Fast Friends: The Impact of Short-term Visits on Firms' Invention Outcomes

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A. Visa Waiver Program and the Number of Visitors

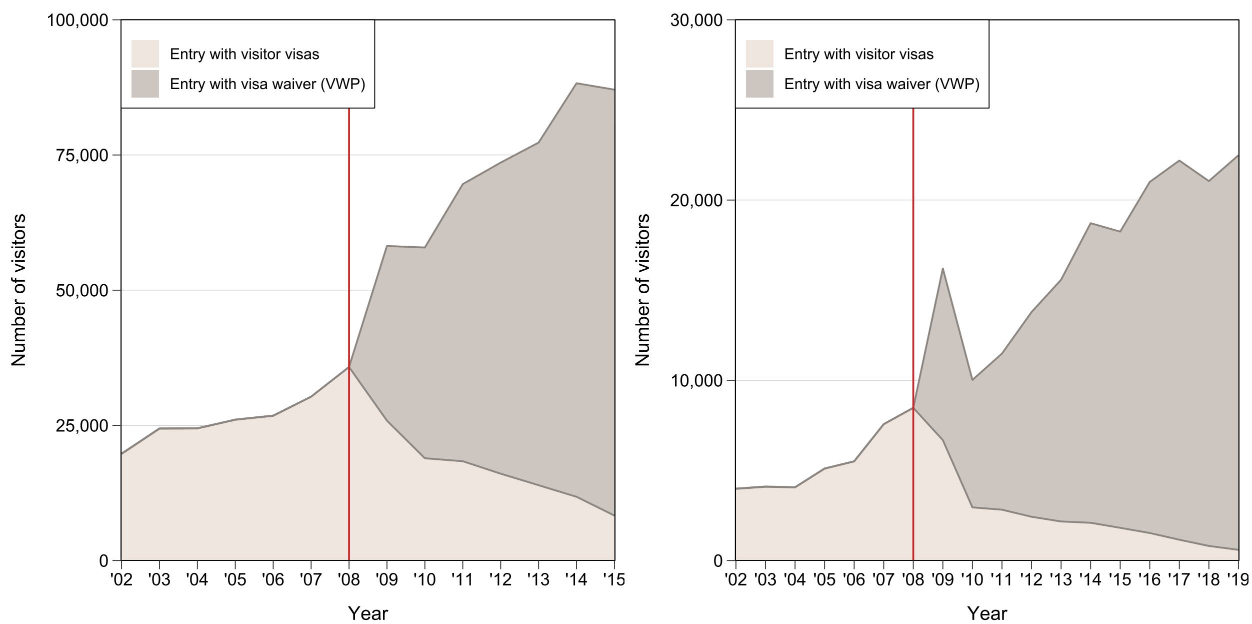
A.1. Visa Waiver Program and the number of visitors to the United States

Figure A1 shows the number of visitors from VWP-designated countries to the United States, divided between those with B-1 (business) and B-2 (tourism) visas (light brown) and those for whom visas were waived under the VWP (dark brown). Since such breakdowns of visitors are only available on or after 2002, Figure A1 includes countries that have introduced the VWP since 2002. We mark the top five countries in terms of the number of visitors to the United States from those countries.

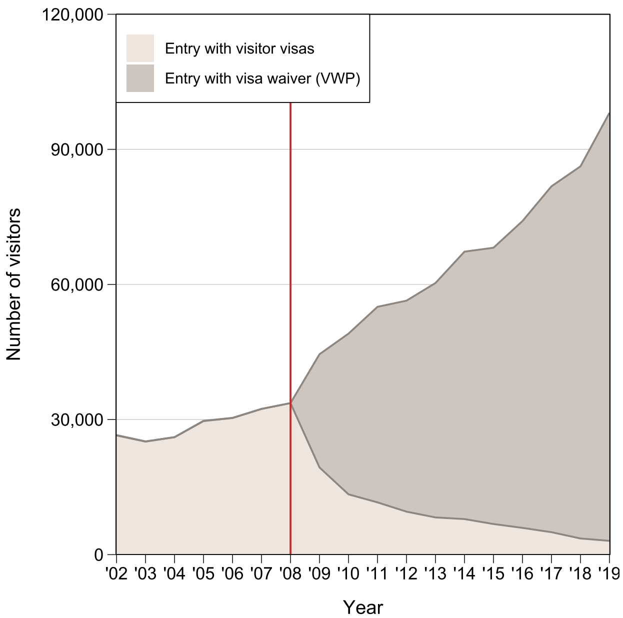
Figure A1. Visa Waiver Program and short-term visitors to the US

(a). Czech Republic (2008)
4th largest number of visitors among sample countries

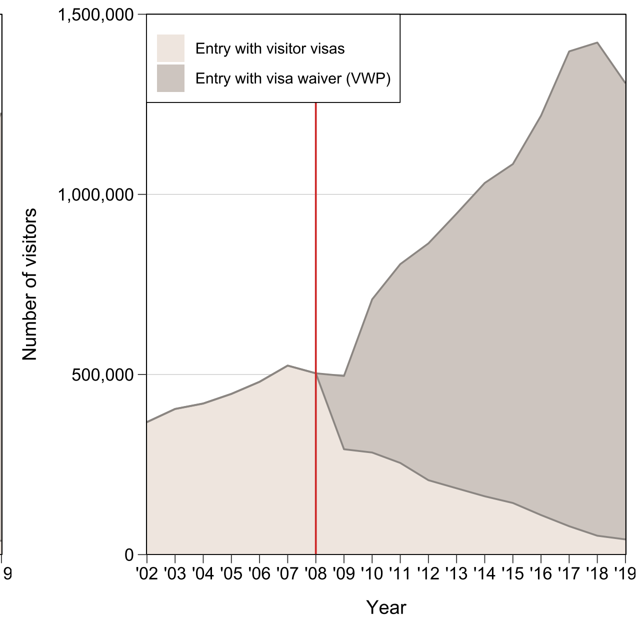
(b). Estonia (2008)



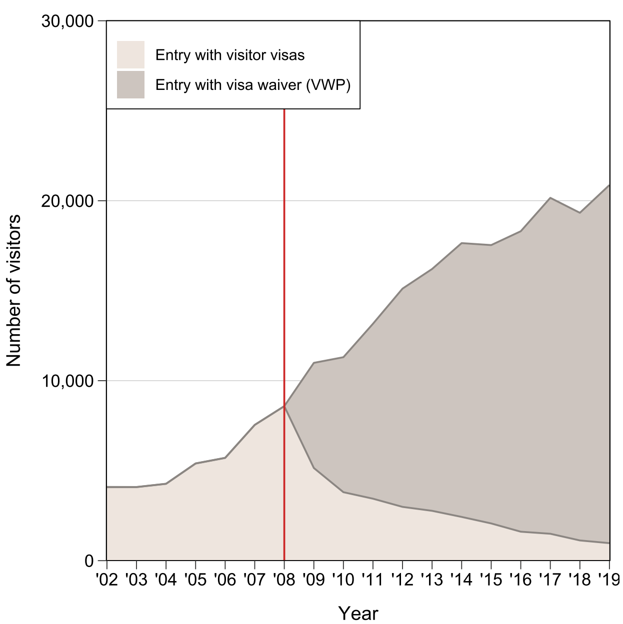
(c). Hungary (2008), *5th in number of visitors*



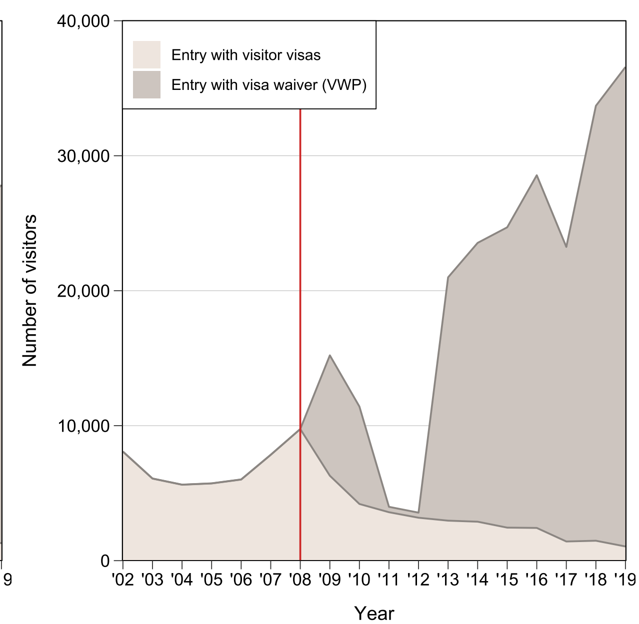
(d). South Korea (2008), *1st in number of visitors*



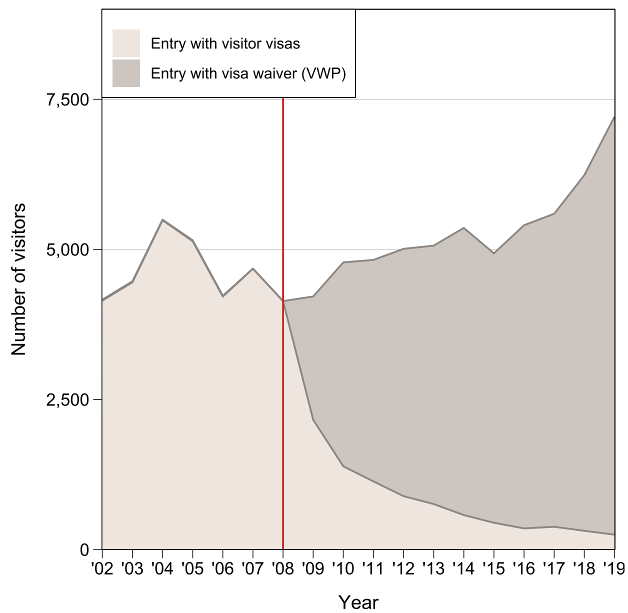
(e). Latvia (2008)



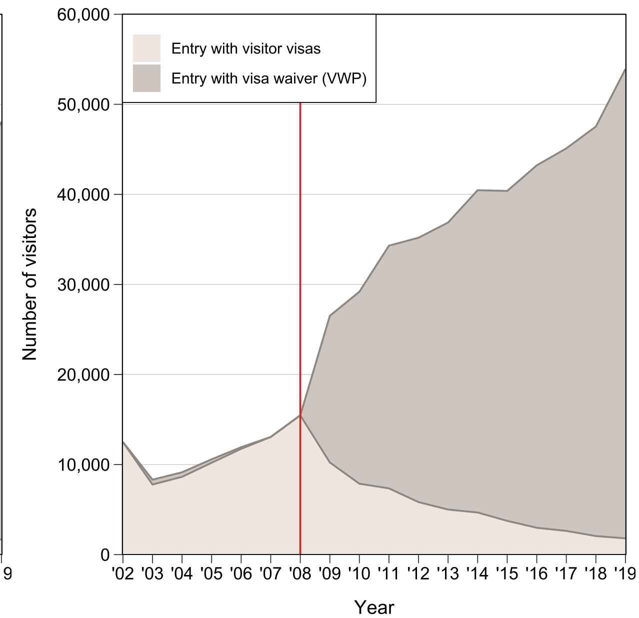
(f). Lithuania (2008)



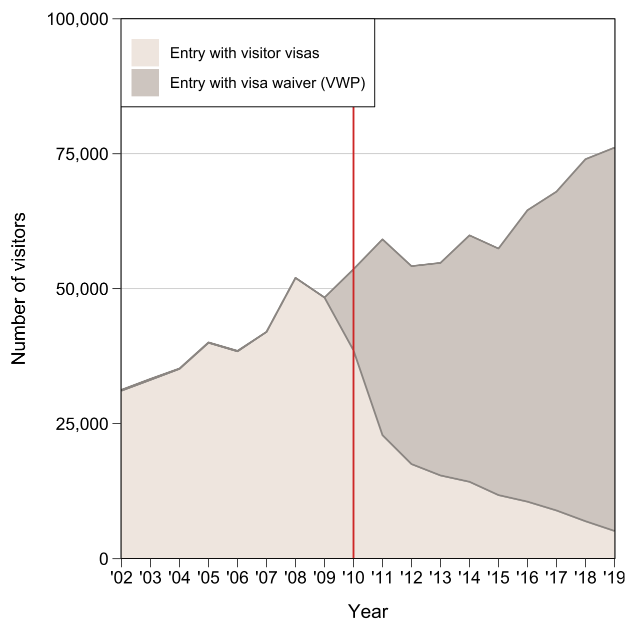
(g). Malta (2008)



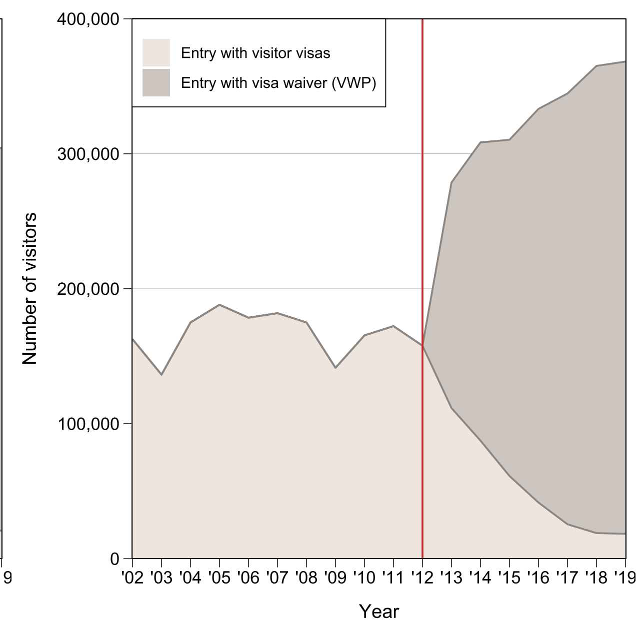
(h). Slovakia (2008)



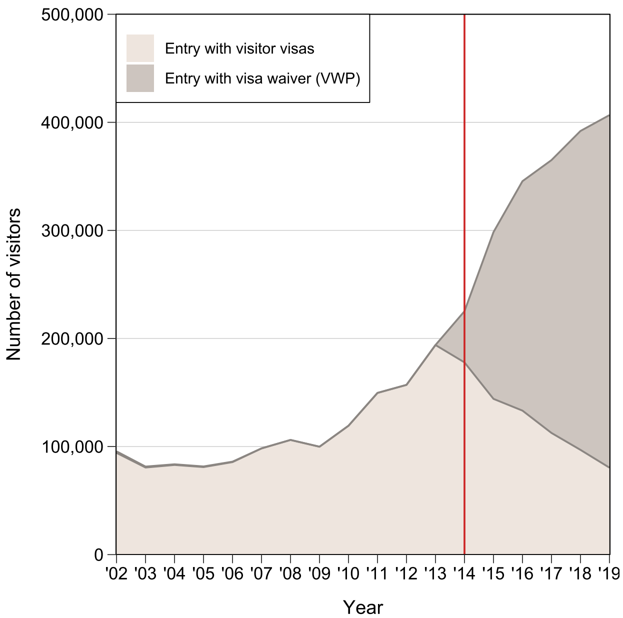
(i). Greece (2010)



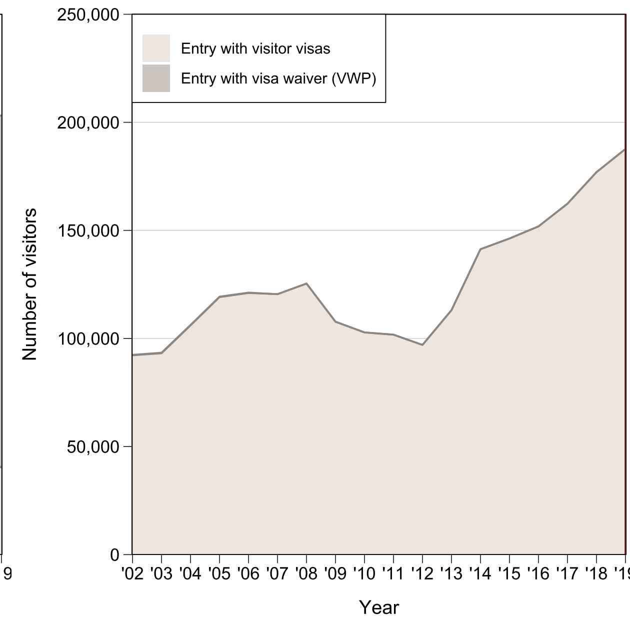
(j). Taiwan (2012), *3rd in number of visitors*



(k). Chile (2014), *2nd in number of visitors*



(l.) Poland (2019)



Notes. These graphs represent the number of visitors from VWP-eligible countries, divided by those with B-1 (business) and B-2 (tourism) visas (light brown) and those for whom visas were waived (dark brown). Only countries that introduced the VWP in 2002 or later are shown, due to the availability of data (2002–2019). Data source: *Yearbook of Immigration Statistics*, US Department of Homeland Security.

A.2. Reciprocity: Visits between the United States and VWP countries

The VWP is a reciprocal agreement in which visitor visas are waived for US citizens visiting a non-US country as well as for non-US citizens visiting the United States. We check how the VWP changed (1) the number of visitors from VWP countries to the United States and (2) the number of visitors from the United States to VWP countries. In most cases, visiting the United States is much more difficult than it is for US citizens to visit other countries. It is expected that easing short-term visits to the United States will have a greater effect than the other way around.

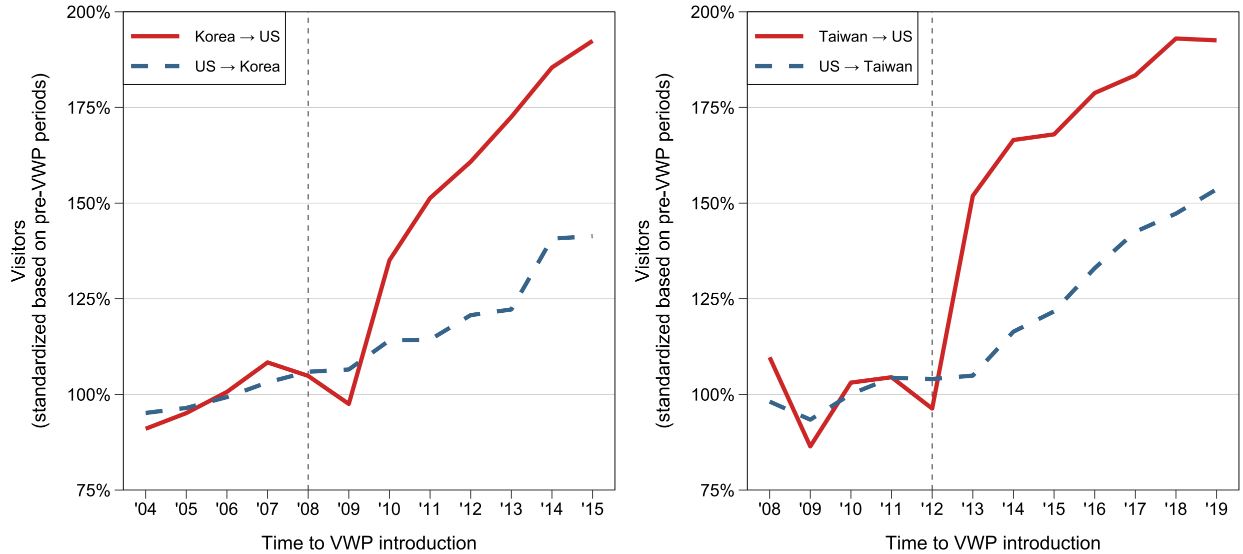
We collected entry data from the governments of South Korea and Taiwan, two of the top countries in terms of the number of short-term visitors to the United States. Note that, as South Korea does not provide any statistics on short-term visitors by nationality (such data is only available since 2009), we used the total number of entrants from the United States each year. For Taiwan, we used the measure of short-term visitors.

Figure A2 shows that the number of visitors from South Korea and Taiwan to the United States increased by 51% and 68%, respectively, three years after the VWP was introduced. In contrast, visitors from the United States to those two countries increased by only 14% and 22%, respectively, during the same period.

Figure A2. Visa waiver and visitors from and to the US: South Korea and Taiwan

(a). US and South Korea

(b). US and Taiwan



Sources. Korean Statistical Information Service (KOSIS) for South Korea; Tourism Bureau, Ministry of Transportation and Communications for Taiwan.

B. Case Study: Geographic and Disciplinary Division of R&D Activities of Ten Leading Firms in Sample

The firms in our sample are large global pharmaceutical companies. We provide two maps to illustrate these companies' global reach with respect to their Research and Development (R&D). These maps indicate the percentage of top-ten pharmaceutical firms (based on 2020 revenues) that have an R&D center in the pertinent country. We focus on major R&D centers that conduct some element of research; we do not include small regional centers that are focused purely on clinical development activities that would increase global coverage significantly. The centers on which we focus undertake research that contributes to the creation of a firm's patents. To determine the firms' R&D center locations we utilized a combination of historical company websites (*waybackmachine.org*) and company financial filings (annual reports, 10-K filings, and 20-F filings). Of these ten firms, five are US-headquartered, two are headquartered in Switzerland, and one each is headquartered in the United Kingdom, France, and Japan. By "center," we simply mean that the firm has major R&D operations in that country; these operations may be at a single site or at multiple sites in that country.

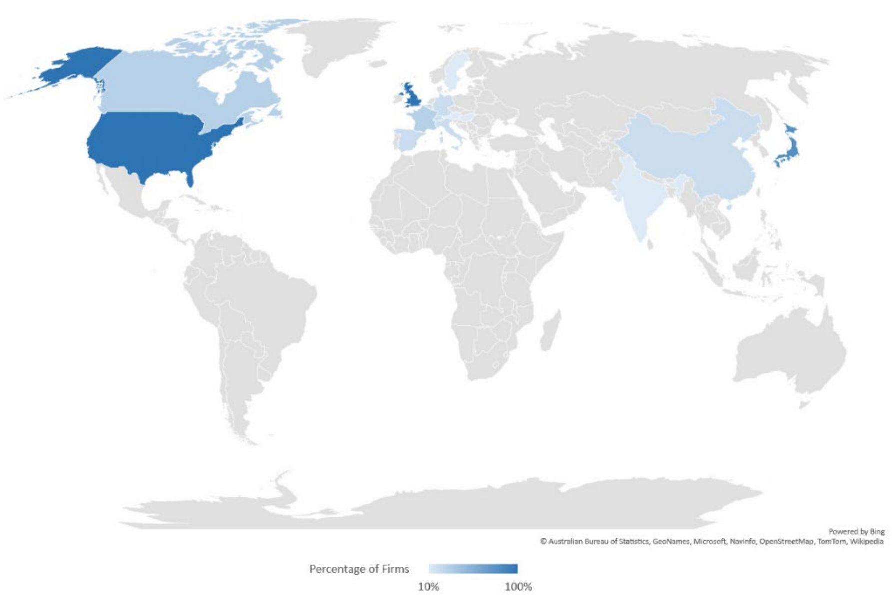
Figure B1 graphically illustrates the global R&D coverage in 2000 and 2020 of the ten largest firms in our sample. The United States is a common center of R&D activities with all firms having some R&D presence there, primarily in the northeast and California. Europe is the site of many firms' R&D activities with the United Kingdom leading the way. These results are not entirely surprising as nine of the ten leading firms are American or European. Between 2000, and 2020 more R&D centers have been placed in large emerging markets such as China and India.

With respect to the specific scientific activities being undertaken across these different R&D centers, less data is readily available. However, for some of these leading firms, we can observe a distinct division of responsibilities between each R&D center. Three specific examples (Novartis, AstraZeneca, and Bristol Myers Squibb) help illustrate this point in Table B1.

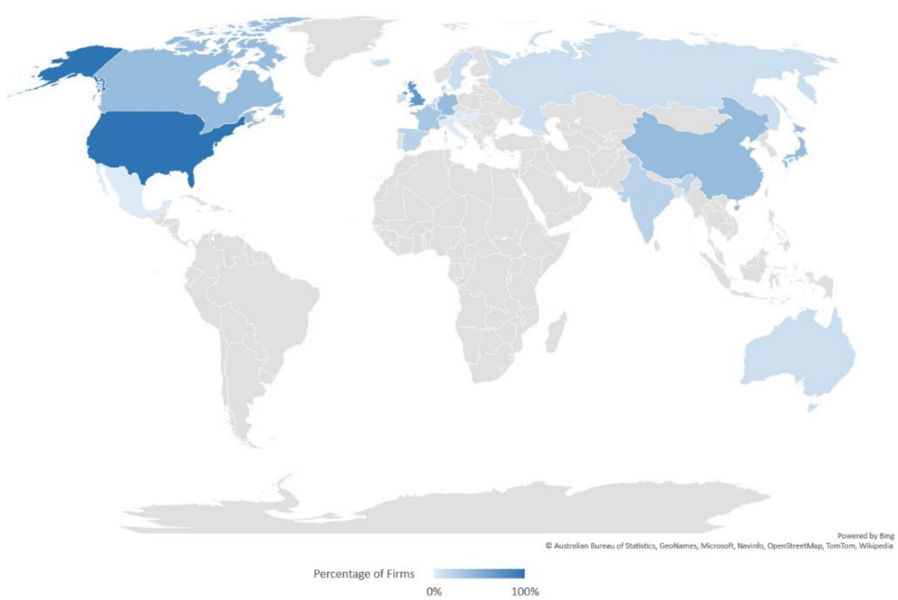
As shown, there is no uniform way to divide responsibilities between R&D centers. Often firms have a mix of activities pertaining to therapeutic domains and more general science domains that apply across therapeutic classes (e.g., pharmacokinetics). However, across all three example firms, we observe that each R&D center has distinct areas of scientific responsibility that often partially overlap with those of other R&D centers. This illustrates that firms can benefit from an increase in the number of short-term visits between centers as both parties will provide unique knowledge that can be recombined in new ways. The scale of the opportunity will vary by firm. For some firms, knowledge is more evenly dispersed, thereby enhancing the benefits of short-term visits between centers. For other firms, in contrast, the knowledge may be more concentrated in a single center such that little benefit can be achieved through changing the number of short-term visits. However, from this very cursory analysis, it appears that the knowledge in most firms in our sample is likely to have been generally distributed across centers. Such centers are likely to benefit from short-term visits that encourage recombination and exchange of these diverse pieces of knowledge across different centers.

Figure B1. Distribution of R&D centers for the 10 largest pharmaceutical firms in 2000 and 2020

(a). R&D center distribution of top-10 pharmaceutical firms by country, 2000



(b). R&D center distribution of top-10 pharmaceutical firms by country, 2020



Source. Company annual reports and websites.

Table B1. Division of scientific domains per major R&D center for Novartis, AstraZeneca, and Bristol-Meyers Squibb

Firm	Country	2000 Responsibility	2020 Responsibility
Novartis	USA	• Oncology • Arthritis • Genomics • Gene therapy • Metabolic diseases • Infectious diseases	• Oncology • Ophthalmology Cardiovascular • Metabolic diseases • Pharmacokinetics • Infectious diseases • Protein engineering • Genomics
	UK	• Respiratory diseases • Chronic pain	• *Not major center*
	Switzerland	• Nervous system • Transplantation • Oncology • Osteo • Genomics • Ophthalmology	• Autoimmunity Transplantation • Inflammation Musculoskeletal diseases Neuroscience • Oncology
	Austria	• Dermatology	• *Not major center*
	Japan	• Oncology • Arthritis	• *Not major center*
	Singapore	• Tropical diseases	• Tropical diseases
	China	• *Not major center*	• Oncology • Biomarker research
AstraZeneca	UK	• Chemistry • Bioscience • Pharmacology • Genetics • Respiratory diseases, inflammatory diseases e.g., arthritis	• Oncology • Cardiovascular • Renal • Metabolism • Immunology • Neuroscience
	Canada	• Pain control	• *Not major center*
	Sweden	• Neuroscience • Respiratory diseases • Inflammatory diseases • Cardiovascular • Gastrointestinal	• Cardiovascular • Renal • Metabolism • Respiratory • Immunology • Neuroscience
	India	• Tuberculosis	• *Not major center*
	France	• Oncology	• *Not major center*
	USA	• Pain control • Neurology • Oncology • Infectious diseases • Gene therapy	• Biotechnology • Protein engineering • Translational science • Cardiovascular • Renal • Metabolism

Firm	Country	2000 Responsibility	2020 Responsibility
Bristol-Myers Squibb	USA	• Cardiovascular • Metabolic Diseases • Oncology • Immunology • Biologics • Global development and medical affairs	• Biotechnology • Antibody therapeutics • Gene therapy • Hematology • Oncology • Immuno-oncology. • Cardiovascular • Metabolic diseases • Immunology
	UK	• New medicinal compounds	• New medicinal compounds
	Belgium	• Clinical research and development • Regulatory	• Clinical research and development • Regulatory
	India	• *Not major center*	• Target identification
	France	• *Not major center*	• Global development and medical affairs
	Spain	• *Not major center*	• Global informatics and predictive sciences

Source. Company annual reports and websites.

C. Additional Empirical Analyses

C.1. Descriptive statistics

In this section, we provide further description of the treated and never-treated firms. Table C1 shows the list of countries where the treated firm's largest non-US units are located. The second column displays the total number of USPTO patents filed in the 1990s by the country's all assignee firms. Table C2 then compares patenting activities of treated firms by the treatment cohort and the never-treated firms for the sample period (1976–2020). The treated firms, on average, are larger and more active in patenting than the never-treated firms and tend to have more inventors per patent. On the other hand, the never-treated firms tend to cite more prior art than the treated ones.

Care must be taken in interpreting and extrapolating the results even though the difference in absolute values is less of a concern because we (1) compare the trends in the outcome variables and (2) also compare the treated firms (e.g., early-treated firms vs. not-yet treated firms). The treated and never-treated firms are indistinguishable in terms of invention scope, forward citations (that are often used to measure the quality of patents), and patent grant lag.

Table C1. Country location of treated firms' largest non-US unit

VWP Country	Total USPTO patents filed by the country's assignee firm (1990–1999)	VWP Year	Number of treated firms (Total: 135)
United Kingdom	17,489	1988	27
Japan	262,533	1988	21
Germany	65,714	1989	18
Switzerland	11,403	1989	16
France	28,543	1989	15
Italy	11,190	1989	7
Sweden	9,586	1989	6
Netherlands	7,006	1989	6
Ireland	580	1995	5
Belgium	3,177	1991	3
Australia	3,744	1996	3
Norway	1,163	1991	2
South Korea	12,839	2008	2
Finland	5,259	1991	1
New Zealand	518	1991	1
Denmark	1,422	1991	1
Spain	1,099	1991	1

Notes. Never-treated firms had their largest non-US units in the following countries: Canada, Israel, India, Mexico, Puerto Rico, Bermuda, Brazil, China, Hong Kong, Russia, Curaçao, and Cayman Islands.

Table C2. Comparison of patents by the treatment cohort and never-treated firms: 1976–2020

	Treated firms						Never-treated firms
	1988 (N=48)	1989 (N=68)	1991 (N=9)	1995 (N=5)	1996 (N=3)	2008 (N=2)	
Invention quantity	10.91	24.81	2.48	21.53	13.75	0.39	2.38
Invention scope	10.55	9.86	9.23	7.93	11.07	7.65	10.47
Inventors per patent	4.95	4.75	4.00	4.17	4.41	4.94	3.93
Backward citations (10 years w/o self-citations)	4.62	5.56	6.56	5.55	4.93	0.83	7.15
Forward citations (10 years w/o self-citations)	6.21	6.13	15.38	10.32	8.91	1.62	6.95
Patent grant lag (days)	1,080.78	1,084.02	1,111.35	1,036.87	1,269.97	987.13	1,105.18

Notes. To compare treated firms with never-treated firms (which do not have a treatment year), we provide the descriptive statistics based on the sample period (1976–2020). For invention quantity, we imputed zero to a firm-year observation where no patent was filed.

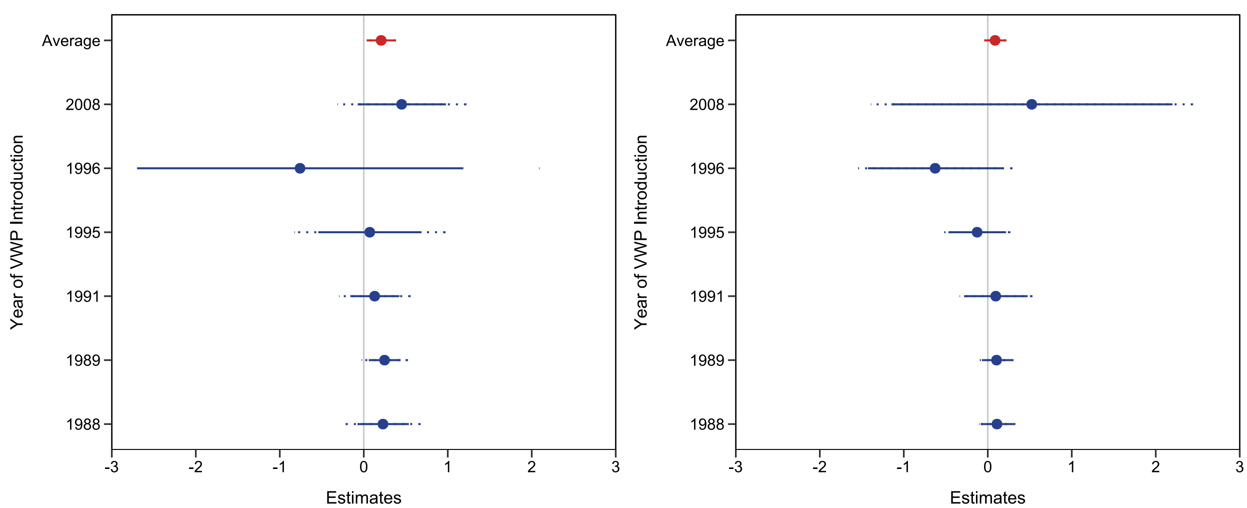
C.2. Main results by the treatment cohort

Figure C1 illustrates the main estimates for invention quantity and scope by the treatment cohort. The sign and magnitude of the cohort-level effects (blue dots) are largely consistent with the average effect (a red dot) except for the cohorts of 1995 and 1996. In 1995, Ireland, an English-speaking country, was the only treated country (five firms in the sample). In 1996, Australia and Argentina were treated, and we have three firms that had their largest non-US units in Australia, an English-speaking country.

These eight firms with the largest non-US R&D centers in Ireland and Australia (that account for 6% of the sample) appear to exert a downward pressure on the average effect. After dropping these firms from the sample, the TWFE estimate of invention quantity increases from 0.257 (p=0.001) to 0.275 (p=0.001); likewise, the TWFE estimate for invention scope increases from 0.107 (p=0.107) to 0.158 (p=0.019).

Figure C1. The effects of visa waiver on invention quantity by the treatment cohort group

(a). Invention quantity (b). Invention scope



C.3. Knowledge and cultural distance: Alternative estimations

Table C3 shows the estimation results on knowledge distance from the three-way interactions with the TWFE model. Although the TWFE models with different treatment timing may be biased, they perform the statistical tests on the moderators. In columns 1 and 3, we use *small overlap* and *large overlap* as omitted categories. In columns 2 and 4, we use *small overlap* as an omitted category. All these models consistently show that the impact of short-term visits on invention quantity and scope is maximized when the knowledge distance between US and non-US units is intermediate (i.e., 33–66%).

Table C3. Three-way interactions with TWFE model: Knowledge distance

	Dependent variables (log point difference):			
	Invention quantity		Invention scope	
	(1)	(2)	(3)	(4)
Treat×Post	−0.256***	−0.545***	−0.317***	−0.502***
	(0.087)	(0.114)	(0.077)	(0.095)
Treat × Post × Small Overlap	–	–	–	–
Treat × Post × Medium Overlap	0.510**	0.690*	0.537***	0.716***
	(0.215)	(0.391)	(0.155)	(0.155)
Treat × Post × Large Overlap	–	0.598***	–	0.369***
		(0.134)		(0.112)
Baseline (Omitted category)	Small & Large overlap	Small overlap	Small & Large overlap	Small overlap
Observations	19,665	19,665	19,665	19,665
Adjusted R^2	0.817	0.821	0.614	0.622
Method	TWFE		TWFE	
Time window	[−5, 7]		[−5, 7]	

Table C4 shows the estimation results on cultural distance from the three-way interactions with the TWFE model. The results, although imprecisely estimated, are consistent with those from the split-sample analyses with CS21 estimator in Table 5.

Table C4. Three-way interactions with TWFE model: Cultural distance

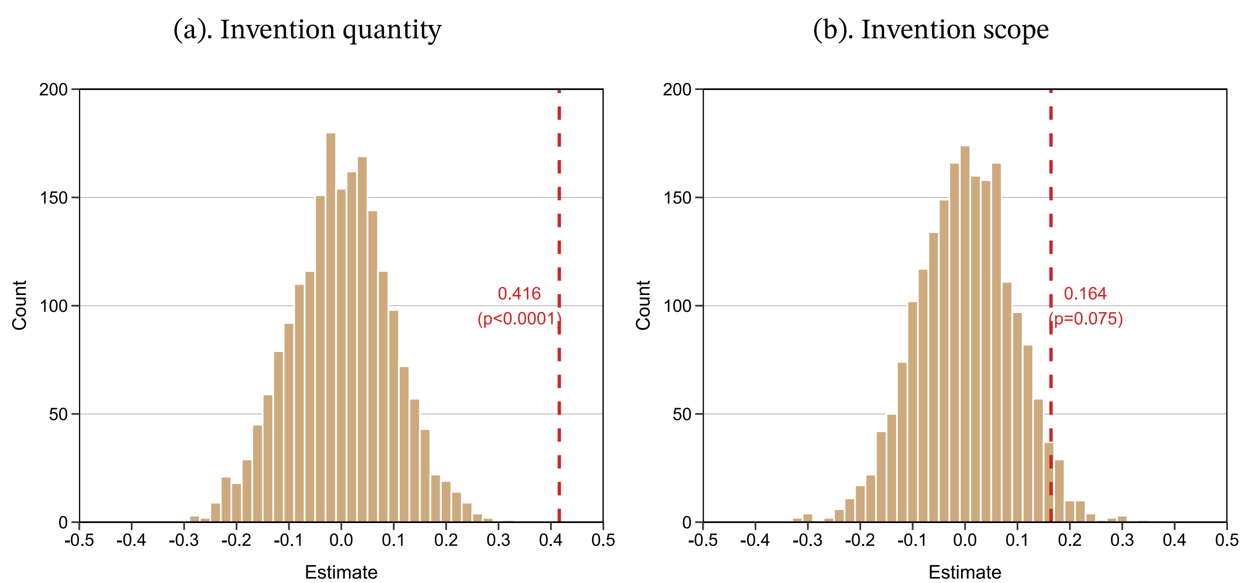
	Dependent variables (log point difference):	
	Invention quantity	Invention scope
	(1)	(2)
Treat×Post	0.124	−0.059
	(0.188)	(0.122)
Treat × Post	0.186	0.214
× Diff. Language	(0.204)	(0.137)
Observations	19,665	19,665
Adjusted R^2	0.477	0.240
Method	TWFE	TWFE
Time window	[−5, 7]	[−5, 7]

C.4. Placebo permutation tests

We run the Fisher's permutation test (also known as a re-randomization test) to assess whether our findings are driven by spurious correlations or by modeling inaccuracies. We randomly reassign the treatment status to all firms while maintaining the distribution of treated timing and the number of treated firms for each year. We then run the same regressions as reported in Table 2, columns 4 and 8. To account for the observed gradual increase in effects over time, as depicted in Figure 4, we calculate average estimates for post-VWP years 5, 6, and 7 ($l \in [-5, 7]$).

Figure C2 shows the results of 2,000 iterations. For the quantity of invention, the permutation mean is –0.00007 with the 95% permutation confidence interval [–0.191, 0.188]. Our estimate for $l \in [-5, 7]$, 0.416, is substantially different from the permutation results (p<0.0001). For the scope of invention, the permutation mean is 0.0006 with the 95% permutation confidence interval [–0.180, 0.173]. Again, the estimate for $l \in [-5, 7]$, 0.164, is distinct from the permutation results (p=0.075).

Figure C2. The effects of visa waiver on invention outcomes: Permutation tests



Notes. The bars illustrate the histogram of 2,000 estimates from the (placebo) permutation tests. We randomly reassigned the treatment status to all firms while maintaining the distribution of treated timing and the number of treated firms each year. We then ran the same regressions as we did for the main analysis: CS21 with not-yet treated and never-treated units as control for [–5, 7] and calculated average estimates for post-VWP years 5, 6, and 7 ($l \in [-5, 7]$). The vertical dashed line shows the estimate with real treatment data, along with the empirical p-values from the permutation tests in parenthesis.

C.5. Main results with alternative estimation techniques and time windows

C.5.1. Alternative estimation techniques

Figure C3 shows the dynamic event-study estimates obtained using the staggered difference-in-differences approach. Panels (a)–(d) and (e)–(h) depict the estimates for the quantity and scope of inventions, respectively. Specifically, for the quantity of inventions, panels (a) and (b) show the estimates based on the methodology by Callaway and Sant'Anna (2021), employing two distinct control group specifications: "never treated" and "not-yet-treated and never treated." The estimates utilizing the Sun and Abraham (2021) method are presented in panel (c) which employs never treated units as controls.

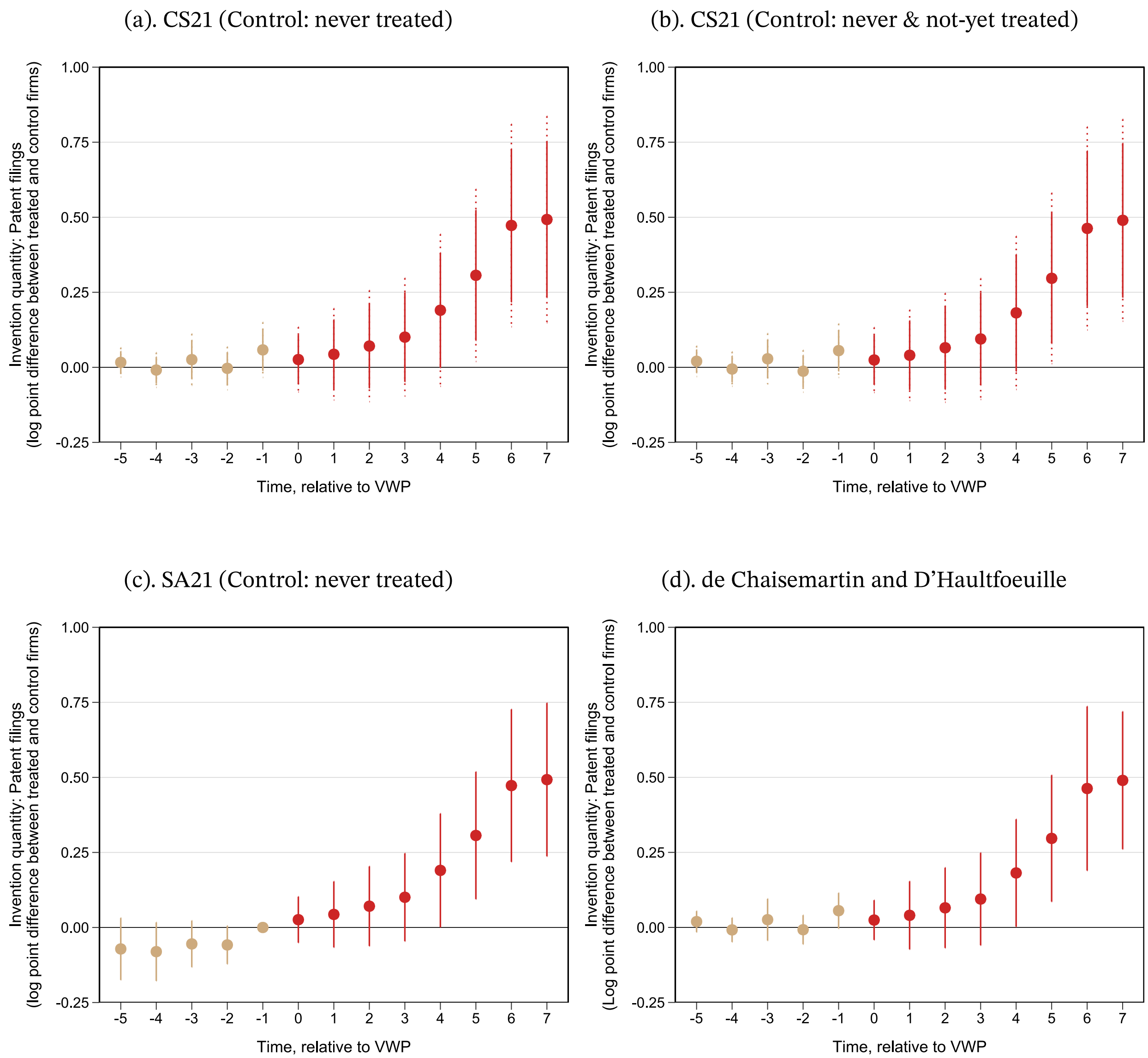
Panel (d) presents the estimates using the de Chaisemartin and D'Haultfoeuille (2020, 2024) estimator. The R package (*DIDmultiplegt*; version 0.1.2) was used for the estimations, with bootstrapped standard errors (repeated 50 times) clustered at the firm level. In this staggered adoption design with a binary treatment, the estimates should be numerically the same as those using the Callaway and Sant'Anna (2021) method with not-yet-treated and never-treated units serving as controls (de Chaisemartin and D'Haultfoeuille, 2023, 2024). We indeed confirm that panels (b) and (d) reveal identical estimates, with only minor differences in the 95% confidence intervals.

Overall, the four methodologies yield consistent estimates for both the quantity (panels a–d) and scope (panels e–h) of inventions. Figure 4 in the main paper presents those in panels (b) and (f).

Note that using only not-yet treated firms (but *not* never treated firms) as control is challenging in our context. First, in our sample, most firms (98.5%) were treated within a relatively short time window (i.e., 1988, 1989, 1991, 1995, and 1996), effectively leaving only two firms treated in 2008 as not-yet treated units. Both firms had the largest non-US unit in a single country, South Korea, and had much lower invention quantity (0.39 patents per firm per year; Table C2). This makes the sole use of not-yet treated units as controls undesirable. Second, using only not-yet-treated for the control (especially when many never-treated firms are available) is not a standard approach and is not supported by the latest version of R packages for SA21 and CS21 estimators.

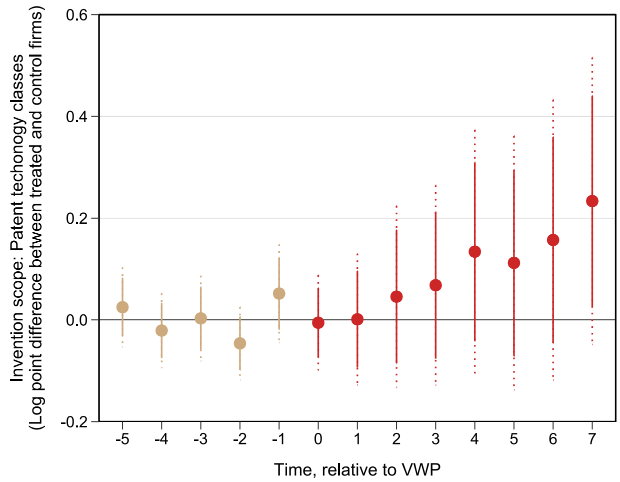
Figure C3. The effects of visa waiver on invention quantity: Alternative estimation techniques

Invention quantity

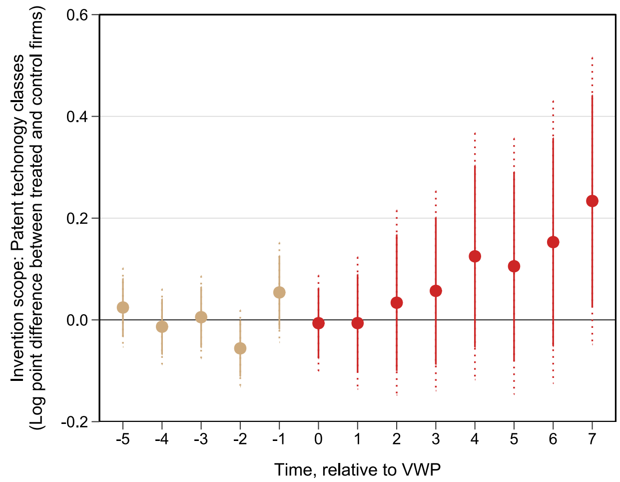


Invention scope

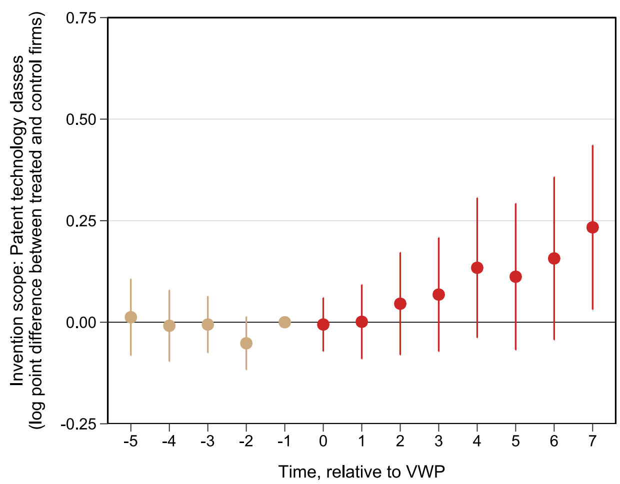
(e). CS21 (Control: never treated)



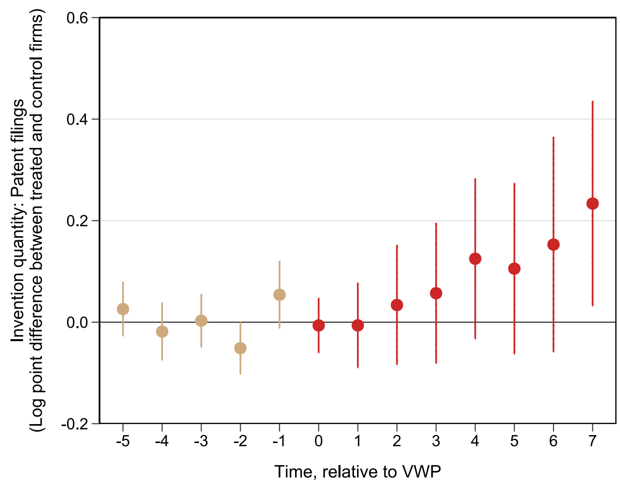
(f). CS21 (Control: never & not-yet treated)



(g). SA21 (Control: never treated)



(h). de Chaisemartin and D'Haultfoeuille

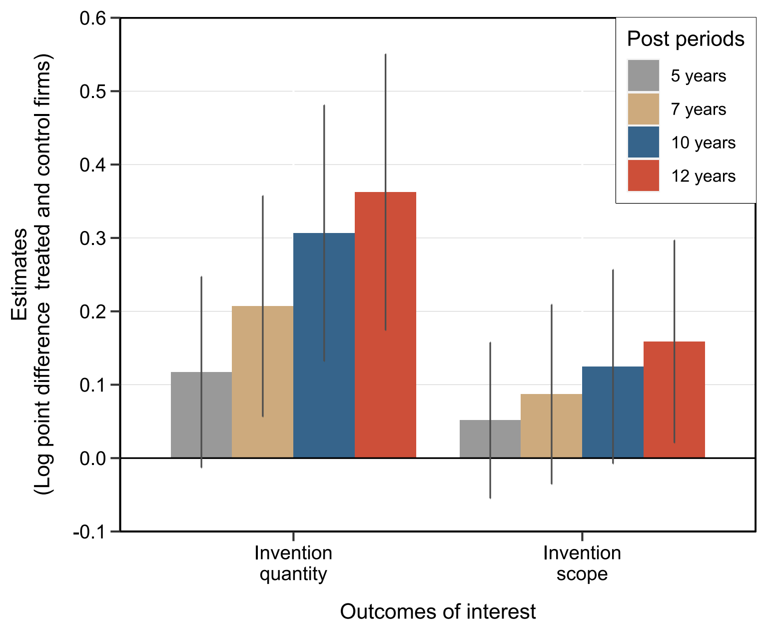


C.5.2. Alternative time windows

Figure C4 illustrates the pooled difference-in-differences estimates (CS21) and the 95% confidence intervals for the innovation quantity and scope with alternative time windows. Since the Callaway and Sant'Anna (2021) estimator uses the entire pre-treatment period (and thus is not sensitive to the number of periods included), the variation comes from the post-treatment periods: 5, 7, 10, and 12 years. As expected, the estimates increase in magnitude and are statistically significant as we include more post-treatment years in the estimation.

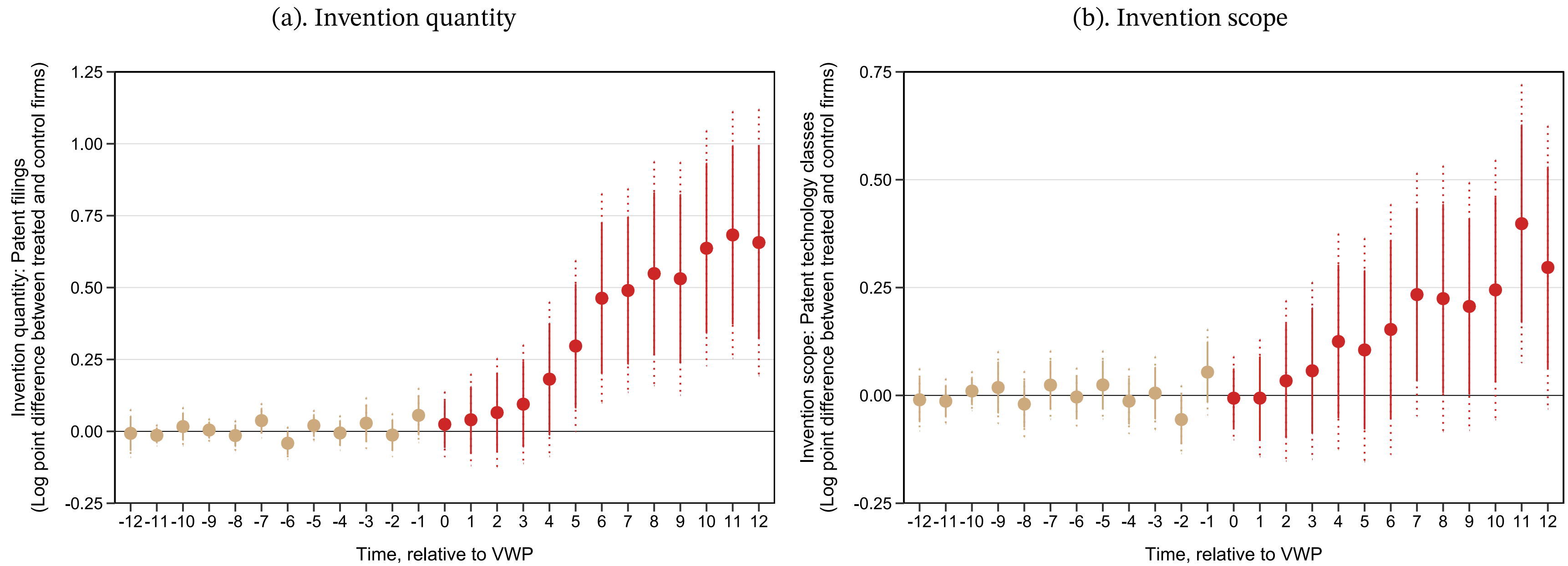
The flexible, dynamic effects are shown in Figure C5, which is a version of Figure 4 (in the paper) but with a longer time window: [–12, 12]. Figure C5 conveys more information than the pooled regression results reported in Figure C4. The invention quantity (Panel a) and scope (Panel b) gradually increased after the introduction of VWP.

Figure C4. The effects of visa waiver on invention outcomes: Different time windows



Notes. Vertical bars indicate the 95% confidence interval based on analytic standard errors.

Figure C5. The effects of visa waiver on invention outcomes: Long-term effects



Notes. The points represent the estimates of *Treat*×*Post* from the staggered difference-in-differences method (Callaway and Sant'Anna, 2021). *T*=0 is the year of VWP introduction. The estimates for pre-treatment periods are colored brown, while the red points represent the estimates for the post-treatment periods. Analytical 95% confidence intervals are reported in solid vertical lines. Bootstrap 95% confidence intervals (10,000 iterations), clustered at the firm level, are provided in dotted vertical lines.

C.6. Main results with alternative sub-samples

C.6.1. US-based firms

A significant portion of treated firms are US-based. To rule out the possibility that idiosyncratic international firms drive the results, we performed the analyses with US-based firms only (i.e., with firms that registered the largest number of patents from their US units). Table C5 shows the estimation results, which are highly consistent with the main findings reported in Table 2 of the paper.

Table C5. The effects of visa waiver on invention outcomes: US-based firms

	Dependent variables (log point difference):							
	Invention quantity				Invention scope			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treat	0.241^{***}	0.209^{***}	0.203^{**}	0.196^{**}	0.093	0.120^{*}	0.094	0.087
× Post	(0.077)	(0.072)	(0.080)	(0.080)	(0.067)	(0.067)	(0.065)	(0.067)
	[0.084, 0.397]	[0.069, 0.350]	[0.047, 0.358]	[0.039, 0.354]	[−0.037,0.224]	[−0.012, 0.252]	[−0.034, 0.222]	[−0.044, 0.218]
Obs.	19,496	19,496	23,400	23,400	19,496	19,496	23,400	23,400
Firms	520	520	520	520	520	520	520	520
Method	TWFE	SA21	CS21	CS21	TWFE	SA21	CS21	CS21
Control group	All	Never treated	Never treated	Never & Not yet	All	Never treated	Never treated	Never & Not yet
Time	[−5, 7]				[−5, 7]			

Notes. The main estimation was performed in R using the *lfe* (TWFE), *fixest* (SA21), and *did* (CS21) packages. The number of observations differs by the estimation methods. For columns (1), (2), (5), and (6), the observations include relative years, −5 through 7, for the treated group and the entire sample period for the control group (1976–2020). Analytic standard errors, clustered at the firm level, are provided in parentheses; the corresponding 95% confidence intervals are in squared brackets. For columns (3), (4), (7), and (8), the data with the entire sample period is used in the estimation, and the results are aggregated for the time window, [−5, 7]. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with clustered bootstrapping at the firm level (10,000 iterations). Since the exact *p*-values are not provided with this approach, we provide the range of *p*-values. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

C.6.2. Firms with single treatment

The estimation results may be confounded by firms that received multiple treatments (i.e., they had units in countries where the VWP was introduced in different years). We thus restricted our sample to firms whose non-US units did not receive another treatment within seven years of the main treatment. That is, we removed firms that had units in countries where the VWP was introduced in years that were different and non-consecutive from the year the VWP was introduced in the country of the firm's largest non-US unit; we kept the firm if that treatment happened in the year immediately following (given the dynamic patterns of the effects in Figure 4). In Table C6, the results are qualitatively similar using this different sub-sample of observations.

Table C6. The effects of visa waiver on invention outcomes: Firms with single treatment

	Dependent variables (log point difference):							
	Invention quantity				Invention scope			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treat	0.223***	0.194***	0.185**	0.179**	0.093	0.122*	0.097	0.091
× *Post*	(0.078)	(0.072)	(0.079)	(0.080)	(0.065)	(0.066)	(0.063)	(0.064)
	[0.071, 0.375]	[0.052, 0.335]	[0.029, 0.340]	[0.023, 0.334]	[−0.034, 0.221]	[−0.007, 0.251]	[−0.025, 0.220]	[−0.034, 0.216]
Obs.	19,561	19,561	23,625	23,625	19,561	19,561	23,625	23,625
Firms	525	525	525	525	525	525	525	525
Method	TWFE	SA21	CS21	CS21	TWFE	SA21	CS21	CS21
Control group	All	Never treated	Never treated	Never & Not yet	All	Never treated	Never treated	Never & Not yet
Time	[−5, 7]				[−5, 7]			

Notes. The main estimation was performed in R using the *lfe* (TWFE), *fixest* (SA21), and *did* (CS21) packages. The number of observations differs by the estimation methods. For columns (1), (2), (5), and (6), the observations include relative years, −5 through 7, for the treated group and the entire sample period for the control group (1976–2020). Analytic standard errors, clustered at the firm level, are provided in parentheses; the corresponding 95% confidence intervals are in squared brackets. For columns (3), (4), (7), and (8), the data with the entire sample period is used in the estimation, and the results are aggregated for the time window, [−5, 7]. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with clustered bootstrapping at the firm level (10,000 iterations). Since the exact p-values are not provided with this approach, we provide the range of p-values. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

C.7. Main results for the US units and for the largest non-US units

Firms may have several non-US units. One concern of our current approach is that non-US units (other than the largest non-US unit) may have been treated at different points in time. To rule out the confounding effects from multiple treatments at different times, we redefine a firm as the combination of a US unit with non-US units that were treated in adjacent years (±1 *year*) as the largest non-US unit. For example, if the largest non-US unit was treated in 1990, we measure the firm's patent filings by its US unit and its non-US units in countries that introduced the VWP during the years 1989–1991 (and exclude patent filings from all the other units). This approach is not susceptible to the potential (confounding) impact of a non-US unit that received the treatment in, for example, 1995. Table C7 shows the estimation results, which are highly consistent with the main findings in Table 2 of the paper.

Table C7. The effects of visa waiver on invention outcomes: US and VWP-eligible units only

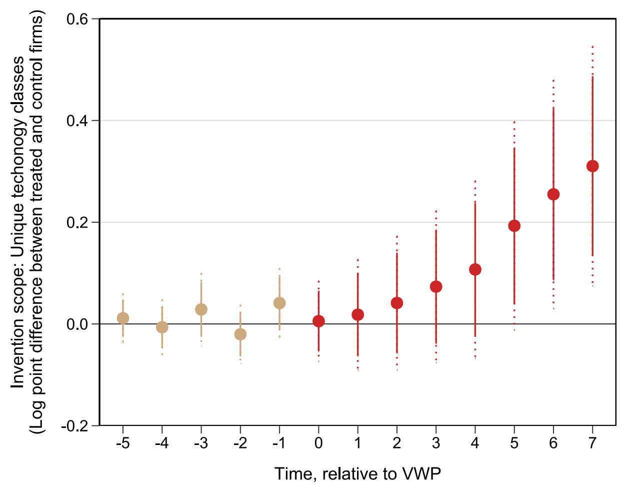
	Dependent variables (log point difference):							
	Invention quantity				Invention scope			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treat	0.211^{***}	0.184^{***}	0.190^{**}	0.185^{**}	0.091	0.094	0.089	0.084
× Post	(0.073)	(0.065)	(0.074)	(0.074)	(0.060)	(0.065)	(0.061)	(0.062)
	[0.068, 0.353]	[0.056, 0.312]	[0.046, 0.335]	[0.039, 0.330]	[−0.027,0.210]	[−0.033, 0.221]	[−0.030, 0.208]	[−0.037, 0.204]
Obs.	19,665	19,665	23,985	23,985	19,665	19,665	23,985	23,400
Firms	533	533	533	533	533	533	533	520
Method	TWFE	SA21	CS21	CS21	TWFE	SA21	CS21	CS21
Control group	All	Never treated	Never treated	Never & Not yet	All	Never treated	Never treated	Never & Not yet
Time	[−5, 7]				[−5, 7]			

Notes. The main estimation was performed in R using the *lfe* (TWFE), *fixest* (SA21), and *did* (CS21) packages. The number of observations differs by the estimation methods. For columns (1), (2), (5), and (6), the observations include relative years, −5 through 7, for the treated group and the entire sample period for the control group (1976–2020). Analytic standard errors, clustered at the firm level, are provided in parentheses; the corresponding 95% confidence intervals are in squared brackets. For columns (3), (4), (7), and (8), the data with the entire sample period is used in the estimation, and the results are aggregated for the time window, [−5, 7]. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with clustered bootstrapping at the firm level (10,000 iterations). Since the exact *p*-values are not provided with this approach, we provide the range of *p*-values. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

C.8. Invention scope: An alternative measure

We use an alternative measure for invention scope at the firm level, rather than taking the average of patent-level technology classes. Specifically, we count the number of different (unique) patent classes (four-digit CPCs) of all patents in each firm-year. The estimation results with this alternative measure are provided in Table C8 and Figure C6. The results are economically large (13.4–18.5%) and statistically distinguishable from zero.

Figure C6. The effects of visa waiver on invention scope: An alternative measure



Notes. The points represent the estimates of *Treat*×*Post* from the staggered difference-in-differences method (Callaway and Sant'Anna, 2021). *T*=0 is the year of VWP introduction. The estimates for pre-treatment periods are colored brown, while the red points represent the estimates for the post-treatment periods. Analytical 95% confidence intervals are reported in solid vertical lines. Bootstrap 95% confidence intervals (10,000 iterations), clustered at the firm level, are provided in dotted vertical lines.

Table C8. The effects of visa waiver on invention scope: An alternative measure

	Dependent variables (log point difference):			
	Invention scope			
	(1)	(2)	(3)	(4)
Treat × Post	0.170***	0.129**	0.129**	0.126**
	(0.055)	(0.052)	(0.052)	(0.052)
	[0.062, 0.278]	[0.028, 0.230]	[0.027, 0.231]	[0.024, 0.227]
Obs.	19,665	19,665	23,985	23,985
Firms	533	533	533	533
Method	TWFE	SA21	CS21	CS21
Control group	All	Never treated	Never treated	Never & Not yet
Time	[−5, 7]			

Notes. The main estimation was performed in R using the *lfe* (TWFE), *fixest* (SA21), and *did* (CS21) packages. The number of observations differs by the estimation methods. For columns (1) and (2), the observations include relative years, −5 through 7, for the treated group and the entire sample period for the control group (1976–2020). Analytic standard errors, clustered at the firm level, are provided in parentheses; the corresponding 95% confidence intervals are in squared brackets. For columns (3) and (4), the data with the entire sample period is used in the estimation, and the results are aggregated for the time window, [−5, 7]. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with clustered bootstrapping at the firm level (10,000 iterations). Since the exact *p*-values are not provided with this approach, we provide the range of *p*-values. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

C.9. Spoken language: English proficiency

In this section, we use an alternative measure of primary language: Education First's English Proficiency Index (EF EPI) created based on test results of more than two million adults in 112 countries. For each country, the index provides the ranks and assigns one of five categories (Very high, High, Moderate, Low, and Very low proficiency). We then define "Very high proficiency" countries as English-speaking ones. Of 135 treated firms, 37 (27.4%) fall into this category. Note that the EPI is not available for 36 treated firms.

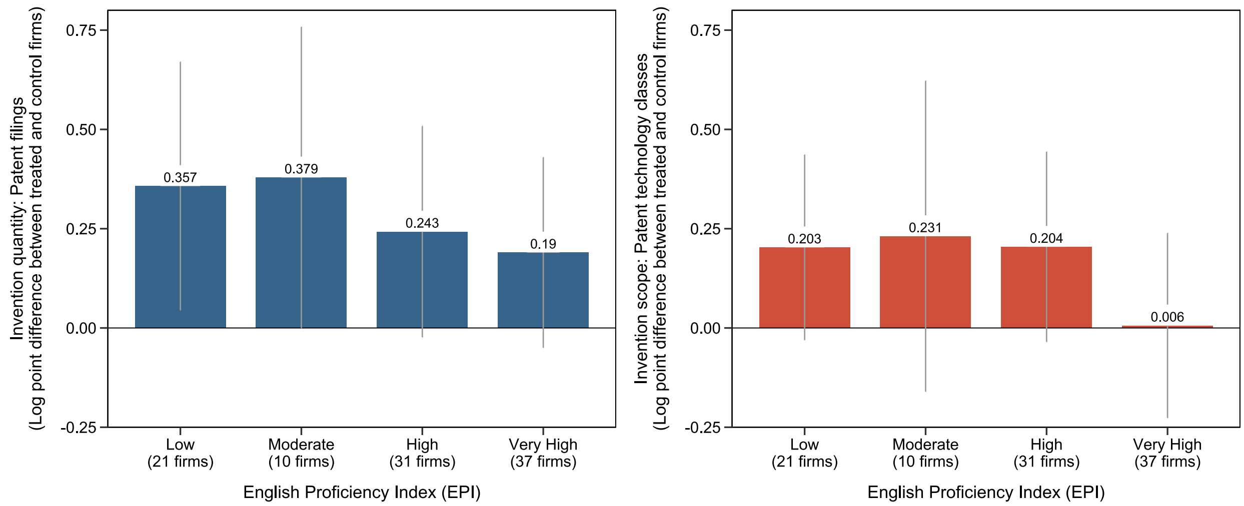
The results from the split-sample analyses, reported in Table C9, are consistent with the main results provided in Table 4 of the main paper. The effects are greater for firms with non-US units in countries that are not proficient in English. A more flexible approach by each category is illustrated in Figure C7.

Table C9. The effects of visa waiver on invention outcomes by English proficiency: split-sample analysis

	Dependent variables (log point difference):			
	Invention quantity		Invention scope	
	Non-US unit: Proficient in English (EPI)		Non-US unit: proficient in English (EPI)	
	Yes	No	Yes	No
	(1a)	(1b)	(2a)	(2b)
Treat	0.190	0.216**	0.006	0.120*
× *Post*	(0.122)	(0.096)	(0.119)	(0.069)
	[−0.011, 0.391]	[0.029, 0.403]	[−0.226, 0.239]	[−0.016, 0.256]
Obs.	19,575	22,320	19,575	22,320
Firms	435	496	435	496
Method	CS21 (control: never treated, not yet treated)		CS21 (control: never treated, not yet treated)	
Time	[−5, 7]		[−5, 7]	

Notes. The estimation was performed in R using the *did* package. The number of observations is different across models because, based on the EF EPI of the largest non-US unit, we split the treated group into two subgroups (those with very high proficiency and those without). Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with (1) Student's *t*-distribution (conventional) and (2) clustered bootstrapping at the firm level (10,000 iterations). We take a conservative approach and report the wider interval in squared brackets. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

Figure C7. The effects of visa waiver on invention outcomes by English proficiency: Split-sample analysis

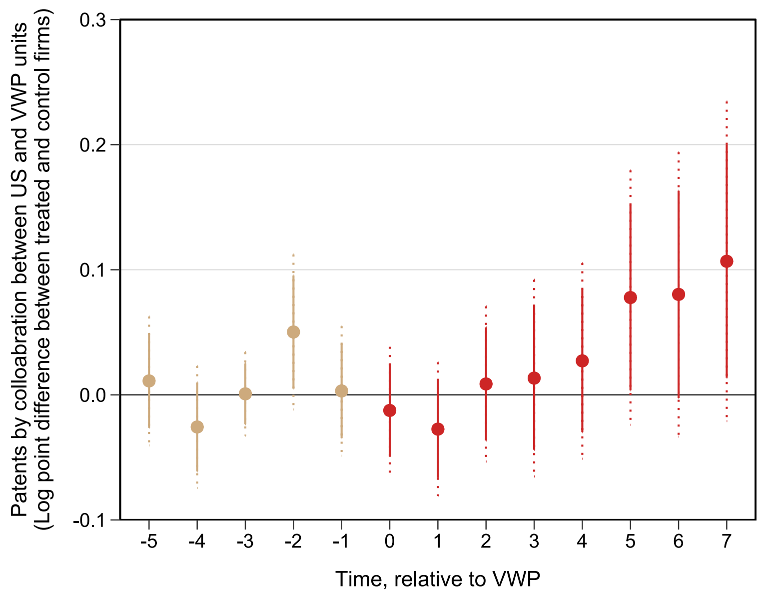


Notes. The blue and red bars show the estimates on invention quantity and scope, respectively, with the CS21 estimation (time window: [−5, 7]). Control group consists of never-treated and not-yet-treated firms. The vertical lines represent the 95% confidence interval based on analytic standard errors.

C.10. Creation of new collaborations

In Section 5.3 of the paper, we examine the creation of new collaboration (collaborative patents) as measured by the number of patents jointly filed by inventors in US and VWP units before and after the introduction of the VWP. Figure C8 illustrates the dynamic effects with distributed time leads and lags. The size of the effect increases to 8.1% (analytic $p<0.05$) in Year 5 and 11.3% (analytic $p<0.05$) in Year 7 of VWP.

Figure C8. Collaborative patents jointly filed by inventors in US and VWP units



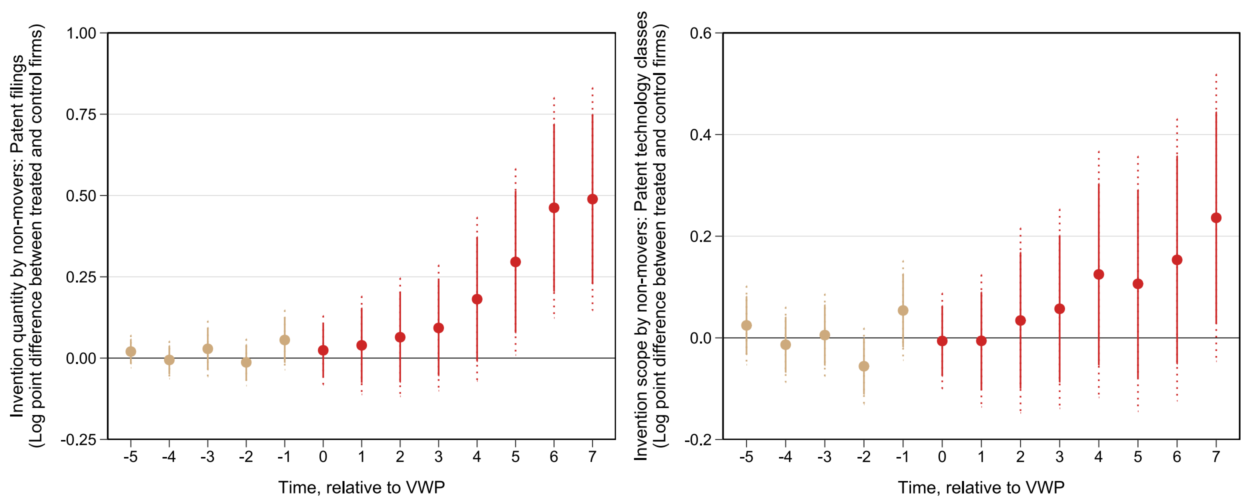
Notes. The points represent the estimates of *Treat*×*Post* from the staggered difference-in-differences method (Callaway and Sant'Anna, 2021). $T=0$ is the year of VWP introduction. The estimates for pre-treatment periods are colored brown, while the red points represent the estimates for the post-treatment periods. Analytical 95% confidence intervals are reported in solid vertical lines. Bootstrap 95% confidence intervals (10,000 iterations), clustered at the firm level, are provided in dotted vertical lines.

C.11. Inventions by stayers (non-moving inventors)

To account for the potential confounding effects caused by long-term migrants from VWP countries to the United States, we identify inventors who did not change their country of residence up until the fifth year after the VWP was introduced. The estimation results with these non-moving inventors are highly consistent with our main findings reported in Table 2 of the paper. The results are summarized in Figure C9 and Table C10.

Figure C9. The effects of visa waiver on invention outcomes: Non-moving inventors

(a). Invention quantity (b). Invention scope



Notes. The points represent the estimates of *Treat*×*Post* from the staggered difference-in-differences method (Callaway and Sant'Anna, 2021). *T*=0 is the year of VWP introduction. The estimates for pre-treatment periods are colored brown, while the red points represent the estimates for the post-treatment periods. Analytical 95% confidence intervals are reported in solid vertical lines. Bootstrap 95% confidence intervals (10,000 iterations), clustered at the firm level, are provided in dotted vertical lines.

Table C10. The effects of visa waiver on invention outcomes: Non-moving inventors

(a). Invention quantity

	Dependent variables (log point difference):			
	Invention quantity			
	(1)	(2)	(3)	(4)
Treat	0.256***	0.213***	0.212***	0.206***
× *Post*	(0.077)	(0.069)	(0.076)	(0.077)
	[0.106, 0.407]	[0.077, 0.349]	[0.063, 0.361]	[0.056, 0.356]
Obs.	19,665	19,665	23,985	23,985
Firms	533	533	533	533
Method	TWFE	SA21	CS21	CS21
Control group	All	Never treated	Never treated	Never & Not yet
Time	[−5, 7]			

(b). Invention scope

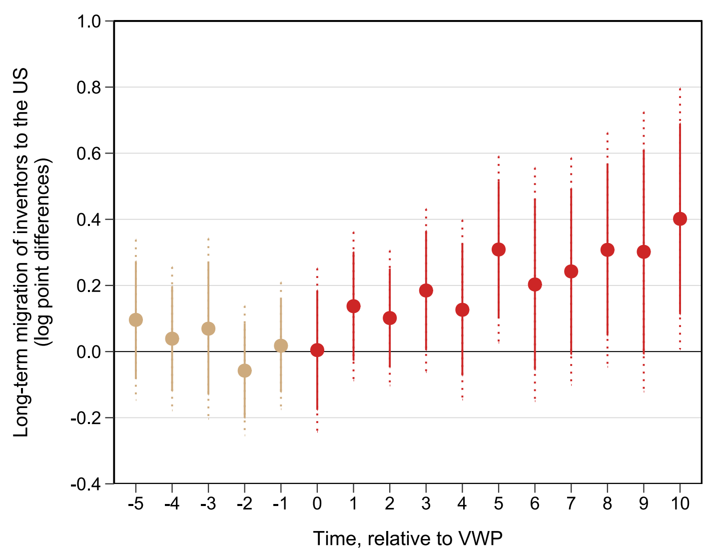
	Dependent variables (log point difference):			
	Invention scope			
	(1)	(2)	(3)	(4)
Treat	0.096	0.113*	0.094	0.088
× *Post*	(0.063)	(0.063)	(0.061)	(0.063)
	[−0.027, 0.219]	[−0.010, 0.237]	[−0.025, 0.213]	[−0.035, 0.210]
Obs.	19,665	19,665	23,985	23,985
Firms	533	533	533	533
Method	TWFE	SA21	CS21	CS21
Control group	All	Never treated	Never treated	Never & Not yet
Time	[−5, 7]			

Notes. The main estimation was performed in R using the *lfe* (TWFE), *fixest* (SA21), and *did* (CS21) packages. The number of observations differs by the estimation methods. For columns (1) and (2), the observations include relative years, −5 through 7, for the treated group and the entire sample period for the control group (1976–2020). Analytic standard errors, clustered at the firm level, are provided in parentheses; the corresponding 95% confidence intervals are in squared brackets. For columns (3) and (4), the data with the entire sample period is used in the estimation, and the results are aggregated for the time window, [−5, 7]. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with clustered bootstrapping at the firm level (10,000 iterations). Since the exact *p*-values are not provided with this approach, we provide the range of *p*-values. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

C.12. Do short-term visits facilitate long-term migration?

We use US patent data to test whether non-US scientists immigrate to the United States after their country is incorporated into the VWP. The results from the staggered difference-in-differences estimation at the country-year level for the years 1976–2020 are illustrated in Figure C10. The number of long-term migrants (or immigrants) from the VWP-incorporated countries to the United States gradually increases after the VWP, compared to the number from non-VWP countries. This indicates that short-term visits can provide a gateway for the longer-term migration of inventors, which could further enhance knowledge flows.

Figure C10. Visa waiver and patent inventors' long-term migration to the US: A country-year level analysis



Notes. The points represent the estimates of *Treat*×*Post* from the staggered difference-in-differences method (Callaway and Sant'Anna, 2021). The outcome is the number of long-term migrants of patent inventors to the US (i.e., those who changed their address to the US). *T*=0 is the year of VWP introduction. The estimates for pre-treatment periods are colored brown, while the red points represent the estimates for the post-treatment periods. Analytical 95% confidence intervals are reported in solid vertical lines. Bootstrap 95% confidence intervals (10,000 iterations), clustered at the firm level, are provided in dotted vertical lines.

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