The impact of postdoctoral training on early careers in biomedicine

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While postdocs are necessary for entry into tenure-track jobs, they do not enhance salaries in other job sectors over time.

The biomedical research enterprise is in crisis. NIH funding rates are near historic lows, the age at which a scientist may attain an independent research career is high, and there are far fewer permanent academic positions than graduating PhDs. Exacerbating this crisis is the peculiar institution of postdoctoral training[1–8]. During the past two decades, official bodies have raised concerns about the working conditions, long hours, lack of benefits, and forced geographic mobility faced by postdocs, as well as the effects of postdoc jobs on families[6,9–15]. Here, we examine the incidence and duration of biomedical postdoc positions, and the associated benefits and costs to those taking such a position, in terms of early career outcomes of employment placement and earnings.

Previous research has determined that increases in both supply and demand of biomedical PhDs fueled the rapid growth in biomedical postdocs[6,7,16–19]. From 1980 to 2010, the number of US biomedical PhDs awarded grew by 132%, with growth largely fueled by foreign nationals and women[2,10], while other STEM (science, technology, engineering, mathematics) fields grew by 76%[18]. In addition, supply increased with large (generally unmeasured) increases in biomedical scientists, awarded PhDs abroad, who took US postdoc jobs. Also, some have argued that the increasing complexity of scientific research requires additional training in postdocs[20–22]. Finally, advisor expectations orient holders of biomedical PhDs toward academic research careers requiring postdoc training[8,23]. While these factors increased the supply of postdocs, increases in research funding resulting from the doubling of NIH grant funding in 1998–2003 likely increased the demand for postdocs[2,6].

While researchers have studied aspects of the postdoctoral system[8,23–27], few have examined the impact of postdoc training on later career outcomes, owing to limited data. Earlier studies that did examine career outcomes have combined many academic fields[23–27], even though the effects in fields like biomedicine, where postdocs are commonplace, differ from the effects in other fields, where people generally start postdocs because they are unhappy with their job offers. One study that examined biomedical careers had small sample sizes and focused exclusively on highly selective National Research Service Award (NRSA) postdoc research fellowships[28] that may not be generalizable to all biomedical PhDs.

Data and variables

We used biennial longitudinal data from the 1981–2013 waves of the National Science Foundation (NSF) Survey of Doctorate Recipients matched to the 1980–2013 NSF Survey of Earned Doctorates. These surveys exclude postdoc trainees with foreign PhDs, and drop those with US PhDs who leave the US permanently. Details on data, methods, and construction of the variables, including postdoc incidence and duration, are described in the **Supplementary Notes**.

Our sample includes only subfields within biomedicine where postdocs were commonplace (i.e., a likelihood larger than 60%) in order to exclude fields where people tended to take postdoc positions as fallbacks. These fields comprised 83% of biomedical PhDs awarded in 2010 (**Supplementary Notes**, table S1). We excluded MD–PhDs (965) from our sample because their careers develop differently, and those PhDs with missing data. Our remaining sample included 10,402 biomedical PhDs who received US PhDs from 1980–2010. Our analysis sample was smaller when we measured subsequent career outcomes since it excluded recent graduates.

We defined the following outcomes for our analysis. Scientists were considered as starting their career in a postdoc if we observed them in a postdoc any time within the first three years after their PhD. We measured 3-year incidence for those who received PhDs in 1980 through 2010. Postdoc duration is defined as the number of years the person was in a postdoc within 8 years from the PhD, by which time more than 95% had completed their postdoc.

We divided jobs into five major sectors: tenured or tenure-track academia conducting research (tenured/TT), non-tenure-track (non-TT) academia conducting research, academia not conducting research, industry, and government/nonprofits. We defined those who reported doing basic or applied research as their primary or secondary work activity as "conducting research." Job sectors were measured a decade past PhD. Salary was adjusted for inflation.

Incidence and duration of biomedical postdocs

The number of scientists with biomedical PhDs starting in postdocs grew dramatically in 1987–1997 and then again in 2001–2009, corresponding to the large growth of biomedical PhD recipients[3,4,17] (**Fig. 1a**). This increase was associated with an explosion of temporary residents among new biomedical PhDs, from 4.7% in 1980 to 30.4% in 2007, then falling to 21.5%

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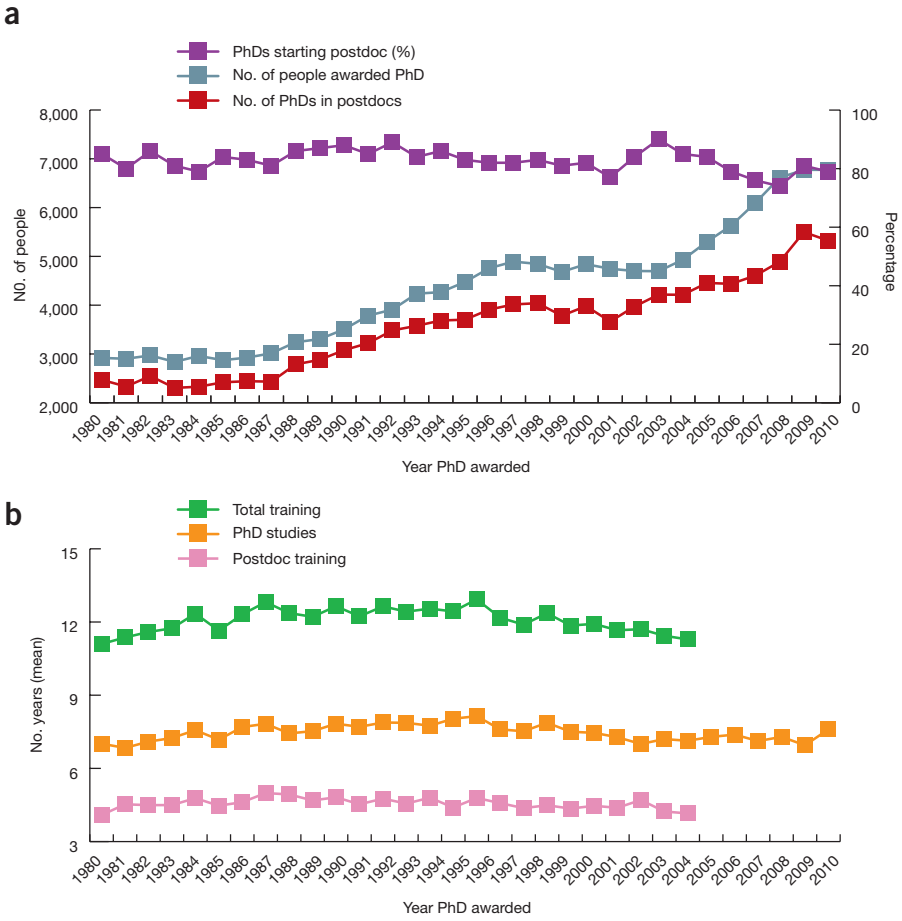

Figure 1 Trends in PhDs and postdoc training. (**a**) Trends over time in the number of biomedical PhDs awarded, number of biomedical PhDs in postdocs, and the percentage of biomedical PhDs starting their careers in postdocs. (**b**) Average number of years spent in graduate school, in postdocs, and in total training.

in 2010. PhD growth was also associated with women increasing from 29.9% of new biomedical PhDs in 1980 to 54.7% in 2010. However, the percentage of US biomedical PhDs starting their careers in a postdoc varied little from its 82.5% average between 1980 and 2010; it was highest for 2003 PhDs (89.8%) at the end of the NIH funding doubling, dipped to 73.9% in 2008, and ended at 78.6% in 2010 (**Fig. 1a**).

For those who started in a postdoc, postdoc duration averaged 4.5 of the first 8 years after the PhD. In contrast to the general belief that average duration of postdocs increased dramatically over these decades[15], we found no long-term trend in average duration (**Fig. 1b**), or long-term redistribution from shorter to longer postdocs (**Supplementary Fig. 1**).

Duration of the postdoc differed by the sector people eventually were employed in (**Supplementary Fig. 2**). Those in tenured/TT or non-TT research jobs 10 years after the PhD averaged 5.1 years in postdocs; those in government/nonprofit jobs, 4.6 years; while those in industry averaged 4.2 years. Postdoc duration for those entering academia peaked in the mid-to-late 1990s. In 1998, the Association for American Universities recommended that postdoc positions be limited to 6 years; 70% of its member universities had done so by 2005 (refs. 29,30), perhaps playing a role in decreasing the duration of postdocs after 1998.

The average number of years in graduate school varied from 6.8 to 8.1 years over the period, peaking in 1996. Combining both trends, total years of training (graduate school plus postdoc) rose for those awarded PhDs in 1980–1987 from 11.1 to 12.8 (**Fig. 1b**), plateaued at more than 12 years in 1987–1996, and then dropped gradually toward 1980 levels. This contrasts with the 7–11 years most physicians spend in medical training (including residencies), depending on specialty[31].

Factors associated with starting in postdoctoral positions

We used a probit model to examine the factors associated with starting in a postdoc for 1980–2010 PhDs, controlling for background, ability, demographic and demand factors, academic field, and year PhD was awarded. These estimates are correlations that may not be causal (**Fig. 2** and **Supplementary Notes**, table S3). People who were temporary residents when they received their PhDs (likely to be on student visas) were 8.1 percentage points (p.p.) more likely to take a postdoc ($P < 0.001$) than US citizens, all else being equal, similar to what was found in previous research[3,7,8,26,32]. Even controlling for temporary residency, Asians were 4.9 p.p. more likely to enter a postdoc than whites ($P < 0.001$), while other under-represented minorities behaved similarly to whites.

Age and family status affected postdoc choices. Older graduates were less likely to start in a postdoc, controlling for family-status variables. Each decade of age lowered the likelihood of starting in a postdoc by 6.3 p.p. ($P < 0.001$). Single males (the baseline category), single women, and married men without children were approximately equally likely to start in a postdoc, but married men with children and married women with or without children were each ~6.5–7 p.p. ($P < 0.001$) less likely to do so than single men.

Our model proxies for scientist quality using PhD attributes. Being from a PhD department ranked 100 spots better added 1.4 p.p. to the likelihood of starting a postdoc ($P < 0.001$). Each additional year in graduate school decreased the likelihood of starting a postdoc by 1.3 p.p. ($P < 0.001$). Research assistants in graduate school had a 5.1 p.p. ($P < 0.001$) higher likelihood of starting a postdoc. The fact that these indicators of high ability were associated with starting a postdoc suggests that individuals in postdocs were positively selected compared with those who skipped postdocs[8].

To capture market demand for PhD scientists at graduation, we included variables

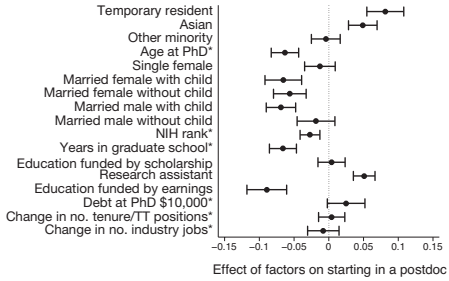

Figure 2 Estimated associations between 17 factors and the likelihood of starting one's career in a postdoc (within 3 years of PhD) with 95% confidence intervals, using probit model. Excluded family category: single males. *Variable coefficients are graphed as the impact of the difference between being at the 10th percentile vs. the 90th percentile.

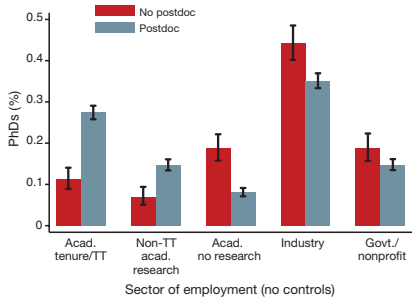

Figure 3 Percent of biomedical PhDs who started their careers with a postdoc, and those who did not, shown for each of five employment sectors, 10 years after degree awarded. Shown with 95% confidence intervals.

measuring the field-specific change in industry employment and in tenure-track but untenured faculty positions from the year before to the year after PhD receipt, both per PhD awarded. Neither variable had a significant effect, perhaps because our fields were defined too broadly to capture market forces.

Employment sector and research activities of biomedical PhDs 10 years after degree awarded

Since postdocs are almost always completed within ten years after the PhD, we examined career outcomes of employed 1980–2003 biomedical PhDs ~10 years after the doctorate.

Although previous research indicated that many people pursue a postdoc in order to obtain tenured/TT research jobs[8,33], just 27.4% of employed ex-postdocs had such positions (**Fig. 3**). We estimated a multinomial logit model of employment sector, holding constant the ability, demographic, field, and PhD-year variables used above, but found that controls explained little of the sectoral differences between those with and without a postdoc (**Supplementary Fig. 3**). Even controlling for these factors, only 29.6% of those employed who started in a postdoc were in tenured/TT jobs 10 years after the PhD.

Where did the nearly three-fourths of ex-postdocs without tenured/TT positions work instead? More ex-postdocs were employed in industry (35.1%) than in tenure-track jobs (**Fig. 3**). Those who skipped the postdoc (non-postdocs) were most likely (44.0%) to work in industry jobs. 14.7% of employed ex-postdocs but 7.2% of non-postdocs were in non-TT research academia, often soft-money jobs, dependent on grants. Non-postdocs were more likely than ex-postdocs to work in government or nonprofit jobs (**Fig. 3**), but were equally likely when controls were added (**Supplementary Fig. 3**).

Conventional wisdom holds that a postdoc is necessary for an academic biomedical career. We found that 7.6% of those employed at tenured/TT research jobs skipped postdocs. However, most of this small sample received their PhDs before 1995. Of the 17 people who received PhDs later, only 3 were in Research I universities. Such small samples are likely to be atypical, and we drop them in our salary discussion.

Dividing jobs by work activity rather than sector, we found a higher proportion of ex-postdocs than non-postdocs were conducting research (72% versus 45%, $P < 0.001$; **Supplementary Fig. 4**). Yet these percentages indicate that more than one-quarter of ex-postdocs were not conducting research, while almost half of non-postdocs were conducting research. Of those outside academia conducting research, 94% reported being in a job related to their PhD, suggesting that most of them were truly conducting biomedical research.

Over time, the probability of obtaining a tenured/TT job has declined. The number of biomedical academic tenured/TT jobs did grow (by 150%, ~8,700 jobs) from 1981–2013, but this could not keep up with the 278% (102,000 people) increase in new US PhDs. The percentage of employed biomedical PhDs in tenured/TT jobs 10 years after the PhD held steady, near 30%, in 1990–2003 (**Fig. 4**). Between 2003 and 2005 it declined to near 20% and remained this low through 2013. Even among ex-postdocs, only 21.0% were employed in tenured/TT jobs at year ten in 2013 (**Supplementary Fig. 5**).

The sharp decline in the percentage of PhDs in tenured/TT jobs coincided with the 2003 end of NIH funding doubling, which had decreased demand, and was exacerbated by increased supply of new biomedical PhDs from 2003–2008.

Finally, unemployment rates were small but higher among ex-postdocs than non-postdocs 10 years after the PhD (1.6% vs. 0.8%, $P = 0.08$; **Supplementary Fig. 6**). Also, non-postdocs were more likely to be out of the labor force than ex-postdocs (6.5% vs. 3.5%, $P < 0.001$), and these were mostly mothers (72%).

The impact of starting in a postdoc on early-career salaries

The NSF and NIH view postdoctoral training as a human capital investment in research skills and research independence, in which case we expected it to yield a positive return in the labor market[34]. Our results indicate that it did not, at least for the first 15 years after the PhD.

Consistent with postdoc jobs being training positions, our data confirmed that scientists were paid much less during postdocs than they would have been had they entered the workforce directly. Of people who started in postdocs, the median annual starting salary during their first four years after the PhD (when they would still be in the postdoc) was $44,724 in inflation-adjusted 2013 dollars compared with $73,662 for those who entered the workforce directly.

To analyze how having held a postdoc position affected later salaries, we regressed inflation-adjusted salary on years-from-PhD conditional on whether they started in a postdoc, including controls for ability, demographics, field, and year, and allowing for nonlinear patterns over time that could differ by whether they started in a postdoc (**Supplementary Notes**, table S5). **Figure 5a** shows the salaries predicted by these regressions for the first 15 years post-PhD, first assuming that everyone starts in a postdoc, and then assuming that everyone skips a postdoc, with other variables held constant at their means.

Controlling for all factors, the 10-year post-PhD salaries of those who started in a postdoc

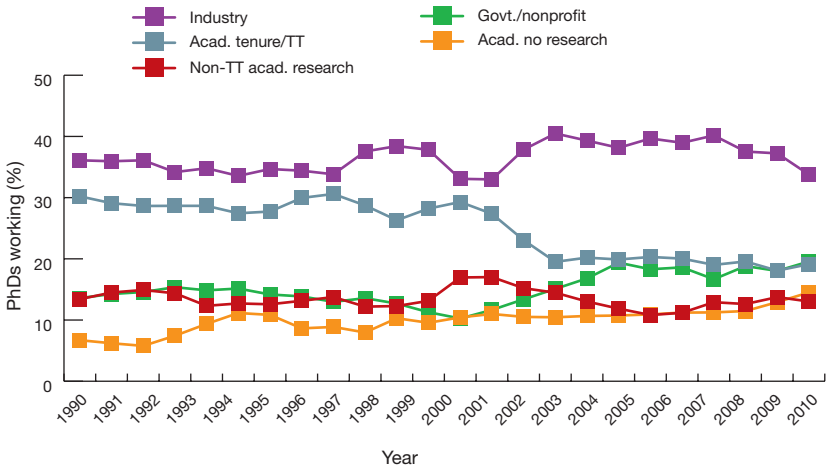

Figure 4 Time trends in the percentage of all working biomedical PhDs employed in each of five sectors, 10 years after degree awarded. Trends are smoothed taking 3-year moving averages.

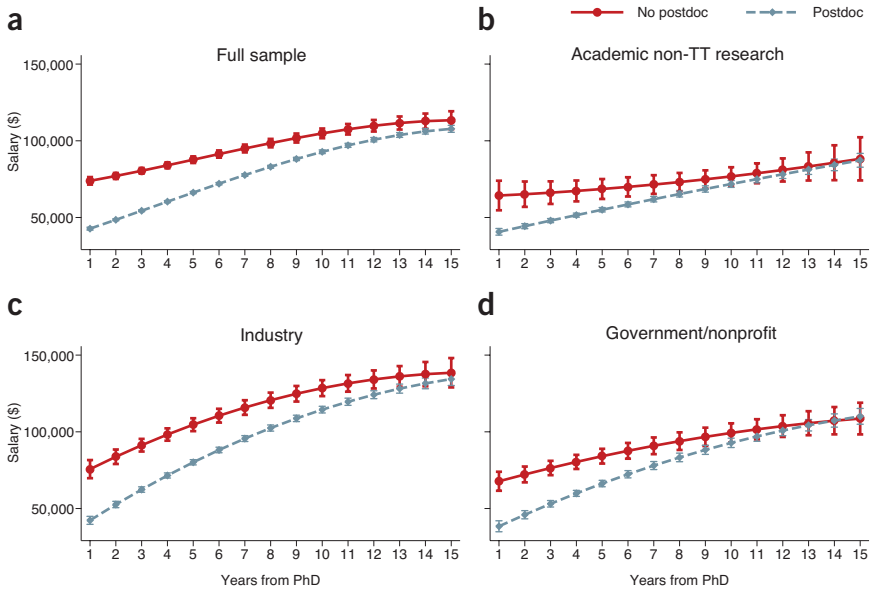

Figure 5 Predicted inflation-adjusted salary (2013 dollars) 1–15 years after PhD completion. (**a**–**d**) Salaries shown for those with and without postdoc experience by 10-year sector (**a**), academic non-TT research (**b**), industry (**c**), and government/nonprofit (**d**). Shown with 95% confidence intervals.

averaged $12,002 lower than those who skipped postdocs. Although the earnings difference narrowed with the years past the PhD, the estimated predicted salary of non-postdocs remained significantly higher ($P < 0.05$) for the first 13 years after the PhD. This suggests that years of work experience are more valuable than years of postdoc experience.

This salary gap might be explained by employment sector, since industry is more likely than academia to hire non-postdocs and tends to pay more than academia. Dividing by 10-year sector, for those sectors with sufficient numbers with and without postdocs to analyze—non-TT research academia, industry, or government/nonprofit—ex-postdocs earned less at first, but the trajectories merged between 8 and 15 years later (**Fig. 5b**–**d**). The same is true but with large confidence intervals for those in tenured/TT jobs and non-research academic jobs (**Supplementary Fig. 7**). There are not enough data available to say whether ex-postdocs pulled significantly ahead of non-postdocs after 15 years, but the graphs tell a story of convergence rather than overtaking. Further, industry salary advantage for non-postdocs was especially strong for those conducting research (**Supplementary Fig. 8**), contrary to what we might expect[35].

Thus, we find a substantial financial penalty for starting biomedical careers in a postdoc. These differences accumulate. Over the first 15 years of their career, ex-postdocs in non-TT academic research who started in a postdoc earned a total present discounted value of $128,297 (17%) less than non-postdocs; ex-postdocs in industry earned a total of $239,970 (21%) less, and in government/nonprofit they earned a total of $161,142 (17%) less. These 15-year cumulative salary gaps accounted for between 2.5 and 3.1 years' worth of average inflation-adjusted income over these 15 years, depending on sector.

Summary and interpretation

Several of our findings challenge published assertions about recent trends in postdocs. Over the past three decades, an approximately constant 80% of US-trained biomedical PhDs started their careers in postdocs. Similarly, postdoc duration has not increased substantially and has recently fallen.

Our paper moves beyond the current literature to compare the later careers of biomedical PhDs with postdoc experience and those without. The likelihood that a postdoc led to a tenured/TT job 10 years after the PhD averaged 27.4% for our whole sample (those awarded PhDs 1980–2003), but was only 21% for the most recent 2001–2003 PhD cohorts (2011–13 jobs). More ex-postdocs than non-postdocs were conducting research ten years after the PhD, but nearly half (45%) of non-postdocs were doing so.

Ex-postdocs continued to earn less on average than non-postdocs ten or more years post-PhD. In-fact, ex-postdocs gave up 17–21% of their present value of income over the first 15 years of their careers. This suggests that postdoctoral education is inconsistent with a model of human capital investment. Instead, it indicates that postdoc positions work as tournaments[16], where individuals compete for an increasingly limited number of tenured/TT jobs by signaling their ability and commitment through long hours in laboratories and years spent underpaid.

One potential explanation for lower early career salaries even after the postdoc years could be that postdocs have lower average abilities. However, our analysis and previous research showed that postdocs have higher average academic abilities[8]. Since higher-ability scientists were more likely to pursue postdoc training, we may actually be underestimating the financial loss from taking a postdoc. Alternatively, ability may be multidimensional: ex-postdocs might excel in academic research while those who skip postdocs might excel outside of academia. Yet, if postdocs excel in academic research, ex-postdocs should have higher salaries in non-TT research academia than non-postdocs. The opposite is true. In short, there is no obvious ability-based explanation consistent with our findings.

Implications

When providing prescriptions for what ails biomedical science, many have called for better information on the impact of postdoc training on biomedical careers[1,2,8]. Our research answers this call. Starting in a postdoc is essentially necessary to obtain a tenure-track research job. However, the chances of obtaining that job have dropped considerably over time, and given the glut of PhDs and scarcity of new tenure-track positions, this trend is likely to worsen.

Outside of tenured/TT academia, employers did not financially value the training or skills obtained during postdoc training. Instead, ex-postdocs pay an earnings penalty for up to 15 years. For the nearly 80% of recent cohorts of ex-postdocs who ultimately end up without a tenure-track academic job, the time spent in a postdoc position not only constitutes a sizeable financial sacrifice, but does not yield the desired academic career. Based on these findings, the majority of PhDs would be financially better off if they skipped the postdoc entirely.

The current system of postdoctoral training benefits the postdocs' supervisors, mentors, their institutions, and funding agencies by providing them with highly educated labor willing to work long hours to produce cutting-edge science at low cost[36]. However, we cannot know whether this system creates more and better science than one where more PhDs directly enter the workforce, which may allow young researchers to direct their own research, perhaps in more creative directions. Meanwhile, the present system entails significant time and

foregone-income costs to individual PhDs and may discourage the best and brightest from pursuing careers in biomedical science in favor of alternatives like medicine or finance with shorter training periods and better pay.

Our findings have implications for science policy. NIH and universities should and have been developing policies to place postdocs more quickly into permanent positions such as staff scientist[2,6,37,38]. Recent NIH increases in postdoc salaries may help encourage this. Academic departments should consider tenure-track hires for top new graduates, now funded by NIH[2]. Finally, some universities are experimenting with postdoc "term limits"[38].

Note: Any Supplementary Information and Source Data files are available in the online version of the paper (doi:10.1038/nbt.3766).

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AUTHOR CONTRIBUTIONS

Both authors contributed to the ideas and writing of this paper. S.K. did the Stata empirical modeling and estimation; D.G. prepared the data.

COMPETING FINANCIAL INTERESTS

The authors declare no competing financial interests.

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