techniques were employed to maximize the response rate of the survey project. After three waves, 38% response rate was achieved, which allowed a comparative analysis between respondents and those who did not respond the survey. No significant differences were detected by *t*-tests and wave analyses. The representation issue of surveyed scientists and engineers was also well addressed by Bozeman and Gaughan (2007).

Table 1 The representation test for scientists with CV

Variables	Survey respondents	Scientists without CV	*t*-Test	Scientists with CV
Sample size	1,475	422		1,053
Gender	.48	.48	n/a	.48
Born year	56.6	56.1	n/a	56.8
Foreign born	.27	.25	n/a	.27
Postdoc	.51.	.49	n/a	.52
PhD year	1,986.1	1,985.7	n/a	1,986.2
Tenure track year	1,989.2	1,988.9	n/a	1,989.3

t-Test, equal variance is not assumed

The survey project was completed in 2005. CV collection was completed in 2008, but for the sake of data consistency, only career events occurring before 2005 were coded

The project succeeded in collecting CVs from 71% survey respondents

careers unfold over time, the study samples shrink accordingly and end up with 388, 245 and 227 scientists for different career stages respectively.

The dependent variables are the number of peer-reviewed articles published by scientists during different career periods. While the simple numbers may not be perfect proxies of scientists' productivity, the literature has been rife with precedents (for example, Long 1978; Long et al. 1993; Allison and Long 1990). Three career stages are introduced in the study: the first 3 years after the receipt of doctorate degrees, the interval between 4 and 8 years, and the interval between 9 and 13 years.

Though it is a challenge to define postdoc status and differentiate postdoc from postdoc-like positions with typical titles such as research scientists and research assistant professor, the difficulty is largely alleviated due to the fact that postdoc training was addressed multiple times. Scientists were asked in the questionnaire whether they had ever had postdoc training, and if so, the duration of postdoc training. Individual CVs generally listed all the positions they accepted and the time spent in each of them. Matching both provides a more accurate picture of scientists' postdoc experience.

The prestige of hiring departments is coded by referring to three national evaluation reports on research-doctorate programs: *A Rating of Graduate Programs* (Roose and Anderson 1970), *An Assessment of Research Doctorate Programs in the United States* (Jones et al. 1982a, b, c), and *Research Doctorate Programs in the United States: Continuity and Change* (NRC 1995). Each report covers 6 years before and after it was released. The reputational measures were generated by delivering questionnaires to carefully-selected faculty soliciting information on the "scholarly quality of the program faculty". Each field was then classified into four groups or "quarters" based on the mean ratings, with 3 or above signifying "highly prestigious," 2.5–2.9 "strong," 2.0–2.4 "acceptable" and others being "unrated." Correspondingly, dummy variables are created to further investigate the stratification within academic departments. Time is essential for departmental prestige to shape individual productivity, and previous studies suggested that 3 year period is required to detect the effect (Long 1978). As such, the scores of departmental prestige reflect the fact that scientists have been placed in the position for at least 3 years. In cases scientists switched their universities, the new scores of departmental prestige are coded after they have been in new positions for at least 3 years.

Four selection variables are constructed to clear the potential spurious relationships between research productivity and the independent variables. Pre-doctoral publication refers to the number of peer-reviewed journal papers published within the scientists' doctoral training periods and proves to be a significant predictor for scientists' future productivity (Long et al. 1979; Clemente 1973). Studies have indicated that the prestige of PhD training departments is highly correlated with that of the departments in which scientists are subsequently employed (Long et al. 1979; McGinnis et al. 1982). The prestige of PhD departments is coded by referring to the same three national evaluation reports as for the prestige of hiring departments; however, the information solicited was the faculty members' opinion of the program's "effectiveness in educating research scholars/scientists." Based on the quarter ranking system, the departments were then classified as "highly effective", "strong", "marginal" and "unrated".[4] The time lapse is measured by the time span between their bachelor degrees and their last doctoral degrees. Age at PhD is also incorporated to account for the potential cohort effect.

In research extensive universities, being tenured or promoted to full professorship reflects at least to some extent academic recognition and the access to resources, both of which prove to be influential on individual productivity (Cole and Cole 1973), and as such need to be controlled. The study uses biology as the reference category, and controls physical sciences (physics, chemistry, and earth and atmospheric science), engineering (civil, chemical, electrical, material and mechanical), and computer and mathematics. Gender and nationality are also included.

Methodologically, the dependent variables, i.e. the number of published articles during specific intervals, challenge the application of linear regression models in that OLS may "result in inefficient, inconsistent and biased estimates" (Long and Freese 2006: 349). Negative binomial models have been proved to be advantageous to OLS (Allison 1980) and are deployed to reveal the determinants of scientists' research productivity during different career stages. The first model focuses on the first 3 years in an attempt to uncover how postdoc experience shapes scientists' early research productivity. As suggested by previous studies, the effect of academic departments on scientists' research productivity requires at least 3 years to be detected (Long 1978); therefore, scientists' early career productivity is largely a function of attributes of their doctoral training, demographic characteristics, disciplines and other specific career events occurring within the period. The next two clusters of models examine the number of papers published in the interval from 4 to 8, and 9 to 13 years. The purposes are to test how departmental prestige affects individual productivity, reveal the stratification within academic departments in research extensive universities, and investigate how postdoc training and departmental prestige interact to shape scientists' productivity.

One big concern is the causal relationship between scientists' productivity and academic departments where they are hired. It is argued that the more productive scientists are, the higher likelihood they end up in prestigious departments. However, previous studies demonstrate that neither the quantity nor the quality of one's early publications play substantial roles on where on ends up in the prestige hierarchy (Long 1978; Long et al. 1979). In contrast, the effect of departmental prestige on scientists' productivity has been well documented (Long 1978; Long and McGinnis 1981; Allison and Long 1990) and even increases steadily over time (Allison and Long 1990). To further clarify the relationship, previous productivity levels are controlled in all three models.

[4] There are scientists who received their doctoral training outside of the United States and obtained an academic position in research extensive universities. Given that the number of these scientists is quite small and their productivity pattern is seemingly different, this study excludes them.

4 Findings

The descriptive statistics of the study variables are presented in Table 2. As mentioned earlier, one of the advantages tied to CV studies is its longitudinal nature; however, the longitudinal design comes from the synthesis of different cohorts rather than one focused group over different time periods. For each variable, the differences across career stages reflect both the longitudinal changes and the changes in the characteristics of different cohorts. Those who have been in academic positions for over a decade may be different from those who landed their placement recently due to the strong selection effects occurring over scientists' careers.

On average, scientists in research extensive universities publish one and half papers annually in the first 3 years after the receipt of doctoral degrees; however, their productivity increases over time and reaches slightly over two papers per year. More than half of the scientists have undertaken postdoc training, and the percentages do not change significantly with time and cohorts. The younger cohort tended to publish slightly more than the elder ones during their doctoral training periods, likely resulting from both the deteriorating job market situations occurring during the past few decades, which required more publications to land an academic position (Perrucci et al. 1983), and the quick development over time in academic disciplines and publication processes. The time span is more than 7 years from the bachelor to doctorate degrees, and the average age for obtaining a doctorate degree is roughly 30. Over two-thirds of scientists were trained in highly effective departments, and the rest of the scientists were trained about evenly in strong, marginal and unrated departments, respectively. Roughly half the scientists are women, reflecting the over sampling of female scientists in the research design. Foreign scientists account for approximately a quarter of the whole sample.

Table 2 also provides detailed information on the prestige of hiring departments. Slightly over a quarter of scientists are employed in highly prestigious departments, and around 10% of scientists work in strong and marginal departments, respectively. About half of the scientists end up being in unrated departments at research extensive universities. Forty-four percent of scientists were tenured before the eighth year after the receipt of doctorate degrees, and 57% were promoted to full professor positions by the year of thirteenth.

As is indicated by Table 3, postdoc training boosts scientists' productivity in the first 3 years after the doctorate degrees. Having postdoc experience amounts to a 17% increase in the expected number of articles as opposed to spending 3 years fully in tenure track positions. For those who entered into industry and later switched back to academia, the industrial experience leads to a 28% decrease in the amount of their publications. Those who spent some time in non-tenure-track positions show no significant differences in their research productivity.

Consistent with previous studies, the number of articles published during doctoral periods proves to be the strongest predictor of their subsequent productivity (Clemente 1973; Long 1978; Long et al. 1979). For a one standard deviation increase in doctoral productivity, a scientist's expected productivity in the subsequent 3 years increases by 30%, holding other variables constant. Male scientists exhibit a higher productivity level (16%) than female scientists.

The first two models in Table 4 reveal the determinants of scientists' productivity during the interval from 4 to 8 years. Model 1 addresses postdoc training and departmental prestige separately, suggesting that within the interval, postdoc training no longer exercises direct positive impact on scientists' productivity. The stratification within academic

Table 2 Descriptive statistics of study variables for scientists' different career stages

	0–3 years ($n = 388$)		4–8 years ($n = 245$)		9-13 years ($n = 227$)	
	Mean	SD	Mean	SD	Mean	SD
Dependent variable						
Productivity (0–3 years)	4.43	3.41	4.24	2.87	–	–
Productivity (4–8 years)	–	–	10.53	7.99	10.8	8.21
Productivity (9–13 years)			–	–	11.57	21.0
Independent variables						
Postdoc training	.52	.50	.56	.50	.55	.50
Industrial experience	.04	.19	–	–	–	–
Non-tenure-track academic positions	.04	.20	–	–	–	–
Immediate tenure track	.39	.49	–	–	–	–
Prestige of hiring departments	–	–				
Highly prestigious			.33	.47	.26	.44
Strong			.15	.36	.08	.28
Marginal			.09	.28	.10	.30
Unrated			.43	.50	.55	.50
Rank						
Associate professorship			.44	.50	.57	.50
Full professorship					.31	.46
Selection variables						
Productivity (doctoral)	2.77	3.86	2.42	3.25	2.39	3.32
Lapse time	7.49	3.39	7.45	3.33	7.37	3.29
PhD age	30.0	4.13	29.68	3.67	29.61	3.68
Prestige of PhD departments						
Highly effective	.70	.46	.69	.46	.69	.46
Strong	.13	.33	.12	.33	.13	.33
Marginal	.06	.25	.09	.28	.09	.28
Unrated	.11	.31	.10	.30	.10	.30
Demographics						
Gender	.43	.50	.47	.50	.48	.50
Foreign born scientists	.25	.44	.23	.42	.23	.42
Disciplines						
Biology	.09	.28	.11	.31	.11	.31
Computer & Math	.17	.38	.15	.36	.15	.36
Engineering	.49	.50	.44	.50	.45	.50
Physical sciences	.26	.44	.29	.46	.29	.46

For the first 3 years, the model does not take into account the prestige of hiring departments since the effect of academic departments on scientists' research productivity requires at least 3 years to be detected (Long 1978)

For the latter two career stages, all scientists hold full-time, tenure track positions. The prestige scores reflect that scientists have been placed in a specific department for at least 3 years

departments suggests that the positive benefits come only from both highly prestigious and marginal departments as opposed to unrated programs. Being placed in highly prestigious departments corresponds to a 26% increase in the expected number of articles, and being in

Table 3 Negative binomial regression on scientists' productivity (0–3 years)

	Regression results		
	B	SE	Exp (xb)
Dependent variable			
Productivity (0–3 years)			
Independent variables			
Postdoc training	.16	.07**	1.17
Industrial experience	−.33	.19*	.72
Non-tenure-track academic positions	.14	.17	1.15
Selection variables			
Productivity (doctoral)	.07	.01***	1.07
Lapse time	−.02	.02	.98
PhD age	−.02	.01	.98
Prestige of PhD departments			
Highly effective	.05	.11	1.05
Strong	.05	.13	1.05
Marginal	.07	.16	1.07
Demographics			
Gender	.15	.06**	1.16
Foreign born scientists	.01	.07	1.01
Disciplines			
Computer & Math	−.21	.14	.81
Engineering	−.08	.12	.92
Physical sciences	−.09	.12	.91

Note: * $p < .10$, ** $p < 0.05$, *** $p < 0.001$

marginal departments leads to a 36% increase. Being tenured within the interval results in a 23% increase in the number of articles compared to those remaining on tenure track. Not surprisingly, the productivity level during the first 3 years turns out to have a strong influence on subsequent publications, and a one standard deviation increase leads to a 10% higher productivity level during the interval.

Previous studies indicated that postdocs are more predisposed to be placed in both highly prestigious and marginal departments (Su 2009); it is highly plausible that the effect of departmental prestige reflects to some extent the indirect influences from postdoc training. Model 2 adds the interaction terms between postdoc training and the prestige of hiring departments. Postdoc training shows no direct impact on scientists' productivity; however, the effects of departmental prestige have been largely attenuated compared with Model 1. Though none of the interaction terms reach the significance level ($p = .05$), the effect of highly prestigious departments on individual productivity shrinks to marginal significance, and the effect of marginal departments vanishes. The productivity level in the first 3 years demonstrates the same magnitude of impact on individual productivity as in Model 1, and the effect of being tenured does not change.

Models 3 and 4 examine scientists' productivity in the interval between 9 and 13 years. Postdoc training remains insignificant in determining scientists' productivity during this interval. With unrated programs as the reference group, highly prestigious departments prove to be strongly affecting scientists' productivity, as do strong and marginal departments. Being in highly prestigious departments corresponds to a 26% higher productivity

Table 4 Negative binomial regression on scientists' productivity in the intervals of 4–8 and 8–13 years

	4–8 years				8–13 years			
	Model 1		Model 2		Model 3		Model 4	
Independent variables								
Postdoc training	.02	.09	.05	.12	.06	.10	.09	.12
Prestige of hiring department								
Highly prestigious	.23**	.09	.24*	.13	.22**	.10	.28**	.14
Strong	−.00	.11	.06	.17	.30**	.14	.24	.21
Marginal	.31**	.14	.39	.24	.27**	.13	.30	.22
Interaction effects								
Postdoc × highly prestigious			−.01	.17			−.10	.19
Postdoc × strong			−.12	.22			.13	.28
Postdoc × marginal			−.12	.29			−.07	.28
Rank								
Associate	.20**	.08	.20**	.08	.10	.14	.10	.14
Full professor	–		–		.32**	.15	.31**	.15
Productivity index								
Productivity (3–8 years)	–		n/a		.05***	.01	.06***	.01
Productivity (0–3 years)	.10***	.01	.10***	.01	.02	.02	.02	.02
Selection variables								
Productivity (doctoral)	.01	.01	.01	.01	.01	.01	.01	.01
Lapse time	−.03	.03	−.03	.03	.02	.03	.02	.03
PhD age	.02	.02	.02	.02	−.03	.03	−.03	.03
Prestige of PhD departments								
Highly effective	−.19	.08	−.19	.13	−.33**	.13	−.33**	.13
Strong	−.12	.17	−.11	.17	−.24	.17	−.22	.17
Marginal	.12	.14	.12	.18	−.16	.19	−.15	.19
Demographics								
Gender	.05	.08	.05	.08	.22**	.08	.22**	.08
Foreign born	.06	.09	.06	.09	.12	.10	.12	.10
Disciplines								
Computer & Math	−.01	.17	−.01	.17	−.42**	.18	−.42**	.18
Engineering	.24*	.14	.24*	.14	−.25	.15	−.25	.15
Physical sciences	.05	.14	.05	.14	−.18	.14	−.18	.14
−2 log likelihood	1,487.4		1487.0		1,366.6		1,366.0	

Note: * $p < .10$, ** $p < 0.05$, *** $p < 0.001$

level, and being in strong and marginal departments to 34 and 31% higher levels, respectively. Promotion to full professorship represents a 38% increase in the number of articles published in the interval as opposed to those without being promoted. The preceding productivity level (4–8 years) maintains its strong predicting power for subsequent productivity, and a one standard deviation increase in preceding productivity results in a 56% increase in the subsequent number of published articles. Surprisingly, those who were trained in highly effective departments demonstrate a lower productivity level (29% less) as opposed to their peers trained in unrated programs. Male scientists are more productive than female scientists. Scientists in the computer and math fields produce fewer articles than scientists in the biology field.

By adding the interaction terms between postdoc training and the prestige of hiring departments, Model 4 shows a different picture regarding how departmental prestige affects scientists' productivity. Compared with unrated programs, only highly prestigious departments exhibit a strong effect, while strong and marginal departments lose their significance. Postdoc training shows no direct impact on individual productivity during the interval, and its indirect effect has been largely captured by the interaction terms. Other significant variables remain their effects as shown in Model 3.

To test whether the overall effect of departmental prestige increases over time, the study runs regression models with nominal scores of departmental prestige as independent variables, suggesting affirmative results (not shown). A one standard deviation increase in departmental prestige leads to a 10% higher productivity level for scientists during the interval between 4 and 8 years, and a 12% higher level between 9 and 13 years.

The gender equity issue in research productivity has attracted a great deal of scholarly attention. Studies have suggested that the inequity in productivity across gender largely stems from sex differences in structural locations (Xie and Shauman 1998), a conclusion well supported in this study. By adding the interaction terms between gender and the prestige of hiring departments, the study finds that gender loses its significant impact on productivity for the elder cohort, and shrinks to be marginally significant for the younger cohort (not shown).

One special concern relates to the duration of postdoc training. There seems a consensus that a longer duration of postdoc training is neither conducive to individual trainees, nor beneficial to the science enterprise (NRC 1981, 1998, 2005; AAU 1998, 2005). By limiting the study samples to postdoc groups, this study suggests that within the same intervals, a longer duration of postdoc training does not result in better research performance, and that departmental prestige maintains the impact on scientists' research productivity (not shown).

5 Discussion and conclusion

This study analyzed scientists' and engineers' CVs to investigate how postdoc training and departmental prestige shape scientists' productivity. The results provided mixed evidence for the common assumption that postdoc training leads to a higher productivity level. Postdoc training does boost the number of research articles within the first 3 years after the receipt of their doctorate degrees; however, the effect fades away quickly, and later is superseded by the effect of the prestige of academic departments where scientists obtained positions.

Echoing previous studies (Long 1978; Allison and Long 1990), the results also show that departmental prestige has strong effect on scientists' productivity, and the effect increases over time. Further investigation on the stratification of academic departments points out that only scientists employed in highly prestigious departments demonstrate a consistently higher productivity level as opposed to their peers who ended up being in unrated programs, if the indirect effects of postdoc training are ruled out. Given that all sample scientists work at research extensive universities where research productivity is highly valued and encouraged, the finding may be read as a sign that academic departments at these universities have been more stratified over the past few decades. This study is an early effort to present such empirical evidence and future scholarship is warranted to uncover how the stratification process evolves over time.

Combining the findings that postdocs are more likely to be employed in highly prestigious departments (Su 2009) and that highly prestigious departments show significant impact on scientists' productivity, the study provides affirmative evidence that postdoc training and placement in highly prestigious departments are conducive to the presence of the accumulative advantage effect. The finding presents a good lens through which the inequity of scientists' research productivity can be well interpreted, and represents a departure from the normative structure of the science system stipulating that prolific scientists presumably go to prestigious departments. While multiple factors may contribute to the presence of the accumulative advantage effect (see Diprete and Eirich 2007), this study provides an empirically justified causal chain in research productivity, and the logic may be extended to other important factors such as recognition and resource allocation.

Not unlike preceding studies examining scientists' productivity, this study found that earlier research productivity strongly predicts individuals' subsequent productivity. The path dependence effect persists over scientists' life cycle even after controlling all other individual and organizational factors relevant to research productivity. The rewards in the science system—obtaining tenure and being promoted to full professor—are consistent with the number of publications scientists produced within a certain time period, though this time period varies across universities.

There are somewhat surprising findings that warrant further investigation. For the elder cohort (Models 3 and 4), those who were trained in highly effective departments turn out to produce less than their peers trained in unrated departments. Previous studies suggested that academic entrance is strongly shaped by the prestige of departmental affiliation and mentor (Long et al. 1979). By this token, the selection dynamics for scientists trained in different ranks of departments may be quite different. Those trained in highly effective departments receive a premium, while scientists with doctoral training in unrated programs need to pay extra to earn an academic position, and there is no better currency in academia than high research productivity. Interestingly, the inequity in research productivity owing to their originating departments disappears in the two younger cohorts. Whether it results from more equal treatment of those originated from unrated departments or from stricter selection dynamics for those trained in highly effective departments remains unknown. Further longitudinal design is required to unfold this phenomenon.

The implications of the research findings are not altogether straightforward. Previous studies have shown that 3 years of postdoc training prepares scientists well for academic positions (Su 2009). In this study, the findings provide favorable support for policies to impose tenure limitations on postdoctoral appointments that postdoc training has no more significant impact on research productivity after 3 years and that a longer duration does not lead to better research outcomes. Noteworthy is the stratification within academic departments, suggesting that only highly prestigious departments significantly shape scientists' research productivity. The differences in research productivity manifested in scientists' academic careers stem largely from their academic employment, questioning the desire to recruit more postdocs to increase research productivity in the long run. The presence of the accumulative advantage effect advances the understanding of inequity in scientists' productivity; however, for funding agencies, it may raise new dilemmas regarding how to distribute research funding. Allocating research resources based upon scientists' productivity may reflect a commitment to the ideal of advancement by merit, but in the meantime, further reinforce the inequity in scientists' career trajectories. Further studies are therefore needed to unravel this predicament.

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Appendix

See Table 5.

Table 5 Variable construct and measurement

Dependent variables: scientists' productivity	
Productivity (0–3 year)	The total number of peer reviewed articles published within the first 3 years after the receipt of doctoral degrees
Productivity (4–8 year)	The total number of peer reviewed articles published from the fourth to the eighth year after the receipt of doctoral degrees
Productivity (9–13 year)	The total number of peer reviewed articles published from the ninth to the thirteenth year after the receipt of doctoral degrees
Independent variables	
Postdoc training	Dummy. 1 indicating that scientists had undertaken postdoc training after the receipt of doctoral degrees and before being employed in research universities in the United States, 0 otherwise Survey question: Have you ever been a university-based post-doctoral researcher or fellow? If so, please provide the years during which you were a postdoc. Yes__, from__ to ___; No__ CV coding: post-doc position, years
Industrial experience	Dummy. 1 indicating that scientists had industrial experience within the first 3 years after the receipt of doctoral degrees, 0 otherwise
Non tenure-track academic positions	Dummy. 1 indicating that scientists had taken such positions as instructor, adjunct professor, research administrator and other part-time job within the first 3 years after the receipt of doctoral degrees. 0 otherwise
Associate professor	Dummy. 1 indicating that scientists were tenured within the study period, 0 otherwise
Full professor	Dummy. 1 indicating that scientists were promoted to full professorship within the study period, 0 otherwise
Prestige of hiring departments	
Highly prestigious	Departments with quality score in the 3.0–5.0 range
Strong	Departments with quality score in the 2.5–2.9 range
Marginal	Departments with quality score in the 2.0–2.4 range
Unrated	Departments with quality score under 2.0 or departments not on the evaluation list
Prestige of PhD departments	
Highly effective	Departments with effectiveness score in the 2.0–3.0 range in 1972, 1980 reports, or with effectiveness score in 3.0–5.0 in 1995 report at the time of the receipt of doctoral degree
Strong	Departments with effectiveness score in the 1.5–1.9 range in 1972, 1980 reports, or with effectiveness score in 2.5–2.9 in 1995 report at the time of the receipt of doctoral degree
Marginal	Departments with effectiveness score in the 0.8–1.4 range in 1972, 1980 reports, or with effectiveness score in 2.0–2.4 in 1995 report at the time of the receipt of doctoral degree

Table 5 continued

Unrated	Departments not listed in all reports or departments with effectiveness score under 2.0 in 1995 report at the time of the receipt of doctoral degree
Selection variables	
Doctoral productivity	The total number of peer reviewed articles published during scientists' doctoral periods
Lapse time	The year span between scientists' bachelor degree and their last doctoral degrees
PhD age	The age scientists obtained their last doctoral degrees
Demographic characteristics	
Gender	Dummy. 1 indicating male scientists, 0 female
Foreign born scientists	Dummy. 0 indicating US citizen, 1 otherwise
Disciplines	
Biology	Reference group. Dummy. 1 indicating that scientists study or work in the biology field, 0 otherwise
Computer & math	Dummy. 1 indicating that scientists study or work in computer or math fields, 0 otherwise
Engineering	Dummy. 1 indicating that scientists study or work in the following engineering fields: electronic engineering, civil engineering, chemical engineering, mechanical engineering, and material engineering, 0 otherwise
Physical sciences	Dummy. 1 indicating that scientists study or work in the following fields: earth and atmospheric science, chemistry and physics, 0 otherwise

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