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Do return requirements increase international knowledge diffusion? Evidence from the Fulbright program

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ABSTRACT

We ask whether policies designed to encourage return migration of scientists increase knowledge diffusion to and from home countries, as measured by citations to articles in STEM journals. We track the post-PhD careers of 249 Fulbright Fellowship recipients who are required to leave the US after PhD receipt and 249 similar foreign-born "control" scientists not subject to return requirements. We find that articles by Fulbright Fellows from countries with a weak science base are cited more frequently in their home countries than articles by control scientists, and that this is due primarily to the fact that they are more likely to locate in their home country. In addition, all Fulbrights direct their own citations toward home-country articles at a higher rate than controls. Overall, the results suggest that return requirements mainly benefit countries that have weak scientific environments.

1. Introduction

Predictions about global shortages of skilled workers have led to policies designed to enable countries to compete in the "global war for talent."[1] Policies specifically designed to attract top scientists have been created in countries like the UK, Canada and Australia.[2] In other countries, efforts have focused on encouraging the return of scientists who have left their home countries for studies or employment abroad.[3] Despite investments in these programs, their effects are not well understood, and some scholars have argued that highly-skilled expatriates contribute substantially to economic growth in their home countries even while living abroad. Saxenian (2002a) claims that "Most people instinctively assume that the movement of skill and talent must benefit one country at the expense of another. But thanks to brain circulation, high-skilled immigration increasingly benefits both sides."

Our understanding of the effects of the mobility of scientists on the diffusion of knowledge is limited because a scientist's decision to move from one location to another is endogenous. Most scientists prioritize research opportunities when making decisions about whether to move to a new location.[4] Those who choose to return home *of their own volition* may have research interests more aligned with their home country or denser collaborative networks within their home country; on the other hand, they may have been unable to obtain an academic job outside their home country. Thus, a source of exogenous variation in location is necessary to identify the impact of location on scientific outcomes. In this paper, we examine a sample of scientists of foreign origin who obtained PhDs at US universities but were forced by visa requirements associated with the Fulbright Fellowship to return to their home countries. We compare these scientists to a group of otherwise similar scientists of foreign origin (who graduated from the same programs at around the same time) who were not subject to return requirements.

To assess the impact of returning scientists on the diffusion of scientific knowledge, we ask whether the research of US-educated scientists who are required to return to their home countries has a larger impact in the home countries (measured by forward citations from the home country) than it would if they were allowed to remain in the US. We also ask whether US-based scientists

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[1] A recent McKinsey report estimates that advanced economies will face a shortfall of 16–18 million college-educated workers by the year 2020 (Dobbs et al., 2012).

[2] These include the Tier 1 Exceptional Talent Scheme in the UK, the Canada Research Chairs Program in Canada, and the Australian Research Council's Federation Fellowships, among others.

[3] The Chinese Ministry of Education and National Research Council encouraged expatriate scientists to return through programs that supplement salary and/or offer research funding. Argentina's Ministry of Science and Technology has the RAICES program that helps cover moving costs for those who return home permanently (Jonkers, 2008).

[4] A recent *Nature* survey found 44.7% of scientists rated "increased availability of research funding" a very important determinant of whether they locate abroad, and 39% rated it quite important (Van Noorden, 2012).

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lose access to knowledge generated by US-educated scientists who leave the country (using forward citations from the US). Finally, we ask whether scientists' own knowledge acquisition both from the home country and from the US is affected by their location.

To correct for any additional unobserved heterogeneity that may exist after conditioning on Fulbright status, we control for the number of publications, for the share of publications in high-impact journals, and for the citations to home-country science in the scientist's pre-graduation research output (a proxy for pre-existing interest in home-country research). Specifications also control for variation in countries' science base and for scientific field. Results are robust to controlling for geographic region of origin and sector of employment.

Our results show that the effect depends on the level of development of science in the home country. Scientific articles by Fulbright Fellows from low-science countries – countries in which the number of articles per capita published in the scientist's field is below the 75th percentile for all countries – are cited more frequently in their home countries than articles by controls. This is due to the fact that they are more likely to locate in their home country than Fulbrights from high-science countries or controls. Citations from high-science home countries are not significantly different at the 5% level for Fulbrights and controls. Thus, while previously we showed that a Fulbright from a low-science country publishes fewer papers (Kahn and MacGarvie, 2012), here we demonstrate that each paper has a bigger impact at home.

We also investigate the effects of return requirements on knowledge flows *to* returning scientists. We find that Fulbright recipients from all countries (high-science and low science) make more citations to articles from their home countries than do controls, implying that return requirements increase diffusion *from* as well as *to* scientists' home countries.

Is there a corresponding loss of this scientific knowledge for the US? To investigate this, we examine forward citations to articles by Fulbrights and controls from US-based scientists. We find weak evidence that Fulbrights from low-science countries are cited less by the US (depending on the specification). In addition, Fulbrights themselves do not cite research by US-based authors significantly less often than do controls. However, the time trend of these cites suggests that their tendency to cite US literature may begin to deteriorate after about eight years post-PhD. There may therefore be some downside to return requirements for home countries, in terms of an eventual reduction in exposure and access to US science.

The major result, however, is that return requirements strengthen knowledge diffusion to and from the home country. This does not rule out the possibility of "brain circulation" with respect to knowledge diffusion from compatriots who received US PhDs and remained in the US. Indeed, we find that papers by foreigners who received US PhDs and remained in the US obtained a higher proportion of potential citations from their home countries than from third countries. Nevertheless, the much stronger impact of scientists who do return home suggests that return requirements substantially increase the diffusion of knowledge to countries with less developed scientific environments.

2. Literature review

In the US, international students make up a large percentage of the doctorates granted in Science, Technology, Engineering and Mathematics (STEM). This percentage has steadily increased in recent decades, rising by 49% between 1983 and 2009 (NSF Science and Engineering Indicators 2006, 2012). Most of these students remained in the US five and ten years after the completion of their degrees (Bound et al., 2009; Finn 2010, 2012). However, 5-year stay rates of international students have declined since 2005 (Finn, 2010, 2012; NSF 2012). Fields differ: Gaulé (2011) finds that only 9% of foreign-born academic chemists in the US return to their home country during their professional career. The foreign-born who remain in the US have been shown to have made disproportionately large contributions to US science (Stephan and Levin, 2001) compared to natives.

A second body of research documents the positive externalities to scientific diffusion as a consequence of geographic proximity. Jaffe and Trajtenberg (1999) identify "home country bias" in knowledge diffusion as measured by patent citations, while Zucker and Darby (2006) find that the presence of star scientists in a region increases the rate of high-tech firm entry in related fields. Boudreau et al. (2014) find that randomizing the people with whom scientists had face-to-face interactions at a conference affected rates of subsequent collaboration. Agrawal et al. (2007) found that patent citation rates between inventors located in India are 6 times higher than between non-co-located Indian inventors, suggesting that the net effect on knowledge flows from emigrating inventors is negative. These findings combine to suggest that policy makers in foreign countries may have reason to be concerned about the migration of some of its most highly-skilled citizens to the US or other high-science countries.

Another set of papers, however, points to the diffusion of knowledge through long-lasting social ties that do not require geographic propinquity. Saxenian (2002b) showed that half of surveyed immigrant entrepreneurs in Silicon Valley have business activity in their home countries and over 80% share information about technology with acquaintances in their home countries. Parthasarathi (2006) found that Silicon Valley-based Indian expatriates helped develop India's IT industry. Using exogenous variation in migration quotas, Kerr (2008) found that co-ethnicity appears to spur knowledge flows between inventors, with non-US inventors citing US inventors of the same ethnicity 50% more often. Agrawal et al. (2006) both developed a model and showed empirically that when an inventor moves to a new location, knowledge flows disproportionately back to the inventor's *prior* location. Similarly, Ganguli (2013) finds that the emigration of Soviet scientists after the fall of the USSR increased the number of citations to Soviet-era papers by authors in their new locations.

Of course, the two facts are not mutually exclusive. Geographic proximity and persistent social ties despite geographic distance might both promote knowledge diffusion. Azoulay et al. (2011) have found just that. They show that academic citations to papers by scientists who move to a new location increase dramatically in the new location and do not change in the old location. Using information from the dismissal of Jewish scientists from Nazi Germany, Waldinger (2012) finds no evidence that the productivity of German scientists was affected by the expulsion of their Jewish colleagues, while Moser et al. (2013) show that this emigration of Jewish scientists from Germany to the US led to a substantial increase in chemistry inventions in the US.

Informed by this prior work, this paper hypothesizes that foreigners who receive US doctorates and then are required to return to their home countries transfer the information they acquired during their studies about US scientific and technological knowledge. Further, we will test whether, as suggested by prior work, scholarly relationships that develop in the course of doctoral study persist when doctoral recipients move to a different location.

3. Data and methods

3.1. Identifying Fulbrights and controls

The Fulbright Foreign Student Program, primarily sponsored by the US Department of State, is the main federal program that brings students from other countries to pursue graduate study in the United States. Foreign Fulbright Scholars are awarded a $J-1$ student visa which stipulates that they must spend at least two years in their home country after the completion of studies before applying for a US visa that would allow them to remain indefinitely in the US.[5]

We have collected a sample of 249 Fulbright scholars who were receiving a Fulbright foreign student fellowship to study in an American doctoral program in a science or engineering field between 1993 and 1996 and who received a PhD in the US between 1993 and 2005. An Online Appendix provides a detailed description of the construction of the match between Fulbrights and controls. To summarize, using directories of Fulbright scholars published in 1993–1996, we matched each Fulbright who completed a PhD in STEM to a control student who graduated within 3 years of the same Fulbright from the same institution and department, in the same field and, where possible, with the same advisor. Since students who receive substantial funding from their home country's government often are required to return for some period, we searched PhD acknowledgements for evidence of substantial foreign governmental funding and did not include the student as a control if we found any.[6]

In robustness checks, we also use an alternative methodology (propensity score weighting) to match Fulbright and control scientists. Our main findings are robust to using this alternative matching method.

We used CVs, faculty websites, publications, and Google searches to identify locations of the scientists each year. We were able to identify locations for 37,822 of the 39,816 total person-years between PhD and 2007, the last year that we used to collect "cited" publications.

The Fulbrights in our sample were more than twice as likely as controls to have been in their home country: for 76.0% of our Fulbright sample, we found evidence that they spent some time in their home country after receiving their PhDs, compared to only 34.5% of our control group.

The ten most common countries of origin for controls are India, China, Turkey, Brazil, Russia, Germany, Canada, Mexico, Hungary and Korea. The top ten countries of origin for Fulbright recipients in our sample are Mexico, Portugal, Colombia, Iceland, Spain, Greece, South Africa, Israel and Norway, and Finland/Thailand/Netherlands (with the last three tied for tenth place). The differences in these lists reflect the Fulbright program's focus on funding students from specific countries. The full distribution of home countries is listed in the Online Appendix (Table A-5).

3.2. Measuring knowledge diffusion, retention and acquisition

Our key measures of knowledge diffusion, retention and acquisition are based on the number of forward citations made by authors in different countries to articles published by the scientists in our sample (which we will refer to here as "source articles") and the number of backward citations made by these source articles to authors in different countries, excluding self-cites. Both forward and backward citation data were provided to us by Thomson-Reuters based on their Web of Science database. Citations to published articles clearly do not capture all knowledge diffusion. Scientists may contribute to knowledge in their home country in many ways that do not result in a published article, for example by teaching and advising students, participating in conferences, consulting with industry, and so on. Our focus here is limited to published knowledge diffused to scientists who then build upon that knowledge in their own published work.

We identify the location of the citing publication as the reprint address (the address of the author one should contact when requesting a reprint of the article).[7] Most citing articles have multiple authors, potentially located in different countries. We use the reprint author to determine the location of the citing article because we assume that this author is more likely to be closely connected to the research than a randomly chosen author. This assumption is based on our experience reading the bibliographic information for publications on Web of Science, in which the reprint author commonly was the first or last author.

Our analysis of forward citations is based on 39,816 observations, each representing a potential person/cited-year/citing-year for one of the 498 scientists (excluding self-citations). We focus on the following main dependent variables:

Forward citations:

1. *Number of (forward) citations in articles published in year T by authors in the scientist's country of origin, to source articles published by the scientist in year t.*[8]
2. *Number of (forward) citations in articles published in year T by authors in the USA, to source articles published by the scientist in year t.*

We analyze forward citations through 2010 to articles authored by the scientist beginning in the year of completion of the PhD up to and including 2007.[9]

In robustness checks, we also analyze citations excluding those to journals focused on issues relevant to the author's home region or country. Specifically, we computed:

3. *Number of (forward) citations (from home country or US) to source articles published in global journals*: We defined "global journals" as journals without the home country or region name in the title.[10] An example of an excluded journal is *Australian Journal of Agricultural Research.*
4. *Number of (forward) citations (from home country or US) to source articles published in global journals AND excluding those in agricultural or the environmental fields:* For this analysis, we also excluded scientists in the fields of agriculture, forestry, fisheries, marine biology, entomology, zoology, and in environmental sciences.

For the backward citation regressions, we collapse the citation data to the scientist/citing-year *T* level, thus combining all cited years. As explained later, we do this because important data about the cited year was not available before 1996. Therefore our dependent variables in these backward citation regressions are:

5. *Number of backward citations in all source articles published by the scientist in year T to authors in the scientist's country of origin.*

[5] More details on selection into the Fulbright program can be found in Kahn and MacGarvie (2012, 2016).

[6] Available at: http://sites.bu.edu/shulamitkahn. Kahn and MacGarvie (2016) uses this same data. To clarify, we included *all* Fulbrights in the annual directories from 1993 to 1996 who later completed PhDs in STEM from the US institution listed in the directory, for whom we could identify a control using the criteria in the text, and for whom we could identify at least one post-PhD location for both the Fulbright and control during a 20 min search.

[7] In cases in which the reprint address is missing, we use the address of the first author listed on the paper.

[8] Throughout this paper, we denote the cited year as t and the citing year as *T*.

[9] Our collection of article data began in 2008, which is why the sample is truncated in this year.

[10] Results are also robust to dropping journals published in languages other than English.

6. *Number of backward citations in all source articles published by the scientist in year T to articles to authors in the USA.*

These variables count all backward citations captured by Thomson-Reuters in source articles published from the year after the researcher's PhD graduation up to and including 2007. As with the forward citation data, we drop self-citations and use the reprint address to identify the country of the cited article (with the address of the first author used when the reprint address is missing). The backward citation analysis includes 5,053 person/citing-year observations.[11]

It is possible that backward citations to the US are driven by papers coauthored with scientists' dissertation advisors. This would cause us to over-estimate the amount of knowledge diffusion that occurs between the US and foreign scientists, since the dissertation advisor may be the one acquiring and disseminating the information reflected in the citations. In order to investigate this possibility, we also compute:

7. *Number of backward citations excluding articles co-authored with the student's main advisor*: We compute backward citations after dropping source articles with an author list that contains the surname of the primary dissertation advisor.[12]

Table 1 gives summary statistics for each of these measures of forward and backward citations.

These measures will capture knowledge diffusion via citations only imperfectly, for several reasons. First, there may be some work published in relatively obscure journals in the home country which are not indexed in Web of Science. However, we performed an investigation of scientists' CVs in which we calculated the percentage of the number of articles listed on a scientist's CV that are indexed on Web of Science, and compared this percentage for US-based scientists and those based abroad. We found no significant difference in this measure between US and foreign scientists.

Secondly, if researchers in certain fields are overrepresented in certain countries, we may be more likely to observe citations between a scientist from that country and scientists at home despite broad field controls, yet these citations could reflect the similarity of their research agendas rather than an increase in the rate of knowledge diffusion due to location. On the other hand, Fulbrights might choose their field of study knowing they will return home, and/or the Fulbright commissions in each country may be biased toward selecting students who are most likely to be able to contribute to these fields upon their return. If any of these are the case, it is unclear whether to consider these citations to be the result of return-requirements or not. We consider this issue in our analysis.

3.3. Empirical model

We estimate a regression model of citation frequencies that draws on the Jaffe-Trajtenberg (1999) model of patent citations and the Adams et al. (2006) model of citations to scientific publications. These papers model a paper's citation frequency measured as the ratio of actual to potential citations, which in our application would be:

$$P_{itFT} \equiv \frac{C_{itFT}}{(N_{it} \times N_{FT})}$$

where C_{itFT} is the number of citations to a paper published by author i in year t from papers in field-country (home-country or USA)[13] F in year T. The denominator represents the product of the number of potentially citing papers (N_{FT}) and potentially cited papers (N_{it}). This product is the maximum number of citations that *could* be made in year T to articles published by author i in year t, so P_{itFT} measures the ratio of actual to potential citations. Combining actual and potential citations in this way assumes that potentially cited and potentially citing papers have the same proportional impact on citations and that this ratio does not vary with the level of N_{it} or N_{FT}.[14] To relax (and test) these assumptions, we model C_{itFT} as our dependent variable and include N_{it} and N_{FT} as separate explanatory variables.

Jaffe and Trajtenberg (1999) and Adams et al. (2006) model this ratio as a function of time-since-publication with a specific functional form that allows them to estimate the rates of knowledge diffusion and obsolescence. We instead use a less restrictive semi-parametric functional form. Specifically, we include a separate dummy for each value of the lag $T-t$ (α_{T-t}). We also add controls Z_{itFT} related to the person, field, and home country at time t and dummy variables for the citing year T (α_T).

We can express the conditional expectation of the dependent variable as:

$$E[C_{itFT}|N_{it}, N_{FT}, Z_{itFT}] = \exp[\beta_1 \ln(N_{it}) + \beta_2 \ln(N_{FT}) + \delta Z_{itFT} + \alpha_T + \alpha_{T-t}]$$

Again, C_{itFT} is the number of forward citations made by publications in field-country F in year T to source articles written by scientist i in year t; N_{FT} is the total number of papers published by authors in citing field-country F in citing year T; and N_{it} is the number of papers published by cited author i in cited year t. We expect the β coefficients to each equal 1 if the original specification with P_{itFT} as dependent variable is correct.[15] Note that since we control for the (log of) the number of the scientist's publications (N_{it}), this allows us to interpret all other coefficients as the impact on citations per publication.

Because citations are a discrete non-negative variable bounded by zero (a count), we use Poisson regression models with standard errors clustered by scientist to estimate the parameters of the above model.

3.4. Control variables

The empirical model implies that two key control variables are potentially cited and potentially citing articles. The specific measures for these variables are:

Potentially citing articles: In our analyses of forward citations, we control for $\mathbf{N_{FT}}$, the number of potentially citing articles published in field-country F in citing-year T. This variable comes from the Scimago Journal & Country Rank (2007) and was computed by a research team from the Universities of Granada, Extremadura and Carlos III (Madrid) using articles contained in Elsevier's Scopus database.[16]

[11] This does not exclude the 2728 person-years in which the scientist had no publications. We include a dummy variable for person-years with no publications. The results are comparable if we instead drop these person-years.

[12] This variable is not available for 30 scientists whose dissertation advisor was not listed on Proquest.

[13] Depending on whether modeling citation frequency from the home country or from the US.

[14] This is unlikely to be the case because people publish on much narrower topics than the broader fields used to define the potentially citing articles.

[15] See Cameron and Trivedi (1998), p. 81.

[16] Retrieved April 03, 2012, from: http://www.scimagojr.com. See González-Pereiraa et al. (2009) for more about this measure. The data start in 1996, and for the 0.24% of observations with citing years before 1996 in our sample, we fill in the missing values with the number of articles in the country-field in 1996. In the final data, the number of articles in the home country-field is equal to zero for 0.29% of

Table 1
Means of variables by home country (high- vs. low-science) and Fulbright status.

	Overall	Low-science	High-science	Fulbright	Controls
Forward citations in year *T* to scientist's articles published in year *t*					
Number of citations from home country	0.063	0.033	0.110	0.058	0.067
Number of citations from USA	0.843	0.515	1.359	0.832	0.853
Number of citations from home country to global journals	0.061	0.032	0.108	0.056	0.066
Number of citations from USA to global journals	0.839	0.514	1.351	0.829	0.848
Number of citations from home country to global journals, excl.agr/environ	0.062	0.026	0.116	0.056	0.068
Number of citations from USA to global journals, excl.agr/environ	0.921	0.547	1.479	0.997	0.847
Backward citations in scientist's articles published in year *T*					
Number of backward citations to home country	0.563	0.187	1.191	0.584	0.543
Number of backward citations to USA	10.734	8.189	14.978	9.410	12.055
Number of backward citations to USA excluding collaborations w. advisor	8.278	5.951	12.161	7.397	9.158
Control variables (mean across observations)					
Fulbright dummy	0.499	0.500	0.496	1.000	0.000
Scientist from a country < 75th pctile articles per capita in field	0.612	1.000	0.000	0.614	0.610
Scientist from a country < 75th pctile of citations per article in field	0.733	0.968	0.361	0.701	0.764
Scientist from a country < 75th pctile GDP per capita	0.608	0.961	0.051	0.618	0.599
ln Number of publications in scientist *i*'s field in home country in citing year	6.440	6.018	7.107	6.058	6.821
ln Number of publications in scientist *i*'s field in US in citing year	10.054	10.093	9.993	10.075	10.034
Publications by scientist *i* in year t	0.903	0.685	1.247	0.769	1.036
Share of scientist's publications in high-impact journals	0.170	0.139	0.219	0.145	0.195
Year of citing publication	2005.835	2005.850	2005.811	2005.848	2005.822
Year of cited publication	2000.669	2000.755	2000.534	2000.695	2000.644
Citation lag	5.165	5.094	5.277	5.152	5.178
Background control variables (mean across persons)					
Fulbright dummy	0.500	0.525	0.454	1.000	0.000
Female	0.215	0.170	0.299	0.229	0.201
Percentile Rank of Ph.D. program	0.320	0.357	0.250	0.323	0.317
From low-science country of origin	0.651	1.000	0.000	0.683	0.618
Citations to home-country articles in pre-grad publications	0.038	0.023	0.067	0.040	0.037
Share of citations in pre-grad publications to home-country articles (imputed)	0.033	0.025	0.048	0.037	0.029

For regressions in which the dependent variable is backwards citations, our control for the number of potential citing articles is simply the log of number of articles published by the author in citing year *T*.

Potentially cited articles: To control for the number of potentially *cited* articles $\mathbf{N_{it}}$, we include the natural logarithm of the number of source articles produced by the scientist in cited year *t* and indexed on ISI's Web of Science.

For backwards citation regressions, we control for the (log of the) number of articles published in year *T* in the scientist's field in his home country in citing-year *T* (or in the US in the case of citations to the US), as a reasonable proxy for the set of potentially cited articles. It is not possible to disaggregate the backward citation analysis by cited year and to control for the number of articles published in the home country in each potentially cited year, because the Scimago field/country articles data are only available for 1996 and later.

Dummy for zero cited articles: We include a dummy variable equal to 1 for observations when the scientist had no publications, i.e. when N_{it} is equal to zero. Results are also robust to dropping observations for which N_{it} equals zero.

Additional control variables are included to control for differences in the characteristics of controls and Fulbrights. Both since Fulbrights have self-selected to apply for the Fulbright fellowship and since their home countries' Fulbright Committee has selected them, it is conceivable that they are systematically different from control scientists. One major way in which they may differ is in research aptitude. We control for research productivity using the scientist publication count described above. It is also possible that the research of Fulbrights is simply of higher quality than that of controls. This might be the case if Fulbright funding attracts the very best people. If so, this would also cause Fulbrights to receive more citations from high impact journals and to have more highly-cited articles. Moreover, this effect might differ between high-income, high-science countries and low-income, low-science countries since Fulbrights from these countries have fewer other opportunities to afford high-quality graduate study. As a result, we have also added as a control variable:

The share of the scientist's articles published in high-impact journals. This variable measures the percentage of the scientist's articles published in journals whose impact factor (standardized using the mean and standard deviation of impact factors in the scientist's field) is above the median in our sample.

Fulbrights may also differ from controls in terms of the focus of their research. Fulbrights, knowing they will return to their home countries, may begin orienting their research toward topics relevant in the home country even before graduation. In such a scenario, it may not be the fact of returning to the home country that explains our results, but rather the choice of a home-country-relevant research topic in graduate school. It is thus possible that Fulbrights, whether or not they are located in the home country, are cited more often by home-country scientists simply because they are working on the same topics. We isolate the post-PhD impact of actually returning home by controlling for citations to the home country in pre-graduation publications. However, we note that this may itself be a part of the effect we seek to estimate: the effect of return requirements on the diffusion of knowledge to and from home countries. In robustness checks, we compare the results with and without the pre-graduation citations.

Specifically, we control for:

The average number of citations to the home country in pre-graduation articles: the pre-sample mean estimator of Blundell

observations, consisting of scientists from Ghana, Haiti, Lesotho, Malawi, Panama, Swaziland, and Uganda.

et al. (1999) corrects for unobserved heterogeneity in panel data by conditioning on the mean of the dependent variable in a pre-sample period. In this paper, we take a similar approach by controlling for the number of citations per article to home-country science in the scientist's articles published up to and including the year following graduation. This variable controls for the scientist's pre-existing interest in home-country research prior to possibly moving to the home country after graduation.

Because the majority of our scientists have no pre-graduation publications, in robustness checks we also add in the following variable:

Percentage share of pre-graduation citations that are to the home country, imputing values for those with no pre-graduation publications. For those with pre-graduation publications, we calculate this share by dividing the number of home country citations in pre-graduation publications by the total citations in pre-graduation publications. For those without pre-graduation publications, we impute this share based on their field, school ranking, number of articles in the field that could be cited, year of PhD and gender.

All of the analyses also include the following control variables Z_{itFT}:

Ranking of PhD institution: We include the (log of the) 1995 relative ranking of the US PhD institution (by field) from the National Research Council (Goldberger et al., 1995) as a control for the quality of PhD training. Note that a lower rank signifies higher quality. Rank is the same for Fulbright and control graduating from the same program. Including this variable only increases the explanatory power of equations with pooled Fulbrights and controls.
Gender: We obtained data on the gender of the scientist using information from web searches (e.g. photographs, the use of personal pronouns in web bios) and using a web-based algorithm for identifying the probable genders of given names when no other information was available.[17]
Field dummies: We categorized each student by the first field listed in their (Proquest) dissertation record. We then match the specific fields to the 21 fields in the Scimago database. The match between dissertation fields and Scimago fields is listed in the Online Appendix (Table A-6).
Dummies for year of PhD receipt: We include a series of dummies for ranges of the PhD year as follows: pre-1997, 1997–1998, 1999–2000, 2001–2002, and post-2002.
Dummies for length of lag: We include a dummy for each value of the gap between the cited-year t and the citing-year T in all analyses of forward citations. Since we must collapse all cited years in the backward citation analysis, these dummies are not included there.
Dummies for citing year T: We include dummies for citing years prior to 2000, 2000–2001, 2002–2003, 2004–2005, 2006–2007, 2008–2009 and 2010.

In addition, different specifications may contain the following dummy variables:

Home country below the 75th percentile ranked by articles per capita in field: In some specifications, we include a dummy variable equal to 1 if the number of articles in the field per capita published in citing year T in the scientist's home country is less than the 75th percentile for other countries.[18] 62.5% of person/citing-year combinations (or 61.2% of the 39,816 person/citing-year/cited-year observations) are from home countries below the 75th percentile of articles per capita in the field. We also interact this dummy and its converse with the Fulbright dummy. We refer to these countries as low-science countries and its converse as high-science countries.
Home country below the 75th percentile ranked by forward citations per article in field: In some specifications, we include a dummy variable equal to 1 if the number of citations per article in the field published that year in the scientist's home country is less than the 75th percentile value for other countries. 73.6% of person/citing-year combinations (73.3% of observations) are below the 75th percentile of citations per publication in the field.[19]
GDP per capita of the home country below the 75th percentile: In some specifications, we include a dummy variable equal to 1 if the real GDP per capita of the student's home country is below the 75th percentile of world countries in the year of completion of the doctoral degree. 61.4% of person/cited-year combinations and 60.8% of observations are in this low-income category.

Finally, all specifications include either a Fulbright dummy, or two variables: the Fulbright dummy interacted with being from a low-science or low-income home country as defined by one of the above three variables, and the Fulbright interacted with being from its converse.
Table 1 gives summary statistics for the control variables.

4. Results

4.1. Forward citations from the home country

Table 2 contains the results of Poisson regression in which the dependent variable is the number of citations in articles in year *T in the home country* to articles published in year t by scientist i (dependent variable 1 above). Column 1 indicates that there is no significant average effect of Fulbright status when neither controls for the number of potentially citing articles (N_{FT}) nor for the number of potentially cited articles produced by the scientist (N_{it}) are included. Column 2 adds these two variables. Controlling for the number of the scientist's articles[20] and for the number of potentially citing articles published in the home country in the scientist's field causes the coefficient on Fulbright to become significant at the 5% level, with a coefficient that corresponds to an 90% increase (coefficient .640)[21] in the number of home-country citations. We thus conclude that articles by Fulbrights are cited more by their home country than articles by controls.

Is this effect similar for those from very different types of home countries? Columns 3–4 allow the Fulbright effect to differ for those from countries that have less developed scientific infrastructures. We define these "low-science" countries as the set of countries with a total number of articles per capita in the scientist's field below the 75th percentile. To ensure that we are not picking up the effect of *being from* a low-science home country, we also control for whether the scientist – whether Fulbright or control – originated in a low-science country.

[17] The gender-guessing program is found at: http://www.gpeters.com/names/baby-names.php.

[18] Source of numbers of articles Scimago Journal & Country Rank (2007).

[19] Because some country-field pairs with very few articles will sometimes have highly-cited articles, we only classify countries as being above the 75th percentile if they are above the 75th percentile of citations per article in the field for more than half of the years in our sample.

[20] Recall that this allows us to interpret other coefficients in the equation as affecting per-article citations.

[21] In Poisson regressions, the percent change is calculated as $\exp(\beta) - 1$.

Table 2
Citations from home country in *T* to scientist's articles published in year *t*.

	(1)	(2)	(3)	(4)	(5)	(6)
Fulbright	0.0805 (0.280)	0.640** (0.252)				
Fulbright from country >75th pctile articles per capita in field			0.274 (0.363)	0.510* (0.296)		
Fulbright from country <75th pctile articles per capita in field			−0.0319 (0.339)	0.821** (0.322)		
Home country <75th pctile articles per capita in field			−0.936*** (0.248)	−0.511** (0.242)		
Fulbright from country >75th pctile cites per article in field					0.466 (0.357)	
Fulbright from country <75th pctile cites per article in field					0.745*** (0.271)	
Home country <75th pctile cites per article in field					−0.373 (0.307)	
Fulbright from country >75th pctile GDPpc						0.615** (0.292)
Fulbright from country <75th pctile GDPpc						0.622* (0.371)
Home country <75th pctile GDPpc						−0.162 (0.330)
ln Publications in field in home country in citing year		0.440*** (0.0888)		0.438*** (0.0874)	0.437*** (0.0882)	0.428*** (0.0886)
ln Publications by scientist in cited year		1.172*** (0.115)		1.120*** (0.114)	1.131*** (0.113)	1.150*** (0.125)
Total citations to home country in pregrad pubs	1.977*** (0.535)	1.039*** (0.401)	2.000*** (0.498)	0.866** (0.395)	0.874** (0.409)	1.008** (0.408)
Share of pubs in high-impact journals	1.757*** (0.195)	0.381** (0.179)	1.632*** (0.202)	0.371** (0.181)	0.376** (0.184)	0.381** (0.178)
1 if female	−0.643** (0.265)	−0.330 (0.220)	−0.828*** (0.254)	−0.388* (0.221)	−0.361 (0.223)	−0.353 (0.221)
ln Rank of PhD program	−0.135 (0.113)	−0.172** (0.0772)	−0.0433 (0.102)	−0.161** (0.0799)	−0.163** (0.0842)	−0.162** (0.0794)

N. obs. = 39,816. Poisson regression coefficients with robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
All specifications include dummies for field, citing year, year of PhD and citation lag. Coefficients of these controls available upon request.

Similar to the previous columns, when we do not control for potentially citing articles or for articles produced by the scientist (Column 3), there is no significant difference between Fulbrights from either kind of country. However, when we do control for these variables (Column 4), we see that Fulbrights from low-science countries have 127% (coefficient .821) more citations from the home country than do controls from low-science countries. In contrast, we see smaller and less statistically significant effects (*p*-value = .09) for Fulbrights from high-science countries.

Column 5 uses a different measure to define the home country's scientific output, based on the country's *citations per article* in the field and cited year. This measure allows us to distinguish countries with high-quality or high-impact articles from countries that simply produce many articles. Controlling for the scientist's publications that year and for potentially citing articles, results are qualitatively similar to the original measure of the home-country's scientific output (Column 4). There is no significant difference in home-country citations to Fulbrights and controls from science-rich countries, but a highly significant difference in citations to those from low-science countries where Fulbrights are again more than twice as likely to be cited by the home country. We thus conclude that scientists subject to requirements to return to low-science countries are better known at home than those not required to return. This is not true for Fulbrights from high-science countries.

Do we observe similar effects when we differentiate according to the country's income level, as opposed to scientific output? Column 6 breaks Fulbrights into those above and below the 75th percentile when countries are ranked by their GDP per capita. Similar to the previous results, articles by Fulbrights from low-income countries are cited more in the home country than are articles by comparable controls, but the coefficient is only marginally significant with a *p*-value of 0.09. The coefficient on articles by Fulbrights from rich countries is significant at the 5% level. We cannot reject the hypothesis that the high-income Fulbright coefficient is equal to the low-income Fulbright coefficient (*p*-value = 0.99).

Comparing log likelihoods across specifications (4), (5) and (6) suggests that the differentiation by the home country's scientific output measured as number of publications (column 4) predicts citations most accurately, so we use this measure of home country development in our robustness analyses.[22]

The coefficients on the two "exposure" variables – the number of publications by the scientist and the number of publications in the field/home country in the citing year are both highly significant in all specifications in which they appear. The coefficient on the number of publications by the scientist is not significantly different from one, as predicted by the model. However, here and in later tables, its numerical value is consistently greater than one, and in some later cases is significantly different from one. This may suggest that there are increasing citation returns to publications, i.e. that scientists who publish more articles are cited more often per article, all else equal.

The coefficient on the number of publications in the field from the home country (i.e. with a home country reprint address) is also predicted to be one in the model, but instead is significantly less than one whenever the scientist's publications are also controlled for. It is quite possible that the fields we use are too broad, so that

[22] The log pseudo-likelihoods are Column 4: −6003.9, Column 5: −6019.4, Column 6: −6028.1.

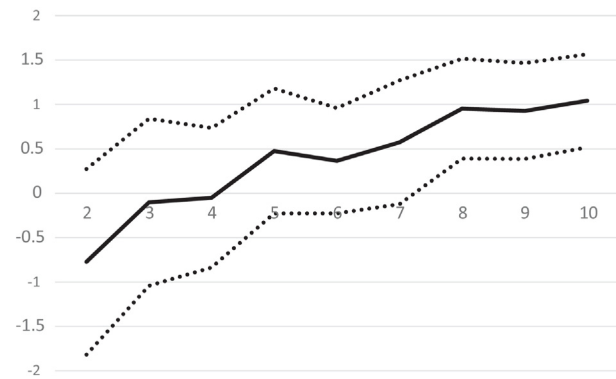

Fig. 1. Fulbright effect on citations from the home country by years since PhD (controlling for covariates).

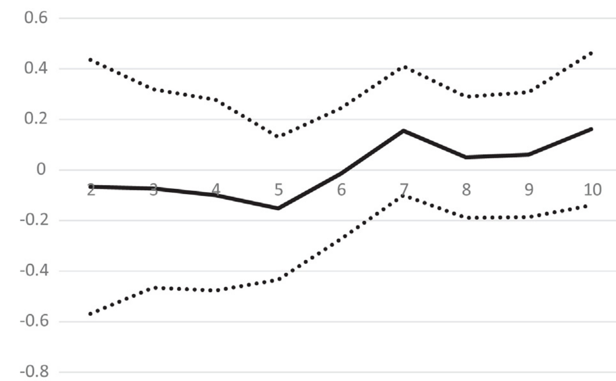

Fig. 2. Fulbright effect on citations from the USA by years since PhD (controlling for covariates).

the number of potentially citing articles according to our measure is larger than the true number of potentially citing articles. It would be extremely difficult, perhaps impossible, to identify the true set of potentially citing articles for each scientist, and our measure is the best available proxy of which we are aware.

Many of the other coefficients are as expected. Controls for the home country citations in pre-graduation publications have a significantly positive and large effect on post-graduation home-country citations. The higher the share of publications in high-impact journals, the more citations are made by home country researchers. Similarly, the higher the status of the scientist's PhD program (the lower the rank), the more home country citations there are.

Interestingly, there is some evidence that articles by female scientists are cited less often in their home countries than those by male scientists, all else equal.[23] The gender difference of approximately 32% is significant only at the 8–11% levels depending on the specification. However, if we separately estimate the effect of the Fulbright dummy for men and women using interaction terms, for women the effect is slightly negative and statistically insignificant. For men it is larger than in Table 2 (Col 2) and highly significant. This implies that the positive effect of Fulbright status on forward citations from the home country is observed only for male Fulbright fellows. While we find this result intriguing, we do not emphasize it because of the small number of females in our already small sample.

In regressions not shown, we re-estimated the basic model (Column 2) controlling for the regular covariates but including separate Fulbright dummies for each year since PhD. Fig. 1 graphs the pattern of the coefficients on these dummies through 10 years post-PhD along with the 95% confidence bands.[24] This graph indicates that as time-since-PhD increases, Fulbrights are cited more in their home country relative to controls. This reinforces the finding that being in the home country diffuses information to other scientists there: the fact that this diffusion increases over time suggests that it is the scientists' actual presence, rather than their topic of study, that increases the visibility of their publications in the home country.

4.2. Forward citations from the USA

The above results suggested that low-science and low-income home countries gain scientific knowledge when their US-educated PhD scientists are required to return home. Is there a corresponding loss of this scientific knowledge in the US? To investigate this question, Table 3 presents similar regressions in which the dependent variable is the number of citations in articles published in year *T in the USA* to source articles published in year *t* by scientist *i*. The same specifications are included, except that the control for potentially citing articles is now all US articles in the field.

Table 3 reveals that on average, there is no significant average difference in US citations between Fulbrights and controls (Columns 1–2). Dividing by home-country type, citations from the US to scientists from high-science/high-income home countries are not lower for Fulbrights than controls when the scientists and potentially citing articles are controlled for (Columns 4–6). In two cases, they may be higher.

In contrast, there are negative coefficients (of 25% or less) associated with US citations to Fulbrights from low-science countries (Columns 4–6), significant only at the 8% level, even controlling for the number of articles produced by the scientist (Column 4). Measuring the country's level of scientific strength by citations per article (Column 5) or by income (Column 6), the point estimate is negative, smaller and not significant. Taken together, the diffusion advantage gained by science-poor home countries may occur at some cost in terms of less scientific knowledge in the US, although there is only weak evidence of this. An alternative or perhaps complementary interpretation if the effect is indeed negative is that the knowledge produced by students from low-science home countries who returned to their home countries is less relevant to scientists in the US than the knowledge produced by the students who did not return.

Coefficients on PhD rank are similar to the home country results. Coefficients on the share of publications in high-impact journals are similarly positive, but twice as large for US citations. Controlling for publications and potentially citing publications, the number of home-country citations in pre-graduation publications do not affect the US citations to post-graduation publications, an unsurprising result. Intriguingly, while citations per article from home countries to females were weakly lower than to males, citations from the US are not lower for females. This suggests that women outside the US – but not within the US – may be at a disadvantage with respect to receiving citations when compared to men.

As above, we re-estimated the basic model of Column 2 adding separate Fulbright dummies for each year since PhD. We graph these dummies in Fig. 2. There is no clear time trend,[25] suggesting that for a sustained period, scientists' work remains equally known in the US whether they are located in their home country or abroad.

[23] This percentage refers to columns 4, 5 and 6.

[24] There are very few citations in our sample less than 2 or more than 10 years post-PhD, making coefficients in those ranges inaccurate.

[25] A test of a non-zero linear relationship over years since PhD is rejected.

Table 3
Citations from USA in year *T* to scientist's articles published in year *t*.

	(1)	(2)	(3)	(4)	(5)	(6)
Fulbright	0.220	0.0827				
	(0.206)	(0.108)				
Fulbright from country >75th pctile articles per capita in field			0.607**	0.258*		
			(0.274)	(0.138)		
Fulbright from country <75th pctile articles per capita in field			−0.420**	−0.282*		
			(0.201)	(0.162)		
Home country <75th pctile articles per capita in field			−0.398**	−0.192		
			(0.197)	(0.170)		
Fulbright from country >75th pctile cites per article in field					0.368**	
					(0.176)	
Fulbright from country <75th pctile cites per article in field					−0.239	
					(0.178)	
Home country <75th pctile cites per article in field					0.0306	
					(0.217)	
Fulbright from country >75th pctile GDPpc						0.229
						(0.145)
Fulbright from country <75th pctile GDPpc						−0.218
						(0.162)
Home country <75th pctile GDPpc						−0.156
						(0.171)
ln US Publications in field in citing year		0.112		0.106	0.130	0.113
		(0.260)		(0.252)	(0.254)	(0.257)
ln Publications by scientist in cited year		1.389***		1.287***	1.319***	1.292***
		(0.107)		(0.0925)	(0.0974)	(0.0948)
Total citations to home country in pregrad pubs	1.024**	−0.0132	1.373***	−0.110	0.0252	0.00306
	(0.422)	(0.502)	(0.412)	(0.550)	(0.523)	(0.532)
Share of pubs in high-impact journals	0.857***	0.822***	1.865***	0.812***	0.813***	0.837***
	(0.158)	(0.137)	(0.148)	(0.137)	(0.135)	(0.136)
1 if female	−0.415	−0.0839	−0.695***	−0.196	−0.187	−0.159
	(0.271)	(0.186)	(0.268)	(0.174)	(0.172)	(0.176)
ln Rank of PhD program	−0.123	−0.247***	−0.0863	−0.190***	−0.200***	−0.208***
	(0.0869)	(0.0557)	(0.0739)	(0.0525)	(0.0534)	(0.0540)

N. obs. = 39,816. Poisson regression coefficients with robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
All specifications include dummies for field, citing year, year of PhD and citation lag ($T - t$). Coefficients of these controls available upon request.

4.3. Explaining the Fulbright premium in forward citations

We have established that Fulbrights from low-science home countries have higher citation rates per article in their home country than controls. There are a number of potential reasons for this higher rate. Prior evidence on the benefits of geographic proximity on citations points to this as the most likely cause.

One potential alternative reason is that the return requirement causes Fulbrights and controls to work in different sectors. For example, Fulbrights from low-science countries may be more likely to work in academia while controls from these countries may obtain employment visas to work in industry in the US. In Column 1 of Table 4, we introduce dummy variables that control for whether the scientist works in academia, industry or government to the specification from Table 2 Column 4.[26] The results are robust to adding these controls.[27]

Another possibility is that Fulbrights are disproportionately drawn from countries with particular strengths in their specific areas of research. To account for this possibility, Column 2 adds narrowly-defined region dummies: the key coefficient on Fulbrights from low income countries remains similar.[28] In Column 3, we add field-specific measures of countries' research strength measured by the country's number of citations per publication in that field in the citing year. Including these controls also has little effect on the coefficient on Fulbrights from low-science countries.

A different way to exclude the possibility that Fulbrights' research is more closely aligned with the research strengths of the home country is to evaluate whether Fulbrights publish at a higher rate in "global" journals (as previously defined). In Column 4 of Table 4, the dependent variable includes only citations to articles published in global journals.[29] We obtain similar results. In case the higher rate of citation in the home country is due to Fulbrights and others in the home country being more focused on agricultural and environmental topics applicable mainly in the home region, Column 5 completely excludes all scientists whose PhDs were in these fields. Here, the coefficient on Fulbrights from low-science countries increases rather than decreases (although not significantly so): their home-country citations are 193% higher (coefficient 1.077) than that of controls.

Another possible reason that Fulbrights are more highly cited in low-science home countries, besides geographic proximity, may be that on average, the research of Fulbrights from low-science countries is simply of higher quality than that of controls or Fulbrights from high-science countries. We investigate this in multiple

[26] In 71% of Fulbrights' person-year observations, they are working in academia, in 11% they are working in government and in% they are working in industry. For controls, the comparable numbers are 61% in academia, 12% in government and 22% in industry.

[27] These dummies are not included in the rest of the specifications in Table 4, although results are similar with them.

[28] Region categories are: Africa, China/Taiwan, Eastern Europe, Japan/Korea/Singapore, Middle East, North America, South America, Southeast Asia/Oceania, and Western Europe.

[29] We do not exclude citations *from* articles published in non-global journals.

Table 4
Citations from home country: robustness.

	(1) Adding sector dummies	(2) Controlling for detailed home region	(3) Adding country field strength	(4) Only global journals	(5) Only global, excluding agri/enviro	(6) Controlling for citations from other countries	(7) <90th pctile of cites	(8) Using imputed hc-share pre-grad pubs	(9) No controls for pre-graduation home cites
Fulbright from country >75th pctile articles per capita in field	0.523*	0.514*	0.490*	0.512*	0.476	0.386	0.272	0.479	0.473
	(0.291)	(0.303)	(0.287)	(0.303)	(0.391)	(0.244)	(0.232)	(0.307)	(0.307)
Fulbright from country <75th pctile articles per capita in field	0.826**	0.972**	0.811***	0.807**	1.077***	1.067***	1.059***	0.946***	0.957***
	(0.326)	(0.386)	(0.313)	(0.329)	(0.371)	(0.313)	(0.292)	(0.327)	(0.328)
Home country <75th pctile articles per capita in field	−0.483**	−1.090***	−0.274	−0.495**	−0.743***	−0.515**	−0.617**	−.0619**	−0.633***
	(0.247)	(0.327)	(0.243)	(0.247)	(0.280)	(0.239)	(0.255)	(0.247)	(0.243)
ln Publications in field in home country in citing yr	0.440***	0.486***	0.441***	0.431***	0.478***	0.502***	0.415***	0.475***	0.477***
	(0.0893)	(0.100)	(0.0854)	(0.0891)	(0.117)	(0.0840)	(0.0903)	(0.0942)	(0.0939)
ln Publications by scientist in cited year	1.132***	1.096***	1.106***	1.133***	1.181***	0.291**	1.276***	1.136***	1.137***
	(0.117)	(0.121)	(0.115)	(0.117)	(0.156)	(0.131)	(0.191)	(0.111)	(0.111)
Cites to home-country articles in pregrad pubs	0.840**	0.665	0.818**	0.855**	0.840	0.632*	0.595*		
	(0.380)	(0.424)	(0.402)	(0.409)	(0.583)	(0.342)	(0.346)		
Share of pubs in high-impact journals	0.373**	0.360*	0.358**	0.407**	0.276	0.0019	0.421**	0.367**	0.372**
	(0.179)	(0.191)	(0.177)	(0.189)	(0.200)	(0.170)	(0.186)	(0.182)	(0.185)
Citations per Publication in home country in field in citing year			0.0544***						
			(0.0066)						
ln Citations from other countries						0.698***			
						(0.0761)			
Imputed share to home country in pre-grad pubs								0.270	
								(0.683)	
Sector dummies	Y	N	N	N	N	N	N	N	N
Observations	39,816	39,816	39,816	39,816	29,729	39,816	35,754	39,816	39,816

Poisson regression coefficients with robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
All specifications include controls for PhD rank as well as dummies for gender, field, citing year, year of PhD and citation lag ($T - t$). Coefficients of these controls available upon request.

ways. First, all estimates include a control variable for the share of the scientists' publications in high-impact journals. Second, the result from Table 3 Column 4 already indicated that Fulbrights from low-science countries do not receive more citations from the US, suggesting that these articles are not of particularly high quality. To take this one step further, in Column 6 of Table 4, we include as a control the log of the number of citations received in year T by the scientist's articles published in year t from all countries *except* the home country (including the US). Not surprisingly, this variable is highly significant since it too measures the scientist's citability. Nevertheless, Fulbrights from low-science countries receive even more (although not significantly so) home-country citations than controls from low-science countries than in the base case, all else equal. Finally, in Column 7, we drop the most highly-cited 10% of articles. The coefficient for Fulbrights from low-science countries is again (insignificantly) higher than in the base case, again indicating that citations to the work of higher-quality Fulbrights were not dominating the original result.

An additional concern is that the control variable "the number of scientists' citations to the home country in their pre-graduation publications" does not adequately capture the scientist's early interest in the topic of research conducted in the home country because the majority of our sample – both Fulbrights and controls – have no pre-graduation publication. To address this concern, we have imputed the hypothetical home country share of the scientists with no pre-graduation publications, based on the measured relationship between this share and field, institutional rank, PhD year, and gender for those who do have pre-graduation publications. Column 8 of Table 4 uses this home-country share of pre-graduation publications (imputed for those without publications) and again finds a larger Fulbright-control difference for those from low-science countries than in Table 2 (of 157%).

Finally, it is possible that the results in Table 2 actually under-estimate the effect of return-requirements on diffusion of knowledge to the home country by controlling for the scientists' cites to the home country in their pre-graduation publications. This would be the case if the return requirement itself induced Fulbrights to orient their PhD study toward research topics that were relevant to their home countries. Results without this control variable, which are likely to be the upper bound of the effect of return requirements, are shown in column 9 of Table 4 and indicate a large (160%) Fulbright-control difference for those from low-science countries, similar to that in column 8.

Similar robustness checks for the results on forward citations from the US can be found in the Online Appendix B. They suggest that the negative coefficient for low-science Fulbrights in Column 4 of Table 3 remains negative, significant at the 10% level, and of similar magnitude in several of the robustness checks, leaving us agnostic about whether Fulbrights from these countries are cited less in the US. Also, whereas the difference between Fulbrights from high-science countries and controls in Table 3 Col. 4 was insignificantly positive, adding sector dummies leads to Fulbrights from high-science countries receiving significantly more citations from the US than controls. However, in regressions that exclude highly cited articles or control for citations from outside the US, Fulbrights from high-science countries are cited less in the US.

4.4. Patterns in backward citations

Table 5 presents regressions of backward citations of the scientist's articles to articles published with a home-country corresponding author (other than him or herself). It indicates that on average, controlling for the number of scientist's publications and for publications in the home country in the field, articles by Fulbrights are 191% (coefficient 1.069) more likely to cite work from the home country (Column 1). Columns 2 through 4 indicate that

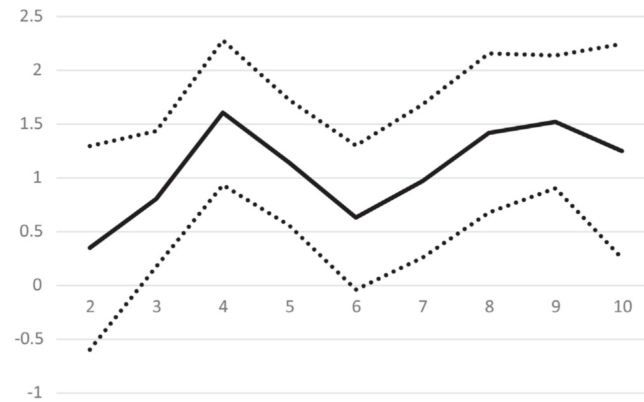

Fig. 3. Fulbright effect on backward citations to the home country, by years since PhD (controlling for covariates).

the effect is largest for those Fulbrights from low-science or low-income home countries, with Fulbright premia ranging from 155% to 212% (coefficients 0.937–1.138). However, Fulbrights from high-science or high-income home countries are also more likely than controls to cite people from the home country, with Fulbright premia between 117% and 168% (coefficients 0.778–0.984).

We have also re-estimated the backward citations regressions controlling for pre-graduate citations to the home country, imputing the share for those people with no pre-graduation publications (column 5). In this case, the effect of Fulbrights from high-science countries hardly changes, but from low-science countries it increases from 212% to 295%. As before, an upper bound of the effect of Fulbright would not control for pre-graduate citations to the home country at all, since the choice of graduate school research topic may be affected by the return-requirement itself. Since both control variable and dependent variable both measure backward citations to home country (before and after graduation), there is even more reason to believe that adding this variable over-controls, thus under-estimating the effect of Fulbrights. Dropping this control variable does not change qualitative results, but the effect of Fulbrights from low-science countries rises further to a 323% increase in backward citations while the effect of Fulbrights from high-science countries falls slightly (from 148% to 128%).

Fig. 3 shows how the greater Fulbright tendency to cite home country work changes as the time since PhD receipt increases.[30] Although the pattern is noisy, on the whole, backward cites rise over time and then seem to flatten out, suggesting that Fulbrights take a few years to become aware of and/or influenced by their home country colleagues.

To round out our analysis, Table 6 models backward citations to the USA. On average, we cannot reject the hypothesis that Fulbrights' and controls' articles cite US authors at the same rate (Column 1). Isolating those from high- v. low-science or income countries (Columns 2–4), the results remain small and insignificant. However Fig. 4, based on estimated separate Fulbright dummies for each year since PhD, suggests that there is a negative effect of being a Fulbright on cites to the USA from Fulbrights starting about eight years after PhD. In other words, backwards citations to the US are maintained by Fulbrights for an extended period, although there is some indication that Fulbrights eventually become less aware than controls of the US literature.

It is possible that backward citations to the US are driven by papers coauthored with scientists' dissertation advisors. This would cause us to over-estimate the amount of knowledge

[30] For backward cites, this remains the time from PhD to the year of the citing article, which in this case is the article written by our scientist.

Table 5
Backwards citations to home country in scientist's articles published in year *T*.

	(1)	(2)	(3)	(4)	(5) Using imputed hc-share pre-grad pubs	(6) No controls for pre-graduation home cites
Fulbright	1.069***					
	(0.275)					
Fulbright from country >75th pctile articles per capita in field		0.907***			0.889***	0.826***
		(0.315)			(0.328)	(0.315)
Fulbright from country <75th pctile articles per capita in field		1.138***			1.373***	1.442***
		(0.399)			(0.389)	(0.386)
Home country <75th pctile articles per capita in field		−0.868**			−1.002***	−1.115***
		(0.342)			(0.343)	(0.336)
Fulbright from country >75th pctile cites per article in field			0.778**			
			(0.355)			
Fulbright from country <75th pctile cites per article in field			1.030***			
			(0.319)			
Home country <75th pctile cites per article in field			−0.981***			
			(0.360)			
Fulbright from country >75th pctile GDPpc				0.984***		
				(0.328)		
Fulbright from country <75th pctile GDPpc				0.937**		
				(0.434)		
Home country <75th pctile GDPpc				−0.445		
				(0.414)		
ln Publications in field in home country in citing year	0.444***	0.354***	0.350***	0.371***	0.440***	0.448***
	(0.0919)	(0.0902)	(0.0865)	(0.0895)	(0.0919)	(0.0933)
ln Publications by scientist in citing year	1.254***	1.158***	1.126***	1.186***	1.201***	1.196***
	(0.134)	(0.123)	(0.127)	(0.132)	(0.124)	(0.119)
Cites to home-country articles in pregrad pubs	1.514***	1.416***	1.235***	1.503***		
	(0.328)	(0.336)	(0.333)	(0.360)		
Share of pubs in high-impact journals	0.0606	0.0324	0.0261	0.0633	−0.0432	−0.0116
	(0.218)	(0.218)	(0.222)	(0.214)	(0.224)	(0.225)
Imputed share to home country in pre-grad pubs					1.567*	
					(0.834)	

N. obs. = 5,053. Poisson regression coefficients with robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
All specifications include controls for PhD rank as well as dummies for gender, field, citing year, and year of PhD. Coefficients of these controls available upon request.

diffusion that occurs between the US and foreign-located scientists, since the dissertation advisor may be the one acquiring and disseminating the information reflected in the citations. To better evaluate whether the scientists with return requirements are less aware of work being done in the US, we re-estimated the analyses of backwards citations *excluding* any publications where the scientist collaborated with their US PhD advisor (Columns 5–8 of Table 6). Comparing these columns to their counterparts (Columns 1–4), all coefficients remain small and insignificant.

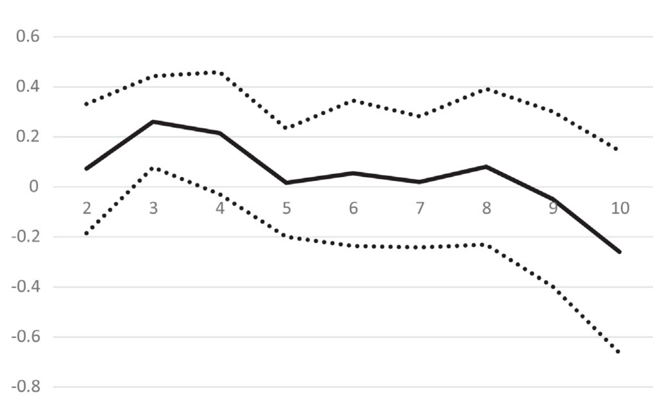

Fig. 4. Fulbright effect on backwards citations to the US, by years since PhD (controlling for covariates).

4.5. Citations and location

Fulbrights are more than twice as likely to be located in their home countries as controls, and almost twice as likely to be in a third country other than the US or home. This is shown in Table 7's linear probability models of location (where each observation is a person-year). Column 1 shows that Fulbrights are 33 percentage points more likely to be observed in home countries each year than controls (26% of whom are in their home country). They are 6 percentage points (column 3) more likely to be observed in third countries than controls (8% of whom are in their home country). While both Fulbrights from low and high-science home countries are more likely to be located at home than controls, there is a 14 percentage point ($p < .01$) difference between them. Only Fulbrights from high-science countries are more likely to be located in a third country (Column 4). Most of these are Europeans who may be located near but not in their home country. In estimation not shown here, we found no impact of being from a high or low-science country on the location of controls. As a result we do not differentiate between them in Table 7.

Column 6 shows that, in fact, Fulbrights from high- and low-science countries are approximately equally likely to be found *anywhere* outside the US post-PhD. Combining results, we conclude that all Fulbrights are more likely to be abroad than controls, but that those Fulbrights who are from low-science countries are more likely to be in the home country and less likely to be in third countries than Fulbrights from high-science countries.

Table 6
Backwards citations to USA in scientist's articles published in year T.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
					Excluding publications with advisor			
Fulbright	0.0269 (0.0693)				0.0532 (0.0884)			
Fulbright from country >75th pctile articles per capita in field		0.0533 (0.104)				0.0983 (0.132)		
Fulbright from country <75th pctile articles per capita in field		−.00608 (0.0844)				−0.0122 (0.105)		
Home country <75th pctile articles per capita in field		−0.0695 (0.0977)				−0.0327 (0.121)		
Fulbright from country >75th pctile cites per article in field			0.217* (0.118)				0.275* (0.150)	
Fulbright from country <75th pctile cites per article in field			−0.0960 (0.0764)				−0.0928 (0.0965)	
Home country <75th pctile cites per article in field			0.157 (0.107)				0.233* (0.137)	
Fulbright from country >75th pctile GDPpc				−0.0030 (0.107)				0.0252 (0.137)
Fulbright from country <75th pctile GDPpc				0.0521 (0.0866)				0.852 (0.110)
Home country <75th pctile GDPpc				−0.0745 (0.0939)				−0.0179 (0.118)
ln Publications in field in US in citing year	−0.330 (0.254)	−0.333 (0.254)	−0.304 (0.255)	−0.323 (0.252)	−.517 (0.338)	−0.519 (0.339)	−0.457 (0.340)	−0.516 (0.337)
ln Publications by scientist in citing year	1.111*** (0.0570)	1.096*** (0.0571)	1.110*** (0.0543)	1.104*** (0.0581)	1.239*** (0.0581)	1.226*** (0.0583)	1.243*** (0.0561)	1.242*** (0.0593)
Cites to home-country articles in pregrad pubs	−0.127 (0.227)	−0.181 (0.244)	−0.0173 (0.223)	−0.182 (0.238)	−0.253 (0.334)	−0.297 (0.366)	−0.0855 (0.330)	−0.269 (0.350)
Share of pubs in high-impact journals	0.303*** (0.0665)	0.298*** (0.0662)	0.301*** (0.0645)	0.302*** (0.0667)	0.295*** (0.0858)	0.292*** (0.0854)	0.298*** (0.0840)	0.295*** (0.0855)

N. obs. = 5053. Poisson regression coefficients with robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$. (0.239)
*** $p < 0.01$.
All specifications include controls for PhD rank as well as dummies for gender, field, citing year, and year of PhD. Coefficients of these controls available upon request.

We believe that the dominant reason that Fulbrights are more likely to be located in their home countries is the return requirements they face. However, to address the potential concern that Fulbrights may be different from controls in other ways that impact location despite our attempts to match them, the rest of Table 7 adds the control variables listed in the table plus dummies for field, year, and PhD year. Comparing these to the previous columns, ceteris paribus the difference between low and high-science countries' Fulbrights' propensities to be located at home is even higher (col. 8 difference = 23 percentage points or ppt), while coefficients for being located in third countries changed very little. As a result, adding control variables somewhat widens the difference between the likelihood that Fulbrights from low v. high-science countries will be located anywhere outside the US (to 17 percentage points, Column 12).

It might seem more natural to directly estimate citations to scientists in the different locations. We have argued above that location for those able to choose is endogenous, since ability and research interests determine the choice set of location for each scientist. However, as a comparison to our earlier tables, in Table 8 we model forward and backward citations from the home country and from the US based on location, in addition to a Fulbright dummy variable. If the estimated difference in citations between Fulbright and control scientists described in prior regressions is explained by the fact that Fulbrights are required to return home, we expect that, if we include a dummy for being located in the home country in the regression, the Fulbright effects estimated previously will be substantially diminished and most of the effect will instead be measured in the location coefficient. This expectation is confirmed by the results displayed in Table 8. When we do not differentiate countries by level of scientific output, we find that those located in the home country are more likely to be cited by scientists in the home country (compared to those located in the US), with an effect larger (181%) than found for Fulbright in Table 2 (90%). Further differentiating between high- and low-science home countries, we find that higher forward cites from home countries are seen in both kinds of home countries and in fact, whereas Fulbrights from high-science home countries were not significantly more likely to be cited by the home country, location in high-science home countries increases cites from these countries even more than from low-science home countries (although not significantly more). For low-science countries, the forward citations coefficient on home location is slightly larger than the effect measured in Table 2 for Fulbrights from low-science countries (compare .821 there to .862 here). Controlling for location, the coefficient on the Fulbright dummy on home country forward citations becomes insignificant whether with or without controls, dividing the location variable by type of home country or not.

Location in the home country has a similar effect on backward cites to the home country as did the Fulbright dummy in earlier tables (compare coefficient 1.067 in column 3 of Table 8 to 1.069 in column 1 of Table 5). Differentiating by country type, the effect of location in a low-science country increases backwards cites to the home country (compared to the US), but insignificantly, and by less than the effect of Fulbright in Table 5 (compare the coefficient of 1.138 there to .415 here in Col. 7), perhaps suggesting that Fulbrights from low-science countries may be somewhat more interested in topics and literature from the home country, whether or not they are located in the home country. This dovetails with a significant effect of Fulbright on the backward citations to home country holding location constant (Table 8, column 7). Being located in a high-science home country increases backward locations to that country by more than the Fulbright effect did, and now more than being in a low-science country. We would have expected that

Table 7
Effects of fulbright status on location (linear probability models).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Located in Home		Located in Third		Located Outside US		Located in Home		Located in Third		Located Outside US	
Fulbright	0.329***		0.0604**		0.389***		0.315***		0.0663***		0.381***	
	(0.0378)		(0.0259)		(0.0363)		(0.0380)		(0.0248)		(0.036)	
Fulbright from country >75th pctile articles per capita in field		0.239***		0.134***		0.373***		0.175***		0.101**		0.276***
		(0.0509)		(0.0407)		(0.0465)		(0.0609)		(0.0489)		(0.0584)
Fulbright from country <75th pctile articles per capita in field		0.383***		0.0167		0.399***		0.402***		0.0448*		0.447***
		(0.0414)		(0.0265)		(0.0394)		(0.0452)		(0.0257)		(0.0438)
Home country <75th pctile articles per capita in field							0.0603	−0.0473	−0.0555**	−0.0290	0.00478	−0.0763
							(0.0413)	(0.0547)	(0.0262)	(0.0353)	(0.0401)	(0.0582)
ln Publications in home country in field							0.00725	0.00723	0.00102	0.00103	0.00828	0.00826
							(0.0118)	(0.0119)	(0.00774)	(0.00772)	(0.0116)	(0.0116)
Citations per publication in home country in field							0.000401	0.000264	0.00204	0.00207	0.00244	0.00233
							(0.00234)	(0.00232)	(0.00174)	(0.00174)	(0.00232)	(0.00230)
ln Publications by scientist in cited year							−0.0121	−0.01000	−0.0628***	−0.0633***	−0.0749**	−0.0733**
							(0.0323)	(0.0343)	(0.0167)	(0.0168)	(0.0320)	(0.0331)
Cites to home-country articles in pregrad pubs							−0.0100	−0.0487	0.0355	0.0450	0.0254	−0.00374
							(0.164)	(0.161)	(0.130)	(0.130)	(0.130)	(0.129)
Share of pubs in high-impact journals							−0.0752**	−0.0725**	0.00933	0.00868	−0.0658*	−0.0638*
							(0.0354)	(0.0352)	(0.0243)	(0.0243)	(0.0366)	(0.0365)
1 if female							0.0246	0.0254	−0.00628	−0.00646	0.0184	0.0189
							(0.0506)	(0.0503)	(0.0350)	(0.0351)	(0.0481)	(0.0477)
Ln Rank of PhD program							−0.00468	−0.0115	−0.0226*	−0.0209	−0.0273	−0.0324*
							(0.0185)	(0.0183)	(0.0129)	(0.0130)	(0.0171)	(0.0170)
Includes field, year, PhD year dummies	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
R-squared	0.111	0.121	0.009	0.025	0.152	0.153	0.189	0.201	0.067	0.068	0.238	0.245

N. obs. = 4,817 including years through 2007. Robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
Coefficients of these controls available upon request.

Table 8
Relationship between citations to the home country and USA and location.

	(1) Fwd cites from home	(2) Fwd cites from USA	(3) Backward cites to home	(4) Backward cites to USA	(5) Fwd cites from home	(6) Fwd cites from USA	(7) Backward cites to home	(8) Backward cites to USA
Fulbright dummy	0.326	0.138	0.682***	0.0779	0.300	0.155	0.623***	0.0934
	(0.200)	(0.105)	(0.230)	(0.0673)	(0.192)	(0.0990)	(0.220)	(0.0655)
Current location: home	1.040***	−0.101	1.067***	−0.109				
	(0.195)	(0.116)	(0.221)	(0.0860)				
Current location: third country	0.151	−0.405*	−0.0402	−0.301**				
	(0.342)	(0.220)	(0.335)	(0.122)				
Current location: home, country> > 75th pctile articles per cap in field					1.136***	0.152	1.305***	0.0448
					(0.221)	(0.123)	(0.224)	(0.100)
Current location: home, country <75th pctile articles per cap in field					0.862***	−0.619***	0.415	−0.307***
					(0.202)	(0.145)	(0.304)	(0.0891)
Current location: third country > 75th pctile articles per cap in field					0.358	−0.325	0.193	−0.244**
					(0.373)	(0.237)	(0.345)	(0.101)
Current location: third country < 75th pctile articles per cap in field					−0.598	−0.666**	−1.055**	−0.431*
					(0.464)	(0.291)	(0.529)	(0.244)
ln Publications in field in home country in citing yr	0.522***		0.493***		0.491***		0.396***	
	(0.0843)		(0.0934)		(0.0803)		(0.0893)	
ln Publications in field in US in citing year		0.0856		−0.311		0.114		−0.332
		(0.269)		(0.253)		(0.261)		(0.253)
ln Publications by scientist in citing year	1.157***	1.376***	1.209***	1.099***	1.138***	1.338***	1.165***	1.084***
	(0.0956)	(0.108)	(0.113)	(0.0582)	(0.0933)	(0.101)	(0.106)	(0.0563)
Cites to home-country articles in pregrad pubs	0.918**	−0.0653	1.282***	−0.138	0.968**	−0.159	1.361***	−0.209
	(0.398)	(0.494)	(0.316)	(0.234)	(0.405)	(0.521)	(0.310)	(0.243)
Share of pubs in high-impact journals	0.533***	0.815***	0.237	0.303***	0.521***	0.827***	0.234	0.304***
	(0.173)	(0.138)	(0.195)	(0.0683)	(0.174)	(0.138)	(0.191)	(0.0660)

N. obs. = columns 1, 2, 5 and 6: 37,822. Columns 3, 4, 7, 8: 4817. Poisson regression coefficients with robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
All specifications include controls for PhD rank as well as dummies for gender, field, citing year, and year of PhD. Coefficients of these controls available upon request.

those who chose to return home because they were more attached to the home country research community would be particularly more likely to have come from a home country with a substantial science community, so self-selection alone would have led to high coefficients for high-science countries.

The results in Table 8 also suggest that ceteris paribus those located in low-science home countries are 46% less likely to be cited by the US and 26% less likely to cite the US literature (Cols. 6, 8). The magnitude of these effects is significantly larger than the corresponding insignificant effect of Fulbrights from low-science countries (Tables 3 and 6). This contrast in the estimated effect of location relative to the estimated effect of Fulbright status may suggest that control scientists who voluntarily return to their home country retain weaker relationships with the US.

Location in a third country (not US, not home) does not increase forward or backward citations to home or to the US. It does seem to decrease backward citations to home and forward citations from the US if in a low-science third country and to decease backward citations to the US.

Finally, we have also run instrumental variable Limited Information Maximum Likelihood methods to estimate of the causal impact of location on citations using Fulbright as an instrument for location and expressing the dependent variables in logs.[31] Results are shown in Appendix Table 1. Many qualitative results are similar to our base results analysis of Tables 2, 3, 5 and 6. The effect on home-country forward citations of being located in a low-science home country is significant at the 10% level and the effect on home-country backward citations is significant at the 5% level. Results for high-science home countries are very imprecise, perhaps reflecting the fact that our instruments are weaker predictors of high-science home country location. There are no results that are significant for citations to or from the US, with very high standard errors.[32]

5. Robustness to matching method

The Fulbright scientists in this sample are matched on the basis of similarity of Ph.D., program/advisor and year of Ph.D. Despite this careful matching and our addition of control variables for research quantity and quality, it is possible that our controls are not in fact comparable to our Fulbrights in research ability, for instance if universities applied different criteria to applications from Fulbright Fellows.

In our previous paper (Kahn and MacGarvie, 2016), we used various ways to show that the inherent research quality of our controls and Fulbrights were similar to each other and also similar to the PhD scientific community as a whole. For instance, we found that the publication records of the publication records of those in our sample who were located in the US – both controls and Fulbrights – were similar to the publication records of early-career US-PhD recipients of foreign origin in the NSF's Survey of Doctorate Recipients. This suggested to us that our Fulbrights and controls in our sample were generally similar in ability, as well as generally representative of the larger population of US PhD recipients of foreign origin. Also, we showed that among STEM US-PhD recipients of foreign origin, the differences between Fulbrights and others were similar in terms of their post-degree employment sector to our much smaller samples of Fulbright and controls.

[31] Because the minimum of each of these variables is zero, we add 1 before taking the natural logarithm.

[32] We believe that the log method is most comparable to our Poisson estimation in the rest of the analysis. We have also estimated this IV in levels rather than in logs. The coefficients on the location variables in these models are similar to uninstrumented results from the same specification, but the standard errors are larger and coefficients are statistically insignificant.

However, to further test the robustness of our matching approach, in the current paper, we have also re-estimated our baseline specifications (forward cites from home and USA, and backward cites to home and USA) weighting controls by the propensity that the scientist is a Fulbright recipient.[33] This propensity is estimated via a probit regression of the Fulbright dummy on controls for gender, rank of Ph.D. program, and the number of pre-graduation citations to the home country, the number of pregrad publications, a dummy for no pregraduation publications, year of PhD, field, and region.[34] We trim the distribution of propensity scores, omitting observations below the 10th and above the 90th percentile of the distribution (see Crump et al., 2009). Results, shown in Appendix Table 2, again indicate that Fulbrights are more likely to receive home country citations and to cite home country literature, in both cases with a coefficient of similar magnitude and similar significance. Dividing into Fulbrights from low and high science countries, most of the coefficients of these baseline results are qualitatively similar to the comparable results in Tables 2, 3, 5 and 6, with the differences being a larger positive coefficient on forward cites to Fulbrights from low-science home countries in Table 2, and a less negative coefficient on forward cites to Fulbrights from the US in Table 3.[35]

6. Brain circulation

Although Fulbrights' articles receive more citations from scientists in their home countries than do articles by controls, there might still be some advantages to home countries' scientists from compatriots receiving US PhDs who then remain in the US. For instance, although these PhDs are cited less by the home country and cite home country work less than those who do return, it is still probable that they are more likely to be cited by and to cite articles by the home country than are American or other scientists.

Our data set is not perfectly suited to test this hypothesis. However, one indication that the home country receives some benefit from its citizens receiving a US science PhD and remaining in the US might be if these scientists are cited more by their home country than by third countries, relative to potential citations.[36] We calculate the proportion of potential citations from the home country by multiplying potentially citing papers from the home country (in the field in year T) times potentially cited papers by our scientist in year t. Similarly, we calculate the proportion of potential citations from a third country by multiplying potentially citing papers from a third country (all articles published in the field in year T minus those published in the home country and in the US) times potentially cited papers by our scientist in year t. We then calculate what proportion of home country and third country potential citations were earned by scientists in our sample who were located in the US.

We find that a scientist in our sample living in the US on average received 0.005% of all potential citations from his or her home country but less than a quarter of that proportion (0.0012%) of potential citations from third countries. This suggests that home country researchers are more aware of the research of their compatriots living in the US than are third country researchers, although additional

[33] See DiNardo et al. (1996) for a similar approach.

[34] We use broadly defined regions because using narrow regions caused all observations from China/Taiwan and Japan/Korea/Singapore to be dropped from the sample.

[35] Our main results are also robust to re-matching using the alternative matching approaches described in Kahn and MacGarvie (2016), namely, propensity score or coarsened exact matching.

[36] They will surely be more likely to be cited by US articles the most due to the strong impact of location and propinquity that we (among others) have demonstrated.

research would be necessary to eliminate alternative explanations for this result.

7. Conclusions

In this paper, we examine the impact of a policy that requires foreign-born, US-trained PhD students to leave the US upon completion of their studies. We ask how such policies affect knowledge diffusion to and from home countries and to and from the US, as measured by citations to published articles in STEM journals. To do this, we track the post-PhD careers of 249 recipients of the Foreign Fulbright Fellowship with return requirement and 249 similar foreign-born "control" scientists not subject to return requirements.

On average, Fulbrights subject to return requirements do not receive more home-country citations than comparable controls. However, on a per article basis (and as a proportion of the maximum number of possible citations the Fulbrights could get from the home country), there is a "Fulbright premium": articles by Fulbrights are cited 90% more frequently in their home countries than articles by controls, and this premium appears to grow as careers develop. Disaggregating, the Fulbright premium is apparent only for Fulbrights from countries with articles per capita in the scientist's field below the 75th percentile ("low-science" countries). Fulbright scientists from these countries are cited 127% per article more at home than are controls from comparable low-science countries. A variety of robustness checks confirm this basic results. We do not observe a similarly robust and significant effect for Fulbrights from high-science countries.

We also find that Fulbrights from both low-science and high-science countries are significantly more likely to themselves cite articles from their home countries (backwards citations) than comparable controls, with somewhat larger effects for Fulbrights from low-science countries.

Thus, return requirements for countries with weak scientific environments do counteract brain drain. Scientific research performed by these US-educated scientists diffuses much more to home countries if the scientists are required to return home, even if only for two years. This does not rule out the possibility of "brain circulation" with respect to knowledge diffusion from compatriots who received US PhDs and remained in the US. Indeed, we find some evidence of brain circulation since in our sample, foreigners with US degrees located in the US obtained a higher proportion of potential citations from their home countries than from third countries. Nevertheless, the much stronger impact is from scientists who do return home.

Further investigation indicates that the reason that return requirements have these impacts on both forward and backward citations to/from the home country is likely due to the increased likelihood of Fulbrights to be located in their home countries. The reason the "Fulbright premium" in forward citations from the home is limited to those from low-science countries for forward citations, and in backward citations is stronger for those in these countries, may be explained by the fact that the return requirements have a much bigger impact on home-country location choices of scientists from low-science countries, increasing their probability of being located at home by 38 percentage points relative to controls (controlling for researcher productivity, home-country science base, field etc.) while only increasing the probability of returning home to high-science countries by 24 percentage points.

We also performed analysis of home country citations using location directly as a control, along with the Fulbright dummy. Our hypothesis is that the estimated difference in citations between Fulbright and control scientists described in prior regressions is explained by the fact that Fulbrights are required to return home. We therefore expect that, if we include a dummy for being located in the home country in the regression, the Fulbright effects estimated previously will be substantially diminished and most of the effect will instead be measured in the location coefficient. Table 8 confirms this. Effects of being in a high-science home country on both forward and backward citations are larger than the effect in the previous tables of being a Fulbright from a high-science country, those who voluntarily choose to return home had more attachment to the richer scientific community in those countries. In contrast, effects of being in a low-science home country are similar to or smaller than the effects of being a Fulbright from a low-science country in the previous tables. Finally, with controls for location in low and high science countries, the Fulbright dummy is no longer significant in terms of forward citations, but is significant in terms of backward citations.

Are the Fulbright scientists' contributions to home-country science achieved at the cost of a decreased impact on US science? In some specifications, we find weak evidence that articles by Fulbrights from low-science countries receive fewer citations from the US. For Fulbrights from high-science countries, there is no reduction in citations from the US relative to controls, and there may be an increase. These findings appear to be partly explained by the fact that few Fulbrights from low-science countries have abnormally high citation rates. In contrast, there were a small minority of Fulbrights from high-science countries who received more than their proportional share of US citations; the rest received less than their share.

On average, Fulbrights themselves cite research by US-based authors as often as do controls. However, the time trend of these cites suggests that their tendency to cite US literature begins to deteriorate after about eight years after the PhD.

We conclude that requiring scientists to return to home countries redirects their focus toward science produced at home. These return requirements were imposed so that the home-country scientific environment would benefit from the PhD education of the Fulbright, and they have indeed accomplished this goal for countries without a strong scientific environment. Graduates returning to these countries share their knowledge with their compatriots, informing their own scientific work.

Of course, we cannot be completely certain that the return requirement of the Fulbright program led to this increased diffusion of scientific knowledge. Fulbrights may have research interests more aligned with their home country or denser collaborative networks within their home country than controls, and that this is the reason that they agreed to be Fulbrights. We have tried to eliminate this by controlling for the scientists' pre-graduation cites to the home country. Indeed, Fulbrights do have an 8% higher average number of pre-graduation home citations to the home country. However, part of the reason for this might be due to Fulbrights choosing topics of study knowing they must return to the country. We remain agnostic about whether the Fulbright's choice of research topic was due to being a Fulbright fellow or partly explains why they became a Fulbright fellow. Nevertheless, we believe that the fact that the results remain even controlling for these pre-graduation citations create a powerful suggestion that at least some of the increased citations to and from the home country were due to return requirements.

These findings add to the results of prior work in which we found that Fulbright recipients collaborate more across borders. Foreign Fulbright recipients publish significantly more articles than controls that represent collaborations with authors in their home countries (Kahn and MacGarvie, 2012). This, combined with the results on citations in this paper, suggests that the return requirements of the Fulbright program benefit recipients' home countries, particularly countries with low scientific production per capita.

The downside of return requirements is that some researchers returning to countries with a weak science base may eventually find their work less likely to receive acknowledgment in the US and may lose some access to information on science produced in the US over time. Another possible downside is that female scientists with return requirements are cited significantly less in home countries than male scientists with return requirements, although given the small number of females in the sample, we are hesitant to emphasize this result. This suggests that return requirements in low-science countries should be combined with policies designed to enhance exposure to the wider scientific world and access to scientific information produced abroad. For example, providing grants for travel to conferences, subsidizing the cost of journal subscriptions, or hosting international conferences may help increase scientific interactions between researchers in low-science countries and other scientists. Which specific policies may be most effective is a topic for future research.

Return requirements do not definitively increase knowledge diffusion to countries with a strong science base (although the requirements do increase returning scientists' citations to home-country articles). This suggests that return requirements may not be necessary to ensure the diffusion of scientific knowledge to high-science countries.

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Appendix A.

Table A1
Two-stage least squares estimates of effects of location on citations.

	(1) Ln(1 + Fwd cites from home)	(2) Ln(1 + Fwd cites from US)	(3) Ln(1 + Backward cites to home)	(4) Ln(1 + Backward cites to US)
Located in home country >75th pctile articles per capita in field	0.0384	0.0182	0.341	−0.105
	(0.0785)	(0.216)	(0.301)	(0.283)
Located in home country <75th pctile articles per capita in field	0.0254*	−0.0165	0.130**	0.0237
	(0.0138)	(0.0492)	(0.0534)	(0.0978)
Home country <75th pctile articles per capita in field	−0.00372	−0.0291	−0.00672	−0.0994
	(0.0303)	(0.0863)	(0.118)	(0.119)
ln Publications in field in home country	0.00517***		0.0165***	
	(0.00119)		(0.00564)	
ln Publications in field in US in citing year		0.00884		−0.145
		(0.0285)		(0.0956)
Observations	37,822		4817	

Robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
All specifications include log(publications by scientist), pregrad citations to home country, female, program rank dummies for field, year, and year of PhD. Coefficients of these controls available upon request.

Table A2
Baseline estimates using propensity score weighting.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Fwd cites from home		Fwd cites from US		Backward cites to home		Backward cites to US	
Fulbright	0.545**		−0.116		0.842***		−0.0161	
	(0.254)		(0.133)		(0.327)		(0.0824)	
Fulbright from country >75th pctile articles per capita in field		0.543		0.247		0.865**		0.0498
		(0.349)		(0.160)		(0.382)		(0.122)
Fulbright from country <75th pctile articles per capita in field		0.548*		−0.496**		0.753		−0.0306
		(0.313)		(0.194)		(0.477)		(0.111)
Home country <75th pctile articles per capita in field		−0.0162		0.0154		−0.374		−0.106
		(0.335)		(0.188)		(0.483)		(0.118)
Observations	31,850				4,055			

Robust standard errors, clustered by scientist, in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
All specifications include log(publications by scientist), pregrad citations to home country, female, program rank dummies for field, year, and year of PhD. Coefficients of these controls available upon request.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.respol.2016.02.002.

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