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Innovation on Wings: Nonstop Flights and Firm Innovation in the Global Context

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Abstract. We study whether, when, and how better connectivity through nonstop flights leads to positive innovation outcomes for firms in the global context. Using unique data of all flights emanating from 5,015 airports around the globe from 2005 to 2015 and exploiting a regression discontinuity framework, we report that a 10% increase in nonstop flights between two locations leads to a 3.4% increase in citations and a 1.4% increase in the production of collaborative patents between those locations. This effect is driven primarily by firms as opposed to academic institutions. We further study the characteristics of firms and firm locations that are salient to the relation between nonstop flights and innovation outcomes across countries. Using a gravity model, we posit and find that the positive effect of nonstop flights on innovation is stronger for firms and subsidiaries with greater innovation mass (e.g., stocks of inventors and R&D spending), located in innovation hubs or countries that are deemed technology leaders, and that are separated by large cultural or temporal distance.

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Keywords: nonstop flights • firm innovation • cultural distance • temporal distance • innovation mass

1. Introduction

The strategy literature has long posited that firms might overcome the constraints of geographically localized search for knowledge and collaborators through employee geographic mobility (e.g., Rosenkopf and Almeida 2003). More recent literature documents how better connectivity through roads and nonstop flights facilitates geographic mobility, enabling innovation outcomes in the United States (Agrawal et al. 2017, Catalini et al. 2020, Dutta et al. 2022). However, for firms and inventors located across different countries, the relation between connectivity and innovation outcomes—such as cross-border knowledge spillovers (e.g., Singh 2005) and the production of global collaborative patents (GCPs) (e.g., Kerr and Kerr 2018)—might be more nuanced. This relates to two core insights in prior literature: (1) the persistence of cultural, temporal, and other dimensions of distance that affect firm innovation in the global context and (2) the "spikiness" in spatial distribution of innovation around the world.

First, a long-standing literature, notably Ghemawat (2001) and Berry et al. (2010), documents the persistence of geographic, cultural, economic, and other dimensions of distance in the global context. Whereas better connectivity through nonstop flights shrinks geographic distance between firm locations, in the global context, cultural, temporal, and other dimensions of distance between firm locations may influence the relation between nonstop flights and knowledge spillovers and collaborations. In particular, prior literature (e.g., Chua et al. 2015) highlights cultural distance between firms and inventors as a key friction for innovation in a global context. Researchers (e.g., Bahar 2020, Chauvin et al. 2020) also document how temporal distance between firms and subsidiaries constrains synchronous communication, a key facilitator for collaborative innovation.

Second, prior literature (e.g., Furman and Hayes 2004, Florida 2005, Kim and Aguilera 2015) documents that the distribution of innovation across countries is characterized by spikes (i.e., disproportionate spatial concentration of innovation in a select few locations around the world) and differences between countries that are technology "leaders" versus those that are "followers." This raises the question of whether the relation between connectivity and innovation across countries depends on the characteristics of firms and firm locations.

Whereas a broader literature in economics studies how nonstop flights affect global economic outcomes, such as firm productivity and regional economic activity (Giroud 2013, Campante and Yanagizawa-Drott 2018), to the best of our knowledge, we lack evidence on whether, when, and how nonstop flights affect innovation outcomes for firms in the global context. This leads to our research questions: Do nonstop flights affect firm innovation outcomes across countries? If so, how, and what characteristics of firms and firm locations connected by nonstop flights are salient to the relationship between nonstop flights and innovation outcomes across countries?

To motivate our empirical analysis, we borrow insights from the gravity model, which is used extensively to predict trade, foreign direct investment (FDI), and migration flows (Vanderkamp 1977, Anderson 1979, Frankel and Rose 2002). We make two sets of predictions regarding how characteristics of firms and firm locations affect the relation between flight connectivity and innovation outcomes. First, we predict that the relation between nonstop flights and innovation outcomes across countries is more salient for firms and subsidiaries with greater innovation mass (measured by R&D spending and number of inventors at firms/subsidiaries) and located within innovation hubs or countries that can be deemed technology leaders. Second, we predict that the relation between nonstop flights and innovation outcomes across countries is more salient for firms and firm locations separated by temporal and cultural distance. We measure temporal distance by computing time zone differences between firm locations, and we measure cultural distance using the ethnic composition of inventors at firms/subsidiaries and using metrics from the World Values Survey of 2020 (WVS), measured at firm locations.

For our empirical analysis, we exploit a proprietary data set comprising the universe of all active air routes globally from 2005 to 2015, sourced from the Official Aviation Guide (OAG). This unique data set contains information on all flights, including nonstop flights, in each year emanating from 5,015 airports around the globe. We then geo-match these airports to the addresses of inventors based on the universe of patents filed with the U.S. Patent and Trademark Office (USPTO) for the aforementioned years. In doing so, we obtain two measures of innovative activities—global citations and global collaborations—for all patenting entities (firms and academic institutions) and inventors near each of these airports.

With these data, we arrive at our results through several steps. First, we apply a regression discontinuity design (RDD) to study the causal effect of nonstop flights on innovation outcomes of interest (i.e., citations and collaborations across locations). Here, we build on the work by Campante and Yanagizawa-Drott (2018), which leverages a discontinuity. They find that airport pairs fewer than 6,000 miles apart are more likely to be serviced by nonstop flights than pairs that are more than 6,000 miles apart because of aviation regulations significantly increasing costs of operating nonstop flights for destinations that are more than 6,000 miles apart. Thus, in the context of innovation outcomes, this exercise enables the comparison of patent citations and collaborations between inventors in location pairs that are just below the 6,000-mile threshold (such as Shanghai and Milan, which are 5,650 miles apart) to those in location pairs that are just above the 6,000-mile threshold (such as Shanghai and Madrid, which are 6,350 miles apart). Insofar as airport designers and planners cannot precisely manipulate their distance from other airports (e.g., position themselves within 6,000 miles of other airports), the regression discontinuity implies that variation in between-airport distance near the 6,000-mile threshold is as good as random (Lee and Lemieux 2010). This feature allows us to interpret our results as causal. Our main estimation using this methodology finds that, for airport pairs around the 6,000-mile threshold, a 10% increase in the number of yearly nonstop flights between two locations increases citations by 3.5% and collaborations by 1.5%.

We further show that the effects of nonstop flights on innovation are driven primarily by firms, not by academic institutions. For firms, a 10% increase in flights increases citations by 3.38% and collaborations by 1.48%; for academic institutions, the same increase in flights is 0.99% and 0.40% for citations and collaborations, respectively. Thus, for the rest of the paper, we focus squarely on firms (and firm subsidiaries) and examine when nonstop flights matter for firm innovation in the global context.[1]

Using the gravity model as a theoretical anchor, we argue that the innovation mass of firms or subsidiaries (measured as the number of inventors and R&D spending), the innovation mass at the firm/subsidiary location (i.e., whether the location is a hub or in a country deemed a technology leader), and nongeographic distances (i.e., temporal and cultural distances) between firms/subsidiaries are key for their joint innovation outcomes and, consequently, how nonstop flights can affect innovation outcomes. In particular, by reestimating our RDD using different samples and subsamples based on characteristics of firms/subsidiaries and firm/subsidiary locations, our empirical results show that the relation between nonstop flights and innovation outcomes is more salient for firms and subsidiaries (1) with greater innovation mass, (2) located in innovation hubs or within countries that are deemed technology leaders, and (3) separated by cultural and temporal distance.

We also explore the two mechanisms outlined in the airline connectivity literature to understand how nonstop flights affect innovation outcomes for firm innovation across countries: reduction in pecuniary travel costs (e.g., Catalini et al. 2020) and travel time (e.g., Bernstein et al. 2016). Using data from Google Flights, we find that travel time reduction, rather than reduction in pecuniary costs, is the most prominent factor explaining the relation between nonstop flights and global citations and collaborations at firms. In additional analyses, we show that our local average treatment effects at the airport-pair level also extend to the airport level, suggesting that the documented effects represent aggregate increases in citations and collaborations.

Our findings contribute to several literatures. First, we contribute to the literature in strategy and economics on knowledge spillovers and collaborative patents for firms in the global context (Singh 2005, Miguelez and Fink 2013, Branstetter et al. 2014, Kerr and Kerr 2018, Bahar et al. 2020). We find that knowledge frictions resulting from national borders, as discussed in Singh and Marx (2013),[2] are attenuated by the availability of international nonstop flights. This finding highlights how airline connectivity mitigates the frictions exerted by political borders and cross-country distance on international collaborations (Ghemawat 2007, Berry et al. 2010, Alcácer et al. 2017). Additionally, our results show that nonstop flights especially facilitate innovation outcomes for firms with high levels of innovation mass, located near hubs or in countries deemed technology leaders, and that are temporally and culturally distant. In light of Rosenkopf and Almeida (2003), this suggests that, whereas nonstop flights help firms build bridges to temporally or culturally distant places, they also disproportionately help firms with more innovation mass or located within regions with greater innovative activities overcome the constraints of geographically localized search for knowledge and collaborators.

Second, by reporting a causal relation between easing human mobility through nonstop flights and the production and diffusion of knowledge at firms across country borders, we contribute to an evolving literature on connectivity/geographic mobility and economic outcomes (Giroud 2013, Bernstein et al. 2016, Agrawal et al. 2017, Choudhury 2017, Campante and Yanagizawa-Drott 2018, Catalini et al. 2020). Whereas prior research documents the economic consequences of flight connectivity for domestic innovation (primarily in the United States),[3] we provide a parsimonious model and document causal evidence related to nonstop flights and firm innovation in a global context. Importantly, our paper also documents the conditions under which flight connectivity is likely versus unlikely to drive innovation at firms globally. By showing that flight connectivity is less effective for facilitating knowledge spillovers and collaborations at firms with smaller innovation masses and located outside regions with significant innovative activity and at firms and firm locations that are temporally or culturally proximate, this paper provides an important account of the limitations of transportation connectivity in driving innovation. Moreover, the insight on how the effects are stronger for firms vis-à-vis academic institutions is a novel insight for this literature. In summary, by focusing on firms in the global context, considering how characteristics of firms and firm locations drive our results, and documenting travel time savings as the underlying mechanism, our study departs from prior research (e.g., Catalini et al. 2020) that studies how flight connectivity and travel cost savings affect innovation in a domestic and academic context.

Finally, this study also provides important and timely policy implications for firms and managers. As companies and knowledge workers debate whether to resume international travel after the pandemic (Weed 2021), our results shed light on the importance of business travel and nonstop flights for knowledge spillovers and collaborations, especially in a global context.

The paper is organized as follows: In Section 2, we introduce the empirical setting, data, and variables. In Section 3, we describe the regression discontinuity approach and present the causal estimates. In Section 4, we explore how characteristics of firms/subsidiaries and firm/subsidiary locations affect our results. Section 5 presents additional analyses in which we estimate the effect of flight connectivity on innovation for a single location (as opposed to a pair of locations) to study whether nonstop global flights result in an aggregate increase in innovation outcomes. In Section 5, we also report results related to underlying mechanisms. Finally, in Section 6, we conclude with a set of research and managerial policy implications. Our paper is accompanied by an online appendix.

2. Data and Setting

2.1. Data Set and Dependent Variables

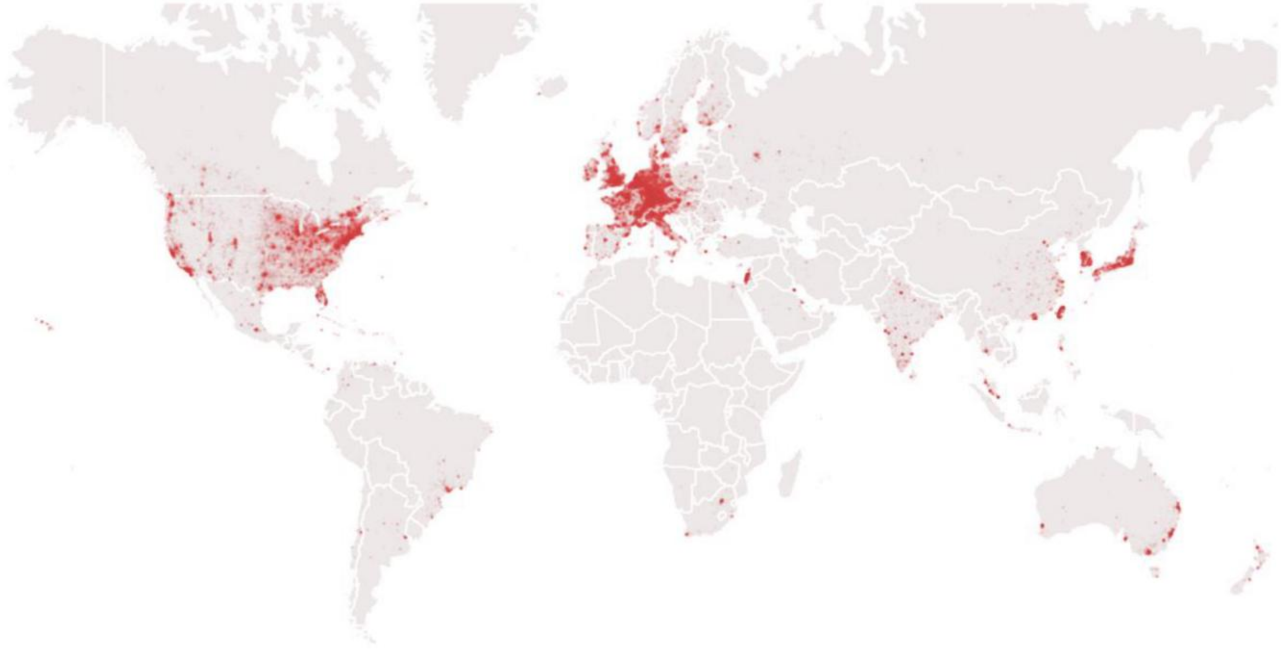
Our data on commercial flights comes from OAG, a private company specializing in aviation analytics. This data contains information on 94,221 routes between 5,068 airports around the globe. We exclude 53 airports that serve only cargo flights or have no flights for the entire period from 2005 to 2015. This yields 5,015 airports. For each route, we calculate the geodesic distance between the origin and destination (using the geodist command in Stata).[4]

Next, we collect patent data and map each patent to nearby airports. We use the universe of patents filed in the USPTO from 2005 to 2015 from the Thompson Reuters patent data set as well as all of its forward citations. To assign patents to airports, we use inventor addresses contained in the patents. First, we map each inventor to all airports within a 50-mile radius of the inventor's location within the inventor's own country.[5] This gives us a patent–inventor–airport–level data set with an inventor potentially assigned to multiple airports. Each patent is then assigned a location based on its inventors. If a patent has only one inventor, we code the patent's location as that inventor's location. If a patent has multiple inventors, we use the first inventor's location. Figure 1 shows the locations of all the inventors in our data set. As expected, given that innovation activities occur predominantly in developed countries, most locations are in the United States, Europe, and East Asia. We categorize assignees into firm or academic institutions based on their names: we checked whether the assignee name contains words and phrases such as "university," "college," "institute of technology," or "school." Because many assignees are foreign, we translated each of those terms into all available languages on Google Translate.[6] Our sample contains 11,756 unique academic assignees and 198,327 unique firm assignees. When applicable, we use the Duke DISCERN database (Arora et al. 2021) and the Compustat database to obtain balance sheet information for firm assignees.

For the first dependent variable, *citations*, we measure activity at the airport-pair level. We count a citation between two airports if there exists a patent citation from a patent mapped to one airport to a patent mapped to another airport. Our data set is not directional—that is, the airport pair CDG–ORD (Paris Charles de Gaulle—Chicago O'Hare) in 2005 appears only once in the data set, but there is no observation for the opposite direction, ORD–CDG, in 2005. This is because citations and collaborations may be driven by either flight direction (CDG–ORD or ORD–CDG). Therefore, we take the sum of all flights and the sum of citations/collaborations that occur between inventors located near two airports, regardless of flight direction, to measure the overall level of citation activity between the two locations. In cases in which a patent inventor is assigned to more than one airport, we inversely weight the patent by the number of airports to avoid double counting citations. For example, if a citation involves one inventor assigned to ORD and another inventor assigned to both CDG and ORY (Paris Orly), our approach assigns 0.5 citations for each of the ORD–CDG and ORD–ORY airport pairs.

For the second dependent variable, *collaborations*, we similarly measure those activities at the airport-pair level. A collaboration between two airports corresponds to a collaborative patent with inventors from locations nearby those two airports. Specifically, for each year and airport pair, we count the number of collaborative patents by inventors from both airports. In cases in which an

Figure 1. (Color online) Inventor Locations



Notes. Each inventor location (prior to mapping to the closest airport) is plotted as a red dot. Inventors with the same latitude and longitude are jittered, so they are not plotted directly on top of each other.

inventor is assigned to multiple airports, similarly to how we count citations, we inversely weight each collaboration by the number of airports in order to avoid double counting.

Our final data set, thus, consists of a yearly panel of citations, collaborations, and the number of flights at the airport-pair level. Given that all collaborations pertain to a single assignee (i.e., multiple subsidiaries of the same assignee) and most citations are between assignees, we are able to conduct separate analyses based on the characteristics of firms/subsidiaries and firm/subsidiary locations. An important caveat here is that we proxy firm/subsidiary location using the airport location—that is, airports proximate to the inventors working at the firm/subsidiaries. Any airport pair appears for all 11 years of the sample (2005–2015) even if there are no flights or no patent information reported in some of those years (which are assumed to be zero), making it a balanced panel. A preliminary analysis using a counterfactual patent-matching method shows that more nonstop flights between inventors are associated with more citations and collaborations.[7]

2.2. Characteristics of Firms and Firm Locations

To study heterogenous effects, we collect information about the innovation mass of firms/subsidiaries and distances between firms/subsidiaries. For innovation mass, we utilize three measures. First, we match firms to their balance sheets using Duke DISCERN and Compustat data, and we obtain R&D spending at the firm level. Second, for each firm, we count the number of unique inventors who filed patents with the firm. A third measure at the firm-location level captures airports' proximity to hubs of academic science: for each airport (i.e., firm/subsidiary location), we check whether it is within a 50-mile radius of a scientific hub as defined in Bikard and Marx (2020). We also differentiate between firms/subsidiaries located in innovation-leader countries and those in innovation-follower countries (Furman and Hayes 2004).

We also collect data on distances between firm/subsidiaries and their locations. First, we collect data on temporal distance, measured by the extent of working hour overlap between two firm/subsidiary locations (proxied by the airport location). For each airport, we obtained the time zone using its latitude and longitude coordinates and the timezonefinder package in Python.[8] Using the time zones, we calculate the time difference between the origin airport and the destination airport and then calculate the working hour overlap to be from zero to eight hours.[9] Next, we measure the cultural distance between two firm/subsidiaries in two ways. First, we obtain the ethnicities of the inventors in our sample through machine learning algorithms for name matching, and we measure whether a group of citing or collaborating inventors are multiethnic or coethnic. The assumption is that a coethnic group of inventors who cite or collaborate with one another have shorter cultural distance (are more culturally similar) than a multiethnic group of citing/collaborating inventors. Second, we use data from a specific question in the World Value Survey: a question that measures how much each country's citizens believe immigrants play important roles in their society. This measure is particularly relevant to the context of global knowledge spillovers and collaborations because it gauges a specific cultural element: people's tendency to appreciate the work of foreigners.

3. Do Nonstop Flights Drive Firm Innovation in the Global Context? A Regression Discontinuity Approach

To causally estimate the impact of nonstop flights on innovation across countries, we utilize a unique feature of the airline industry: airport pairs that are fewer than 6,000 miles apart are more likely to be serviced by nonstop flights than pairs that are more than 6,000 miles apart. This pattern exists because of higher operating costs to service routes that are more than 6,000 miles long; this expense is due to a combination of administrative and legal rules as well as technological factors. This paves the way for a regression discontinuity design. Whereas Campante and Yanagizawa-Drott (2018) pioneered this approach, to our knowledge, we are the first to apply this method to explore innovation outcomes.

The 6,000-mile threshold corresponds to 12 hours of flight time given customary flight speeds (Campante and Yanagizawa-Drott 2018); flights above the 12-hour and 6,000-mile thresholds are known as ultra-long-haul (UHL) flights (McKenney et al. 2000). These UHL flights must meet special personnel availability requirements. For instance, the Federal Aviation Administration requires flights that are more than 12 hours long to have an additional flight crew member as well as adequate sleeping quarters on the plane. Such requirements lead to greater operational costs for these flights as the crew corresponds to about 36% of nonfuel costs (Federal Aviation Administration 2016). Technological advances in the 1980s and 1990s made this discontinuity more pronounced as long-range airplane models introduced during this period made long-haul flights more fuel efficient, which accentuated the importance of minimizing nonfuel costs (e.g., crew costs).[10]

Using this feature of the data, we implement a fuzzy regression discontinuity analysis. The fuzzy design responds to the fact that, whereas there are still nonstop flights above the 6,000-mile threshold, there are many fewer of these than there are flights below the 6,000-mile threshold. The unit of analysis, similar to the one adopted in Campante and Yanagizawa-Drott (2018), is

Table 1. Summary Statistics of the Full Sample

	Count	Mean	Standard deviation	Minimum	Maximum
Number of citations	538,054	2.14	36.67	0.00	5,702.40
Number of collaborations	538,054	2.00	56.47	0.00	7,228.03
Number of citations (firms)	538,054	1.96	35.20	0.00	5,498.18
Number of collaborations (firms)	538,054	1.90	55.07	0.00	7,048.09
Number of cCitations (academic)	538,054	0.04	0.49	0.00	67.16
Number of collaborations (academic)	538,054	0.07	1.41	0.00	239.69
Has nonstop	538,054	0.49	0.50	0.00	1.00
Nonstop flights (count)	538,054	611.95	1,799.85	0.00	74,002.00
Distance (miles)	521,477	1,110.86	1,246.99	0.00	11,873.40
Hub-to-hub flight	537,878	0.26	0.44	0.00	1.00
Working hour overlap	537,878	7.04	1.58	0.00	8.00
Immigrant friendliness distance	402,523	0.19	0.28	0.00	1.87
Average price	20,350	946.48	528.11	214.30	4,538.75

Notes. Observations are at the route–year level, excluding average price and average duration, which are at the route–ticket level. Citations and collaborations are inversely weighted based on the number of airports within 50 miles (to avoid double counting). Cross-citations measures the number of citations across different assignees. Distance is in miles. Hub-to-hub measures (whether the origin and destination airports are within 50 miles of an innovation hub) are as defined in Bikard and Marx (2020). Inventor mass and publication mass count the number of inventors/publications in either airport of an airport pair. Immigrant friendliness distance measures the difference between different countries' attitudes toward immigrants, which is a question (Q121) in wave 7 of the World Value Survey (source: https://www.worldvaluessurvey.org/WVSDocumentationWV7.jsp).

at the airport-pair level. The "treatment" in this setting corresponds to an airport pair being slightly below the 6,000-mile threshold, allowing for a higher likelihood of having nonstop flights between the two airports.[11] This is the key assumption: there is no reason to believe that innovation activities occurring between locations that are slightly more than 6,000 miles apart should be significantly different from those occurring between locations that are slightly less than 6,000 miles apart. In other words, arguably, whether the distance between any airport pair lies just above or below the 6,000-mile threshold is as good as randomly assigned. We provide summary statistics for our RDD data set in Table 1.[12]

From Table 1, we see that the average airport pair has 2.14 citations and 2.00 collaborations in a given year, but the distribution is skewed to the left. Average firm citations between airport pairs are 1.96, and firm collaborations are 1.90. About half the airport pairs (in a given year) have nonstop flights with the average number of nonstop flights at 611.95. The average distance between two airports in our data set is around 1,111 miles. Hub-to-hub flights (flights between two airports that are both innovation hubs) are about 26% of the routes. The average location pair has a working hour overlap of 7.04 hours (1.83 hours for location pairs in the regression discontinuity sample). The average difference in immigrant friendliness scores between locations (explained in detail in the Table 1 notes) is 0.19. Finally, the average price for any ticket in our sample is \$946.48, and the average travel duration is 13.72 hours.

A benefit of the regression discontinuity approach is that it is possible to visualize the effect of the discontinuity on innovation outcomes. Figure 2 presents a visual summary of our reduced-form results.[13] We see from both panels that airport pairs that are slightly less than the 6,000-mile threshold have more citations and collaborations than airport pairs that are slightly more than the 6,000-mile threshold.

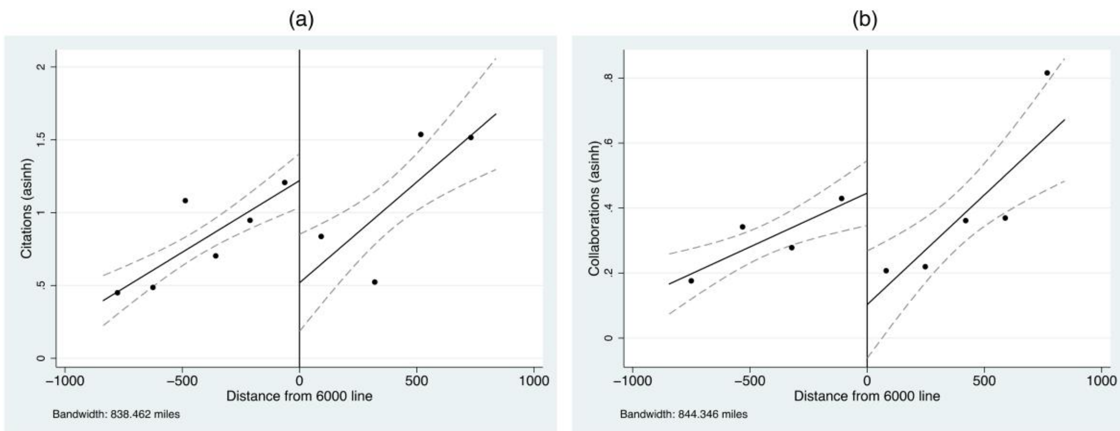
Our main analysis for the regression discontinuity quantifies the graphical relationship. Because this is a fuzzy regression discontinuity, the estimation involves two stages, in which the first stage estimates the discontinuity in the number of flights around the 6,000-mile threshold and the second stage estimates the impact of the discontinuity on the outcomes of interest (innovative activities):

$$\begin{aligned}&\text{asinh}(Nonstop\ Flights_{a_o,a_d,t})\\&\quad=\gamma_1 1\{Dist_{a_o,a_d}<6,000\}+\gamma_2(Dist_{a_o,a_d}-6,000)\\&\qquad+\ \gamma_3 1\{Dist_{a_o,a_d}<6,000\}\times(Dist_{a_o,a_d}-6,000)\\&\qquad+\phi_{c_o,c_d,t}+\epsilon_{a_o,a_d,t},\end{aligned}\tag{1}$$

$$\begin{aligned}&\text{asinh}(Y_{a_o,a_d,t})\\&\quad=\beta_1\ asinh(Total\widehat{Flights}_{a_o,a_d,t})\\&\qquad+\beta_2(Dist_{a_o,a_d}-6,000)+\beta_3 1\{Dist_{a_o,a_d}<6,000\}\\&\qquad\times(Dist_{a_o,a_d}-6,000)+\phi_{c_o,c_d,t}+\epsilon_{a_o,a_d,t}.\end{aligned}\tag{2}$$

Here, a_o and a_d refer to the origin and destination airports for a given route and t refers to a calendar year. Our main variable of interest, $TotalFlights_{a_o,a_d,t}$, measures the number of nonstop flights between a_o and a_d in year t, which is estimated through the first stage in Equation (1).[14] Similarly, $Dist_{a_o,a_d}$ measures the distance in miles between the airports, a_o and a_d, and our running variable (the variable

Figure 2. (Color online) Impact of Nonstop Flights on Citations and Collaborations



Notes. These graphs use observations based on the optimal bandwidth, which corresponds to 844.35 miles for collaborations and 838.46 miles for citations, at either side of the 6,000-mile threshold. We use a triangular kernel to estimate the optimal bandwidth. It also uses a linear estimator as well as the mimicking variance evenly spaced method to define the number of bins, which results in relatively small bin sizes, reducing the possibility that few outliers on either side drive the discontinuity. Varying the number of bins does not alter the result. Online Sections B3–B5 show our graphical results are robust to changing the number of bins as well as to using quantile-spaced binning methods, kernel choice, and different levels of fixed effects and clustering.

that determines which observations are treated with additional nonstop flights) is denoted as $(Dist_{a_o,a_d} - 6,000)$. The coefficient of interest is β_1, which measures the discontinuity at the 6,000-mile threshold. Intuitively, β_1 measures the jump in $Y_{a_o,a_d,t}$ at the 6,000-mile threshold from fitting separate regression slopes on either side of the discontinuity. To absorb the effects resulting from differences between two countries (e.g., language and time zone differences) on citations or collaborations, we include country–country year fixed effects, marked as $\phi_{c_o,c_d,t}$. We utilize the inverse hyperbolic sine transformation (asinh) because it allows us to preserve observations with zeroes (MacKinnon and Magee 1990).[15]

First stage regressions confirm the existence of discontinuity around the 6,000-mile threshold, at which airport pairs just below the threshold have on average 260 to 550 more nonstop flights per year than airport pairs just above the threshold (see more details of the first stage in Online Appendix Section B2; Online Figure B1 provides visual evidence for the existence of the discontinuity). In Table 2, we present results of the second stage specification.[16]

Columns (1) and (2) show that a 10% increase in the number of nonstop flights between two locations leads to an increase in patent citations of 3.4% and a 1.4% increase in the number of collaborations.[17]

3.1. Firms vs. Academic Institutions

An important question is which entities—firms or academic institutions—benefit more from the presence of

Table 2. Regression Discontinuity: Effect of Nonstop Flights on Innovation in a Global Context Is Stronger for Firms Than for Academic Institutions

	Overall		Academic institutions		Firms	
	(1) Citations (asinh)	(2) Collaborations (asinh)	(3) Citations (asinh)	(4) Collaborations (asinh)	(5) Citations (asinh)	(6) Collaborations (asinh)
Nonstop flights (asinh)	0.346***	0.152***	0.099***	0.040**	0.338***	0.148***
	(0.101)	(0.053)	(0.030)	(0.016)	(0.099)	(0.052)
(6,000-Distance)	−0.001**	−0.000	−0.000**	−0.000*	−0.001**	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(6,000-Distance) × *Under6,000*	0.001*	0.000	0.001**	0.000**	0.001*	0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Observations	3,795	3,795	3,795	3,795	3,795	3,795

Notes. Observations at the airport pair–year level, excluding singletons. Standard errors in parentheses, clustered at the country pair–year level. Variables inverse hyperbolic sine transformed are denoted by asinh. Bandwidth set at 550 miles. Observations weighted using a triangular kernel. All specifications include country pair–year fixed effects. Distance denotes the geodesic distance (in miles) between airport pairs. *Under6,000* is an indicator variable equal to one if the distance is less than 6,000.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

nonstop flights. An answer to this question also sheds light on which individuals (i.e., employees at firms versus academics) are likely taking the nonstop flights and contributing to knowledge spillovers. Firms, in particular, increasingly rely on global collaborations and learning in their innovative activities as evidenced by the rising number of GCPs and the higher quality of GCPs relative to that of same-country patents for firms (Kerr and Kerr 2018).

We determine whether a patent's assignee is a firm or an academic institution by searching based on a set of keywords (e.g., "school," "university," "institute")[18] in its name. Then, we count citations and collaborations between locations for firms and academic institutions separately, and we test whether the marginal effect of nonstop flights is greater for firms or academic institutions using seemingly unrelated estimations (Mize et al. 2019) as well as bootstrapping. Table 2, columns (3)–(6) present the results. We find that a 10% increase in the number of nonstop flights between two locations leads to an increase in citations of 3.38% between two firms in those two locations and 0.99% between two academic institutions. A comparison of the coefficients shows that the two coefficients are significantly different (Diff = 0.2398, s.e. = 0.0929). Similarly, a 10% increase in nonstop flights between two locations leads to an increase in collaborations of 1.48% between two subsidiaries within a firm and 0.40% between two entities within an academic institution. The point estimates are also significantly different (Diff = 0.1072, s.e. = 0.0527). These results show that nonstop flights mainly serve to facilitate citations between firms and collaborations between subsidiaries within a firm (and much less so between academic institutions or between their branches). In light of the relative importance of firms in driving innovation across countries through nonstop flights, the next section focuses squarely on further exploiting variation in firms/subsidiaries and between firm/subsidiary locations.

4. Firm Heterogeneity: A Gravity Model

What characteristics of the firms/subsidiaries and firm locations and of firm/subsidiary locations being connected by nonstop flights affect the relationship between nonstop flights and innovation across countries? To answer this question, we build on the gravity model, which scholars use to explain migration, bilateral trade flows, and FDI between countries (Vanderkamp 1977, Anderson 1979, Frankel and Rose 2002). When applied to trade, the model states that bilateral trade volume is proportional to the product of the countries' masses (measured in countries' GDP) and inversely proportional to the distance between the countries. When applied to innovation, the gravity model states that knowledge flows and collaborations between firms are proportional to the product of the innovation masses in those firms (commonly measured as patenting activities or number of inventors in nearby locations) and inversely proportional to the distance between those firms (Picci 2010, Montobbio and Sterzi 2013). The following parsimonious equation illustrates the gravity model's key assumptions:

$$Y_{ij} \sim M_i \cdot M_j / D_{ij}, \tag{3}$$

which translates to the following equation after taking the logarithms of both sides and adding the temporal dimension:

$$log(Y_{ijt}) = \beta_0 + \beta_1 log(M_{it}) + \beta_2 log(M_{jt}) + \beta_3 log(D_{ij}) + \epsilon_{ijt}. \tag{4}$$

In these equations, Y is the outcome of interest (knowledge flows and collaborations between two firms), M represents the innovation masses in firms i and j, and D is the distance between firms i and j.[19] Whereas distance is usually the geographic distance, it can also stand for other types of distance (e.g., cultural, economic, and language distances). By the gravity model, we expect the coefficients on the mass terms (β_1, β_2) to be positive and the coefficient on the distance term (β_3) to be negative.

In this study, we modify the gravity model in Equation (4) to predict the conditions under which nonstop flights facilitate (do not facilitate) knowledge flows between firms and collaborations between subsidiaries within a firm. We present two arguments: one regarding innovation masses of a pair of firms and one regarding the distances between those firms/subsidiaries and their locations. Rather than focusing on mass and distance as the main effects, we discuss their roles as moderators that amplify or suppress the effect of nonstop flights on innovation outcomes. The following equation illustrates the modified gravity model:[20]

$$\begin{aligned} log(Y_{ijt}) = \beta_0 &+ \beta_1 log(M_{it}) \\ &+ \beta_2 log(M_{jt}) + \beta_3 log(D_{ij}) \\ &+ \beta_4 log(M_{it}) \cdot Flights_{ijt} \\ &+ \beta_5 log(M_{jt}) \cdot Flights_{ijt} \\ &+ \beta_6 log(D_{ij}) \cdot Flights_{ijt} + \beta_7 Flights_{ijt} + \epsilon_{ijt}. \end{aligned} \tag{5}$$

First, regarding innovation mass, prior literature shows that firm innovation in a global context is spiky; that is, the spatial distribution of innovative activities is highly concentrated in a few locations (Bresnahan et al. 2001, Florida 2005, Kerr and Robert-Nicoud 2020).[21] We extend this logic to firms. A lack of ex ante innovation mass at firms being connected (e.g., number of nearby inventors, level of R&D) acts as an innovation bottleneck that cannot be directly alleviated by nonstop flights. Just as connecting two countries with low GDPs and low populations is unlikely to create a significantly higher trade flow (because those two countries have few things to trade in the first place), connecting two firms with nonstop flights is unlikely to lead to increased citations and collaborations if those firms are characterized ex ante by low innovation masses. Conversely, nonstop flights connecting firms with large innovation masses are particularly likely to increase citations and collaborations between those firms because nonstop flights build a bridge between two firms with ex ante high innovation stocks, at which inventors otherwise find it more difficult to meet each other face to face. Therefore, we posit that the positive effect of nonstop flights on innovation is stronger for firms and subsidiaries with greater innovation mass and located in innovation hubs or countries that are deemed technology leaders.

In contrast to innovation mass, the lack of which is a bottleneck that cannot be alleviated by nonstop flights, the distance between two firms or subsidiaries is a bottleneck that might be alleviated by nonstop flights. International business scholars develop various types of distance measures to study firms' internationalization decisions and other firm-level outcomes (Ghemawat 2007, Berry et al. 2010). Their key insight is that different types of distance across countries (e.g., geographic, cultural, temporal) create communication barriers that deter mobility, exchange, and collaboration. In our study, we focus on cultural and temporal distance given the importance assigned to these two dimensions of distance in prior literature.

If two inventors are culturally distant, they are likely to carry different understandings of power relations and individualism (Hofstede 1980). Cultural distance prevents information flow and increases uncertainty in a relationship and the cost of communication and collaboration (Lazear 1999, Berry et al. 2010). Two recent studies in the literature on innovation in a global context (Chua et al. 2015, Kerr and Kerr 2018) highlight the importance of cultural distance for our research question. Whereas Kerr and Kerr (2018) posit that cultural sensitivity promotes global collaboration between innovators, Chua et al. (2015) provide a theoretical reasoning for why cultural distance matters for innovation in a global context. In particular, Chua et al. (2015) theorize that, for global collaborative innovation to be successful, there has to be cultural alignment around the proposed solution between individuals in the two countries. They also theorize that cultural distance between the two countries as well as the degree of "cultural tightness" in each country—that is, the degree of acceptance of "deviant" views of foreigners—determine whether there is cultural alignment.

Prior research also suggests the importance of studying temporal distance for our research question. Greater working hour overlap (short temporal distance) is associated with greater levels of collaboration and knowledge sharing because working hour overlap can reduce frictions in synchronous communication (Espinosa et al. 2015, Bahar 2020, Chauvin et al. 2020, Bircan et al. 2021, Mell et al. 2021). A long-standing literature argues how being face to face facilitates the sharing of tacit knowledge and collaboration (e.g., Gaspar and Glaeser 1998, Nardi and Whittaker 2002). In the age of proliferation of synchronous communication technologies, such as Zoom and Skype, knowledge can also be shared virtually, especially if individuals are in the same time zone and have common working hours. It is possible that direct flights help temporally distant innovators more than temporally proximate innovators given that temporally proximate innovators have greater working hour overlap and opportunities to communicate synchronously using technologies even without direct flights. Thus, we posit that the effect of nonstop flights on innovation is more positive for firms and subsidiaries separated by large cultural or temporal distance.

To test these predictions, we carry out analyses using different measures of mass and cultural/temporal distance in the context of the regression discontinuity framework.

4.1. Importance of Innovation Mass of Firms and Firm Locations

For innovation mass, we consider two firm-level variables: inventor mass and R&D spending. Inventor mass refers to the total number of inventors who have filed patents with a firm. R&D spending is also a proxy for the level of innovation productivity at a firm. To obtain the R&D spending data, we build on the Duke DISCERN data set (Arora et al. 2021) to match assignees to Compustat. For all matched assignees, we obtain the average of their R&D spending for 2005 to 2015.

To estimate the differential effect of flights for different levels of inventor mass and R&D spending, we split patent assignees into groups of high and low mass. A firm has high inventor mass if it has an above-median number of inventors, and a firm has low mass otherwise. Similarly, a firm has high R&D spending if its average R&D spending from 2005 to 2015 is above the median in our sample. Once firms are categorized as high or low mass, we count the number of citations for high-/low-mass firms separately to the airport pair–year level. Thus, we create two sets of variables: the number of citations by high- and low-mass firms. Finally, we twice run the same regression discontinuity specification as Equation (2), once using the number of citations at high-mass firms and another time using the number of low-mass firm citations. Similarly for collaborations, using the same high- and low-mass split, we aggregate the number of collaborations to high-/low-mass firm patents

Table 3. Regression Discontinuity: Effect of Nonstop Flights on Firm Innovation Is Stronger for Firms with Greater Innovation "Mass"

	Inventor mass				R&D spending			
	Citations (asinh)		Collaborations (asinh)		Citations (asinh)		Collaborations (asinh)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Firm mass	High	Low	High	Low	High	Low	High	Low
Nonstop flights (asinh)	0.329***	0.185***	0.141***	0.020	0.180***	0.187***	0.093***	0.031
	(0.099)	(0.051)	(0.051)	(0.013)	(0.052)	(0.054)	(0.030)	(0.028)
(6,000-Distance)	−0.001**	−0.001**	−0.000	−0.000	−0.001***	−0.001***	−0.000*	−0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(6,000-Distance) × *Under6,000*	0.001*	0.001**	0.000	0.000	0.001***	0.001***	0.000	0.000*
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	3,795	3,795	3,795	3,795	3,795	3,795	3,795	3,795

Notes. Dependent variables are counts of citations/collaborations for firms of different types, all aggregated to the airport pair–year level. We divide firms into high/low inventor mass firms (above/below median count of inventors, columns (1)–(4)), and firms with high/low R&D spending (above/below median R&D spending, columns (5)–(8)). Thus, column (1) uses the number of citations to patents by firms with high inventor mass, whereas column (2) uses the number of citations to patents by firms with low inventor mass, as dependent variables. Inverse hyperbolic sine transformed variables are denoted by asinh. RD bandwidth set at 550 miles. All specifications include country pair–year fixed effects. R&D spending for a firm is obtained through the DISCERN data set (Arora et al. 2021). Distance denotes the geodesic distance (in miles) between airport pairs. *Under6,000* is an indicator variable equal to one if the distance is less than 6,000. Standard errors in parentheses, clustered at the country pair–year level.

$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

to the airport pair–year level. We present the results subsequently.[22]

We find support in Table 3 for predictions from the modified gravity model: the effect of nonstop flights on innovation across countries is greater for firms with high innovation mass. For firms with high inventor mass, a 10% increase in nonstop flights increases citations by 3.29%; the change is 1.85% for low inventor mass firms (columns (1) and (2)). Block bootstrapping tests reject the null of no difference in point estimates between the regressions for high- and low-mass firms (Diff = −0.143, p = 0.032).[23] Similarly for collaborations, a 10% increase in nonstop flights increases collaborations across subsidiaries by 1.41% for high-mass firms and 0.2% for low-mass firms (Diff = 0.121, p = 0.027). Columns (5)–(8) show a similar picture: firms with high R&D spending benefit more from nonstop flights, but the difference is not significant for citations. For collaborations, firms with higher R&D spending benefit more with a 10% increase in flights increasing collaborations by 0.93% for high R&D spending firms but 0.31% for others (Diff = 0.062, p = 0.212).

Next, we study the importance of firms/subsidiaries being located in scientific hubs. Innovation hubs are locations (usually cities) where patenting activities in a technical field are geographically concentrated (Bikard and Marx 2020).[24] We mark an airport as belonging to an innovation hub if it is within a 50-mile radius of any hub.[25] We split the data into two subsamples: (1) routes that connect two firm/subsidiary locations (proxied by airport locations) that are both located near innovation hubs and (2) routes in which at least one airport is not located near an innovation hub.[26] The two subsamples contain similar numbers of observations. For both subsamples, we repeat the regression discontinuity analysis to test whether the effect of nonstop flights on innovation depends on innovative activity levels. As with the RDD analysis, we conduct these subsample analyses at the airport pair–year level.

Table 4 shows the results for our subsample analysis. Columns (1) and (2) show that nonstop flights increase both citations and collaborations, respectively, for hubs. A 10% increase in nonstop flights increases citations by 5.2% and collaborations by around 2.7%. However, when neither airport is near an innovation hub, collaborations and citations are not impacted. Both coefficients in columns (3) and (4) suggest that the effect sizes are close to zero and not statistically significant. This result indicates that nonstop flights enhance production of GCPs and knowledge flows mainly through connecting inventors located at various innovation hubs. This result should be interpreted with caution as hubs and nonhubs differ inherently in terms of the likelihood of having nonstop flights and the ability to produce innovative ideas.

Finally, we study knowledge diffusion between firms and subsidiaries located in countries at the technological frontier and those in follower countries. We borrow from the Furman and Hayes (2004) categorization of leader versus follower countries in terms of their historical innovative productivity. According to their categorization, the leading innovating countries include Germany, Japan, Sweden, Switzerland, and the United States. These

Table 4. Regression Discontinuity: Effect of Nonstop Flights on Firm Innovation Is Stronger for Firms That Are Both Located Near Innovation Hubs

	Both airports are hubs		One or more nonhub airports	
	(1) Citations (asinh)	(2) Collaborations (asinh)	(3) Citations (asinh)	(4) Collaborations (asinh)
Nonstop flights (asinh)	0.522***	0.269***	−0.021	0.053
	(0.178)	(0.097)	(0.032)	(0.037)
(6,000 − Distance)	−0.003**	−0.001	−0.000	−0.000
	(0.001)	(0.001)	(0.000)	(0.000)
(6,000 − Distance) × *Under6,000*	0.006**	0.003*	0.000***	0.000
	(0.003)	(0.002)	(0.000)	(0.000)
Country pair–year fixed effects	Y	Y	Y	Y
Observations	1,870	1,870	1,760	1,760

Notes. This table presents the results from the regression discontinuity design, divided into subsamples that consist of (1) hub–hub location pairs and (2) location pairs with at least one nonhub location. Standard errors are in parentheses, clustered at the country–country level. Dependent variables are inverse hyperbolic sine transformed. Bandwidth set at 550 miles. Airports are located near an innovation hub if they are within a 50-mile radius of innovation hubs as defined in Bikard and Marx (2020).

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

countries are categorized as leaders, and the other countries (countries labeled as "middle tier," "third tier," and "emerging innovators" in the Furman and Hayes (2004) terminology) are categorized as followers. Then, we restrict the sample to citations and collaborations by firms located in these leader and follower countries, and we gauge the flights' effects on citations and collaborations that occur between (1) leaders, (2) followers, and (3) leaders and followers.[27] Table 5 shows that a 10% increase in nonstop flights between firms in two leader countries leads to a 17.95% increase in citations and a 4.96% increase in collaborations. We also find statistically nonsignificant effects for firms located in leader–follower and follower–follower country pairs.

4.2. Importance of Temporal and Cultural Distances

In this section, we explore how cultural and temporal distances between firms/subsidiaries and their locations (proxied by airport locations) affect the relation between nonstop flights and innovation outcomes. The analysis is done at the airport pair–year level. We consider the effects of two types of distance: temporal and cultural. For each type of distance, we compare the effect of nonstop flights on firms' innovation outcomes at airport pairs that are distant or close. Because our RDD setup includes only location pairs that are similar in terms of geographic distance, we focus on nongeographic measures of distance. Whereas the location pairs in the RDD setup are of similar geographic distance (around 6,000 miles), there is significant variation in temporal and cultural distances.

First, we test whether the positive effect of nonstop flights on innovation is stronger for firms and subsidiaries separated by large temporal distance. To test this, we divide the sample into airport pairs with above-median working hour overlap (greater than 1.5 hours) and those with below-median working hour overlap (1.5 hours or

Table 5. Regression Discontinuity: Effect of Nonstop Flights on Firm Innovation Is Stronger for Firms in Innovation-Leading Countries

	Citations (asinh)			Collaborations (asinh)		
	(1) Leader–leader	(2) Follower–follower	(3) Leader–follower	(4) Leader–leader	(5) Follower–follower	(6) Leader–follower
Nonstop flights (asinh)	1.795***	2.225	0.118	0.496***	0.397	0.095
	(0.423)	(5.553)	(0.121)	(0.154)	(1.146)	(0.079)
(6,000-Distance)	−0.006*	−0.019	−0.001***	0.000	−0.004	−0.001***
	(0.003)	(0.052)	(0.000)	(0.001)	(0.011)	(0.000)
(6,000-Distance) × *Under6,000*	0.014**	0.029	0.002***	0.001	0.006	0.001***
	(0.005)	(0.077)	(0.001)	(0.002)	(0.016)	(0.000)
Observations	583	748	1,562	583	748	1,562

Notes. Observations at the airport pair–year level. Standard errors in parentheses, clustered at the country pair–year level. Variables inverse hyperbolic sine transformed are denoted by asinh. Bandwidth set at 550 miles. All specifications include country pair–year fixed effects. Leader and follower denote firms in countries that are defined in table 6 in Furman and Hayes (2004). Leader countries are historically high in innovation productivity and include Germany, Japan, Sweden, Switzerland, and the United States.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

Table 6. Regression Discontinuity: Effect of Nonstop Flights on Firm Innovation is Stronger for Firm Locations Separated by Temporal and Ethnic Distances

	Temporal distance				Ethnic distance			
	Citations (asinh)		Collaborations (asinh)		Citations (asinh)		Collaborations (asinh)	
Distance:	(1) High	(2) Low	(3) High	(4) Low	(5) High	(6) Low	(7) High	(8) Low
Nonstop flights (asinh)	0.420***	0.328*	0.215***	0.190*	0.356***	0.202***	0.130***	0.087***
	(0.127)	(0.187)	(0.064)	(0.107)	(0.101)	(0.050)	(0.046)	(0.033)
(6,000-Distance)	0.000	−0.002	−0.000	−0.001	−0.001**	−0.001**	−0.000	−0.000*
	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
(6,000-Distance) × *Under6,000*	−0.001	0.004**	−0.000	0.002**	0.001*	0.001**	0.000	0.001*
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Observations	1,398	2,365	1,398	2,365	3,795	3,795	3,795	3,795

Notes. Dependent variables are counts of citations/collaborations for firms of different types, all aggregated to the airport pair–year level. We divide airport pairs into high/low temporal distance pairs (above/below median temporal distance, columns (1)–(4)), and citations/collaborations into multiethnic or coethnic (high/low ethnic distance, columns (5)–(8)). Thus, column (1) uses the number of citations to patents by firms/subsidiaries at airport pairs with high temporal distance, whereas column (2) uses the number of citations to patents by firms with low temporal distance, as dependent variables. Standard errors in parentheses, clustered at the country pair–year level. Variables inverse hyperbolic sine transformed are denoted by asinh. Bandwidth set at 550 miles. All specifications include country pair–year fixed effects. For temporal distance, "high" indicates two locations that are greater than one hour apart in time zone difference; "low" indicates one hour or less in time zone difference.

$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

less). In Online Section D1, we also conduct robustness checks showing that a similar pattern emerges when using other cutoffs for high versus low temporal distances. In Online Section D2, we also show that the effect of nonstop flights on innovation outcomes is stronger for routes with shorter north–south distances (routes that cross over less longitudinal distance).

Table 6 (columns (1)–(4)) reports the results. We see that nonstop flights help overcome temporal distance: nonstop flights increase citations and collaborations for firms in location pairs with below-median working hour overlap (long temporal distance) but not for above-median pairs (short temporal distance). A 10% increase in flights for airport pairs with less than 1.5 hours of working hour overlap leads to a 5.25% increase in citations between firms and a 1.87% increase in collaborations between subsidiaries within a firm. For airport pairs with above-median working hour overlap, we see the coefficient sizes are smaller and statistically insignificant at conventional thresholds. Chow test results show that, for citations, temporally distant location pairs benefit more than temporally proximate ones (Diff = 0.665, p = 0.003). For collaborations, we cannot reject the null of no difference (Diff = 0.088, p = 0.602) because of the large standard errors for our estimates for low-temporal distance pairs. Overall, nonstop flights do not seem to enable knowledge spillovers and collaborations between inventors that are temporally close to one another.

Second, we test whether the positive effect of nonstop flights on innovation is stronger for firms and subsidiaries separated by large cultural distance. We use two measures of cultural distance. First, we adopt a direct measure of cultural distance at the firm level by using the ethnic composition of the inventors who cite one another at two geographically distant firms and who collaborate with one another at two geographically distant subsidiaries within a firm. We determine inventors' ethnicities using NamePrism, a tool based on machine learning algorithms that accurately predict a person's ethnicity based on the full name. Inventors in a citing or collaborating relationship are deemed coethnic if they share an ethnicity and multiethnic if there is more than one ethnicity in that relationship. Then, we compare the effect of nonstop flights on coethnic and multiethnic innovation. Table 6 (columns (5)–(8)) shows that, for inventor pairs that share the same ethnicity (low ethnic distance), coethnic collaborations increase by 0.87%, whereas coethnic citations increase by 1.43%. However, for inventor pairs with different ethnicities (high ethnic distance), multiethnic collaborations increase by 1.30% and citations by 3.54%. A Chow test for difference of coefficients shows that coethnic citations benefit more than multiethnic citations (Diff = 0.154, p = 0.001). Results for collaborations lack statistical significance (Diff = 0.043, p = 0.124). In summary, we find some evidence for the relationship that nonstop flights tend to facilitate innovation across countries for firms that are culturally distant.[28]

Next, we construct another measure for cultural distance. We utilize the data from the 2020 WVS to gauge individuals' attitudes toward foreign workers. Berry et al. (2010) and others adopt the WVS data to create indices of cultural distance between countries. Instead of using an index, the interpretation of which is difficult to decipher, we utilize one specific question on the WVS that asks respondents to "evaluate the impact of immigrants on the development of your country," for which the answer choices range from "very bad" to "very good." We then aggregate the answers at the country level and obtain a value for each country, which we then match to the data on flights and patenting. The assumption is that immigrant friendliness is a good proxy for individuals' ability to appreciate the work of foreigners—a cultural dimension that is highly relevant to our context given that it relates to cultural tightness (Chua et al. 2015). We divide our sample into location pairs that are (1) both immigrant friendly, (2) both immigrant unfriendly, and (3) one immigrant friendly and one immigrant unfriendly. We find that nonstop flights increase citations and collaborations among firms in locations that are marked by a high degree of cultural distance: when one location is immigrant friendly and another is immigrant unfriendly. Interestingly, when both locations are unfriendly to immigrants, nonstop flights do not facilitate innovation. Table 7 presents results of the regression discontinuity subsample analysis. For firms in location pairs with high cultural distance (in terms of friendliness toward immigrants), a 10% increase in nonstop flights leads to a 7.2% increase in citations. Finally, Online Section D4 presents an alternative immigrant analysis using firms' labor condition applications as a proxy for firms' employment of immigrants, showing that nonstop flights drive knowledge diffusion among firms with high levels of immigrant labor.

5. Additional Analyses

5.1. Airport-Level Instrument

Our regression discontinuity results show that, at the airport-pair level, pairs slightly below 6,000 miles apart have increased knowledge flows. However, an open question is whether this result extends more globally above and beyond the 6,000-mile threshold. One specific concern is that measurements at the airport-pair level may be confounded by redirection of knowledge flows from other airport pairs to the focal pair. We analyze how direct flights affect citations and collaborations at a single airport. This approach calculates the net effect and mitigates concerns of compositional changes in innovation outcomes.

We implemented an instrumental variable–based identification strategy proposed by Campante and Yanagizawa-Drott (2018) to extend the results from the airport-pair level to the airport level. At the airport level, we use exogenous variation in that airport's connectedness to measure its impact on the number of publications and citations. Variation in an airport's connectedness stems from the cost of operating 6,000+ mile flights: airports with many other "potential" airports slightly less

Table 7. Effect of Nonstop Flights on Firm Innovation Is Stronger for Firms in Countries That Are Culturally Distant in Terms of People's Attitudes Toward Immigrants (Immigrant Friendliness)

	Citations (asinh)			Collaborations (asinh)		
	(1) Friendly–friendly	(2) Unfriendly–unfriendly	(3) Friendly–unfriendly	(4) Friendly–friendly	(5) Unfriendly–unfriendly	(6) Friendly–unfriendly
Nonstop flights (asinh)	−2.698	−0.265***	0.789***	−0.897	−0.022	0.473**
	(3.064)	(0.081)	(0.292)	(1.136)	(0.033)	(0.194)
(6,000-Distance)	0.028	−0.004**	−0.000	0.009	−0.002*	−0.000
	(0.033)	(0.001)	(0.001)	(0.012)	(0.001)	(0.001)
(6,000-Distance) × *Under6,000*	−0.050	0.003*	−0.000	−0.017	0.002*	−0.000
	(0.060)	(0.002)	(0.001)	(0.022)	(0.001)	(0.001)
Observations	616	748	1,760	616	748	1,760

Notes. Observations at the airport pair–year level, excluding airport pairs with missing immigrant friendliness measures (25.33% of the sample). Standard errors in parentheses, clustered at the country pair–year level. Variables inverse hyperbolic sine transformed are denoted by asinh. Bandwidth set at 550 miles. All specifications include country pair-year fixed effects.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

than 6,000 miles apart are more "connected" in terms of number of flights. We use an instrumental variable approach in which the share of airports slightly below 6,000 miles shifts the total number of realized connected airports, thus impacting innovation. Our first and second stage regressions are as follows:

$$ConnectedAirports_i^t = \alpha_0 + \alpha_1 ShareBelow6K_i + X_i + \varepsilon_i, \quad (6)$$

$$Y_i^t = \beta_0 + \beta_1\, \widehat{ConnectedAirports}_i^t + X_i + \varepsilon_i. \quad (7)$$

The variable $ConnectedAirports_i^t$ measures the number of airports with which airport i has a nonstop flight in year t. $ShareBelow6K_i$ counts the total number of airports (connected or unconnected) slightly below 6,000 miles and divides this by the total number of airports (again, connected or unconnected) around 6,000 miles. Y_i^t is our dependent variable: the number of either firms or academic publications near airport i in year t or citations to those patents.[29] X_i includes control variables, including the total number of airports near 6,000 miles for airport i, its distance from the equator, and the time zone difference from GMT as well as region fixed effects.[30]

Generally, we find that more connected airports lead to more citations and publications. Table 8 shows that an additional connected airport in 2015 increases the total number of citations by about 12.7% and the total number of publications by 10.6% for firms.[31] Given that the median number of connected airports in our sample is four (mean = 15.87, s.d. = 42.92), the economic magnitude of connectivity seems to be quite significant.[32] In Online Section F, we break down the effects across different years and find similar results. Online Section F also tests how connectivity affects the number of collaborators and duration and finds that both increase, suggesting the existence of intensive and extensive margins.

5.2. Mechanisms: Ticket Prices and Flight Duration

We next turn to the mechanisms by which nonstop flights affect collaborations and citations in our context. The two mechanisms of interest relate to travel cost (e.g., Catalini et al. 2020) and time (e.g., Bernstein et al. 2016) reductions. Advances in technology and increased competition have significantly impacted both the monetary cost as well as the time it takes to transport people. For instance, a typical trip from Los Angeles to Boston cost about $4,500 in 1941 (2015 dollars) and took more than 15 hours across 12 stops. In contrast, in 2015, the same route could be traveled nonstop for just $480 (just 11% of the 1941 cost) and take only six hours (Garcia 2017).

Determining whether nonstop flights impact innovation across countries through travel duration or ticket price has important implications for theory and informing policy. Prior work on collaboration over distance focuses primarily on travel costs as a key barrier to collaboration. For instance, pecuniary travel costs and the importance of face-to-face interactions in facilitating collaborative outcomes can explain why distance still matters for collaboration (Catalini et al. 2020). However, for many innovators, "time famine"—that is, a shortage of time—is a more salient constraint (Perlow 1999), especially for firm-employed inventors who, relative to academic inventors, might care more about time spent on international journeys than about monetary costs of travel. Delving into the components of

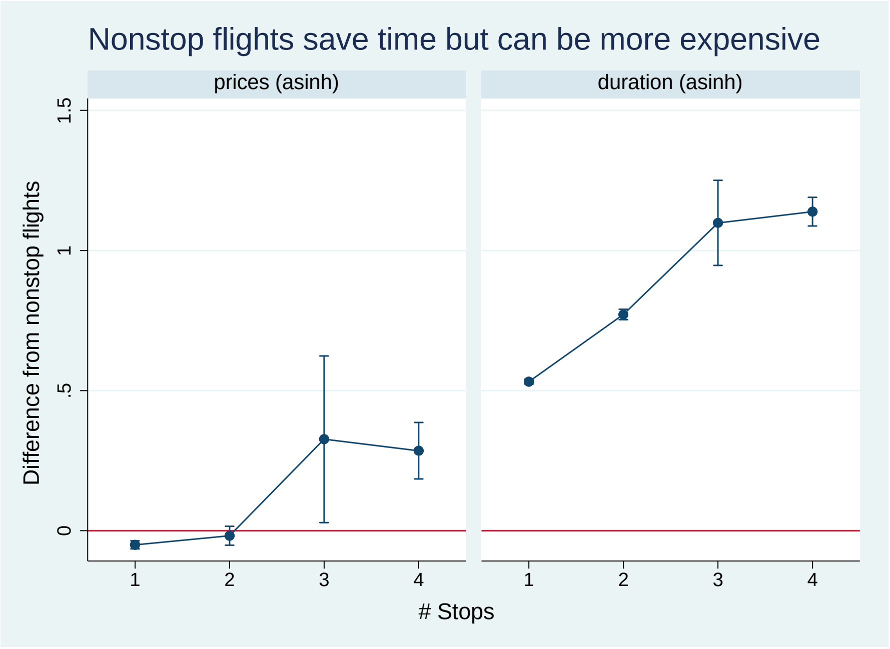
Table 8. Firms Near More Connected Airports Have More Citations and Scientific Publications

	Firms		Academic institutions	
	(1) Citations (asinh)	(2) Publications (asinh)	(3) Citations (asinh)	(4) Publications (asinh)
Number of connected airports (2015)	0.124***	0.105***	0.085***	0.061***
	(0.046)	(0.036)	(0.027)	(0.019)
Airports near 6k	0.163	0.115	0.047	0.043
	(0.109)	(0.084)	(0.065)	(0.048)
Distance to equator	−0.000	−0.000	−0.000	−0.000
	(0.001)	(0.000)	(0.000)	(0.000)
Time zone difference from GMT	−0.287	−0.197	−0.121	−0.091
	(0.362)	(0.281)	(0.217)	(0.153)
Region fixed effects	Y	Y	Y	Y
Observations	4,956	4,956	4,956	4,956

Notes. Coefficient estimates from two-stage least squares. Observations at the airport level. Standard errors in parentheses, clustered at the country level. All specifications include region fixed effects. All dependent variables are asinh transformed. Number of connected airports counts the number of connected airports between 5,500 and 6,500 miles. Airports near 6k counts the number of airports (connected or not) in the same bandwidth. We instrument for the number of connected airports using *ShareBelow6k*, which divides the number of airports (connected or not) 5,500–6,000 miles away by the number of airports (connected or not) 5,500–6,5000 miles away.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

Figure 3. (Color online) Nonstop Flights Are More Expensive Than One-Stop Flights



Notes. Coefficient plot of the relationship between number of stops and flight price and flight duration obtained from Google Flights in January 2020. Each point measures the percentage difference between ticket price/duration for nonstop flights (omitted category) and flights with a given number of stops. Outcome variables are inverse hyperbolic sine transformed and are interpreted similarly to a log-transformation. Thus, the *y*-axis measures log-differences in price and duration against nonstop flights.

travel costs is crucial to understanding the existence of barriers to collaboration other than, for instance, geopolitical borders (Singh and Marx 2013).

For each airport pair, we obtain the average ticket price and duration of travel sourced from Google Flights. Specifically, from January 5 to February 6, 2020, we queried Google Flights for flights leaving Thursday, June 18, 2020, and returning Sunday, June 21, 2020. The mid-June dates were chosen to represent a typical conference weekend.[33] Our query window for flight price and duration information (i.e., from January 5 to February 6, 2020) was before most COVID-induced travel bans took place (e.g., travel bans to and from China took place mostly in late January and early February 2020), which suggests that our flight data are representative of data that would be obtained during normal, nonpandemic times. We obtained ticket information for airport pairs that are more than 3,000 miles apart and have more than 1,000 flights between them from 2005 to 2015 (i.e., 100 flights per year or about one weekly round-trip flight) for a total of 3,708 routes. With this information, we calculate the average ticket price and average time duration of all routes between an airport pair. By constructing the data set as described, we assume that flight durations and prices in 2020, adjusted for inflation, are similar to what they would have been in our sample period, 2005 to 2015.

A major appeal of nonstop flights is their ability to decrease flight time significantly, and customers frequently pay extra to take nonstop flights. Figure 3 plots how prices and travel duration vary with number of stops using the data we gathered from Google Flights. Each point on the graph represents the average difference in price and travel time between a nonstop flight and a flight with stops. The left panel shows that a one-stop flight is, on average, 5.1% cheaper than a nonstop flight. This constitutes an average price difference of about $40. However, the average one-stop flight is about 53% longer in terms of travel time than a nonstop flight, a time difference of about 5.8 hours. This trade-off between more expensive tickets and shorter flight durations is stronger for long-distance flights (Online Section G shows that the magnitude of the coefficient on duration increases for airport pairs more than 6,000 miles apart).

To shed light on the relationship between firms' innovation activities and ticket prices/travel duration, we estimate the number of collaborations and citations using the following specification:

$$\begin{aligned}\operatorname{asinh}(Y_{a_o,a_d}) &= \beta_0 + \beta_1 \operatorname{asinh}(Price_{a_o,a_d}) + \beta_2 \operatorname{asinh}(Duration_{a_o,a_d}) \\ &\quad + \delta \operatorname{asinh}(X_{a_o,a_d}) + \eta_{c_{a_o},c_{a_d}} + \epsilon_{a_o,a_d}, \end{aligned} \tag{8}$$

where Y_{a_o,a_d} measures the total number of collaborations or citations between a_o and a_d. $Price_{a_o,a_d}$ is the average ticket price for flights between a_o and a_d, and $Duration_{a_o,a_d}$ measures the average number of hours

Table 9. Shorter Flight Duration Is Associated with More Citations and Collaborations

	(1)	(2)	(3)	(4)
	Citations (asinh)	Collaborations (asinh)	Citations (asinh)	Collaborations (asinh)
Duration (asinh)	−0.628*	−0.659***	−0.808***	−0.764***
	(0.331)	(0.248)	(0.246)	(0.230)
Price (asinh)	−0.337	−0.240	−0.381**	−0.266
	(0.216)	(0.208)	(0.176)	(0.185)
Distance (asinh)			0.886	0.518
			(1.213)	(0.745)
Constant	6.826***	5.382***	−0.110	1.328
	(2.461)	(2.026)	(11.733)	(7.537)
Observations	1,247	1,247	1,247	1,247
R^2	0.742	0.590	0.744	0.591

Notes. This table tests the validity of two mechanisms that potentially drive the connectivity–innovation relationship: flight duration and flight price. Standard errors are in parentheses, clustered at the country–country level. Dependent variables are inverse hyperbolic sine transformed. Both dependent variables are asinh transformed.

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

for those flights.[34] In all specifications, we control for the distance between airport pairs (X_{a_o,a_d}) as well as country–country fixed effects ($\eta_{c_{a_o},c_{a_d}}$), which control for between-country differences such as language and time zone differences. We cluster our standard errors at the country–country level.

We present estimates of the specification in Table 9. Across all specifications, we see that flight duration has a negative and significant partial correlation with collaborations and citations. In our preferred specification for collaborations (column (3)), a 10% increase in duration (1.3 hours) is associated with an 8.9% decrease in collaborations (1.8 fewer collaborations per route across the entire sample period). Similarly, for citations (column (4)), a 10% increase in duration is associated with an 8.7% decrease in citations (1.9 fewer citations per route). However, whereas prices are negatively correlated with citations and collaborations, the coefficients are not statistically distinguishable from zero for collaborations. This result hints that it is a cost—not price—reduction in terms of the time duration of nonstop flights that would facilitate the collaborative production of innovation and the diffusion of knowledge across firms globally.

6. Discussion and Conclusion

Firms continue to benefit from global knowledge diffusion and the production of global collaborative patents, but national borders remain relevant as a source of friction (Singh and Marx 2013). Alcácer et al. (2017, p. 1) detail how "figurative distances" stemming from political borders were creating frictions that impeded knowledge collaboration and spillovers, and Aguilera et al. (2019) bemoaned the deglobalization trend. In the context of this prior literature, this paper shows how, in the global context, geographic mobility of individuals through nonstop flights boosts the diffusion of knowledge through patent citations and collaboration of inventors, especially at firms. To provide causal evidence, we use an RDD framework and find that a 10% increase in the number of nonstop flights between two locations increases citations by 3.4% and collaborations by 1.4%. This positive effect is driven primarily by firms as opposed to academic institutions. We find the effects to be more salient at firms/subsidiaries (1) with more inventors and R&D spending, (2) located in hubs or countries deemed technology leaders, and (3) that are located in culturally distant or temporally distant places.

Our study has several limitations. Similar to Bernstein et al. (2016), Catalini et al. (2020), and most prior studies on airline connectivity and innovation/economic outcomes, we do not observe individuals traveling between locations and instead impute travel patterns by aggregating citations and collaborations to the level of airport pairs. One consequence of this is that we are unable to disaggregate who is traveling and for what reason.[35] A recent McKinsey report (Curley et al. 2020) documents that, in 2018, international airline business travel spending exceeded $1.4 trillion; this travel encompassed transient travel and travel for meetings, incentives, conferences, and events, from large group off-site gatherings to industry-wide exhibitions. Future research should attempt to disaggregate the effects of airline travel for company meetings versus attending conferences and contribute to the literature on temporary colocation and innovation outcomes (Boudreau et al. 2017, Chai and Freeman 2019). Additionally, there is an increasing adoption of alternative work arrangements and communication technologies, such as Zoom (which might come to characterize the post-COVID world; Marr 2021); future research may study whether the effects of transportation connectivity on innovation across countries are weakened or strengthened by the use of new communication technologies. Finally, because of data limitations, we examine only USPTO patents, not including patents issued by other patent offices, such as the European or the Japan Patent Office. Even though our results hold when limiting the sample to airport pairs with at least one U.S. city, the analysis would be more complete if it included patents from the rest of the world.

Despite these limitations, our findings contribute to several streams of the strategy and innovation literature: notably, the literature on connectivity/geographic mobility and economic/innovation outcomes. We contribute to this literature by showing whether, how, and when mitigating travel constraints can foster greater knowledge diffusion in a global setting (Baum-Snow 2007, Duranton and Turner 2012, Ghani et al. 2016, Agrawal et al. 2017). Our findings are related to Agrawal et al. (2017), who exploit historical data on planned highways, railroads, and exploration routes as sources of exogenous variation in order to estimate the effect of interstate highways on regional innovation.[36] Notably, we highlight the scope conditions of greater connectivity fostering innovation outcomes and document that, for firms with relatively lower innovation mass, firms/subsidiaries that are located outside hubs/countries that represent the technological frontier, and firms and firm locations that are culturally or temporally proximate, adding nonstop flights is less likely to enhance innovation outcomes. This result sheds light on why it may be difficult for firms and inventors in some follower countries to get to the technological frontier.

A relevant paper in this literature is Catalini et al. (2020), which uses a difference-in-differences empirical strategy combined with a series of robustness and falsification tests to document that the availability of cheaper options for airline travel has a causal effect on the probability, intensity, and direction of collaborations among academic scientists. However, whereas the Catalini et al. (2020) study focuses on academic scientists within the United States (for whom temporal and cultural distance with collaborators or being located in a country that is a technological follower might be less salient) and on savings in travel costs as the underlying mechanism, our study focuses on firms—how characteristics of firms/subsidiaries and their locations matter for the relation between nonstop flights and innovation outcomes across countries—and documents savings in travel time as the underlying mechanism.

Our findings also contribute to the literature on knowledge spillovers and collaborative patents for firms in the global context. Branstetter et al. (2014) document that multinational corporations (MNCs) from advanced economies are largely responsible for the "exponential" growth in U.S. patents filed from China and India. Kerr and Kerr (2018) cite analysis from the Bureau of Economic Analysis to state that the share of R&D for U.S. MNCs conducted by foreign subsidiaries rose from 6% in 1982 to 14% in 2004. Our findings contribute to this literature by outlining an important mechanism—that is, international travel and flight connectivity—that facilitates knowledge flows and GCP production across countries. To quote Kerr and Kerr (2018, p. F268), the "use of cross-border teams is a very attractive technique for multinationals conducting innovation abroad and careful thought by nations about short-term travel policies … may have a big impact as multinationals weigh their options." Our findings speak directly to this assertion and provide empirical evidence for whether, how, and when nonstop flights facilitate GCP production.

Finally, we contribute to the international business literature on distance. That research shows that interfirm alliances and employee geographic mobility create "bridges to distant contexts" that mitigate the constraints of geographically localized search for knowledge and collaborators (Rosenkopf and Almeida 2003). Our study suggests that flight connectivity is an important facilitator for firms to build bridges to distant contexts, but the effectiveness of the bridges depends on the characteristics of the firms and the contexts being connected. Similarly, scholars show that temporal distance and a lack of working hour overlap impede knowledge-intensive communication in firms (Bahar 2020). Our study suggests that nonstop flights may feasibly overcome the temporal barrier and facilitate the spread of knowledge across temporally distant firms and subsidiaries within a firm by bringing individuals face-to-face. Another possibility is that nonstop flights may facilitate knowledge diffusion across global firms by allowing inventors to work from similar time zones within business hours although not necessarily meeting face to face. Online Section D3 offers support for the mechanism of similar time zone work by showing that nonstop flights enable knowledge flows for firms that are highly temporally distant (8+ hours difference). This result is not conclusive, and it warrants more research to further unpack the difference between the mechanism of face-to-face meetings versus that of similar time zone work. Additionally, our study relates to the interplay between geographic and nongeographic distances. Whereas geographic distance physically limits knowledge flows, nongeographic factors, such as cultural frictions, also constrain the point of contact and hamper interactions (Shenkar 2001, Shenkar et al. 2008). Our study suggests conditions under which geographic distance may not be a friction; that is, if firms and firm locations are culturally similar or temporally proximate, firms may not need a physical bridge (e.g., through nonstop flights) to exchange knowledge or collaborate.

Our study suggests several additional directions for future research. First, future research should explore whether the introduction of synchronous and asynchronous communication technology substitutes for or complements airline travel. Second, future research should explore the importance of global immigration policies as they relate to airline travel and how that affects the utility of choosing a nonstop flight versus a flight with more stops. In other words, whereas a nonstop flight avoids the need for securing a "transit visa," such visas might be salient for global travel that involves stopovers (O'Keefe 1993). Finally, future research should study the importance of global airline travel in an era of increasing distributed work and "work from anywhere" (WFA) (Choudhury et al. 2021). It would be interesting to study whether the importance of airline connectivity, travel, and temporary colocation increases when more firms adopt WFA and workers become more globally distributed.

Our study also has several managerial and policy implications: notably, that business travel to culturally and temporally distant places might be beneficial for innovation outcomes at firms with large innovation masses, especially when the travel connects two hubs. For decades, airports and policy makers have offered incentives to airlines to start nonstop flights.[37] Our study provides useful evidence for when policy makers should design incentives to attract airlines to start nonstop flights. Our study also points to the importance of business travel for fostering innovation and suggests conditions for when such travel might be more effective. For example, direct flights may disproportionately benefit firms with greater innovation mass compared with universities and smaller firms. As the McKinsey report published by Curley et al. (2020) documents, whereas business travel spending exceeded $1.4 trillion in 2018, "historically, business travel has been more volatile and slower to recover than leisure travel after economic downturns and other disruptions to travel patterns." Our study indicates that, if indeed international flights exhibit a slow recovery in the aftermath of pandemics and economic downturns, cross-border knowledge spillovers and collaborations at some firms could be adversely affected.

In conclusion, this paper presents, to the best of our knowledge, the first set of causal evidence and boundary conditions for whether, when, and how nonstop flights positively affect firm innovation in a global context. Using unique data and a two-pronged empirical approach (including a cutting-edge RDD and tests of firm and firm location heterogeneity using a modified gravity model), we shed light on whether, when, and how nonstop flights affect knowledge spillovers (citations) and collaborations (GCP production) for firms in a global setting. Our study contributes to the literatures on connectivity/geographic mobility and innovation outcomes, knowledge spillovers and collaborative patents for firms in the global context, and how cultural and temporal distances affect innovation across countries. Finally, it provides policy and managerial implications on the value of business travel.

Acknowledgments

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Endnotes

[1] We study citations between firms and collaborations between subsidiaries within a firm. This is because, in the patenting data set, a citation is usually between two different assignees (e.g., firms), and a global collaborative patent (collaboration) is between inventors within a single assignee. In other words, we assume that, for a global collaborative patent assigned to a firm, collaborating inventors are located at different subsidiaries within the firm.

[2] Singh and Marx (2013) find that, even after accounting for geographic proximity between patent inventors, country and state borders still constrain knowledge diffusion in the form of citations.

[3] For example, Catalini et al. (2020) find that, after Southwest Airlines introduced new routes in the United States, collaborations between academic scientists increased from 0.3 to 1.1 times. The authors highlight travel costs as an important hurdle to innovation collaborations. Agrawal et al. (2017) study roads and innovation. They find that a 10% increase in the availability of highways in a region is associated with a 1.3% increase in citation-weighted patents. Their study points to a mechanism through which roads drive innovation (within-region knowledge flows) as roads make it easier for innovators located in the same region to interact with one another.

[4] As Campante and Yanagizawa-Drott (2018) point out, the geodist command in Stata computes the geodesic distance: the length of the shortest curve between two points along the surface of (a mathematical model of) the Earth, not the actual flight distance. As such, this proxy is exogenous to the geopolitical factors that determine actual flight distance.

[5] Specifically, we map inventors to all airports within a 50-mile radius with territorial contiguity and within their own country with the exception of the Schengen area for which we relax the "within same country" rule as long as there is territorial contiguity between the location of the inventor and the nearby airport.

[6] The final list of keywords is available upon request.

[7] We conducted a correlational exercise using the counterfactual patent-matching methodology. This procedure helps map out the broad relation between flight connectivity and innovation outcomes across countries. In Online Sections A4 and A5, we show that nonstop flights provide an additional 2.6 percentage point increase in citations and a 2.9 percentage point increase in collaborations for international airport pairs.

[8] More information can be accessed at https://pypi.org/project/timezonefinder/.

[9] Working hour overlap was defined as eight hours if the time difference between the origin and destination airports is 0, 24, or −24 hours; seven hours if the time difference is −1, 1, or 23 hours, and so forth.

[10] The Boeing 747-400 commenced commercial operations in 1989, followed by the Airbus A330 and A340 models as well as the Boeing 777 series. The 747-400 family was about 20% more fuel efficient than the previous best-selling planes, and the 777 pushed this gain to about 30% (Kharina and Rutherford 2015).

[11] For instance, 6,000 miles corresponds roughly to the distance between Los Angeles and Munich (slightly less than 6,000 miles) or from Cologne to Sao Paulo (slightly more than 6,000 miles).

[12] We present summary statistics for the RDD sample in Online Table B1.

[13] In Online Section B7, we show that our graphical results are robust to using higher order polynomials to fit the data points to either side of the discontinuity.

[14] In this analysis, we use the total number of nonstop flights instead of the binary variable for the existence of nonstop flights. Using a binary indicator as the instrument, we also conclude that the existence of a nonstop flight increases citations and collaborations, but the effect size is greater: the existence of a nonstop flight increases citations by 90.89% ($\beta_1 = 2.3964$, $p < 0.01$) and collaborations by 65.25% ($\beta_1 = 1.0571$, $p < 0.01$). Our preferred specification, to be conservative, is using the continuous number of flights variable given that the very small changes in the binary variable exploited using the fuzzy regression discontinuity design might overestimate the Wald estimator.

[15] Online Section B12 shows that our results are robust to using raw counts, log + 1 transformations, and Poisson quasi-maximum likelihood estimators.

[16] Generally, RD results are sensitive to which observations near the threshold are included. We provide two thresholds: a 500-mile bandwidth and an "optimal" bandwidth. The optimal bandwidth is calculated following the methodology described in Calonico et al. (2020), which builds on prior work on optimal bandwidth choice in RD by Imbens and Kalyanaraman (2012). In Online Sections B3–B5, we show our RD results are robust to varying the number of bins, the bin selection method, and kernel choice as well as different levels of fixed effects and clustering.

[17] In Online Sections B8 and B9, we conduct permutation tests on the 6,000-mile threshold to check whether we see similar discontinuities at thresholds other than our 6,000-mile mark. We show that the RD coefficients are insignificant when using random thresholds far from the 6,000-mile mark, confirming the validity of our 6,000-mile threshold. We also conduct permutation tests on the running variable (e.g., the distances to 6,000-mile variable) to test whether airports strategically locate themselves closer to other airports. We find no discontinuities in our running variable and, thus, no precise manipulation of airport locations. Online Section B11 further shows the effects are indeed driven by nonstop flights not one-stop flights.

[18] In addition to these keywords, we use Google Translate to translate the keywords across all available languages, and we include those keywords in our categorization as well.

[19] To develop conceptual arguments, when we mention "firms," we imply both firms and their subsidiaries.

[20] We do not estimate the point estimates outlined in Equation (5), but rather use the modified gravity model to motivate how innovation mass of firms and temporal/cultural distance between firms affect the relation between direct flights and innovation outcomes. As we explain later, we employ subsample analyses and regressions for heterogeneous firms.

[21] Richard Florida's (2005) article documents a spiky map of innovation in which the global patenting peaks are Tokyo, Seoul, New York, and San Francisco. Innovation activities are more concentrated in a few global locations than is economic activity or population. Bresnahan et al. (2001) present case studies that illustrate the necessary preconditions for the formation of new innovation hubs (concentration of firm-building capabilities and managerial skills, supply of skilled labor, and connections to markets). Recently, Kerr and Robert-Nicoud (2020) document the uneven distribution of innovation globally. The top 10 global innovation clusters in terms of patent count include large cities in Asia, the United States, and France. The first place cluster (Tokyo–Yokohama) holds twice the patent count of the second place cluster (Shenzhen–Hong Kong).

[22] In Online Section C6, we present an additional set of mass results based on firm-level variables, including revenue and employee count, in addition to R&D spending.

[23] Online Section E provides a detailed overview comparing RD coefficients across models. We use a seemingly unrelated estimates approach to compare effect sizes (Mize et al. 2019), and we also provide block bootstrapping results.

[24] The authors define innovation hubs as cities with significant patenting for a given subclass for all subclasses. Specifically, they code a hub as being within a 50-mile radius of a city with (1) more than 5% of patents in a given subclass and (2) at least five patents within that subclass. Bikard and Marx (2020) provide additional details (including the location data for hubs).

[25] Online Section C1 contains examples of airports near hubs and those not near hubs. Online Section C2 tests the relationship between flight distance and the likelihood of a flight connecting two innovation hubs.

[26] We consider hub-to-hub connections versus routes with at least one nonhub airport in the main draft. OnlineAppendix C4 shows that nonhub-to-nonhub routes do not benefit from nonstop flights.

[27] Online Section C5 contains the original list of leader countries.

[28] In addition to cultural distance, firm boundaries may serve to amplify institutional distance. Thus, nonstop flights may have different effects, depending on whether those citations are cross- or within-assignee. However, as Online Section B10 shows, most citations (more than 95%) are cross-assignee, limiting our ability to test for differences.

[29] We use the number of connected airports in 2015 and sum the number of publications and citations across all years in our patent sample (2005–2015). Online Section F1 shows that our findings are robust to using alternate years.

[30] Region data from World Bank Development Indicators categorize countries into seven regions: East Asia and Pacific, Europe and Central Asia, Latin America and the Caribbean, Middle East and North Africa, North America, South Asia, and Sub-Saharan Africa. Note that we are unable to add country–country fixed effects in this setting because the nature of the sample has no bilateral dimension (each observation is an airport).

[31] Because our dependent variables are inverse hyperbolic sine transformed, we can interpret them as log-transformed variables. Therefore, we use $\exp\{\text{coefficient}\} - 1$ to calculate the effect sizes.

[32] In general equilibrium, when looking at highly aggregated data, we cannot rule out the possibility of some firms self-selecting to be located near the most connected airports. However, our empirical design exploits exogenous variation to estimate the connectedness of airports, and therefore, given our assumptions, our estimates using the regression discontinuity framework are causal. Moreover, a long-standing literature in strategy outlines how firm location choice is driven by considerations such as access to resources (Alcácer and Chung 2007) and location of competitors (Ghemawat and Thomas 2008), among others; there is less evidence on firms actively using closeness to connected airports as a key determinant of their location decisions.

[33] For instance, in 2019, the Association of Clinical Research Professionals Annual Meeting was held April 12–15 (Friday to Monday), and USPTO's Inventors Conference was held September 13–14 (Friday to Saturday).

[34] Our results are robust whether we average for direct and one-stop flights or consider averages across all flights (2+ stops).

[35] To the best of our knowledge, the only prior study that uses actual international flight travel data for individuals is Choudhury (2017). Business travelers may include both managers who do not participate in patenting and firm-employed inventors who participate in patenting. We are unable to ascertain which types of travelers

contributed more to outcomes of interest, and policy implications may differ depending on the traveler type.

[36] More broadly, our findings are also relevant to the literature on international labor mobility and knowledge diffusion (Almeida and Kogut 1999; Kapur 2001; Rosenkopf and Almeida 2003; Kapur and McHale 2005a,b; Singh 2005; Agrawal et al. 2006, 2011; MacGarvie 2006; Kerr 2008; Oettl and Agrawal 2008; Obukhova 2009; Papageorgiou and Spilimbergo 2009; Nanda and Khanna 2010; Foley and Kerr 2013; Ghani et al. 2014; Hovhannisyan and Keller 2015; Choudhury 2016; Choudhury and Kim 2019; Bahar et al. 2020).

[37] From 2012 to 2014, regional airports in the United States spent in excess of $171 million in incentives to attract new routes (Centre for Aviation 2018). Whether to operate nonstop flights between airports is a topic of active managerial discussion (Routes Online 2019). Many airports offered incentives to attract new international flights: Hartsfield–Jackson Atlanta International Airport offered to waive landing fees (Williams 2014), Tampa International Airport offered cash and airport fee waivers to attract Edelweiss (Thalji 2013), Indianapolis International Airport offered Delta $5.5 million in conditional incentives (Lange and Cook 2017), Pittsburgh was able to attract an international flight to London by offering British Airways $3 million in funding over two years (Belko 2019), New Orleans waived landing fees for British Airways (Buchanan 2016), and so forth. Cities in Ohio were unable to attract international airlines (Glaser 2018), even trying to kickstart local airlines that would serve international locations (Teasley 2018). Globally, Greece launched a fee waiver program to attract international routes during the winter season (Greek Travel Pages Editing Team 2018).

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