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Technology adoption and innovation: The establishment of airmail and aviation innovation in the United States, 1918–1935

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Abstract

Research Summary: This article explores how technology adoption can shape innovative activity. We study this issue within the historical context of the introduction and expansion of airmail across the United States between 1918 and 1935 using archival material and a novel dataset of early 20th century patents. A joint qualitative and quantitative investigation indicates that local individual and corporate actors applied diverse pools of knowledge and intensified their work with aviation innovations following airmail entry into their county. Moreover, we find evidence that the co-location of aircraft manufacturing and airmail operations was associated with more corporate innovations that facilitated economies of scale and corresponded to increased technological diversification of firms' aviation patent portfolios. Ultimately, this paper deepens our understanding of the antecedents, consequences, and organizational processes that underpin innovation.

Managerial Summary: This research investigates how aviation innovation in the United States was influenced by the postal service's early 20th century introduction and expansion of airmail routes. Our results indicate that

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counties with an airmail route experienced increased aviation-related patenting by individual and corporate inventors relative to similar counties that did not receive an airmail route. Moreover, we find that corporate inventors working in airmail counties that also contained aircraft manufacturers were particularly active in technological areas that enhanced aircraft economies of scale and patented in a wider range of aviation-related domains. An implication of this work for managers and policymakers is that early access to nascent technology can be a driver of local innovation and that spillovers can benefit diverse economic actors working in close proximity.

KEYWORDS

aviation industry, business and economic history, geography of innovation, industry formation, local innovation, patent portfolios, technology adoption, technology strategy

1 | INTRODUCTION

Understanding antecedents of innovation is an important topic for strategy scholars, managers, and policymakers because of the pivotal role that new technology and innovation play in economic growth (Jaffe, 1989; Romer, 1990; Solow, 1957; Stuart, 2000). Prior work has emphasized how differences in economic and technological environments can set different geographic regions on different trajectories of innovation (Audretsch & Feldman, 1996; Frost, 2001; Phene et al., 2006). Related research has examined how geographic variation in policies, institutions, and infrastructure has influenced innovative output in those regions (e.g., Agrawal et al., 2017; Conti, 2014; Joshi & Nerkar, 2011; Vakili & Zhang, 2018). Accordingly, we know that the course of technological innovation can be shaped by a variety of localized factors.

One important yet under-investigated topic is how geographic variation in the arrival of new technologies can affect the subsequent rate and direction of innovation in a region. Local differences in the arrival of new technologies are especially salient for emerging industries. While the arrival of new technologies in a region may be an outcome of ongoing R&D or superior absorptive capability, regional policymakers also view the adoption of new technologies as a means to trigger and support innovative activity. For example, policymakers in Arizona and Nevada recently implemented early testing and commercial operation of autonomous driving technology in real-world settings with the clear intention to "create an environment that supports autonomous vehicle innovation" (Office of the Arizona Governor, 2018). These initiatives seek to establish those states as innovation hubs, even though they were not necessarily the pioneers of autonomous driving technology.

Despite the optimism of policymakers and practitioners, whether and how the arrival of new technologies can provide opportunities and incentives for local innovation is an open question, and it remains an important issue for strategy scholars. We aim to contribute to the broader body of scholarship on strategic management and technology adoption by addressing the following overarching questions: Does the arrival of new technologies in a region affect subsequent innovative activity in that region? How do different types of local economic actors respond to technology adoption? What drives inventors to work in certain technological domains? How do these responses contribute to changes in innovation and the evolution of industries?

To address these questions, we investigate how the introduction of airmail routes influenced aviation innovations in the United States during the early 20th century. Aircraft technology was still nascent when airmail was first introduced between New York City and Washington, DC in 1918. These services provided ample opportunity for both operational and technological improvements, and the subsequent privatization of the new airmail routes also brought financial incentives for innovators in the civil sector. The introduction of airmail routes was staggered geographically and over time, with the initial primary goal of the United States Post Office Department (USPOD) being the establishment of the transcontinental route between New York City and San Francisco as quickly as possible. Accordingly, this empirical setting also provides us with useful sources of temporal and geographic variation that can help us better examine the relationship between the arrival of a new technology and subsequent innovation.

We begin by examining the historical record around the establishment of USPOD airmail delivery and innovation in the early aviation industry. This type of historical case approach provides a foundation for understanding important contextual issues [see Argyres et al. (2020) and Kahl et al. (2012)], which then allows us to develop more general insights for strategic management theory (e.g., Agarwal et al., 2020; Holbrook et al., 2000; Park et al., 2021; Silverman & Ingram, 2017). In our case, abductively linking our theoretical development with a detailed qualitative analysis of archival material underscores how the adoption of airmail provided local individual and corporate inventors opportunities for innovation, in particular, through end-user learning and the co-location of upstream and downstream value chain actors. We use this foundation to then quantitatively estimate the impact of airmail entry on local aviation patenting output between 1918 and 1935.

Our primary quantitative analysis suggests that airmail entry into a county was associated with a substantial increase in subsequent aviation innovation in that county. Estimates indicate that aviation-related patents approximately doubled in airmail-treated counties. Our follow-on analyses suggest that both corporate and individual inventors produced more aviation patents after the establishment of an airmail route in a county. The increase in aviation patenting was not limited to airmail locations with aircraft manufacturing companies, which implies that the increase in patenting was partially driven by inventors who independently exploited the emergence of technological opportunities from new technology adoption. While the increase in local individual patenting was broad-based and reflected inventors' awareness of opportunities to innovate in this emerging technological domain, the increase in corporate patenting exhibited a pattern that corroborates our qualitative findings: Airmail locations with aircraft manufacturing companies had a notable increase in patenting output in aviation domains where economies of scale play an important role. Making progress in these domains was a primary determinant of operational profit for airmail companies. Hence, the emerging downstream airmail market seems to have provided specific opportunities for local corporate inventors, which indicates that commercial applications were important in shaping the trajectory of innovation. These results ultimately indicate that airmail shaped the locus of aviation innovation in the United States during the early 20th century, and it also shaped the aviation industry by leading both individual and corporate inventors to engage with aviation technology in novel ways.

Our study contributes to the existing literature in several ways. First, we add to the sparse theoretical and empirical work on the role of technological opportunity in facilitating local or regional innovation, as highlighted by Cohen (2010, pp. 172–181). Second, we shed light on consequences of technology diffusion [see Comin and Hobijn (2010)] and how the different orientations of local economic actors may yield differences in subsequent focus [see Breschi and Lissoni (2001)]. Among other things, this highlights how the co-location of different types of actors at an industry's inception can shape the trajectory of innovative activity (Agarwal et al., 2017). Third, using historical texts, we produce a detailed case study of innovation in the early aviation industry as it relates to airmail, which builds on recent scholarship about the birth and development of the aviation and airline industries (e.g., Bryan, 2016; Goldfarb et al., 2017; Hanlon & Jaworski, 2019; Hiatt et al., 2018). Our extensive review of primary sources informs our analyses and provides context for the specificities of innovation in our empirical setting, which allows us to disentangle the trajectories of technical advances in different regions. For strategists in particular, deepening our understanding of the consequences of technology adoption helps to underscore how new opportunities may arise from changes in local conditions (Arthur, 1989; Bresnahan et al., 2001; Cohen, 2010; Katz & Shapiro, 1986), and our work offers rich insights for researchers, policymakers, and managers seeking to understand the strategic consequences of technology adoption in different settings. Finally, we make our data available to other scholars interested in building on this work.

2 | TECHNOLOGY ADOPTION AND LOCAL INNOVATIVE ACTIVITY

Understanding the sources of geographic variation in technological innovation is an important topic in the strategic management literature. A major strand of this research has studied how different institutions in close geographic proximity, such as industry, academia, government, and consumers, influence the cost and productivity of technological R&D (e.g., Etzkowitz & Leydesdorff, 2000; Malerba, 2002; Nelson, 1993; von Hippel, 2006). Although prior work has acknowledged the role of upstream R&D in shaping technological opportunity in a region, examining "local histories" of downstream technology use and adoption appears to constitute a fruitful avenue of research (Adams et al., 2015; Gross, 2018; Roy & Cohen, 2017), as there are often marked geographic differences due to regional variance in the benefits and costs of innovation (Griliches, 1957).

In many industries, innovative activities around a technological product precede the emergence of a consumer market. New technological industries can develop over a considerable amount of time in the incubation stage, the period between a technological breakthrough and its initial commercialization (Moeen & Agarwal, 2017), while an industry's downstream value chain begins to develop. As the geographic rollout unfolds gradually over time (Comin & Hobijn, 2010), regions that adopt technologies relatively early may find that proximity to an emerging technology intensifies their innovative activities. Building on the existing literature, we highlight several plausible mechanisms through which geographic proximity to a new technology can affect the trajectory of innovation: (1) local end-user experience, (2) emergence of local value chains, and (3) local perception of entrepreneurial opportunities.

One mechanism is user experience and learning at the site of technology adoption. Prior literature has pointed out that users are repositories of tacit knowledge and experience that may be crucial in identifying and addressing important technological bottlenecks (Chatterji & Fabrizio, 2012, 2014; Rosenberg, 1982; Tyre & Orlikowski, 1994; von Hippel, 1988). Problem-solving inventors need frequent technological feedback, which is easily transferred between various types of end-users and economic actors that are in close physical proximity owing to the "sticky" and tacit nature of user-identified information. These broader ideas about contact and knowledge transfers underlie much of the research on the localized nature of economic spill-overs, such as that by Marshall (1920), Jacobs (1969), Glaeser et al. (1992), and others.

This technological-feedback mechanism may be particularly salient in nascent technological industries where select groups of users gain early access to technology. Although locational advantages can eventually dissipate with time as inventors elsewhere invest in "unsticking" the same types of information (von Hippel, 1994), knowledge diffusion and codification may remain relatively limited during early phases of industry development. In situations where downstream use of an emerging technology is geographically constrained, local tinkerers can advance technological frontiers through hands-on experiments and learning-by-doing. Such tinkerers provide a supply of techniques and ideas to modify and improve important macroinventions, creating a feedback loop that reinforces growth of epistemic knowledge behind corresponding technologies (Mokyr, 1992, 2011).

Developments related to the Internet provide anecdotal evidence that early exposure to an important macroinvention can affect the local supply of user innovations. In 1985, the University of Illinois Urbana Champaign (UIUC) was selected as one of the universities to host the National Science Foundation's Supercomputer Centers. The National Center for Supercomputing Applications (NCSA) allowed UIUC researchers to gain early exposure to the emerging World Wide Web. This led to the invention of Mosaic, the first user-friendly graphical Internet browser software that helped popularize the web and engendered applications in various domains (McEnery, 1995; Ricart, 1994). Although the establishment of NCSA was facilitated by government funding, this example suggests that early adoption and exposure to technology can stimulate local user innovation that goes beyond the intended scope of funding.

Another mechanism that contributes to an increase in innovation is the emergence of an industry value chain and profit incentives at the site of technology adoption. This happens when technology adoption does not simply mean the beta-testing of a product, but also the emergence of a business opportunity to create and capture value from the product. Industry participants in the downstream market may want to invest in profit-increasing innovation by directly entering into upstream R&D or collaborating with other innovators to solve their business-specific needs. When upstream R&D and downstream operations are located in close proximity to each other, diverse participants in the technology value chain can more easily identify commercial opportunities and communicate about them. This geographic co-location of the value chain may help inventors to tap into diverse and complementary resources and knowledge to take advantage of such opportunities (Cohen & Malerba, 2001).

Finally, local technology adoption raises awareness of and interest in the new technology among potential innovators and entrepreneurs, even those who were not initially involved with creating or using the focal technology. Inventors working in other technological domains may recognize new ideas and try to exploit perceived market demand by combining ideas from the new technology with an existing technology (Fleming, 2001). When active users and business opportunities related to the new technology are nearby, potential innovators can be more certain that necessary resources will be available should they decide to engage in commercialization or entrepreneurship (Stuart & Sorenson, 2003). Innovators may also include intrinsically motivated tinkerers with less clearly defined economic objectives. Those who are inspired by the possibility of leveraging their existing knowledge and capabilities to advance an emerging technology may intensify their existing efforts to innovate in this new space, which could be facilitated by more frequent interaction with the focal technology. A strategic implication of localized technology adoption, therefore, may be that it shapes not only the type of innovation that occurs, but also who innovates.

When technology adoption occurs in a region, the mechanisms outlined above can trigger a self-reinforcing concentration of innovative activity that leads to industry specialization or cluster formation at the regional level (Baptista, 2000). However, the impact of technology adoption on the specialization of economic actors within these locations is more nuanced. On one hand, the concentration of innovative activity in a region may enable the division of innovative labor among local industry participants, resulting in greater technological specialization of firms (Marshall, 1920; Scott, 1988). Alternatively, co-location of innovative activities may instead provide incentives for technological diversification. Especially when new technologies are involved, effective problem-solving requires shared knowledge and overlapping processes between industry participants rather than clear-cut boundaries (Iansiti & Clark, 1994; Takeishi, 2002). A focal firm, which holds key architectural knowledge, may coordinate and integrate different types of specialized knowledge gained from user learning and experimentation. Geographical proximity facilitates these coordination processes. Thus, firms at the site of technology adoption may be at an advantage to access and integrate more diverse pools of knowledge because of their co-location with a technology's downstream use, and corporate technological diversification can arise in response to this advantage.

These theoretical underpinnings highlight the mechanisms through which the arrival of a new technology can influence the trajectory and locus of innovation. Moreover, it suggests that different types of economic actors may react to aspects of local innovative opportunity in different ways and that heterogeneity in local industry conditions will shape their responses. In practice, other factors in a given context may enable or constrain inventors. A deep appreciation for the specificities of an empirical context is, therefore, needed to provide critical insight into the potential responses of local actors. In the following section, we address these factors by situating our study of technology adoption in the historical context of aviation and the establishment of airmail in the United States.

3 | BACKGROUND: AVIATION INNOVATION AND AIRMAIL

3.1 | Technological progress in early 20th century aviation

Aircraft and aviation technology evolved rapidly during the years between the World Wars (Bednarek & Launius, 2003). Government initiatives such as funding for R&D facilities and the dissemination of international research findings were designed to encourage progress in aviation, while the patent pool developed by the U.S. Manufacturers' Aircraft Association was intended to overcome competitive intellectual property obstacles that could limit innovation (Mowery, 2015). Accordingly, aircraft development progressed quickly in the years immediately following World War I, with dozens of firms producing hundreds of models and prototypes over the next two decades, but no dominant design emerged until the late 1930s (Tushman & Murmann, 1998).

During the interwar period, aviation companies led by ambitious adventurers, engineers, and entrepreneurs sprang up across the United States. These firms sought to push the envelope of powered flight, anticipating that this nascent market would create long-term opportunities. Early aircraft innovation was geographically dispersed, as were the locations of the major manufacturers (see Appendix Figure A.1 in S1). Firms such as Boeing, Curtiss, Ford, Douglass, Lockheed, Pratt & Whitney, Robertson, Ryan, Sikorsky, Sperry, Stearman, Vought, and Wright were all significant players in the early industry that found themselves at times competing and at times cooperating as the industry developed. Many of these early aircraft manufacturers would go on to merge and continue to play a major role in aviation throughout the 20th century.

The rapid advances that occurred in the early 20th century can be exemplified by contrasting the Curtiss JN-4 with the Douglas DC-3. First produced in 1915, the Curtiss JN-4 was a single-engine plane with 90 horsepower and two seats. It was a simply constructed biplane made of wood and fabric (Johnson et al., 2015). By 1935, however, the new metal-constructed DC-3 had two engines producing 1000 horsepower each; it reached speeds of over 200 miles per hour and regularly crossed the United States in just 16 h. The DC-3 could transport up to 21 passengers as well as other cargo, such as mail (Howe, 1946). The DC-3 was particularly significant in the history of aviation because it was the first aircraft to make commercial passenger traffic economically feasible and became the first dominant aircraft design (Tushman & Murmann, 1998). While airlines offering passenger travel started to emerge around the world in the late 1910s (see also Hiatt et al. (2018) for a look at commercial airlines in South America, from 1919 through 1984), passenger traffic was minimal in the United States before the introduction of the DC-3.

3.2 | The establishment of airmail in the United States

On May 15, 1918, six World War I converted Curtiss JN-4s, with U.S. Army pilots at the helm, established the first permanent airmail route between New York City and Washington DC, with a stop in Philadelphia (Nielson, 1962). Although delivery was successful and the USPOD began planning to extend the routes, airmail was still considered a novel and unreliable (as well as dangerous) means of postal transportation at the time. Given the need for experienced pilots, mechanics, and managers, initial airmail routes were operated by the U.S. Army working under the direction of the USPOD.

The USPOD's initial overt priority was to quickly develop a transcontinental airmail network that could connect New York City to San Francisco. Less than 3 years after the New York–Washington route opened, the first transcontinental airmail trip was made in February 1921 (Wolfram, 2004). Postmaster General Harry S. New, who served in this capacity from 1923 to 1929, established feeder lines that branched out from the transcontinental route in order to distribute mail to different regions of the country. These feeder routes were determined by the Postmaster General, who initially contracted out their services to civilian carriers, which acquired their planes from the retired airmail fleet or ordered them from Curtiss, Douglas, de Havilland, or another early aircraft manufacturer.

Some operational control moved away from the USPOD and into the private sector in 1925 when the U.S. Congress passed the Kelly Act, which awarded government mail contracts to private carriers through competitive bidding. For example, Ford Air Transport, a subsidiary of Ford Motor Company, began transporting mail on commercial Contract Air Mail (CAM) routes between Detroit and Chicago and between Detroit and Cleveland on February 15, 1926 (Kane & Vose, 1978, pp. 26–27; Lawrence, 2004, pp. 83–85). As piloting was still a very new career field, many of the pilots hired by these newly formed private carriers had gained their initial flight experience while in the military, and some had even previously been assigned to fly airmail routes when it was still under operational control of the U.S. Army.

Though the government sought to make sure "monies were spent supporting a few financially sound companies that could expand" the aviation industry, there was still significant variance in the characteristics of the CAM routes (Van der Linden, 2002, p. xi). The existence of aircraft technology in a region was not necessarily a prerequisite for the opening of a route there, nor did it

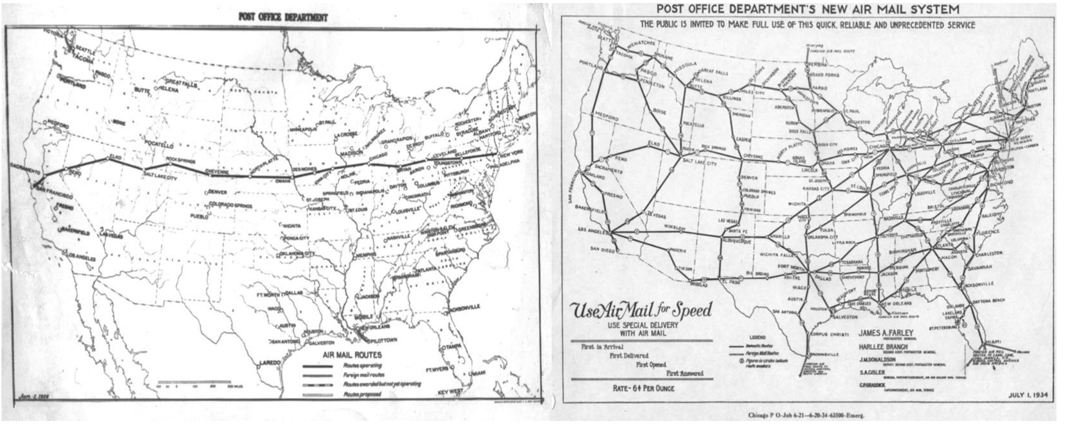

FIGURE 1 United States Post Office Department Airmail route maps. The map on the left depicts the United States transcontinental airmail route from a map dated January 1, 1926 (route originally established in 1920 with regular night service beginning in 1924). The map on the right depicts airmail routes of the United States as of July 1, 1934. The maps have been color adjusted for ease of presentation, and are taken from the United States Postal Service's collection.

affect the selection of firms that were awarded contracts to fly airmail when CAMs were introduced. A few early aircraft manufacturers were born at the airmail hub locations, and some established firms, such as Boeing and Ford, intentionally entered into airmail delivery.[1] However, many of the "well known aircraft manufacturers themselves doubted the advisability of [initially] embarking upon a regular air mail service" (Smithsonian Air & Space Magazine, 2008). As a result, many winning bidders, such as Vern Gorst (founder of Pacific Air Transport) or Harris Hanshue (founder of Western Airlines), were not even in the aviation industry before bidding on an airmail route (Van der Linden, 2002, p. 25).[2] Between 1925 and 1929, 34 permanent CAM routes were established and operated by a variety of firms, and the airmail network included 39 distinct routes by 1933. The two USPOD airmail route maps in Figure 1 show the extent of this expansion across the United States.

4 | PATHWAYS TO INNOVATION ALONG AIRMAIL ROUTES: QUALITATIVE INVESTIGATION

The expansion of airmail delivery over time and place, with 39 routes established over the first 14 years of operation, led to many opportunities for different actors to engage with the new technology. Several historians have emphasized that the interwar aviation industry was built and developed around airmail (Rosenberg & Macaulay, 2006; Van der Linden, 2002). In this vein, we direct our examination of historical records toward developing an understanding of

[1]Other issues only became apparent after the process was underway. For example, Colorado Airways was created to serve CAM routes; however, when it became clear that it had colluded to try and win the airmail contract its bid was terminated and the contract was given instead to Western Air Express (Van der Linden, 2002, p. 25).

[2]Some of the early contractors for these CAM routes would ultimately turn into the major mid-century commercial airlines. For example, American Airways was born as a merger between of Colonial Air Transport and Robertson Aircraft Corporation, which operated CAM Route 1 and 2, respectively. Western Air Express of the CAM Route 4 and Pitcairn Aviation of the CAM Route 19, later became parts of Transcontinental & Western Air and Eastern Air Lines, respectively.

how different inventors responded to airmail entry and what resulted from their responses. As part of our abductive approach, this qualitative work forms a foundation from which we develop quantitative analyses in Section 5.

4.1 | Technology adoption and local end-user experience

When airmail was introduced, aircraft and supporting technologies were still quite primitive, and individuals often had to serve in multiple capacities as navigators, radio operators, and repair mechanics as they sought to work out aviation-related bugs. Indeed, the emergence of airmail operations seems to have also raised the general awareness and interest of other amateur inventors working in close geographic proximity. In our review of historical records, we observe many instances in which the opening of airmail routes into areas was followed by a surge of first-time aviation patenting by inventors in those areas. Many of the new inventions had no clear links with their inventors' prior patenting history,[3] which suggests that the effect of airmail and exposure to aircraft technology was to inspire these tinkerers to venture into aviation-related domains.

As already noted, many of the airmail aviation pioneers were current or former military pilots with considerable flying experience.[4] They were able to transfer their prior experiences directly to resolving technical challenges in early civil aviation. Soon, with the establishment of a wide-ranging airmail aviation network, military-pilots-turned-airmail-pilots became primary user-innovators. In our investigation of inventor data, we found examples of multiple local airmail pilots with records of aviation innovations.[5] Their innovations largely reflected their

[3]For example, examining the opening of airmail routes in a number of cities in 1926, we observe that airmail entry was followed by a surge of first-time aviation patenting by inventor-tinkerers in those localities. Anton Nosan was a carpenter in Cleveland, OH, who had invented a saw sharpening machine (US1599674A) in 1925; then, in 1926, Nosan filed eight aviation-related patents, including patents for an aircraft air purifier (US1637873A), a fuselage wall construction (US1637871A), and an altitude gauge (US1640051A). Similarly, Cloice B. Hull of Cleveland filed two aircraft patents (US1641760A and US1769180A) in 1926, having worked on electric lamps (US674770A) and soldering solutions (US1568669A) in the years before the entry of airmail. John B. Herget of Seattle, Washington, who patented a railway dump-car in 1916 (US1249624A), patented an aircraft flight control-related patent (US1721818A) in 1926.

[4]Two of the most prolific individual aviation inventors in our dataset, Colonels Carl Joseph Crane and William Charles Ocker, were U.S. Army officers who received training from the military flying school and served as pilots. As military pilots, they became deeply interested in the hazard of flying into clouds and the limitations of human sensory system in giving the pilot all the necessary information for safe navigation. Their subsequent research led to inventions of key instruments and navigational devices, such as a "testing and training device for aviators" (US1715304A), a "fog training device for airplanes" (US1882087A) and an "aerial flight instrument" (US1955488A). Another example is Hazen C. Pratt of Cambridge, Massachusetts, a U.S. Marine Corps lieutenant, who in 1922 applied for an "Airplane Landing Mechanism" (US1499472A). This patent directly reflects the needs of military pilots "to overcome the aforesaid disadvantages and to provide a landing mechanism which will quickly and safely stop aircraft within a restricted space and which can be controlled by the aircraft operator, or pilot, with facility and certainty."

[5]For example, after Army flight instructor Dean Smith became an airmail pilot in 1920, he patented inventions related to electronic instruments (US1552513A). Frank J. Andre of College Park, Georgia, while serving as an airmail pilot between Atlanta and Macon (Monthly Weather Review, 1930, p. 118), filed a patent for aircraft landing devices (US1998429A) in 1933. Silas Amos Morehouse, after serving in the Marine Corps and then the Army, became the Chief Pilot for Western Air Express (which would later become part of TWA). During his career as a civilian air pilot, he patented numerous inventions, including a windshield cleaner for airplanes (US1902254A), a control system (US2100059A), and an oxygen mask (US2344718A). Accordingly, individual pilots without military experience could also now become inventors thanks to the opportunities afforded by airmail. Civilian pilot Harry Atwood, an electrical engineering graduate of MIT, went on to become the first pilot to deliver airmail in New England after learning to fly at the Wright Brothers' Flying School and held multiple patents, including one for wing structures (US2020759A).

individual end-user experiences and problem-solving needs, such as safety- and maintenance-related devices, or navigation- and flight control-related technology.

Learning from user experience also led to more organized corporate efforts to resolve technological bottlenecks that became salient as a result of frequent operation. Low-visibility and bad weather conditions made airmail delivery particularly dangerous since pilots navigated predominantly by sight and often followed railroad tracks to stay on course (Lawrence, 2004, pp. 73–75, Lehrer, 2014). While air-to-ground radio transmission was a feature of early airplanes, it was easily affected by engine noise and other interference and required a wireless telegraph operator on flights. Since this was not an option for single-crew mail planes, airline companies quickly saw a need for a reliable and efficient ground-to-air communication to report weather changes to their pilots flying different airmail routes. When Boeing started airmail operations in 1927, founder William Boeing sought to address this issue by hiring Thorpe Hiscock, who was his brother-in-law and also an avid radio enthusiast, as the communications engineer for Boeing Air Transport. After numerous attempts, they succeeded in developing a radio system that was capable of overcoming interference from an airplane's ignition system and metal parts, thus allowing their aircraft to be actively supported by ground-to-air communication. This technology was first applied to Boeing's Model 40B-4 plane and eventually was adopted by the entire air transportation industry (Graff, 2008).

4.2 | New technology and the emergence of local value chains

As was the case with individual actors, historical records also provide evidence that airmail stimulated corporate actors to re-organize their innovative activities around airmail routes. Indeed, airmail was the core business opportunity for most aviation companies during the early part of the interwar period, and the commercial aviation industry emerged directly from the USPOD's establishment and expansion of airmail routes (Van der Linden, 2002). Since the airmail contracts became designed to be paid by weight and volume, corporate actors had a strong incentive to reduce flight costs by flying larger planes that could carry more cargo.[6] A series of mergers in the late 1920s resulted in the birth of several vertically integrated firms that combined air transport, airframe manufacture, and engine production, which contributed to aviation innovations and operational cost reductions (Mowery & Rosenberg, 1981).

Boeing provides an illustrative example of how airmail contracts more generally influenced and structured corporate innovation around airmail routes. In 1927, Boeing won the airmail contract for Chicago and San Francisco because, as a vertically integrated company that manufactured its own planes, Boeing was able to take advantage of its own cutting-edge engine technology. Its lower bid was based on the performance of a brand-new Boeing plane, the Model 40A, that had a bigger fuselage and lighter air-cooled radial Wasp engine built by Pratt and Whitney. Thanks to its technological superiority, Boeing's new airmail business was a

[6]Such discussions can be found in a wide range of historical records, including within the broader discourse about developments in aviation during our period of investigation. For example: "Speed is not the only objective in modern aviation. Efficiency in the form of the greatest possible commercial pay load for a given horsepower is much sought after by designers and constructors" (Klemin, 1925); "[W]orld competition for both military and commercial aircraft has compelled engine and aircraft engineers and metallurgists to study the weight problem in minute detail and all its phases and effects, so that maximum efficiency in the comprehensive sense of the term may be obtained" (Barlow, 1929); "To make the aeroplane more useful as a commercial [air]craft, both dead weight and atmospheric resistance must be reduced, the former in the interests of a greater "pay-load" and the latter for greater speed and economy in fuel" (Newest Aeroplanes, 1932, p. 45).

success and allowed the company to then acquire Pacific Air Transport, which operated the Seattle to Los Angeles route. Soon after winning the contract, Boeing began actively patenting innovations that focused on the efficiency, capacity, and safety of its planes.[7] Prior to its entry into the airmail business in 1927, Boeing had filed for a relatively small number of patents. The number of its patent applications increased substantially from 1927 onward.

This example from Boeing suggests that airmail had a generally positive effect on innovation by firms beyond just spillovers from co-location. Co-location, nevertheless, appears to have led to relatively greater intensity in innovative output. Indeed, evidence suggests that airmail-induced collaboration between the upstream and downstream businesses in the same geographic region had effects on innovation similar to those of vertical integration. For example, our review of historical records suggests this was the case for Douglas Aircraft Company of Santa Monica, California, and Transcontinental & Western Air (TWA), which operated the New York-Los Angeles CAM route. Douglas Aircraft's DC-1, the first twin-engine transport airplane, was built in 1933 in close collaboration with TWA, which needed an all-metal aircraft for its flight operations after the 1931 crash of a wooden TWA airliner (Inside the Douglas Transport, 1934). Their interdependent relationship is well captured in a statement that said TWA "helped the Douglas Aircraft Company define the DC-1, the airplane that helped to pioneer comfortable and profitable passenger service" (Boeing, 1999).

4.3 | Local perception of entrepreneurial opportunity surrounding the new technology

Our qualitative investigation into patent records suggests that many companies identified the introduction of airmail as an opportunity to exploit their existing capabilities and expand their businesses into new domains. There were many examples of horizontal diversification in which nonaviation companies entered into aircraft and aviation-related patenting after the Kelly Act of 1925. That is, after the commercial opportunities provided by airmail became apparent. Many automobile parts companies developed and supplied aircraft components such as tires, wheels, and airframes. Examples include B.F. Goodrich (tires), Budd Manufacturing (an automobile body maker that developed aircraft wheels and stainless-steel wing ribs), and Bendix-Eclipse (a brakes company that developed aircraft hydraulic systems and aviation instruments).

We also find evidence of a wide range of companies who applied their expertise in mechanical components and furnishings to the context of aviation. In Chicago, for example, many engineering companies filed for their first aircraft-related patents shortly after the opening of an airmail route into the city.[8] National Pneumatic Corporation of Chicago had been patenting

[7]Examples of efficiency patents include an "adjustable airplane strut terminal" (US1695611A) and "retractable landing gear for geared propeller airplanes" (US2030293A). Capacity patents include a "convertible seat and berth arrangement" invention (US2250193A), and safety patents include "airplane emergency flotation gear" (US1733973A) and a fire prevention and "extinguishing system for aircraft" (US2015995A).

[8]The same pattern can be found in many other airmail locations as well, especially areas with a high concentration of manufacturing such as Detroit and Cleveland. For example, Mechanical Rubber Company of Detroit, which held patents in hoses, tank valves, and rubber varnish as early as 1906, patented its first aircraft-related invention, devices made of vulcanized rubber for use in airplanes to cushion shocks (US1871390A) in 1928. Cleveland Pneumatic Tool Company, founded in 1894, also patented its first aircraft-related invention, a "shock absorber for landing gears for aeroplanes" (US1759674A), in 1926. Automatic Sprinkler Corporation of Cleveland, which had patented sprinklers and fire extinguishers, filed for its first aircraft-relevant patent in 1929: a dry pipe sprinkler system for use in airplane hangars (US1826072A).

pneumatic streetcar and railcar doors, seats, and signals as early as 1907, and in 1928 the company patented a "door-locking equipment for cabin-type aircraft" (US1701491A), which directly transferred its expertise in pneumatic train car doors to aircraft. Associated Electric Lab Inc., which had patented an automatic telephone system and a remote control system as early as 1917, patented an "airport control and signaling system" (US2028722A) in 1929.[9] All of these companies directly transferred the engineering capabilities used to develop products for their main markets to the aircraft market shortly after the opening of the airmail routes. This body of evidence suggests that the locus and trajectory of aviation innovation were affected by local corporate actors' responses to airmail entry.

Similarly, historical records indicate that individual inventors also quickly recognized the profit potential of the new technology. Indeed, we identify a number of cases in which individual inventors with prior experience in nonaviation fields applied their expertise in the context of aviation after the entry of airmail into their home counties. Christopher C. Holmes of Pasadena, California, who had patented a "signal apparatus for autovehicles" (US1128250A) in 1914, patented a "message carrying signal apparatus for airplanes" (US2013729A) in 1933. Elmer Johnson of Washington, DC, who patented a powder-dusting machine (US1282697A) in 1918, later patented an airplane powder-dusting apparatus (US1703308A) in 1926. These examples indicate that both the observation of and access to new technologies may reorient economic actors toward an understanding of how their business activities could have applications in other fields (Cattani et al., 2018).

5 | STATISTICAL ANALYSES

5.1 | Extending our qualitative findings to a quantitative investigation

Our historical investigation suggests that local economic actors responded to the introduction of airmail in ways that ultimately affected the local trajectory of aviation innovation. As a baseline, we posit that there exists a positive relationship between the entry of airmail in a location and subsequent local aviation-related innovations. The qualitative analyses indicated that a variety of economic actors, working in different domains, contributed to the increase in aviation-related innovation. Since the archival material suggests that the entry of airmail affected innovative output through different mechanisms, we follow an abductive approach in exploring various plausible explanations for observed effects [see also Behfar and Okhuysen (2018) and King et al. (2021)]. Thus, our quantitative analyses are a corroborative exercise that helps us better understand core issues and offer a detailed account of airmail's effect on local innovation. In the following sections, we conduct a series of statistical analyses to assess the effects of airmail entry on subsequent innovation in a given area, which economic actors were driving any such effects, and how heterogeneity in local conditions influenced the trajectory of innovation.

[9]This pattern can be found in many different industries. Pyle National Co, which had patented valve gears, steam turbines, and locomotive lights since 1916, patented a "landing light for airplanes and the like" (US1799285A) in 1929. Lewis Differential Company, a brakes company in business as early as 1915, patented its first aircraft-related patent, a "steering and braking device" (US1814576A), in 1929. Vapor Car Heating Company, a train car heating company with its first patent in 1916, patented "a heating system particularly adapted for use on aeroplanes" (US2103835A).

5.2 | Statistical method

The main goal of our statistical analyses is to assess the treatment effect of the establishment of an airmail route on subsequent aviation innovations within a county, as measured by counts of patents. Our identification strategy is based on the conditional independence assumption that, given the set of observable covariates, the opening of airmail routes is an independent or quasi-random assignment to the outcome of interest. As we detailed in Section 3, our examination of historical records suggests that the primary goal of the USPOD was to establish timely transcontinental mail delivery, not to aid pre-existing aircraft manufacturing locations.[10] To help address concerns about route locations being correlated with potential determinants of innovation, such as the size of local population and economy, we use propensity score matching to match the airmail-treated counties to comparable control counties.[11] We use the following set of observables for this matching: (1) A county's logged population and (2) manufacturing establishments in the year 1920 (obtained from the 1920 Decennial Census), (3) a county's aircraft patents and (4) non-aircraft patents filed between 1900 and 1917 (which is the year before the introduction of airmail), (5) the presence of an aircraft manufacturer in a county before the treatment, (6) the presence of an Army air base in a county, (7) a county's logged count of automobile and railroad mechanics, and (8) a county's logged count of aircraft engineers[12] for the year 1920.

The following estimating equation relates patent output y of county i in year t to the treatment effect of airmail route opening:

$$E[y_{it}|X_{it}] = exp\left[\beta_1 Post\text{-}Airmail_{it} + \beta_2 ln(population)_{it} + \gamma_t + \lambda_i\right] \quad (1)$$

Our coefficient of interest β_1 estimates the treatment effect of airmail route entry. The county fixed effects λ_i control for many time-invariant characteristics that might affect a county's propensity to patent, including education, experience, financial capital, legal access, and engineering knowledge. The calendar year effects γ_t control for the growth of the aviation industry over time and other macro-economic events that might affect all counties in a given year. We estimate all regressions using control weights generated from matched counties in a given year (Dehejia & Wahba, 2002; Rosenbaum & Rubin, 1983), and we also include the log of population at the county-year level to help control for other confounding factors that may change at the county level over time.[13]

[10]In Supporting Information Appendix Table B.1, we quantitatively investigate whether the pre-existence of aircraft technology determined the selection of airmail routes. We ran a series of logit models to predict airmail entry into a county, and included several geography-specific explanatory variables, such as the number of early aircraft patents in a county (pre-1918). Overall, the strong effect of Army air bases and mechanics relative to aircraft-technology-related variables further corroborates the qualitative historical evidence: The USPOD's goal was to deliver mail across the entire country as quickly and efficiently as possible, and the best way to do this was to connect transportation hubs that ran along the central corridor of the United States.

[11]We used the PSMATCH2 propensity score matching module in Stata to match samples using the nearest four neighbors. Since propensity score matching fails to achieve covariate balance in the presence of outliers (and note that some of the treated counties are exceptionally large population centers such as New York City), we truncated the sample by using population cut-offs prior to matching. Appendix B in Supporting Information provides robustness tests using different cut-offs.

[12]Census Occupation Code 002 (airplane pilots and navigators) and 545 (airplane-mechanics and repairmen).

[13]These county-level estimated populations are interpolated annual values taken from Fishback et al. (2011) and provide the best time-varying county-level demographic control for which we could find reliable data.

5.3 | Dataset and variable construction

We built our dataset by linking geographic information about the establishment of airmail routes with novel historical data about U.S. patents between 1915 and 1935.[14] We obtained the information on airmail routes from David (1934) and from annual reports to Congress by the U.-S. Postmaster General (1910–1935). To incorporate local patenting information, we combined data that we collected from historical patent information available from the U.S. Patent and Trademark Office (USPTO) together with data from the Google patent database. In linking these sources together, we constructed a dataset that contains information about all USPTO patents granted between 1900 and 1940. We then used patent PDFs from the USPTO to collect location information about these patents. We used the Google patent database to supplement the USPTO data with the following information: Inventor name, assignee name, filing date, grant date, cooperative patent class, international patent class, U.S. patent class. Inventor information was obtained from the patent text and we then engaged in a fuzzy-matching procedure (because of tainted text and typos) to link each patent to a geographic location using a U.S. address database. We derive the following variables from our dataset.

5.3.1 | Dependent variables

Our primary dependent variable, *Aviation Patents*, is the number of aviation patent filings at the county-year level for granted patents. We assigned patents to the aviation category if the words "aviation" or "aircraft" (including related words and variations that were common in the era, such as "aeroplane," or "flying-machine") appeared in the title or main text of the patent, or if the patent was classified as aircraft and aviation related by the patent office [i.-e., assigned to International and Cooperative Patent Class (IPC/CPC) B64, B21D 53/92 or U.S. Patent Class (USPC) 244].

We distinguish between *Individual Aviation Patents* and *Corporate Aviation Patents* using assignee information. We define unassigned patents and individual-assigned patents to be individual patents, whereas patents assigned to a firm are defined as corporate patents. Although it may be the case that not all corporate-assigned patents resulted from the work of corporate inventors because corporate entities may have bought independent inventions before the patent grant, our use of assignee data helps construct a first approximation.

In the regressions where we explore and compare different types of aircraft patents, we define the corresponding technological domain according to the nature of the patent's underlying innovation. Thus, in order to examine the impact of airmail entry on the specific content of an aviation innovation, we inductively grouped the CPC categories for aviation patents using the guidance headings and main groups of the CPC classification schemes. We coded the

[14]Although we chose patents as a pragmatic measure of innovative output, we also acknowledge that patents may only capture a portion of the innovative activity taking place in the aviation industry during that time. While many of the pioneering aviation inventors were enthusiasts with purely intrinsic or altruistic motives and did not patent, the number of aviation related patents increased sharply after the Wright brothers received their first key patent in 1906 (Meyer, 2013). Aviation patenting continued to increase during and after World War I, which helped establish an early market for airplane technology. For instance, the automatic variable-pitch propeller, one of the most important aeronautical inventions of the 1920s, was patented and licensed to the company Curtiss-Wright. Similarly, the air-cooled radial engine, another major invention of the 1920s, had its underlying technologies patented by companies such as Lawrance Aero Engine Corporation and Pratt & Whitney Company.

following 12 subareas: (1) air-flow surface, (2) alternative flying devices, (3) engine, (4) flight control and stabilization, (5) fuselages, (6) infrastructure, (7) landing gear, (8) navigation, (9) parts and materials, (10) propellers, (11) safety, and (12) wings. After we established the inductive categories, we also added text-identified patents to the relevant group (e.g., if a patent mentions "power plant" or "engine" in the patent title, it is coded as an "engine" patent).[15]

We used this patent classification information to distinguish between *Flight-focused Aviation Patents* and *Scale-focused Aviation Patents*, which map to distinct orientations of innovative activity. To measure innovative activity that is closely tied to end-user experience as discussed in Section 4.1, we identified a subset of main groups that are most likely to provide direct performance feedback to end-users as a result of pilot and support staff operations, thus reflecting flight-focused patents: navigation, safety, wings, stabilization and control components. To measure innovative activity primarily motivated by the profit incentives from local value chain co-location as discussed in Section 4.2, we group together innovations related to engines, fuselages, and landing-gear components because they were the primary scale-focused patents intended to support larger plane sizes and heavier weights; thus, they were crucial for achieving economies of scale in airmail operations. We also used these technology classifications to construct a measure of corporate technological specialization at the patent assignee level, which will be described in more detail in Section 5.4.3.

5.3.2 | Independent variables and controls

Our main independent variable, *Post-Airmail*, is an indicator variable that equals one for a county that contained any stop on an airmail route from the year when the airmail route was established. As noted in prior sections, routes were initially chosen in order to link the East and West Coasts of the United States as quickly as possible (specifically, New York City and San Francisco). Along the way, airmail stops tended to connect the largest population centers along this East–West corridor (areas with more population send and receive more mail), and the later establishment of regional feeder routes expanded the network to other cities. Therefore, we control for county population, which was correlated with both the entry of airmail route into a county (see Appendix Table B.1 in S1) and the growth of innovative output. Another independent variable, *Aircraft Mfg. Location*, is an indicator variable that equals one for a county that had one or more aircraft manufacturers in a given year identified in the annual Yearbook of Aircraft Manufacturers (which began publication in 1919) and archival searches.

The data used in our analyses reflect patents filed between 1915 and 1935, unless otherwise specified. We chose this date range because 1915 predates the creation of the first U.S. airmail route in 1918 and 1935 is the first full year of USPOD airmail reorganization by Congress, following the passage of the Airmail Act of 1934. Table 1 presents the summary statistics for the outcome variables for the treated counties and the control counties in our matched sample. In Table 2, a number of selected demographic and patent data variables illustrate the balance between the treated and the control counties on pretreatment dimensions that may be relevant to the innovative capacity of the county. As noted above, only a subset of the potential range of county-level variables were used for the propensity score matching, but this matching nevertheless helped achieve a balance for other potentially relevant economic dimensions. This result

[15]A more detailed account of the grouping procedure can be found in Supporting Information Appendix C.

gives us confidence in our matching approach, which has effectively reduced remaining differences between airmail-treated and control counties to small deviations.

5.4 | Quantitative results

5.4.1 | Main effect of airmail entry on aviation innovation

Our first set of quantitative results, presented in Table 3, is a set of fixed-effects quasi-maximum likelihood (QML) Poisson regressions estimating the effect of an airmail route on counts of aircraft patents at the county-year level.[16] Model (1) presents results for all years and all counties (treated and control) without controlling for population, and Model (2) includes a population control. In both models, the coefficient of *Post-Airmail* is positive, suggesting that the opening of an airmail route was associated with a subsequent increase in aviation-related patenting. Using the coefficient for *Post-Airmail* from Model (2) ($\beta = 0.852$; 95% CI: [0.440, 1.264]), we interpret the results to suggest that, following the entry of an airmail route into a county, there is an approximately 134%[17] increase in the number of aviation patents, on average, holding other variables constant. Model (3) replicates Model (2) but restricts the years to 1915–1930 in order to ensure that any potential confounding effects of the Great Depression and the Airmail Act of 1930, which consolidated the ownership of some airmail routes, are not driving our main results. Model (4) replicates Model (2) but restricts the sample to treated counties only. The results are consistent across all of these models. Model (5) estimates the effect of *Post-Airmail* using nonaviation patents as a placebo test, and we find no effect. In Appendix B in Supporting Information, we also provide the results from a variety of additional robustness checks. For example, we re-run the analyses presented in Table 3 on samples using different cutoffs, we use conditional fixed effects logit instead of Poisson, and we conduct our regressions using the full dataset instead of using the matched sample—these results are all in line with those reported in the main text. Ultimately, our quantitative results corroborate the qualitative findings: We observe a general positive response in local aviation innovation following the entry of airmail in an area.

Figure 2 plots the coefficient estimates from a regression in which the number of aviation patents is regressed on the interaction terms between the treatment dummy variable (the entry of an airmail route in a county) and a suite of indicator variables, each of which corresponds to the number of years before/after the treatment event. We depict the effects for 5 years before/after the airmail treatment (the years before $Year-5$ were grouped together with $Year-5$; same with $Year+7$). We again use robust standard errors that are clustered at the county level. The dashed gray lines show the 95% confidence intervals around these estimates. The graph indicates an uptick in aviation-related patenting after airmail entry, and it provides suggestive evidence that the effect is strongest around $Year+3$ after the arrival of airmail into a county.

In Table 4, we investigate the effect of airmail entry on different actors patenting in the region. Models (1), (2), and (3) examine the effect of airmail entry *Post-Airmail* on all sources of aircraft patenting, corporate-assigned patenting, and individual-assigned patenting, respectively. This set of regressions allows us to examine whether the increase in patenting is

[16] All results include both county and year fixed effects and standard errors clustered at the county level to account for potential serial correlation.

[17] $e^{0.852} - 1 = 1.34 = 134\%$.

TABLE 1 Summary statistics and pairwise correlations ($n = 2499$).

	Mean	SD	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Aviation patents	1.33	4.14	0.00	51.00								
(2) Individual aviation patents	0.85	2.89	0.00	47.00	0.854							
(3) Corporate aviation patents	0.48	2.25	0.00	33.00	0.743	0.287						
(4) Flight-focused aviation patents	0.70	2.43	0.00	34.00	0.937	0.900	0.567					
(5) Scale-focused aviation patents	0.34	1.33	0.00	16.00	0.883	0.618	0.831	0.762				
(6) Post-airmail	0.25	0.44	0.00	1.00	0.073	0.059	0.059	0.062	0.054			
(7) Aircraft Mfg. location	0.26	0.44	0.00	1.00	0.304	0.217	0.280	0.267	0.287	−0.001		
(8) Number of corporate assignees	0.21	0.71	0.00	6.00	0.775	0.471	0.822	0.674	0.747	0.070	0.320	
(9) Population	196,330.01	186,991.64	4493	1,188,382	0.408	0.257	0.422	0.355	0.382	0.214	0.397	0.472

TABLE 2 Treated and control counties' pretreatment characteristics (matched sample).

Variables	Treated	Control	Difference	T-stat (*p*-value)
Controls used in the propensity score matching				
Total population (1920)	190,578.83 (27,683.68)	147,858.16 (15,771.27)	42,720.67 (31,860.94)	1.34 (0.183)
Manufacturing establishments (1920)	542.57 (106.60)	418.11 (58.83)	124.46 (121.7)	1.02 (0.309)
Mechanics population (1920)	754.17 (116.78)	560.29 (56.92)	193.89 (129.9)	1.49 (0.138)
Aircraft engineers population (1920)	0.74 (0.38)	0.64 (0.17)	0.11 (0.42)	0.26 (0.799)
Existence of early aircraft manufacturers	0.20 (0.07)	0.32 (0.05)	−0.12 (0.09)	−1.42 (0.159)
Existence of army air base	0.31 (0.08)	0.27 (0.05)	0.04 (0.09)	0.46 (0.647)
Pre-1918 Sum of aircraft patents	9.31 (2.65)	14.79 (3.79)	−5.48 (4.63)	−1.18 (0.239)
Pre-1918 sum of non-aircraft patents	701.29 (177.71)	563.54 (81.05)	137.75 (195.3)	0.71 (0.482)
Controls not used in the matching				
Urban population (1920)	162,256.94 (27,171.90)	112,570.63 (14,727.18)	49,686.32 (30,906.34)	1.61 (0.111)
Population density (1920)	856.96 (271.94)	412.29 (92.68)	444.67 (287.3)	1.55 (0.124)
Population in schooling, 18–20 (1920)	1330.37 (201.85)	1000.22 (101.94)	330.15 (226.1)	1.46 (0.147)
Male population, 18–44 (1920)	44,602.60 (6458.28)	33,824.09 (3612.96)	10,778.51 (7400)	1.46 (0.148)
No. of manufacturing wage earners (1920)	19,221.14 (4089.87)	16,779.98 (2580.25)	2441.16 (4835)	0.50 (0.615)
Value of manufacturing output, 18–44 (1920)	1.56e+08 (3.23e+07)	1.25e+08 (2.02e+07)	3.12e+07 (3.81e+07)	0.82 (0.416)
Manufacturing value added, 18–44 (1920)	5.45e+07 (1.18e+07)	4.63e+07 (7,586,569.50)	8,175,843.50 (1.41e+07)	0.58 (0.562)
Bank deposit (1920)	69,894.34 (12,414.96)	56,864.69 (7634.44)	13,029.64 (14,574.49)	0.89 (0.373)
Polytechnic University (1920)	0.06 (0.04)	0.01 (0.01)	0.04 (0.04)	1.02 (0.308)

Note: Standard deviations are in parentheses.

TABLE 3 How airmail entry affects local aviation innovation.

	(1) Aviation patents: 1915–1935 β/SE/p	(2) Aviation patents: 1915–1935 β/SE/p	(3) Aviation patents: 1915–1930 β/SE/p	(4) Aviation patents, treated counties: 1915–1935 β/SE/p	(5) Non-aviation patents: 1915–1935 β/SE/p
Post-airmail	0.854	0.852	0.998	0.434	−0.074
	(0.201)	(0.210)	(0.220)	(0.262)	(0.082)
	[.000]	[.000]	[.000]	[.097]	[.370]
Population (logged)		0.957	2.051	0.941	0.879
		(0.496)	(0.624)	(0.370)	(0.227)
		[.054]	[.001]	[.011]	[.000]
County FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Obs	2016	2016	1456	651	2415
Group	96	96	91	31	115
Log-Likelihood	−1380.95	−1375.27	−974.22	−617.59	−4789.52

Note: Poisson regression coefficients with QML robust standard errors clustered at the county level in parentheses. *p* value in square brackets. County FE, Year FE included in all models.

predominantly driven by a particular group of inventors. Models (1), (2), and (3) indicate a positive effect of airmail entry on subsequent patenting. In line with our qualitative analyses, this suggests that entry of an airmail route enhanced innovative activity among both corporate ($\beta = 1.491$; 95% CI: [0.474, 2.508]) and individual inventors ($\beta = 0.695$; 95% CI: [0.268, 1.122]) in the treated counties.

The next set of models in Table 4, Models (4), (5), and (6), introduce the interaction effect between airmail entry and local aircraft manufacturing. They include the variable *Aircraft Mfg. Location*, which is a time-varying variable that equals 1 in years when there was an active aircraft manufacturing company in the county (and 0 otherwise), and the interaction term *Post-Airmail×Aircraft Mfg*. By including these additional variables, we examine whether airmail entry increased corporate innovation in the region by enhancing the innovative capability at the site of aircraft manufacturing facilities. Likewise, we are also able to assess whether the increase in individual innovative activity as a result of airmail entry was an independent outcome or a positive spillover from more corporate activity. The coefficient on *Aircraft Mfg. Location* is marginally positive but with confidence intervals encompassing zero in the specifications in Table 4. Thus, we find no clear evidence that the presence of aircraft manufacturing in a county alone would have increased the patenting output of corporate or individual inventors.

The dependent variable in Table 4 Model (5) is corporate patents. When considering the positive coefficient on *Post-Airmail×Aircraft Mfg*. ($\beta = 1.558$; 95% CI: [0.033, 3.084]) in light of findings from our qualitative analyses, our results suggest that this positive effect may be driven by the efforts of local airmail companies seeking to take advantage of economies of scale and profit from downstream operation. This would likely involve investing in key technological

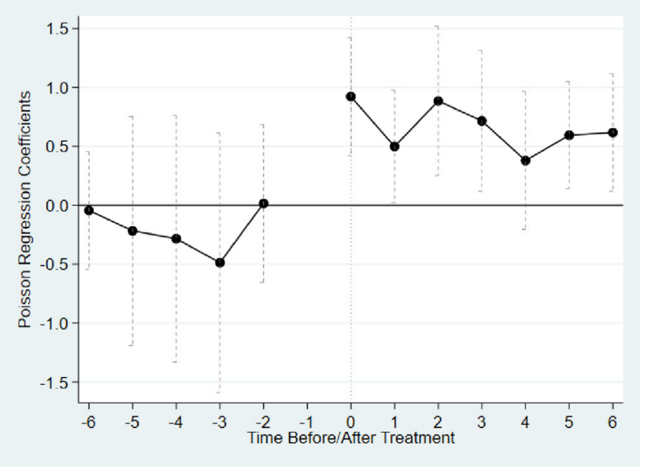

FIGURE 2 Coefficient plots—aviation patents. The black solid line corresponds to the coefficient estimates from conditional fixed-effect quasi-maximum likelihood Poisson regression, with year and county fixed effects, in which the number of patents is regressed upon the interaction terms between the airmail entry dummy and the indicator variables for each number of years before/after the introduction of an airmail route into a county.

areas for more effective planes—as was the case with Boeing that we discussed in Section 4.2. In contrast to corporate inventors, Model (6) shows that airmail entry (*Post-Airmail*) has a positive effect on individual patenting output, whereas there appears to be no clear effect of the interaction term *Post-Airmail*×*Aircraft Mfg*. This suggests that individual inventors were able to capture the innovative opportunity that airmail entry provided, regardless of the existence of corporate R&D. These results are consistent with the notion that individual inventor responses to airmail included those that had direct experience with airmail operations such as airmail pilots or mechanics, as well as individual tinkerers who saw the emergence of airmail operations as an inspiration to apply their existing knowledge to a new market context. The positive coefficient on *Post-Airmail* ultimately suggests that local airmail operations were able to provide enough awareness or incentives for individual inventors who operated outside the realms of organized aircraft corporate R&D to direct their attention to aviation-related issues.

5.4.2 | Heterogeneity in the co-location of industry value chains

In Table 5, we consider how the co-location of the local industry value chain actors may have shaped the trajectory of innovation following the entry of airmail. From our qualitative historical analyses, we observed that the local integration of downstream use of airmail operations and upstream production with aircraft manufacturing oriented local actors to the incentives for investing in innovations that enhanced economies of scale in flight operations. Profit from airmail operations was enhanced by an airmail company's capacity to fly bigger planes, which required innovations to enable the production of stronger engines, larger fuselages, and sturdier landing gear (see Section 4.2). In contrast, our historical analyses indicated that end-user innovators who were working directly with the technology made significant contributions to flight-focused domains, in particular. These navigation, control, and safety patents emerged from close contact with aircraft and operational experience (see Section 4.1). To extend these

TABLE 4 How co-location of airmail entry and aircraft manufacturing affects individual and corporate patenting.

	(1) Aviation patents: All β/SE/p	(2) Aviation patents: Corporate only β/SE/p	(3) Aviation patents: Individual only β/SE/p	(4) Aviation patents: All β/SE/p	(5) Aviation patents: Corporate only β/SE/p	(6) Aviation patents: Individual only β/SE/p
Post-airmail	0.852	1.491	0.695	0.720	0.383	0.854
	(0.210)	(0.519)	(0.218)	(0.241)	(0.474)	(0.238)
	[.000]	[.004]	[.001]	[.003]	[.419]	[.000]
Aircraft Mfg.				0.142	0.288	0.465
				(0.246)	(0.772)	(0.472)
				[.563]	[.709]	[.325]
Post-airmail × aircraft Mfg.				0.199	1.558	−0.560
				(0.269)	(0.778)	(0.408)
				[.459]	[.045]	[.170]
Population (logged)	0.957	2.074	0.828	0.847	1.793	0.922
	(0.496)	(1.433)	(0.301)	(0.530)	(1.457)	(0.306)
	[.054]	[.148]	[.006]	[.110]	[.218]	[.003]
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	2016	945	1974	2016	945	1974
Group	96	45	94	96	45	94
Log-Likelihood	−1375.27	−571.52	−1107.46	−1372.71	−561.18	−1103.15

Note: Poisson regression coefficients with QML robust standard errors clustered at the county level in parentheses. p value in square brackets. County FE, Year FE included in all models.

TABLE 5 How value chain co-location affects innovative focus.

	(1) Aviation patents: Flight β/SE/p	(2) Aviation patents: Scale β/SE/p	(3) Aviation patents: Flight β/SE/p	(4) Aviation patents: Scale β/SE/p
Post-airmail	0.600	1.136	0.617	0.576
	(0.274)	(0.311)	(0.372)	(0.272)
	[.029]	[.000]	[.097]	[.034]
Aircraft Mfg.			0.065	0.114
			(0.305)	(0.505)
			[.830]	[.822]
Post-airmail × aircraft Mfg.			−0.063	0.784
			(0.367)	(0.462)
			[.865]	[.090]
Population (logged)	0.732	0.740	0.738	0.522
	(0.541)	(0.892)	(0.548)	(0.914)
	[.176]	[.407]	[.178]	[.568]
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Obs	1575	1218	1575	1218
Group	75	58	75	58
Log-Likelihood	−909.99	−517.99	−909.94	−515.44

Note: Poisson regression coefficients with QML robust standard errors clustered at the county level in parentheses. p value in square brackets. County FE, Year FE included in all models.

qualitative insights into a quantitative investigation of the moderating role of local economic conditions, we separately examine the effect of airmail entry on either flight-focused or scale-focused patents.

In Models (1) and (2) of Table 5, the coefficient on *Post-Airmail* is positive in each case (β = 0.600; 95% CI = [0.062, 1.138] and β = 1.136; 95% CI = [0.527, 1.745], respectively). This suggests that the entry of airmail was associated with an increase in patenting activity that was broad-based. Accordingly, we observe a positive effect of airmail entry when the outcome variable is restricted to being either the county-year count of flight-focused or scale-focused aviation patents only.

We next include *Aircraft Mfg. Location* and *Post-Airmail×Aircraft Mfg.* to assess the conditions in which these types of patents were the focus of innovative activity. The coefficient of *Post-Airmail×Aircraft Mfg.* in Model (4) suggests that the counties that had both airmail operations and aircraft manufacturing experienced an increase in scale-based patents (β = 0.784; 95% CI = [−0.121, 1.689]). In contrast to scale-based patents, the *Post-Airmail* coefficient from Model (3) indicates that flight-based patents increased in all counties that had airmail operations, regardless of aircraft manufacturing (β = 0.617; 95% CI = [−0.112, 1.346]). These results are consistent with our earlier qualitative analyses, which suggested that areas with geographically localized value chains, as exhibited by the co-location of airmail and aircraft manufacturing, saw relatively greater increases in scale-focused innovation. Hence, it seems that areas with aircraft manufacturers responded to airmail entry with a particular emphasis on innovating in scale-based areas that could enhance the profitability of aviation activities. On the other hand, our results show that increases in flight-focused patenting seem to have occurred in all airmail locations regardless of the presence of aircraft manufacturers, suggesting that user-driven innovation can occur independent of upstream value chain activity. Thus, both the qualitative and quantitative evidence indicates that differences in local industry conditions can serve to influence the trajectory of innovation following technology adoption.

5.4.3 | Corporate innovation at the extensive margin, intensive margin, and across technological domains

Our results have, thus far, indicated that the introduction of airmail into a geographic area was linked to subsequent increases in aviation-related innovative activity in that locale. We see that increases in innovative activity were wide-ranging, and we corroborate these findings with evidence from historical records that help to contextualize these effects. However, there still remain open questions about the strategic responses of local actors. Thus, we extend our investigation and next orient our focus to corporate activities to explore how potential opportunities provided by airmail affected firm patenting behavior.

In this section, we are primarily focused on corporate behavior and on examining whether or not firms' technological portfolio of patents was affected by being located along an airmail route. This is motivated by the idea that airmail co-location exposed these firms to a broader set of the industry value chain; thus, we reason that such corporate actors would be better positioned to engage in more broad-based innovation strategies when commercialization opportunities emerged. We investigate the specialization of firms' technological portfolios based on patenting across different aviation technological subfields. Here, we leverage our patent classification information in order to more precisely assess the nature of an innovation beyond the more general CPC Main Class categorization (at that level, most of these patents are classified within Class B64: aircraft; aviation; cosmonautics, previously USPC 244). By focusing on the specific dimensions of innovations being patented, we consider innovations across the 12 aviation technological domains described in Section 5.3: (1) air-flow surface, (2) alternative flying devices, (3) engine, (4) flight control and stabilization, (5) fuselages, (6) infrastructure, (7) landing gear, (8) navigation, (9) parts and materials, (10) propellers, (11) safety, and (12) wings.[18]

Our first step in this investigation is to estimate a baseline effect of airmail on aviation patenting across different technological domains. We do so by replicating the approach taken within the primary analyses, but with split samples by each of the dozen technological domains. Holistically, as illustrated in Figure 3, we observe a consistent positive effect across technological domains. Our point estimate magnitudes for *Post-Airmail* across the split sample do display some variance and range from a substantial 410% increase ($\beta = 1.63$; 95% CI = [0.404, 2.860]) for air flow-focused patents to an imprecisely estimated 27% increase ($\beta = 0.239$; 95% CI = [−0.430, 0.910]) for innovations classified as safety and accessories. Overall, these results appear consistent with our main findings, and it establishes a foundation to understand how firms' patent portfolios changed as a result of airmail entry.

[18]Appendix C.3 in Supporting Information provides more details and illustrative examples of these classifications.

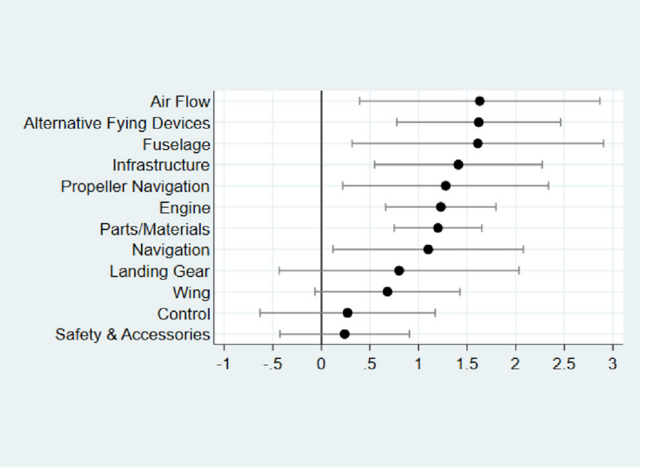

FIGURE 3 Coefficient plots—aviation patents by technological domain. The black dots correspond to the split sample coefficient estimates from conditional fixed-effect quasi-maximum likelihood Poisson regressions in which the number of aviation patents in each category in a given county-year is regressed upon the variable *Post-Airmail*. The gray lines show the 95% confidence intervals around these estimates.

We proceed with our investigation of firm behavior by examining the extensive margin, intensive margin, and technological specialization displayed by corporate actors following the entry of airmail into a county. With respect to the extensive margin, we estimate the effect of airmail on the number of corporate actors patenting in any aviation technology subfield. In considering the intensive margin, we estimate airmail's effect on the number of patents produced by these corporate actors. Finally, for technological specialization, we estimate how airmail influenced the scope of patenting conducted by corporate actors. We do so by using the aviation technological subfields to construct firm-level patent portfolios for each corporate assignee to calculate a Herfindahl–Hirschman Index (HHI) of cumulative patenting output.[19] Thus, our firm-level HHI is a technology specialization index that measures the technological breadth of corporate patent portfolios across the different technological subfield classifications at the firm-year level. This provides us with an opportunity to understand changes in firms' patent portfolios over time.[20]

Table 6 presents the results from our analyses of airmail's effect at the extensive margin, intensive margin, and with respect to changes in firms' technological portfolio. Models (1) and

[19]We calculated the HHI using cumulative output filed up to a given year, and the share of cumulative patenting in each of the given subfields is squared and summed up across the 12 technological domains. Rather than just calculating a measure with patenting output filed only in a given year, this is to account for the fact that aviation patenting activity is a sporadic activity for many firm assignees. For example, if one firm only patented in subfield A in year *t* and only patented in subfield B in year *t*+1, HHI calculated using the noncumulative values would make it seem as if the company stayed completely specialized during both periods. In contrast, HHI using the cumulative values allows us to capture the temporal increase in technological diversification. However, this means that the cumulative HHI measure will be probabilistically greater for firms with a bigger number of patents. To address this issue, we control for the log of total number of cumulative patents in our regressions. Our variable construction and analytical approach seeks to deal with any such concerns to ensure we draw appropriate inferences from subsequent analyses.
[20]Note that higher HHI means greater technological specialization (i.e., less diversification) and lower HHI means less technological specialization (i.e., more diversification).

TABLE 6 Effect of airmail entry on the extensive margin, intensive margin, and technological specialization.

	(1) Number of corporate assignees: County level	(2)	(3) Number of corporate-assigned patents: Assignee level	(4)	(5) Log of tech. specialization index: Assignee level	(6)
	β/SE/p	β/SE/p	β/SE/p	β/SE/p	β/SE/p	β/SE/p
Post-airmail	0.528	0.249	1.110	−1.363	0.131	0.299
	(0.363)	(0.375)	(0.817)	(0.951)	(0.136)	(0.070)
	[.145]	[.506]	[.175]	[.152]	[.342]	[.000]
Aircraft Mfg.		0.504		−4.374		0.387
		(0.527)		(1.180)		(0.168)
		[.339]		[.000]		[.026]
Post-airmail × aircraft Mfg.		0.341		2.989		−0.296
		(0.473)		(1.090)		(0.167)
		[.471]		[.006]		[.083]
Population (logged)	1.794	1.646	−1.175	−1.436	−0.146	0.005
	(1.340)	(1.363)	(4.145)	(4.107)	(0.795)	(0.769)
	[.181]	[.227]	[.777]	[.727]	[.855]	[.995]
Assignee FE	Yes	Yes	No	No	No	No
County FE	No	No	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	924	924	398	398	467	467
Group	44	44	73	73	196	196
Log-Likelihood	−331.33	−329.36	−416.58	−410.89	303.48	308.97

Note: Columns (1)–(4) report Poisson regression coefficients with QML robust standard errors clustered at the county or assignee level in parentheses. Columns (5) and (6) report OLS regression coefficients with robust standard errors clustered at the assignee level. p value in square brackets.

(2) investigate airmail's effect at the extensive margin. Results from Model (1) show that the entry of airmail has a positive impact on the number of corporate assignees in a given county ($\beta = 0.528$; 95% CI = [−0.183, 1.239]), albeit with a confidence interval that encompasses zero. The results from Model (2) suggest that while the airmail counties with an aircraft manufacturing company may have experienced a greater increase compared to those without one, but the coefficient is again only directionally positive with the confidence interval encompassing zero. With Models (3) and (4), we observe that the intensive margin was affected by airmail entry. However, this intensive margin increase in the patents assigned to a given firm appears to be driven by those corporate actors that are co-located in counties that had aircraft manufacturing capabilities prior to the arrival of airmail ($\beta = 2.989$; 95% CI = [0.852, 5.126]). Indeed, this provides some new evidence for heterogeneity in firm outcomes due to technology exposure, and it also reinforces our earlier point about the potential performance implications of localities' stock of R&D capabilities.

The results from Models (5) and (6) provide insight into the level of technological specialization within corporate patent portfolios. As indicated by the coefficient on *Post-Airmail* in Model (5), the effect of airmail entry on the technological specialization of corporate patenting appears nominally positive but noisy, on average ($\beta = 0.131$; 95% CI = [−0.143, 0.405]). In Model (6), when we add the interaction, we observe a positive effect of *Post-Airmail* ($\beta = 0.299$; 95% CI = [0.158, 0.441]), and a negative effect of *Post-Airmail × Aircraft Mfg.* ($\beta = -0.296$; 95% CI = [−0.632, 0.040]). That is to say, these results indicate that firms co-located in areas with aircraft manufacturers had patent portfolios that became more technologically diversified following the entry of airmail, meaning that they were relatively more likely to patent in a wider array of technological domains.

These results are consistent with the idea that there arose significant changes in the orientation of firms' innovation strategies following the entry of airmail and this varied by the extent to which they were exposed to co-location of upstream R&D and downstream use of technology.[21] In line with our prior results, and qualitative evidence, a likely explanation for these findings is that the co-location of value chain actors in geographic areas allowed firms to more effectively coordinate and integrate a diverse pool of knowledge and ideas.

6 | DISCUSSION

This article uses the establishment of USPOD airmail routes to examine technology adoption and its role in aviation innovation during the early 20th century. Our main result suggests that there was an increase in aviation-related patenting in areas that happened to be along these newly established airmail routes, which underscores how innovation can be an unintended consequence of local access to technology. Our analyses show that these post-airmail increases in regional aviation patenting were driven by both individual and corporate inventors. We also observe that this overarching effect on aviation innovation was broad-based and spanned multiple technological domains. In this section, we build from these findings to provide a richer

[21] In our review of these patent records, we observe that few companies maintained consistent rates of patenting during the observation period, while a large number of small corporate assignees filed patents sporadically and had extended intervals between filings. To help alleviate concerns that this general pattern is biasing our estimates, we also take an alternative approach to our panel regressions that exclude nonpatenting years. With this alternative approach, we obtain results that align with those presented in the main text; see Supporting Information Appendix Table S.5.

integration with the broader literature on innovation and strategic management. In doing so, we seek to provide a foundation for future scholarship to advance work in this area, and we offer insights for managers and policymakers who may wish to consider pragmatic implications of our research.

While our findings come from a single industry and generalizations are inherently constrained by the historical and technological setting, our "history-to-theory" approach to studying technology adoption and innovation provides us with opportunities to advance our understanding of key issues in strategic management (Argyres et al., 2020). Indeed, this study provides a comprehensive investigation of the effect of changes in technological opportunity, together with local innovative capacity, on localized innovative activity. Beyond contributing to our understanding of how the adoption of technology affects subsequent innovation outcomes of individuals, firms, and regions, this research helps to develop and refine our understanding of the mechanisms that drive innovation processes. This paper speaks to the demand-pull perspectives in the innovation literature by shedding light on the role of user and market needs that arise because of technology adoption (Di Stefano et al., 2012). These findings also add to the literature on the consequences of new technology access, which has received relatively little attention in comparison with the abundance of work that explores the antecedents of technology adoption (Rogers, 2010). Moreover, it speaks to issues related to better understanding why innovators and researchers work in the domains that they do. Thus, our paper helps to enhance the linkage between technology adoption and the behavior of individuals and firms working in emerging industries and with new technologies.

Our work also complements studies by others on the birth and development of the aviation and airline industries, which helps advance our understanding of this focal technology along with the industries that it spawned. These include Bryan (2016), who shows how European aircraft companies became technologically dominant by 1914, despite the airplane being a recent American invention; Hiatt et al. (2018), who explain how nonmarket strategies, specifically stakeholder relationships with political and military actors, affected airline survival in Latin America between 1919 and 1984; Hanlon and Jaworski (2019), who examine how changes in intellectual property law affected innovation rates for different aircraft components in the 1920s; and Goldfarb et al. (2017), who produce a historical account of technological progress during the establishment of a commercially viable airline industry. Our findings similarly complement other studies showing how investment in transportation may increase innovative activity, either through knowledge flows or access to markets (Agrawal et al., 2017; Perlman, 2016; Sokoloff, 1988).

As with these other historical studies of the aviation industry, along with historical work in strategic management at large, there are both core generalizable dimensions and context-specific boundary conditions to consider when drawing lessons for modern-day firms. One of the key features in our setting appears to be the relationship between aircraft manufacturers and the operation of airmail routes. Vertical integration between manufacturers and airmail often provided steady demand for the manufacturer, potentially helping to reduce product market uncertainty. Vertical integration likely also allowed for easier and faster feedback between the innovator and the user; in this case, the vertically integrated manufacturer and airmail provider. However, opportunities for vertical integration may not be present in other settings. Indeed, in some settings, it may be disallowed altogether due to government restrictions. The Air Mail Act of 1934, which was prompted by the concern over industry monopolization and collusion, disintegrated the holding companies that housed aircraft manufacturers and airlines under one roof. As a result, the mechanism of internalized feedback from vertical integration became less applicable in later stages of industrial aircraft development. However, scholars have shown that government procurement contracts can help new innovations succeed (Aschhoff & Sofka, 2009; Mowery & Simcoe, 2002), which suggests that demand-related benefits of vertical integration can also be partially addressed via other mechanisms.

Another boundary condition concerns the role of localized user feedback. With the availability of various digital tools that enable faster and easier communication today, physical location no longer restricts access to information and learning to the extent that it did in the past. Likewise, with respect to industry life cycle, our findings are mostly relevant in the early phase of industry emergence where user-innovators are geographically concentrated and knowledge codification is low. The early era of aircraft manufacturing that we examine in this paper is, perhaps, an ideal case study of this since aeronautical knowledge at the time was imprecise and inventors had to rely upon written correspondence, verbal descriptions, and personal collaborations (Meyer, 2013). Although user feedback can be shared across distances, the initial adoption of technology may still determine where the main focus of innovative activity lies, to the extent that tacit user knowledge is more effectively exchanged in geographically localized interactions.

The ability to learn about demand may also be less spatially concentrated in related modern contexts. For instance, while inventors and firms outside of Nevada or Arizona may have fewer opportunities to be exposed to technology spillovers from autonomous vehicles due to local restrictions, they are still expected to have access to information about the overall market potential of autonomous vehicles. However, in the very early stages of industry development, more distant economic actors may not have reached a clear consensus about the market potential of a given technology. In this sense, early exposure to technology may give local firms a head start in perceiving the market potential. These boundary conditions suggest that, relative to the early 20th century firms in our study, present-day firms may need to engage with additional strategies to ensure demand for their innovations and good feedback mechanisms with their customers, while also having protection against knowledge spillovers.

There is also a set of boundary conditions worth considering as they relate to the economic conditions during the time period studied in our paper. For example, one boundary condition might include the presence of a sufficiently trained workforce. Some scholarship suggests that it now takes many more years for workers to be trained in specific technologies than it did decades ago (Bloom et al., 2020; Jones, 2009). Thus, even if a location had early access to a new technology, firms may not be able to quickly hire or train the appropriate workers needed to innovate with that technology. Another boundary condition might be the role of industry concentration, which evidence suggests has increased in recent decades (Covarrubias et al., 2020). Industry concentration may affect a firm's incentives to invest in highly specialized assets, for fear of hold-up from suppliers or customers with relatively high bargaining power (Williamson, 1979). Pragmatically, these boundary conditions suggest that modern-day firms may require more investment and training in their workforce, and need more safeguards against hold up, in order to realize the positive effects of technology adoption.

7 | CONCLUSION

This article examines the link between the establishment of USPOD airmail routes and subsequent aviation innovation in the early 20th century. Our analyses of historical qualitative and quantitative data indicate that opening an airmail route into a county was associated with an increase in aviation patenting in that county and that this effect is driven by both individual and corporate actors. In documenting how an increase in local innovative activity was an unintended consequence of the arrival of a new technology, our work speaks to rich streams of research in strategic management and economics of innovation that have considered the relationship between technology adoption and the trajectory of innovation.

Ultimately, this research highlights that technology adoption can have a positive effect on innovation. We find that the trajectory of innovation is contingent on local industry conditions, and the impact of changes in technological opportunity can span multiple industries, affect a range of value chain actors, and influence the technological profile of new innovations. These results suggest that being an early site of adoption of a technology can have positive consequences for future innovation within a local economy. This finding is especially relevant for both managers and policymakers navigating the potential costs and benefits of new technology adoption. While more research is certainly needed to develop richer models of innovation and technological development, we believe that the findings presented in this work help to deepen our understanding of the antecedents, consequences, and organizational processes that underpin innovation.

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OPEN RESEARCH BADGES

This article has earned Open Data badge. Data are available at https://github.com/ehsohn/airmail_data.

DATA AVAILABILITY STATEMENT

The data are uploaded to GitHub and are available at https://guthub.com/ehsohn/airmail_data.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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