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Novelty, Knowledge Spillovers and Innovation: Evidence from Nobel Laureates*

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ABSTRACT

Using a new identification strategy and unique, rich data on Nobel laureates, we show that being in new or multiple locations, as measures of exposure to novel combinations of ideas, and the number of other local important innovators, all increase the probability that eventual Nobel laureates begin their Nobel prize winning work. Strikingly, and consistent with our identifying assumptions, we find that none of these measures increase the probability of doing Nobel prize winning work. Our results strongly suggest that spillovers affect the generation of ideas, and help us understand the weak spillover effects previously estimated in the economics literature.

Keywords: Knowledge spillovers, Innovation, Nobel Prize, Duration models.

I. Introduction

In 1911, twenty-six-year-old Niels Bohr moved from Copenhagen to Cambridge's storied Cavendish Laboratory to work with J. J. Thomson, discoverer of the electron, and then on to Manchester to work with one of Thomson's former students, Ernest Rutherford, who had recently identified the nucleus of the atom. While in Manchester in 1912, Bohr began his Nobel Prize winning work (hereafter Nobel work) on a revolutionary model of the atom inspired by Thomson and Rutherford's findings, where the nucleus determines the nature of the atom while electrons arranged in rings around it control chemical reactions. But it was not until Bohr returned to Copenhagen in 1913 that he completed his Nobel work, by adding an analysis of radiation spectra.

Non-economists have identified all three of these figures, their labs, and others like them, as generating large knowledge spillovers leading to fundamental scientific discoveries across disciplines - see, e.g., Moore [1966]; Zuckerman [1977]; and Larsson [2002]. However, this research contrasts with a body of recent work by economists discussed below that finds little evidence for positive spillover effects. Understanding whether economists or non-economists are right about the extent of spillovers has important implications for economic growth, urban agglomerations, international trade (Romer [1986]; Lucas [1988]; Glaeser, Kallal, Scheinkman, and Schleifer [1992]; and Krugman [1991]), the support and design of research institutions, and the development of innovative clusters, such as those in Silicon Valley and at top research institutions.

This paper makes three interrelated contributions to the emerging literature on spillovers among innovators. First, we take a recombinant approach as we believe that the start of many important innovative research programs may involve combining existing ideas in important and novel ways. Doing so, in turn, requires exposure to a wide range of ideas that have not previously been combined. While people remaining in an environment with many important contributors may be exposed to many ideas, as Bohr's example illustrates, the most insightful combinations of ideas often arise when people move to a new location where they are exposed to ideas for the first time, and/or when they span multiple environments. Thus, we introduce two new measures that we hypothesize affect the production of important innovations: (1) a measure for moving to a new location in each year, to measure initial, intense exposure to a new set of ideas and (2) a measure

for being in multiple locations in each year. In other words, we see innovations as potentially resulting from a type of intellectual arbitrage where researchers combine ideas across locations.

Second, we build on, and extend, the pioneering work by Kim, Morse, and Zingales (2009) Azoulay, Graff-Zivin, and Wang [2011], Waldinger [2010, 2012], Borjas and Doran [2012, 2015], and Catalini [2015], by examining separately the effects of the quality of a scientist's colleagues on when important research ideas are developed, and when the main body of the research is completed.

Third, we assemble and utilize a unique dataset ideally suited to our challenging data requirements. We need to be able to observe whether a researcher is in a new location, or in multiple locations, in different years. We also need to be able to determine when important work is started and when it is completed, and the quality of the scientists' colleagues at different points in the research cycle. By focusing on Nobel Prize laureates in Chemistry, Medicine, and Physics from 1901 to 2003, we can meet the above requirements.[1] Extensive, high-frequency biographical data, including their location and their colleagues in each year, are available on Nobel laureates. Moreover, there is rich data on when they started their Nobel work and when they did the body of that work. We believe it is important to distinguish between when people start their Nobel work from when they do it (separated by 6.1 years on average) since exposure to new ideas is likely to lead to insightful recombination that generates the formulation of a Prize-winning research program. However, such exposure may be far less valuable for conducting important work, and the latter may in fact be enhanced by staying in one location.

Specifically, we separately estimate annual hazard functions for starting Nobel work, and for doing the Nobel work, which depend on being in a new location, being in multiple locations, and being exposed to high-quality researchers. Within this framework, we assume that any factor that increases the probability of starting (doing) Nobel work in a given year increases a scientist's productivity in the respective part of a research program. In estimating these hazard functions, which describe how spillovers affect Nobel work, we face the same issues as in previous work (discussed in detail below). First, what constitutes a high-quality colleague? We define high-

[1] We exclude Nobel laureates in Economics because the Economics Prize is much more recent than the Prizes we consider here, and hence there is much less data for Economists.

quality colleagues as those who have won, or who will win, the Nobel Prize.[2] Secondly, are being in a new location, being in multiple locations, and especially the number of high-quality colleagues independent of unobserved factors (i.e. unobservable to the econometrician) that increase a researcher's productivity, i.e. the unobserved heterogeneity terms in the hazard functions? [3]

We believe it is reasonable to assume that productivity differences that are unobservable to us will be at least partially observed by departments in a scientist's field, which implies that it is untenable that these independence assumptions hold in the general population of scientists – better scientists will have more opportunities to move, more offers of multiple appointments, and better colleagues. However, we argue in some detail below that these independence assumptions are potentially reasonable among those who eventually win the Prize. We also provide diagnostics suggesting that these assumptions seem consistent with the data.

Our most conservative estimate of the effect of always being in multiple locations, as opposed to never being in multiple locations, is that it significantly reduces the expected time until starting Nobel work by 2.5 years on a base of 10.5 years. Further, our most conservative estimate of the effect of being in a new location every other year, as opposed to never being in a new location, is that it significantly reduces the expected duration until starting Nobel work by 1.99 years (again on a base of 10.5 years). Finally, our smallest estimate of being around one more Nobel laureate each year is that it significantly reduces time until beginning such work by 1.90 years.[4] Thus, we find that being in a new location, being in multiple locations, and the quality of one's colleagues all significantly (and substantially) increase the probability of staring Nobel work in each year and decrease the expected length of time until starting Nobel work. However, neither being in multiple locations, nor the quality of one's colleagues, significantly affects the expected duration for doing Nobel work, and moving to a new location (significantly) increases the expected

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[2] The finding that Nobel laureates are frequently associated with one another dates back at least to Zuckerman's [1977] well-known work, which shows that over half of American Nobel laureates studied with or worked under another Nobel laureate. But this finding does not imply that spillovers operate because of endogenous sorting among important scientists or nepotism.

[3] We do not know of another group of scientists for whom we would have the data necessary to carry out our research program.

[4] These conservative estimates are from a specification that includes all three factors; these estimated effects have small confidence intervals.

duration until a researcher does Nobel work.

Our study has at least two important implications. First, it helps reconcile the apparently diverging views of economists and non-economists by noting that non-economists are right that spillovers matter but only in the beginning of a research program, while economists are correct that the effects of these spillovers are small or nonexistent at later stages in a research project. Since previous economics research on the effect of the quality of one's colleagues did not have the detailed biographical information that is available for Prize winners, it could not distinguish between the effects of spillovers at different points in a research program.[5] Thus, this research estimated an average of productivity effects in terms of both beginning and doing Nobel work, and we find the latter to be zero. Hence, it is not surprising that these researchers obtained statistically insignificant results. Second, programs that allow researchers to temporarily visit different departments and research institutes and/or split time between multiple locations may be quite effective in increasing innovative activity but may be undervalued by home institutions.

The outline of the paper is as follows. We discuss the previous literature in Section II. In Section III we describe how we determine when scientists began their Nobel work and when they did that work. We present our econometric model, empirical specification, and identification strategy in Section IV. We discuss our data in Section V and present our results in Section VI. Section VII concludes the paper.

II. Literature

There is a sizeable body of work on knowledge spillovers, but much of it takes a markedly different approach from our analysis of the determinants of scientists' productivity. For instance, Jaffe, Trajtenberg, and Henderson [1993] and Thompson and Fox-Kean [2005] seek to infer the presence of spillovers from the geographic concentration of citations in patents. Glaeser, Kallal, Scheinkman, and Schleifer [1992] and Glaeser and Ellison [1997] study the geographic concentration of industries. The existence of an urban wage premium (e.g. Gould [2005]) has also been viewed as evidence of spillovers. Kaiser [2005] provides a particularly interesting analysis,

[5] One could allow the quality of one's colleagues to affect scientists of different experience levels. However, this approach would raise both statistical power issues and the age-old problem of distinguishing experience effects from cohort effects in a cross-section.

tracking the diffusion of Feynman diagrams through the physics community. Zucker, Darby, and Brewer [1998] presents striking evidence on the relationship between star researchers (primarily in biotechnology) and startups companies, but they do not explicitly study spillovers or address causality.

In terms of the previous literature, we know of no papers that have focused on the spillover effects to individual innovators of experiencing new and multiple locations. Recently, researchers have sought to estimate knowledge spillovers *directly from colleagues* in several fields. Mairesse and Turner [2006], using data on scientists, find that immediate proximity increases the probability of collaborating. Kim, Morse, and Zingales (2009) assemble rich data on economists in the top 25 university departments worldwide and show that spillovers have declined over time.

On the other hand, several innovative recent studies emphasizing identification via natural experiments find little or no evidence of positive knowledge spillovers on publications based on proximity to peer scientists; in what follows we refer to these papers as the natural experiment papers. In a study of vertical spillovers, Azoulay, Graff-Zivin, and Wang [2011] find that the death of superstar bio-scientists reduces the productivity of collaborators, especially collaborators who are at a distance from the superstar, suggesting that spillovers affect the vibrancy of entire subfields, not only close colleagues. Waldinger [2010, 2012] find that the dismissals of scientists by the Nazis had little effect on previous or new colleagues but had large effects on graduate students at their home institutions. Further, Borjas and Doran [2012, 2015] find negative spillovers from high quality colleagues in the following sense. Specifically, Borjas and Doran [2012] show that the migration of mathematicians after the collapse of the Soviet Union reduced the productivity of (most) U.S. mathematicians by crowding out research and researchers in the areas in which Soviet math was the strongest. Further, Borjas and Doran [2015] show that Russian mathematicians whose collaborators left for the West became less productive, while those in research areas where many people left became more productive. [6]

Our work can help reconcile the positive spillovers from being around high-quality peers in other literatures with the puzzling lack of evidence of positive spillovers found in the natural

[6] The source of variation in our work differs from that in Boras and Doran because we keep constant the number of top people in the field. If one considers the US and Russian academic communities as divided, their work captures the effect of taking scientists from one market to another.

experiment papers. The recombinant view of innovation we take highlights the importance of measuring spillovers using exposure to new combinations of ideas (e.g. being in new or multiple locations) in starting Nobel Prize-winning work (Nobel work). Moreover, we find no significant positive effect of being around more high-quality colleagues (or other exposure variables) on the probability of doing Nobel work in a given period. The natural experiment papers, by looking at the effect on contemporaneous publications of contemporaneous colleagues, estimate a weighted average of our starting and doing impacts (with a higher weight on the doing effect). Our recombinant approach also can help explain why Waldinger [2010] finds that graduate students, who are largely being exposed to ideas for the first time, were affected by the Nazi dismissals while faculty were not. Further, our focus on exposure to novel combinations of ideas is in keeping with Azoulay, Graff Zivin, and Wang's [2011] emphasis of the effects of spillovers on the vibrancy of fields. Our work is also consistent with Catalini [2015], who shows that exogenous relocations, measured at a very fine geographic level, affect the nature of work.

III. Determining When Scientists Start and Do Their Prize-Winning Work

Given the above discussion, a crucial component of our work is our ability to identify when researchers began their Nobel work and when they did their Nobel work, and we turn to this issue now. Here we rely on rich biographical information on the laureates available from Nobel autobiographies as well as the statements of the Nobel Committees and other sources. *We define when people began their Nobel work by when they began the broad research agenda that lead to the contribution cited by the Nobel committee in awarding the prize.*[7] *We identify when people did their Nobel work as the year that their Prize-winning work was completed.*[8] We focus on their broad research agendas to capture when they first had the idea that ultimately lead to their Nobel work. As an alternative, one might focus on when people began the specific work (e.g. experiment

[7] Nobel Prizes in the natural sciences are typically awarded for specific contributions, with the Nobel committee often pointing to a specific paper or papers. A small number of (the most distinguished) laureates make more than one contribution that might well qualify for a Nobel Prize. Very few people are awarded more than one Nobel Prize (and we drop any second Prizes awarded to one person). Thus, our estimates focus on whichever work was cited by the Nobel committee, which is typically the first Prize-worthy contribution.

[8] If it is impossible to identify when the work was completed, we turn to the publication year. Fortunately, publication lags tend to be short in the natural sciences.

or theory) for which they received the Prize. However, many Prize-winning contributions are the consequence of long periods working on a particular topic. Focusing on when people began the specific work would effectively ignore the work that brought the laureates to the point of being able to do the specific work.[9]

To illustrate how we operationalize this distinction and some of the wide range of ways in which moving between locations, being in multiple locations, and spillovers from other (current or future) Nobel laureates can lead people to begin their Nobel work, we consider a few examples. Returning to Niels Bohr, Bohr began his Nobel work in 1912, inspired by Rutherford's model of the atom, shortly after having arrived in Manchester. He completed his Nobel work in 1913, after returning to Copenhagen (slightly less than) one year later. The timing here is well documented (see, for instance, Moore [1966]).

Robert Lefkowitz and Brian Kobilka received the 2012 Nobel Prize in Chemistry for "groundbreaking discoveries that reveal the inner workings of … G-protein–coupled receptors. (Nobel Foundation [2014a])" Over *half* of prescription medications act on such GPCRs, which allow cells to receive signals from hormones such as adrenaline. Originally more interested in clinical work than research, Lefkowitz applied for and received a fellowship to work at the National Institutes of Health (NIH) in 1968, which provided a Vietnam War draft exemption. He joined the NIH during a period remarkable for the large number and vibrant interactions among future Nobel laureates there (Goldstein and Brown [2012]). By his own account, he began his work on GPCRs in 1971, shortly after moving to Massachusetts General Hospital for a residency, and it was far from clear that he wanted to do research. He pursued this research agenda for over 40 years, beginning by tracing cells' receptors using radioactivity. Because GPCRs are found in very low concentrations in cells, Lefkowitz spent over a decade obtaining purified samples of various receptors. It took additional years for him to show i) that when adrenaline receptors were inserted into reptile cells that natively lack them, they generated a responsiveness to adrenaline and ii) how to clone the complementary DNA (cDNA) for many GPCRs.

Over his career, Lefkowitz worked with over 200 trainees in his lab. In 1984, Brian Kobilka

[9] Moreover, the difference between when the work began and was done would tell us only about how long the specific experiment or theory took to complete.

joined Lefkowitz's lab (then at Duke) interested in cardiac intensive care (Kobilka [2014]). In his autobiography, Kobilka describes the many steps in his research program, including isolating and producing enough β2-adrenergic receptor to study and painstakingly developing and improving imaging (Kobilka [2014]). Ultimately, Lefkowitz and Kobilka had a "eureka moment," in 1987 when they realized the presence of a broad family of receptors with a similar structure and operation. In 2011 Kobilka imaged the receptor "when it transfers the signal from the hormone on the outside the cell to the G protein on the inside the cell (Nobel Foundation [2014a, b])". We identify 1971 and 1984 as the years in which Lefkowitz and Kobilka (respectively) began the broad research agendas on GPCRs, for which they won the Nobel Prize. We identify 1987 and 2011 as the years in which Lefkowitz and Koblika (respectively) did their Nobel work.

These cases also illustrate the serendipitous nature of beginning Nobel work. Bohr went to the Cavendish Lab only to be frustrated with the lack of interaction with Thomson. (Bohr used their first meeting to point out some mistakes in Thomson's papers (Moore [1966]).) It was only when he moved to Manchester that he began his Nobel work. Kobilka was attracted to Lefkowitz's lab because of his broad interest in intensive care as a practicing physician and began working (with considerable challenges, given his lack of research preparation) on GPCRs because that was Lefkowitz's specific focus. More strikingly, Lefkowitz was not even planning on a research career when he joined Massachusetts General and began his work.

These cases also illustrate some of the ways in which interactions can operate. Kobilka began his Nobel work when he joined Lefkowitz's lab and began collaborating with Lefkowitz explicitly. Collaborative work can arise, as was the case with Kobilka, when working as a trainee or out of a collaboration among two or more established researchers. Bohr illustrates a markedly different case. His work was inspired by the work that Rutherford and Thomson (to a lesser extent) were doing, but his Nobel work was not joint with Bohr or Thomson. More generally, these cases illustrate the organization of research in the Nobel fields, where scientists collaborate on projects and frequently publish as large teams (at least much larger than many economists).

Our data on when people began and did their Nobel work were drawn from Jones and Weinberg [2011], which builds on data on the year in which each laureate began (and ended) his or her Prize-winning research agenda from Stephan and Levin [1993], and data on the year in which each laureate did his or her Nobel work from Jones [2010]. We integrated and extended

both series and, as discussed below, added data on the location of each Nobel laureate in each year of his or her career. In our sample of 485 laureates, the average laureate begins her Nobel work 10.52 years into her career in 1939 and does her Nobel work 16.61 years into her career. Figure 1 shows the histogram for the number of years between when a scientist in our sample begins and does her Nobel work. This figure indicates that a few scientists start and do their work in the same year, while the modal gap is one year. The figure is skewed, with a long right tail; the mean difference of approximately six years is about twenty per cent larger than the median difference of approximately five years.

IV. Empirical Specification, Identifying Assumptions and Econometric Approach

IV.1 Empirical Specification and Identifying Assumptions

Duration studies typically begin by specifying the relevant hazard function, i.e. the probability of entering state k, (or leaving state j) in period *t*, conditional on not entering in the previous *t-1* periods.[10] Since we have annual data, we use a discrete time hazard model to determine the probability that individual *i*, who *started* her career in calendar year τ_i,[11] *begins* her Nobel work *t* years later

$$\lambda_{bi}(t \mid \theta_{bi}) = \frac{1}{1+\exp\{-h_b(t) - X_i(\tau_i + t)\beta_b - g_b(\tau_i + t) - \theta_{bi}\}}. \qquad (1)$$

In (1) t represents duration since the scientist started her career, and $h_b(t)$ denotes duration dependence. Further, $X_i(\tau_i + t)$ denotes the explanatory variables (several of which change over the spell), $g_b(\tau_i + t)$ represents a quadratic function in calendar time, and θ_{bi} denotes an unobserved (to the researcher) heterogeneity term.

We specify the probability that individual *i* transitions to *doing* her Nobel work t years after leaving graduate school, conditional on not having done it up to that point, as

$$\lambda_{di}(t \mid \theta_{di}) = \frac{1}{1+\exp\{-h_d(t) - X_i(\tau_i + t)\beta_d - g_d(\tau_i + t) - \theta_{di}\}}, \qquad (2)$$

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[10] See, e.g., Ham and Rea (1987).

[11] An academic career is assumed to start three years before the individual receives her highest degree.

where all terms in (2) are defined analogously to those in (1), but of course are measured at different durations and calendar time.

In addition to field dummy variables, $X_i(\tau_i + t)$ contains the following explanatory variables in calendar year $\tau_i + t$:

i) A dummy variable coded 1 if the scientist is in a new location that year — one she has not been in over the last five years — and zero otherwise;

ii) A dummy variable coded 1 if the scientist is in multiple locations that year and zero otherwise;[12]

iii) Our measure of the quality of her colleagues over the year: the sum of the number of *eventual* Nobel laureates in her own field over all the locations that she is in that year. Note that the length of time that a scientist is exposed to a laureate during the year is assumed to not affect the spillovers from the laureate.[13]

We used the rich biographical information on Nobel laureates to hand-collect data on the institutional affiliations of each Nobel laureate in each year of her career (no laureate had more than three locations in each year). The data also contain a variety of other background information, including the years of any bachelor's, master's, or doctoral work. As noted above, we define the beginning of a laureate's career as 3 years before the receipt of her first doctorate or highest other degree.[14]

Variables i) and ii) are measures of the opportunities the scientist has to arbitrage ideas over the year. Variable iii) reflects that any study on the impact of spillovers from high-quality colleagues must have a way of defining such colleagues. Our measure has the advantages that it certainly captures the presence of high-quality colleagues, and that there are no judgment calls on who is a high-quality colleague. However, it is invariably too narrow, since there will also be very good colleagues who provide substantial spillovers.[15]

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[12] Our resolution is such that we can pick up locations where researchers spend roughly 1 or 2 months.

[13] We also reran our model where we weighted each laureate by the amount of time that the scientist spent with the laureate. This did not affect the sign or significance of the coefficient, but since it is essentially a rescaling, it did affect the size of the coefficient.

[14] In the early years in the sample, not all Nobel laureates received doctorates. Some laureates, especially in Medicine or those trained in Germany, have two doctorates. For these laureates, the first doctorate was used.

[15] Since the number of high quality colleagues who do not win the prize is likely to be positively correlated with the number of eventual Prize winners, our coefficients on the number of laureates are probably too high.

Consider estimating the transition rate for beginning Nobel work. Estimates of hazard models generally assume that $X_i(\tau_i + t)$ and θ_{bi} are independent at the beginning of the spell for some sample. For example, one of the most common uses of duration models is to study unemployment durations, and there one often assumes that this independence condition holds for the flow of individuals who enter unemployment, rather than the stock of the unemployed at a given time As noted above, it is patently implausible to assume that $X_i(\tau_i + t)$ and θ_{bi}, or $X_i(\tau_i + t)$ and θ_{di}, are independent in the sample of all scientists. Instead, we investigate the plausibility of these assumptions for the very select group who eventually do Nobel work. For simplicity we focus on the independence of $X_i(\tau_i + t)$ and θ_{bi} among those who win the Prize since it is difficult to think of situations where independence holds with respect to θ_{bi}, but not with respect to θ_{di}, among those who win the Prize.

Consider first our independence assumption about new or multiple locations. To move to a new location, a scientist must be offered a new job and then accept the job. Since these are choice variables, they will depend on individual tastes. However, for our purposes, the crucial question is whether the decision to move to a new location or spend time in multiple locations, conditional on having an offer to do so, depends on scientists' unobserved productivity. We argue that among the very select sample of eventual prize winners, the decision whether to move to a new place will be driven by family circumstances and tastes for change/psychic costs of moving, and uncorrelated with productivity.

In terms of receiving outside offers, we argue that the scientists in our sample of Prize winners are so good that they would all merit offers. A similar argument applies to being in multiple locations: all the scientists in our sample would be good enough to obtain appointments in multiple locations. Thus, we would argue that being in a new location or having multiple locations is likely to be independent of unobserved (to the econometrician) productivity differences in our sample.[16]

[16] Note that these binary variables will not be affected by the fact that scientists with higher unobserved productivity will receive offers from better places.

However, there is a real possibility that an independence assumption about the quality of a scientist's colleagues and θ_{bi} will be violated, since even within this elite group of scientists, those with higher perceived productivity may attract even quicker appointments to top universities or invitations to join the highest quality research institutes. Hence, they are likely to have more exposure to more eventual Prize winners. Thus, we cannot directly rule out the case where a scientist's quality leads to higher quality colleagues instead of the reverse. However, we argue that it is possible to obtain indirect evidence concerning ing our independence assumptions about the quality of a scientist's colleagues in the following manner. If the quality of colleagues variable is significantly positive in the beginning work hazard function because of its correlation with θ_{bi}, we would also expect it to be positively correlated with θ_{di}, and hence significantly increase the hazard function in the doing hazard. In fact, one might expect that the effect of number of eventual laureates to be even stronger in the doing hazard, since productivity differences are more likely to be observed by schools as a scientist's career progresses. Notably, we find that the quality of one's colleagues affects only when a researcher starts his Nobel work, and does not affect when he or she does his or her Nobel work. We believe that this gives strong support to our independence assumption concerning our quality of colleagues variable. Note that if differences in new locations or multiple location are not independent of unobserved productivity differences, we would also expect them to be positively related to how quickly laureates do their Prize-winning work, but we do not find that this is the case.

IV.2 ***Econometric Approach***

We estimate the parameters of the beginning hazard function in (1) for our select sample by maximum likelihood. In calculating a scientist's contribution to the likelihood function, we need to account for the fact that she started her Prize-winning work within a certain time interval, which we denote by *BP=1*. For notational convenience, we drop all *i* subscripts and *b* subscripts. The contribution for a scientist who begins her Nobel work at t' is derived in full in the Appendix, where we show it equals[17]

[17] For expositional ease, in first two lines of (3) we let the term $\Pr(t', \theta \mid \mathrm{BP} = 1)$ denote a mixture of a discrete variable t' and a continuous variable θ_b, as is clear from the third line of (3).

$$\Pr(t' \mid BP = 1) = \int_{\theta} \Pr(t', \theta \mid \mathrm{BP} = 1)\, d\theta$$

$$\int_{\theta} \Pr(t' \mid \mathrm{BP} = 1, \theta)\; g(\theta \mid \mathrm{BP} = 1)\; \theta$$

$$= \int_{\theta} \left[\frac{\lambda(\mathrm{t}' \mid X(\tau + t'), \theta) \prod_{r=1}^{\mathrm{t}'-1} (1 - \lambda(r \mid X(\tau + r), \theta))}{1 - \prod_{r=1}^{A^*} (1 - \lambda(r \mid X(\tau + r), \theta))} \right] g(\theta \mid BP = 1)\, d\theta\,; \qquad (3)$$

recall that $\lambda(\mathrm{t}' \mid X(\tau + t'), \theta)$ is the conditional probability of beginning Prize-winning work in year t' (after the start of their career). In (3), for those who reach age 70 before 2003, the last year of our data, A* equals 70 minus the age when they started their career; otherwise, A* equals their age in 2003 minus their age when they started their career. Finally, we model $g(\theta \mid \mathrm{BP}) = 1)$ using the Heckman-Singer (1984b) approach, where θ follows a discrete distribution with J points of support θ_j, ($\mathrm{j} = 1, ..., J$) and associated probabilities P_j respectively.

Because the estimated hazard function coefficients can be difficult to interpret, we also use these coefficients to calculate the counterfactual effect of changing an independent variable on the expected duration of time until beginning Nobel work. As noted above, calculating effects based expected durations has the advantage that these estimated effects have been found to be much less sensitive than the actual coefficients to misspecification of the duration dependence function or unobserved heterogeneity distribution (Li and Smith [2015]). We note that, conditional on the unobserved heterogeneity θ, the probability that a scientist begins his or her Nobel work *t* years after she began her career is given by the density function

$$f\left(t \middle| \theta\right) = \left[\lambda(\mathrm{t} \mid X(\tau + t), \theta) \prod_{r=1}^{\mathrm{t}-1} (1 - \lambda(r \mid X(\tau + r), \theta)) \right] / \left[1 - \prod_{r=1}^{A^*} (1 - \lambda(r \mid X(\tau + r), \theta)) \right]. \qquad (4)$$

Since individuals are assumed to retire at age 70, we instead calculate a truncated expected duration to conduct our counterfactuals:

$$ED_b^{trunc} = \int_{\theta} \left(\sum_{t=1}^{A^*-1} f\left(t \middle| \theta\right) + A^* S\left(A^* \middle| \theta\right) \right) g(\theta \mid \mathrm{BP})\, d\theta, \quad \text{where} \qquad (5)$$

$$S\left(A\middle|\theta\right)=\left[\prod_{r=1}^{A^*}(1-\lambda(r\mid X(\tau+r),\theta))\right]/\left[1-\prod_{r=1}^{A^*}(1-\lambda(r\mid X(\tau+r),\theta))\right]. \quad (6)$$

For example, suppose we want to know the effect on the average expected time until beginning work of increasing the number of laureates in each year by one for each scientist. We calculate (5) for each scientist given the values of his or her explanatory variables and take the average across the sample. We then calculate (5) for each scientist when he or she has one additional laureate in his or her location in each period, and again take the average across the sample. The effect of adding one laureate in each period on expected time until beginning Nobel work is the difference in these two quantities. Obtaining standard errors for these counterfactuals is straightforward as the delta method can be used because the difference in the expected truncated durations is a differentiable function of the parameters with non-zero, bounded derivatives.[18]

Our approach for estimating the parameters of the hazard function and changes in expected durations for doing the work is completely analogous to that for beginning the work, and is omitted for expositional ease. Before turning to our empirical results, we emphasize that our focus on Nobel laureates should not be viewed as an assumption that the Nobel laureates are the most important innovators in their fields. Rather, we view them as a group of people who have made important contributions, and perhaps the only such group for whom the data necessary to estimate our model are available.

V. Data

As noted, our data cover the period 1903-2003. There are 485 laureates in our sample: 140 in Chemistry, 166 in Physics, and 179 in Medicine. Besides the time when the scientist starts and does Prize-winning work, the only complicated data issue is calculating the number of laureates in each city in each year. Since we know the location of each laureate in each year, we can calculate the total number of current or future laureates in field *f* in each city *c* in each year *t*, N_{fct}. For each laureate *i* in each year, *t*, we then identify the set of cities in which they are located in year *t*, C_{it}.[19]

[18] Interestingly, the only other studies we know of that calculate such counterfactual effects and their standard errors are Ham, Li and Shore-Sheppard (2016) and Bocca et al. (2016).

[19] Here metropolitan areas, not institutions are the units of analysis, so that the laureates in a city are counted once

We then take the sum of the number of laureates in *i*'s field across all the cities that *i* is in during *t*, i.e. $N_{it} = \sum_{c \in C_{it}} N_{fct}$. Summing laureates across cities as opposed to weighing them by the fraction of time spent in each city, assumes that ideas can transfer in a relatively short period of time (i.e. that splitting time does not reduce the amount of spillover).[20]

Table 1 provides means for our variables of primary interest in the years that: i) scientists started their Nobel work; ii) scientists did their Nobel work; iii) all years. We see that the means in i) are much higher than those in ii) and iii), while the means in ii) and iii) are relatively similar. This leads us to expect that these strong univariate correlations between the variables of interest and beginning (but not doing) Nobel work will show up in our more formal analysis. In the same vein, in Figure 2 we conduct some simple univariate data analysis of our three explanatory variables of interest around the time that a laureate makes a transition to starting her Nobel work and makes a transition to doing her Nobel work.

Panel A indicates that five years before beginning Nobel work, the mean value of new locations is 0.18. This number falls steadily to 0.1 until the year of transitioning to starting her Nobel work, at which point it increases to over 0.2. After people have begun their work, the mean falls to roughly 0.05 and remains at that level for the rest of the period. Thus, there is a sharp increase in the mean value across the sample of being in a new location in the year that people begin their Nobel work.

Panel B reports the analogous figure for being in multiple locations. Here too there is a marked increase in the mean value of being in multiple locations in the year that people transition to beginning their Nobel work. Panel C shows the corresponding information for the number of (own field) laureates that people are around; this variable shows the same patterns as in Panel A and in Panel B. All told, these figures suggest that there is something markedly different about the years in which people begin their Nobel work compared to previous or later years.

Panels D, E, and F report analogous results for the years that people transition to doing

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even if someone has more than one affiliation in a given city.

[20] Our measure based on summing laureates across cities, as opposed to the measure formed by prorating them by city, will tend to diminish the estimated coefficient on the multiple locations. This occurs because the first measure will be more positively correlated with the multiple location variable than the second measure, since the number of laureates present across cities tends to be higher when people are in multiple locations.

their Nobel work. These figures for doing Nobel work contrast with the previous ones for starting Nobel work, showing no breaks around the transition to the doing work years. As indicated, we find this contrast reassuring insofar as reverse causality would imply that people would be at least as likely to be recruited to new places, additional places, or places with more other laureates when they are on the verge of doing their Nobel work rather than beginning it. We now provide a more formal analysis of these relationships.

V.2 Estimating Hazard Parameters and Counter-Factual Effects

Table 2 reports our main results on the determinants of the probability of beginning Nobel work. Panel A provides estimates of the coefficients of the hazard functions, while Panel B provides information on the effects of changes our independent variables of interest on the expected time until beginning Nobel work. Since there is no difference in the statistical significance of the coefficients of interest and the respective expected duration effects, we focus on the latter since they are much easier to interpret. Our hazard functions depend on our primary variables of interest and duration, as well as (coefficients not shown) calendar year, calendar year squared, and field of specialization dummy variables.

In no specification were we able to find any evidence of unobserved heterogeneity; one potential explanation of this result is that the differences in unobserved productivity between scientists in our sample are relatively small. However, as noted above, even if our hazard parameter estimates are biased by not being able to control for this unobserved heterogeneity, our expected duration calculations are unlikely to be affected by it.

In column (1) we enter the new location variable but not the multiple locations' variable or the number of laureates' variables. We estimate that being in a new location every 2, 3 and 5 years lowers significantly the expected time until starting Nobel work by 2.88, 2.12 and 1.09 years respectively; all estimated effects are statistically significant. In column (2) we consider only the effect of being in multiple locations, i.e. we do not control for the new location and number of laureates' variables. The parameter estimates indicate that always being in multiple locations, as opposed to never being in multiple locations, reduces the expected time until starting Nobel work by a very statistically significant 4.14 years. In column (4) we control for both the new location variables and multiple location variables but not the number of laureates variable. We estimate that being in a new location every 2 years lowers the expected time until starting Nobel work by a

statistically significant -1.979 years, and that always being in multiple locations, as opposed to never being in multiple locations, significantly reduces the expected time until starting Nobel work by 3.240 years. We begin by focusing on our estimates without the number of laureates variable included, since consistent estimation of their coefficients does not require that the number of laureates is independent of the unobserved heterogeneity term. Further, the multiple location and new location variables highlight our original contribution to this literature implied by a recombinant view of innovation. In column (3) we control for the number of laureates, but not for new and multiple locations. We estimate that being around one more Nobel laureate each year reduces the expected time until beginning Nobel work by a statistically significant 2.98 years.

As indicated, columns (4) - (6) introduce our primary variables of interest two at a time. The expected duration effects for each independent variable decrease by a small amount, but the estimated effects are still quite statistically significant. We see some of our smallest counterfactual effects when we enter all three variables of interest simultaneously in column (7), but all of these estimated effects remain statistically significant. In this case, we find that being in a new location every other year reduces the expected duration until starting Nobel work by between 1.99 years, while always being in multiple locations, as opposed to never being in multiple locations, reduces the expected time until starting Nobel work by 2.50 years. Finally, being around one more Nobel laureate each year reduces time until beginning such work by 1.90 years. Note that all the above effects also are economically significant, since the mean estimated expected length of time until starting is approximately 10.57 years.

In Table 3 we consider the effect on the parameter estimates of adding interactions between each of our variables of interest. In columns (1)–(3) we add each one of the three possible interactions, while in column (4) we add all of the three two-way interactions at once. None of the coefficients on these interactions effects even approaches statistical significance; moreover, our main estimates are robust. Not surprisingly, adding the interactions does not affect our expected duration calculations.

In Table 4 we examine the robustness of our results to the definition of new location. Column (1) repeats the results in Column (7) of Table 1, where a new location is defined as one where the scientist has not been in the last 5 years. In columns (2) and (3) we redefine a new location defined as one where the scientist has not been in the last 10 and 20 years respectively.

Changing the definition of a new location has a negligible effect on the parameter estimates or the counterfactual expected durations.

Table 5 reports our results when we estimate the hazard function for making a transition to *doing the Nobel work,* analogous to our basic results for *beginning Nobel work* presented in Table 2. The multiple location variable and number of laureates variable never have a statistically significant coefficient or a significant effect on expected durations. The new location coefficient is always negative (i.e. lowers the probability of doing Nobel work) and is significant at the 10% level in column (5); it is on the verge of statistical significance at the 10% level in the other columns. From Column (7) of Panel B of Table 5 we see that being in a new location every other year increases the expected time to doing Nobel work by a non-trivial, and statistically significant, 1.628 years on a base of 16.65 years.[21] Further, we estimate that being in a new location every 3 or 5 years increases the expected time until doing the Nobel work by (a quite significant) 1.074 and 0.478 years respectively. The estimated increase in the expected time until doing Nobel work from being in a new location presumably reflects the transaction costs of moving.

As noted above, if our results for starting Nobel work reflected a scientist's unobserved productivity causing her to move to a new location, be in multiple locations, or have a larger number of laureates locally, we would expect these variables also to significantly reduce the expected time until doing Nobel work. Moreover, we would expect the absolute value of the effects on doing are expected to be bigger than the absolute value of the effects for beginning. Since this is clearly not the case, a comparison of Tables 2 and 5 suggests that our results are not being driven by reverse causality. Moreover, if part of the effect of being around more laureates simply reflected lobbying by her colleagues, we would expect this variable to also significantly reduce the expected time until doing, with the absolute value of this effect again being larger than the effect on beginning Nobel work.

Finally, these estimates give a sense of how being in a new location, multiple locations, or around more other important scientists affects the probability of starting important work for people who do very high-quality work. We consider the effects as local in the sense that we would not

[21] The standard errors for the expected duration effects depend on the entire variance-covariance matrix of all the estimated parameters.

want to extrapolate these effects to much less able scientists, i.e. forecast way out-of-sample. Unfortunately, we know of no data set that will allow us to estimate these effects for scientists doing less important work.

VI. Conclusion

Drawing on recombinant innovation logic, we provide evidence for novel knowledge spillover mechanisms. Being in a new location, as a measure of exposure to new ideas, and being in multiple locations, as a measure of exposure to a wider ranging set of ideas than most others are exposed to, both increase the probability of beginning Nobel work in the natural sciences.

We analyze an extremely highly selected sample – Nobel laureates – for whom we have data that is rich enough that we can exploit timing and measure our variables of interest in each year. We argue above that we do not expect the new location and multiple location variables to be endogenous for beginning or doing the work within our sample of people who win Nobel Prizes. While the case for number of proximate Nobel laureates variable to be endogenous, a priori, is considerably strong, the fact that we find that this variable does not affect the probability of doing Prize-winning work suggests that our results for beginning Prize-winning work are not being driven by reverse causality. We find large positive effects of all of the spillover variables on beginning Nobel work, but only a negative spillover of moving to a new location in terms of doing Nobel work.

Our work can also help reconcile existing estimates and the apparently opposing views of economists and researchers in many other disciplines on the value of having better colleagues. Specifically, our work points to the importance of identifying the point at which spillovers from having better colleagues operate – at the start of the research agenda rather than at the time when the scientist is executing the work (or *a fortiori* publishing the work). Thus, we argue that many non-economists are correct that good colleagues are very important for beginning important work, but that economists are correct in the sense that better colleagues do not help a scientist do important work. The differences in timing can also can help explain the why Waldinger [2010, 2012] finds larger effects of important colleagues for graduate students, who are new to a field, than faculty colleagues. Finally, our work explains the importance of field vibrancy identified in Azoulay, Graff Zivin, and Wang [2011] in terms of starting important work.

At a practical level, our estimates point to the value intense cross-pollination as a way of stimulating important innovative work as might arise from visiting-style arrangements. This implication stands in contrast to previous conceptualizations of knowledge spillovers, which emphasize concentrating innovators in clusters over the research life-cycle.

Appendix

In this Appendix, for notational convenience we drop all *i* subscripts and *b* subscripts. As in the text, let *BP=1* denote the event that a scientist begins Prize-winning work over our sample period; note that *BP=1* for everyone in our sample. While we will work with the heterogeneity distribution conditional on *BP=1*, we must adjust the density function conditional on the unobserved heterogeneity to account for out sample selection. The event *BP=1* occurs if a laureate begins her work by *A*,* where the latter is defined to be equal to the calendar year when the scientist turns 70 years old (if that occurs before 2003) minus the calendar year she starts her career, or by 2003 minus the calendar year she starts her career if she turns 71 years old after 2003. For expositional ease denote the event BP=1 by BP. We need to show the probability of beginning Nobel work in period t is given by

$$\Pr(t \mid BP) = \int_{\theta} \left[\frac{\lambda(\mathrm{t}' \mid X(\tau+t),\theta) \prod_{r=1}^{\mathrm{t}'-1} (1-\lambda(r \mid X(\tau+r),\theta))}{1-\prod_{r=1}^{A^*} (1-\lambda(r \mid X(\tau+r),\theta))} \right] g(\theta \mid BP)\, d\theta. \qquad \text{(A1)}$$

By definition

$$\Pr(t \mid BP) = \int_{\theta} \Pr(t,\theta \mid BP)\, d\theta = \int_{\theta} \frac{\Pr(t,\theta,BP)}{\Pr(BP)}\, d\theta. \qquad \text{(A2)}$$

Considering the numerator in (A2) we have

$$\Pr(t,\theta,BP) = \Pr(t \mid \theta,BP) \Pr(\theta,BP)$$

$$= \Pr(t \mid \theta,BP) \Pr(\theta \mid BP) \Pr(BP). \qquad \text{(A3)}$$

Substituting (A3) into (A2) yields

$$\Pr(t \mid BP) = \int_{\theta} \frac{\Pr(t \mid \theta, BP)\Pr(\theta \mid BP)\Pr(BP)}{\Pr(BP)}\, d\theta$$

$$= \frac{\Pr(BP)}{\Pr(BP)} \int_{\theta} \Pr(t \mid \theta, BP)\Pr(\theta \mid BP)\, d\theta$$

$$= \int_{\theta} \Pr(t \mid \theta, BP)\Pr(\theta \mid BP)\, d\theta. \qquad \text{(A4)}$$

The first term inside the integral in (A4) is

$$\Pr(t \mid \theta, BP) = \frac{\Pr(t, BP \mid \theta)}{\Pr(BP \mid \theta)} = \frac{\Pr(BP \mid \theta, t)\Pr(t \mid \theta)}{\Pr(BP \mid \theta)} = \frac{\Pr(t \mid \theta)}{\Pr(BP \mid \theta)}. \qquad \text{(A5)}$$

The simplification in the numerator of (A5) arises from the fact that $\Pr(BP \mid \theta, t) = 1$ since $A^* \geq t$ by definition. The numerator in (A5) can be written

$$\Pr(t \mid \theta) = \lambda(t' \mid X(\tau + t'), \theta) \prod_{r=1}^{t'-1} (1 - \lambda(r \mid X(\tau + r), \theta)). \qquad \text{(A6)}$$

Consider the denominator of (A5) and note that the probability that a scientist does not complete her Nobel work by A^* is simply the survivor function

$$\Pr(t > A^* \mid \theta) = \prod_{r=1}^{A^*} (1 - \lambda(r \mid X(\tau + r), \theta)).$$

Thus, the denominator in (A5) is

$$\Pr(BP \mid \theta) = 1 - \left[\prod_{r=1}^{A^*} (1 - \lambda(r \mid X(\tau + r), \theta)) \right]. \qquad \text{(A7)}$$

Substituting (A6) and (A7) into (A5) yields (A1), i.e. the expression in the text of the paper.

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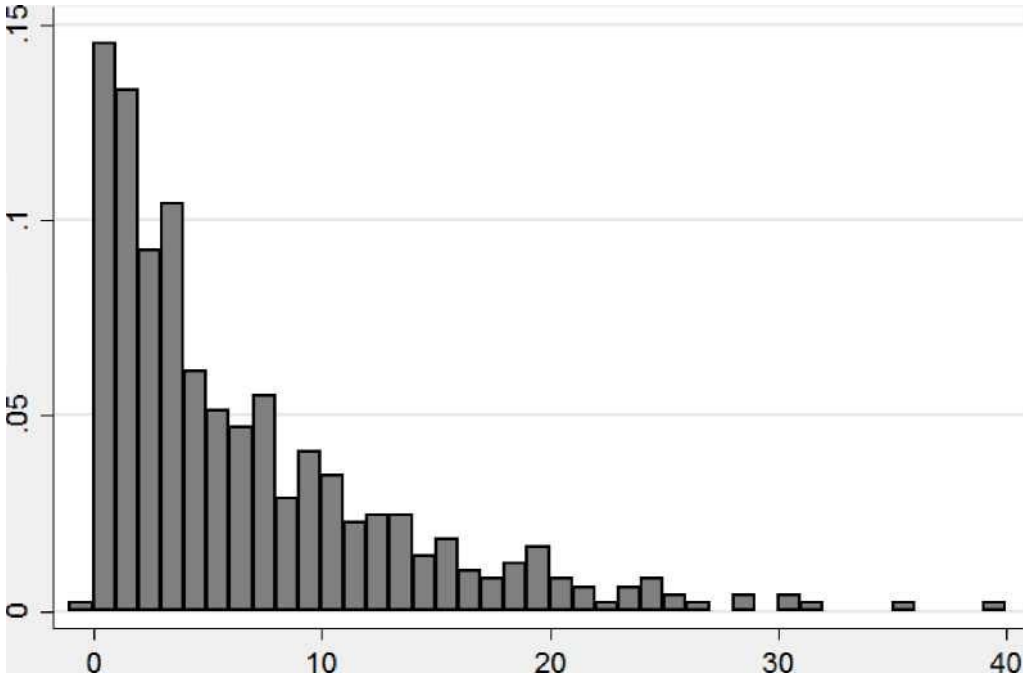
Figure 1

Frequency Distribution of the Difference in the Number of Years Until Doing Nobel Prize-Winning Work and Until Starting Nobel Prize-Winning Work



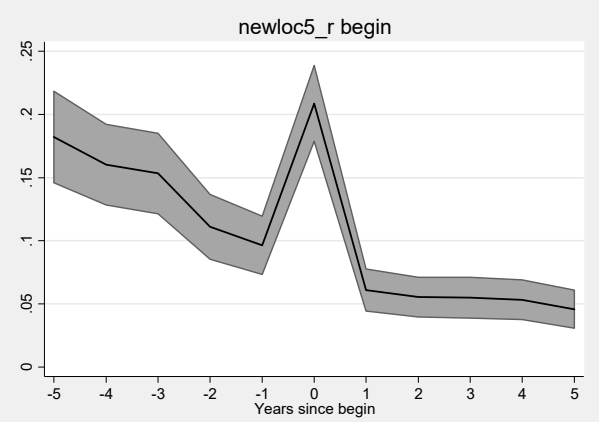
Note: This and the following figures are based on 485 Nobel laureates. The minimum gap is 0. The modal gap is 1 year. The median gap is 5 years and the mean gap approximately 6 years.

Figure 2.

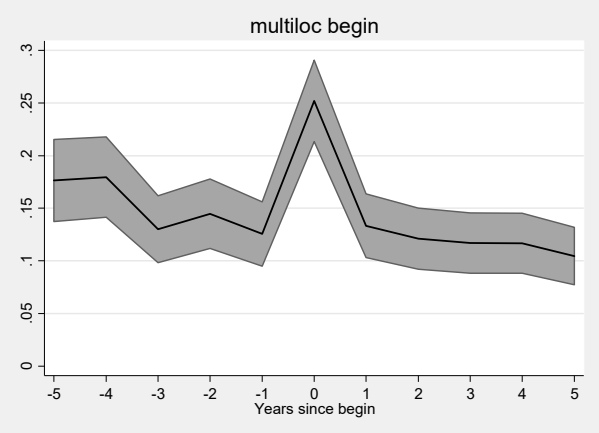
Number of Current and Future Laureates in a Laureate's Location around the Time She Begins and Does her Prize-Winning Work

Years Before / Since Began (N=4,966)

New Location



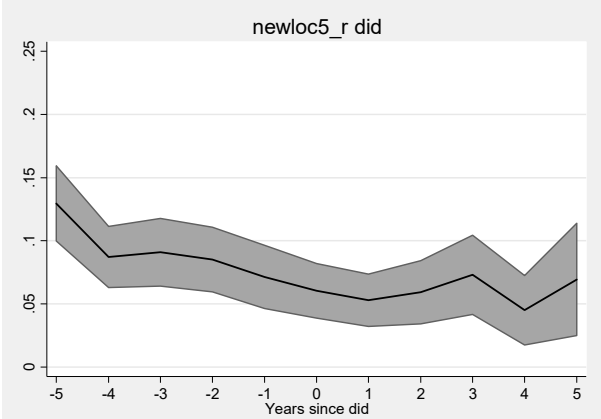
Multiple Locations



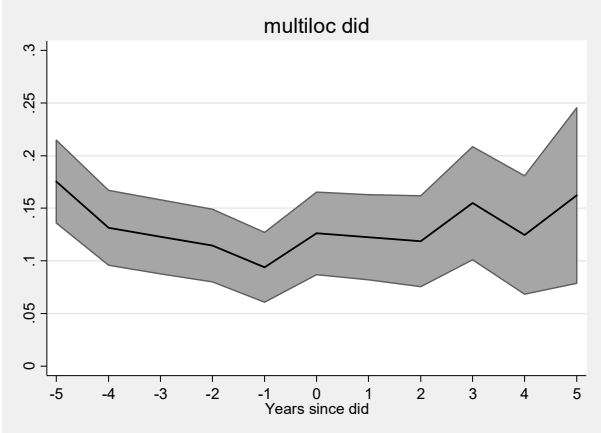
Own Field Laureates Present

Years Before / Since Did (N=5,264)

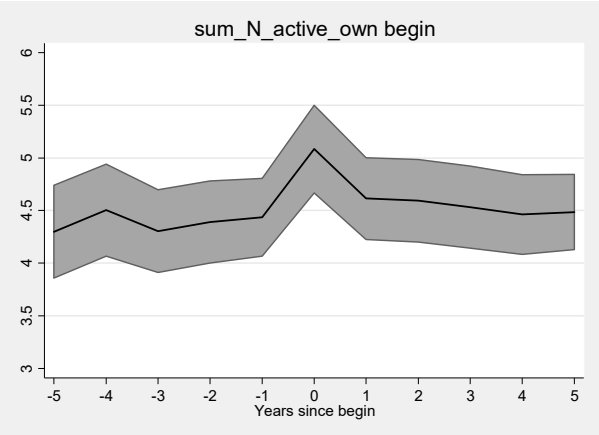
New Location

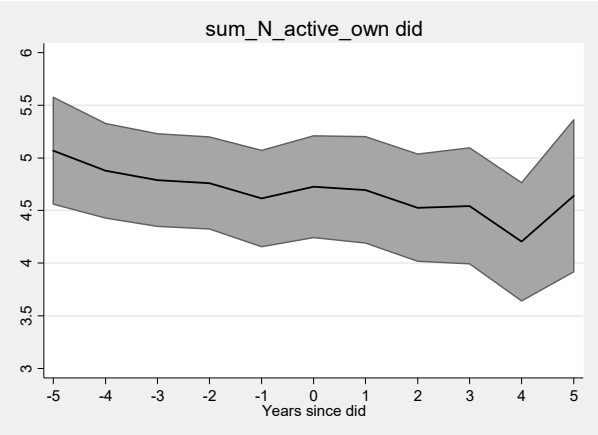


Multiple Locations



Own Field Laureates Present





Note: The year each laureate makes a transition to starting/doing Prize-winning work is normalized to 0. The figure reports means and 95% confidence intervals.

Table 1

Means of Our Variables of Interest in Various Years

	Begin Years	Did Years	All Years
New Location	0.209	0.0488	0.0640
In Multiple Locations	0.252	0.0990	0.0943
Own Field Laureates	5.084	4.546	4.325

Table 2
Parameter Estimates for the Hazard Function of Beginning Prize Winning Work in a Given Year – Base Model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. Coefficients							
New Location	0.855***	-	-	0.586***	0.777***	-	0.592***
(Five Year Definition)	(0.162)			(0.175)	(0.165)		(0.175)
Multiple Locations	-	0.730***	-	0.544***	-	0.600***	0.409***
		(0.117)		(0.127)		(0.127)	(0.136)
Number of Laureates	-	-	0.529***	-	0.448***	0.313**	0.317**
			(0.111)		(0.117)	(0.124)	(0.127)
First 5 Years of Career	-1.149***	-0.964***	-0.908***	-1.120***	-1.152***	-0.974***	-1.130***
	(0.142)	(0.130)	(0.129)	(0.143)	(0.143)	(0.132)	(0.144)
Second 5 Years of Career	-0.333***	-0.370***	-0.323**	-0.383***	-0.364***	-0.380***	-0.394***
	(0.124)	(0.126)	(0.126)	(0.126)	(0.127)	(0.127)	(0.128)
B. Expected Duration Calculations							
Expected Duration (years) to Begin	10.471***	10.546***	10.592***	10.534***	10.564***	10.578***	10.566***
	(0.125)	(0.119)	(0.123)	(0.123)	(0.128)	(0.121)	(0.125)
Effect on Expected Duration of:							
A New Location	-2.884***	-	-	-1.979***	-2.630***	-	-1.999***
Every 2 years	(0.326)			(0.379)	(0.346)		(0.383)
A New Location	-2.119***	-	-	-1.376***	-1.900***	-	-1.391***
Every 3 years	(0.216)			(0.216)	(0.219)		(0.219)
A New Location	-1.090***	-	-	-0.686***	-0.965***	-	-0.692***
Every 5 years	(0.069)			(0.061)	(0.067)		(0.061)
Always Multiple Location	-	-4.141***	-	-3.240***	-	-3.493***	-2.499***
vs Never Multiple Location		(0.371)		(0.479)		(0.470)	(0.606)
One Extra Laureate	-	-	-2.983***	-	-2.616***	-1.865***	-1.904***
Each Year			(0.295)		(0.359)	(0.446)	(0.476)
Log L	-1555.74	-1552.4	-1559.6	-1546.88	-1547.7	-1549	-1543.39

Table 3
Parameter Estimates for the Hazard Function of Beginning Prize Winning Work in a Given Year – Allowing for Interactions

	(1)	(2)	(3)	(4)
A. Coefficients				
New Location	0.666***	0.592***	0.589***	0.621***
(Five Year Definition)	(0.185)	(0.175)	(0.208)	(0.217)
Multiple Locations	0.599**	0.506***	0.409***	0.438
	(0.237)	(0.181)	(0.136)	(0.285)
Number of Laureates	0.318**	0.400**	0.315*	0.312
	(0.127)	(0.174)	(0.171)	(0.193)
*New Location*Multiple Locations*	-0.466	-	-	-0.100
	(0.478)			(0.502)
*New Location*Number of Laureates*	-	-	0.008	-0.040
			(0.326)	(0.372)
*Multiple Locations*Number of Laureates*	-	-0.183	-	0.031
		(0.251)		(0.279)
First 5 Years of Career	-1.133***	-1.129***	-1.130***	-1.130***
	(0.144)	(0.144)	(0.144)	(0.144)
Second 5 Years of Career	-0.398***	-0.394***	-0.394***	-0.395***
	(0.128)	(0.128)	(0.128)	(0.128)
B. Expected Duration Calculations				
Expected Duration (years) to Begin	10.569***	10.572***	10.566***	10.567***
	(0.127)	(0.125)	(0.125)	(0.128)
Effect on Expected Duration of:				
A New Location	-2.260***	-1.997***	-1.989***	-2.100***
Every 2 years	(0.432)	(0.384)	(0.530)	(0.587)
A New Location	-1.589***	-1.388***	-1.383***	-1.467***
Every 3 years	(0.257)	(0.219)	(0.302)	(0.340)
A New Location	-0.799***	-0.691***	-0.688***	-0.733***
Every 5 years	(0.075)	(0.061)	(0.085)	(0.097)
Always Multiple Location	-3.532**	-3.037***	-2.496***	-2.663
vs Never Multiple Location	(1.586)	(0.979)	(0.609)	(2.555)
One Extra Laureate	-1.911***	-2.348***	-1.891**	-1.877*
Each Year	(0.474)	(0.809)	(0.866)	(1.102)
Log L	-1542.8	-1543	-1543.4	-1543.3

Table 4
Parameter Estimates for the Hazard Function of Beginning Prize Winning Work in a Given Year – Allowing for Different Definitions of New Location in the Base Model

	(1)	(2)	(3)
A. Coefficients			
Multiple Locations	0.409***	0.415***	0.414***
	(0.136)	(0.135)	(0.135)
Number of Laureates	0.317**	0.318**	0.318**
	(0.127)	(0.127)	(0.127)
New Location	0.592***	-	-
(5 Year Definition)	(0.175)		
New Location	-	0.594***	-
(10 Year Definition)		(0.175)	
New Location	-	-	0.603***
(20 Year Definition)			(0.176)
First 5 Years of Career	-1.130***	-1.137***	-1.141***
	(0.144)	(0.145)	(0.145)
Second 5 Years of Career	-0.394***	-0.398***	-0.399***
	(0.128)	(0.128)	(0.128)
B. Expected Duration Calculations			
Expected Duration (years) to Begin	10.566***	10.565***	10.566***
	(0.125)	(0.125)	(0.126)
Effect on Expected Duration of:			
A New Location	-1.999***	-2.002***	-2.030***
Every 2 years	(0.383)	(0.379)	(0.380)
A New Location	-1.391***	-1.393***	-1.414***
Every 3 years	(0.219)	(0.217)	(0.218)
A New Location	-0.692***	-0.693***	-0.704***
Every 5 years	(0.061)	(0.061)	(0.061)
Always Multiple Location	-2.499***	-2.531***	-2.528***
vs Never Multiple Location	(0.606)	(0.596)	(0.597)
One Extra Laureate	-1.904***	-1.910***	-1.910***
Each Year	(0.476)	(0.472)	(0.473)
Log L	-1543.39	-1543.4	-1543.23

Table 5
Parameter Estimates for the Hazard Function of Doing Prize Winning Work in a Given Year – Base Model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. Coefficients							
New Location	-0.442	-	-	-0.552	-0.463*	-	-0.549
(Five Year Definition)	(0.278)			(0.341)	(0.281)		(0.341)
Multiple Locations	-	-0.066	-	0.122	-	-0.088	0.102
		(0.165)		(0.200)		(0.169)	(0.203)
Number of Laureates	-	-	0.030	-	0.065	0.052	0.046
			(0.128)		(0.128)	(0.132)	(0.131)
First 5 Years of Career	-1.770***	-1.864***	-1.872***	-1.761***	-1.768***	-1.863***	-1.762***
	(0.200)	(0.195)	(0.194)	(0.201)	(0.200)	(0.195)	(0.201)
Second 5 Years of Career	-0.693***	-0.706***	-0.712***	-0.698***	-0.694***	-0.706***	-0.698***
	(0.132)	(0.132)	(0.131)	(0.132)	(0.132)	(0.132)	(0.132)
B. Expected Duration Calculations							
Expected Duration (years) to Begin	16.643** *	16.641** *	16.642** *	16.640** *	16.650** *	16.647** *	16.645** *
	(0.229)	(0.230)	(0.230)	(0.228)	(0.229)	(0.230)	(0.229)
Effect on Expected Duration of:							
A New Location	1.352**	-	-	1.638**	1.406**	-	1.628**
Every 2 years	(0.564)			(0.742)	(0.558)		(0.741)
A New Location	0.898***	-	-	1.079***	0.932***	-	1.074***
Every 3 years	(0.235)			(0.299)	(0.231)		(0.299)
A New Location	0.403***	-	-	0.481***	0.418***	-	0.478***
Every 5 years	(0.045)			(0.055)	(0.044)		(0.055)
Always Multiple Location	-	0.453	-	-0.839	-	0.604	-0.699
vs Never Multiple Location		(1.295)		(1.861)		(1.362)	(1.937)
One Extra Laureate	-	-	-0.210	-	-0.444	-0.362	-0.316
Each Year			(0.779)		(0.772)	(0.820)	(0.806)
Log L	-1702.30	-1703.71	-1703.76	-1702.10		-1703.63	-1702.04