Technological Opportunity and the Locus of Innovation:

Airmail, Aircraft, and Local Capabilities

Eunhee Sohn[1] Robert Seamans[2] Daniel Sands[2]

[1]Georgia Tech

[2]NYU

Mar 2018 @ NBER



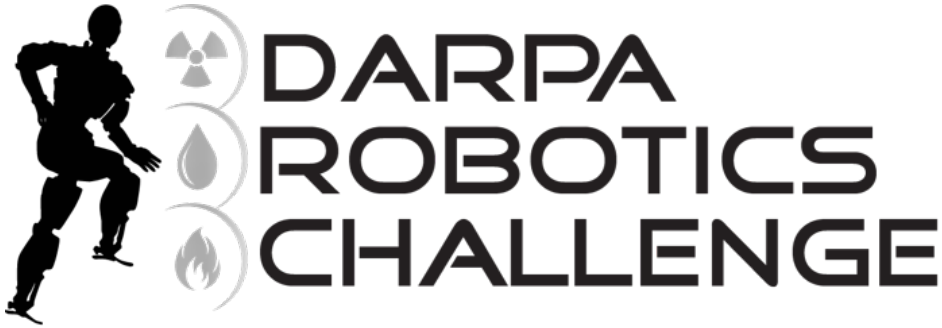
Dual Role of Government in Innovation: Upstream

GRANTS.GOV AND FEDERAL GRANT FORMS

(Li et al., 2017)



(Lerner, 1999; Howell, 2017)

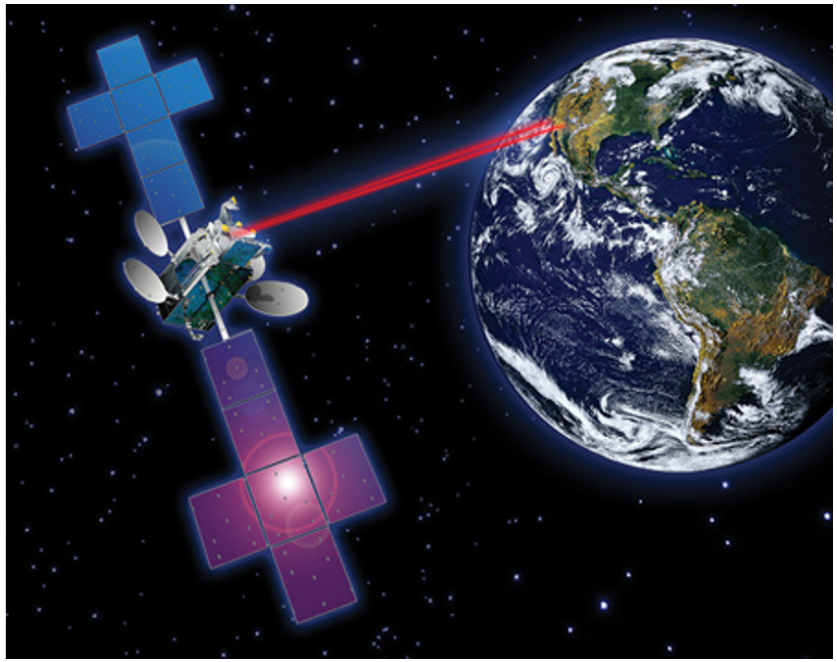


(Boudreau et al., 2011; Murray et al., 2012)

Dual Role of Government in Innovation: Downstream



Use of Packbots in Afghan War

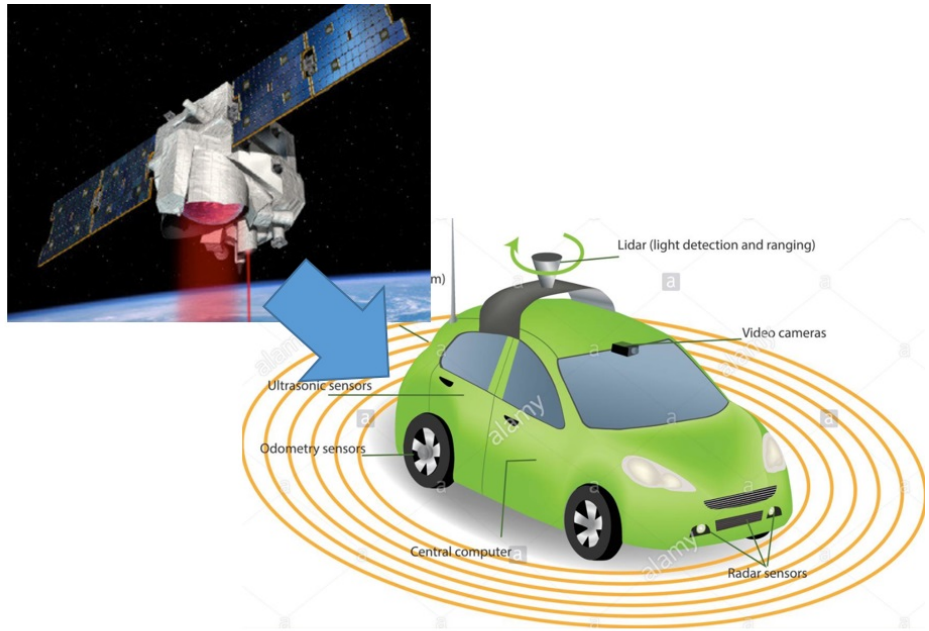


Use of LIDAR (Light Detection and Ranging) in Space Missions (Apollo 15)

Unintended Technology Spillovers from Use and Application



From Packbots to Roombas



From Space Mission to Self-Driving Cars

Dual Role of Government in Innovation

Top-down Push
Intended Spillovers

- Support and Funding for R&D
- Government-led R&D projects
- Focus on Input Provision
- Upstream of the R&D Chain
- Investment and Planning

Bottom-Up Pull
Unintended Spillovers

- Adoption of Technology
- Procurement and Wars
- Focus on Output Use
- Downstream of the R&D
- Feedback and Experimentation

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Causual Ambiguity

Research Questions & Setting

Research Question

- What is the impact of government-led adoption of technology on private sector innovation?
- How do different economic actors respond to the new opportunity? (i.e. What is the role of local inventors, companies and regions?)

Research Questions & Setting

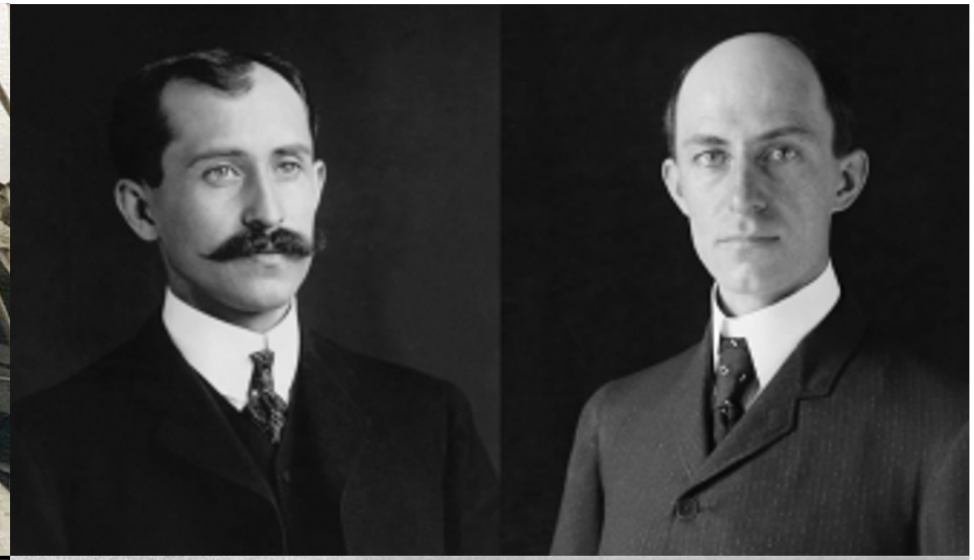
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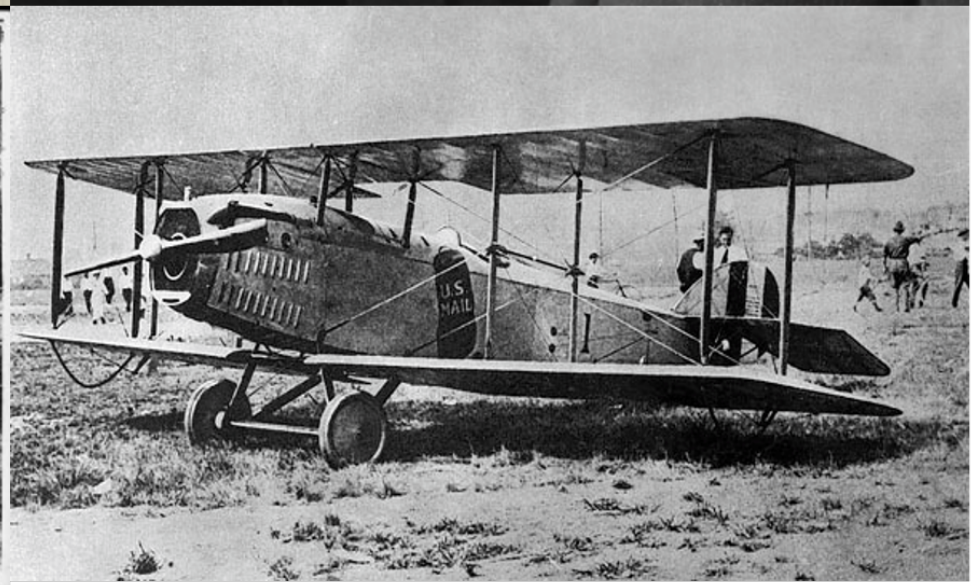
- Introduction of airmail routes (1918-1930) and their impact on aircraft innovation in the connected counties
- Local exposure to new technology & experimentation
- Local shock to incentives and opportunities for aircraft-related innovation without provision of direct R&D input


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THURSDAY
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U.S. MAIL

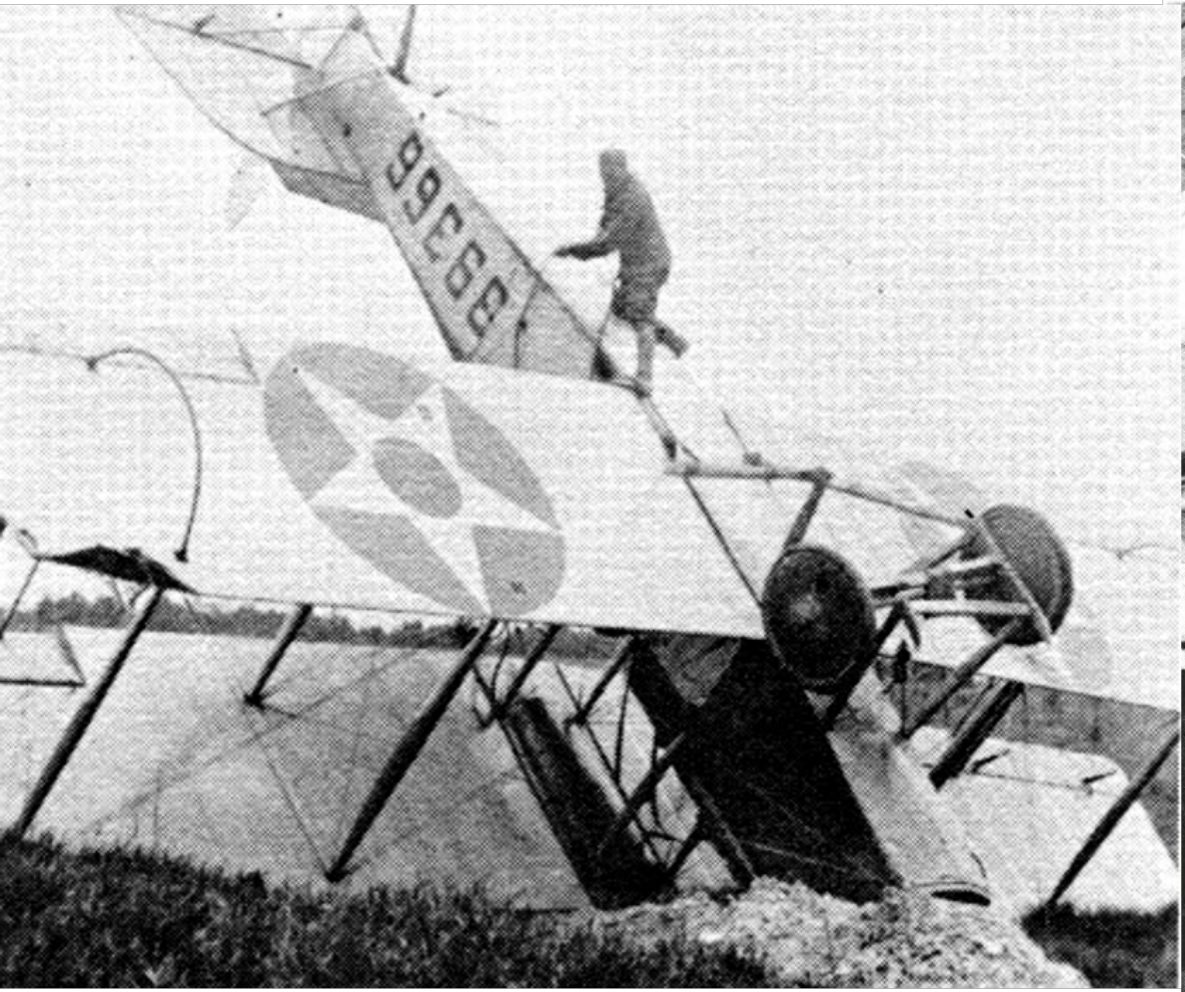
Why Airmail? Local Experimentation & Feedback

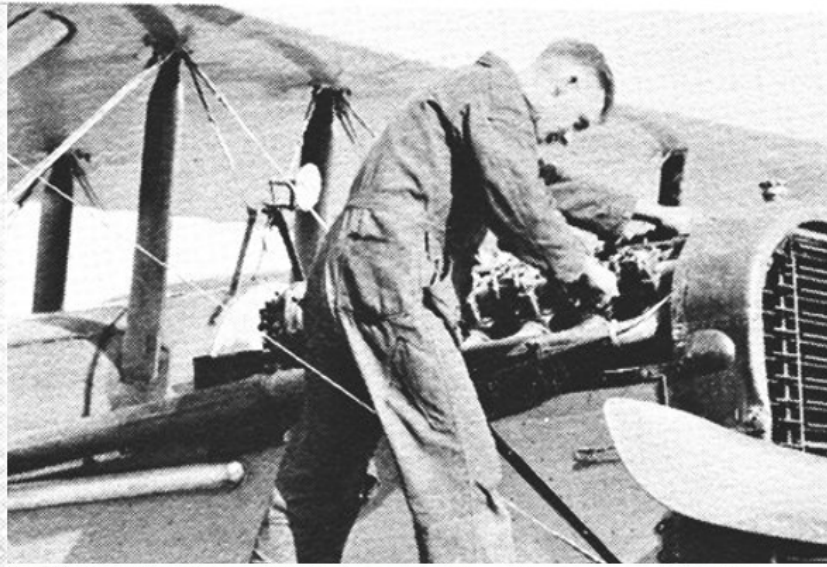
Opportunities For Learning in a Nascent Technological Industry

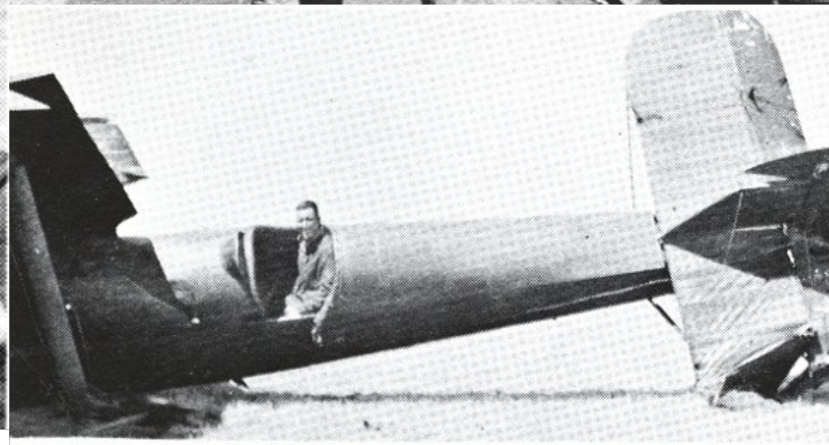
- Aircraft first invented by the Wright Brothers in 1903; Still crude in 1910s
- Airmail first introduced in 1918 using army aircrafts (Reuben H. Fleet)
- Privatized to civilian contractors and rapidly expanded after 1925
- Regular airmail flights provided opportunities to test and improve new technology





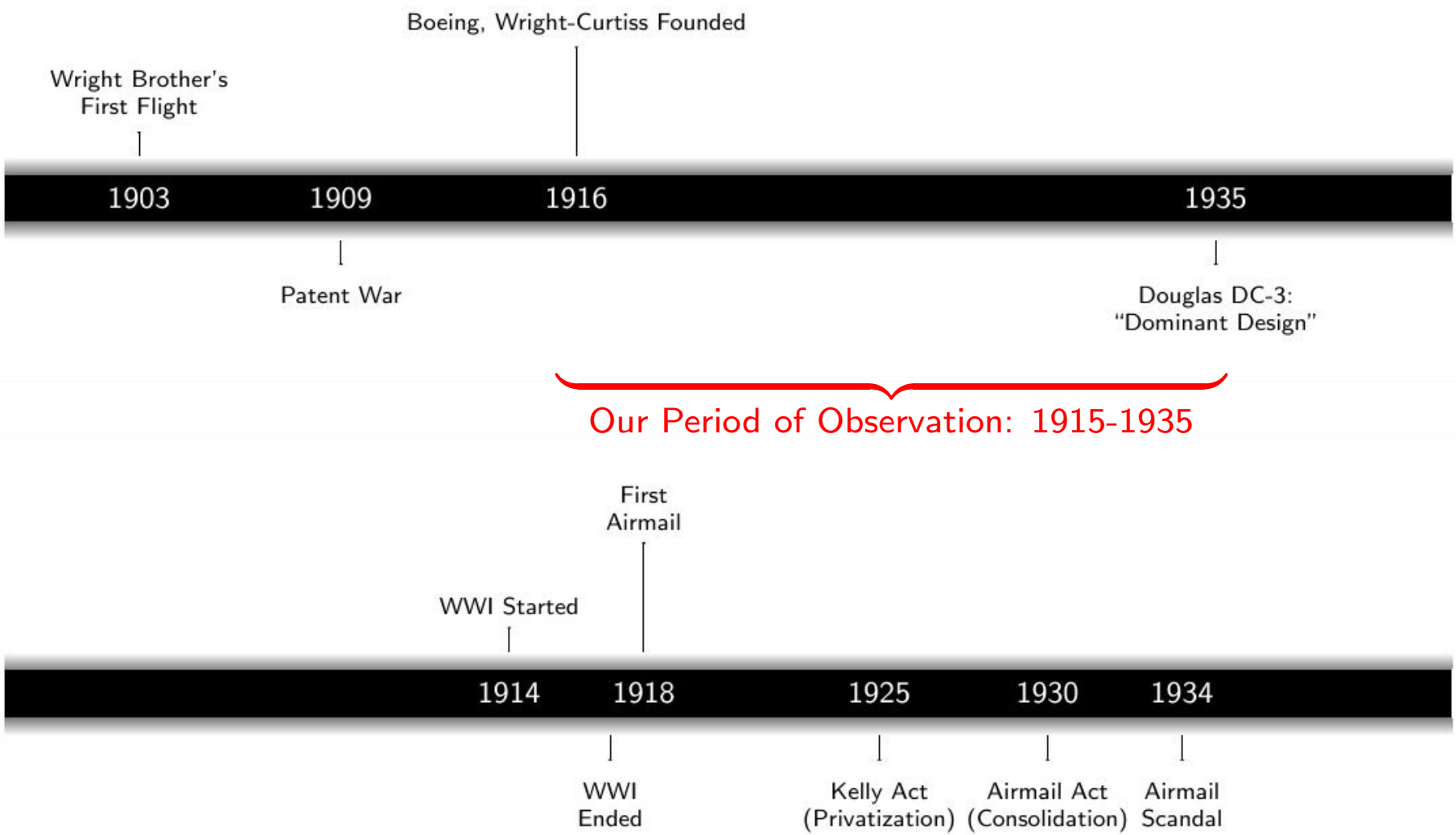






"Prolonged experimentation with landing lights had led to the development of adequate wing tip lights, the light from which was not reflected into the eyes of the pilot by the propeller." [David 1934, pp. 38-39]
"Machines break. Schedules suffer [But] the mechanical problems should be sorted out eventually." [Rosenberg & Macauley 2006, p. 51]

The History of Aviation



Why Airmail? Identification Assumptions

Local shock to incentives and opportunities for aircraft-related innovation without providing direct R&D input

- Also not a procurement contract with specified R&D output
- Postal funding is going to aviation not aircraft

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Airmail routes not chosen in order to exploit aircraft innovation

- Chosen in a path-dependent way to complement railroad delivery
- Population and military bases are key factors, not innovation

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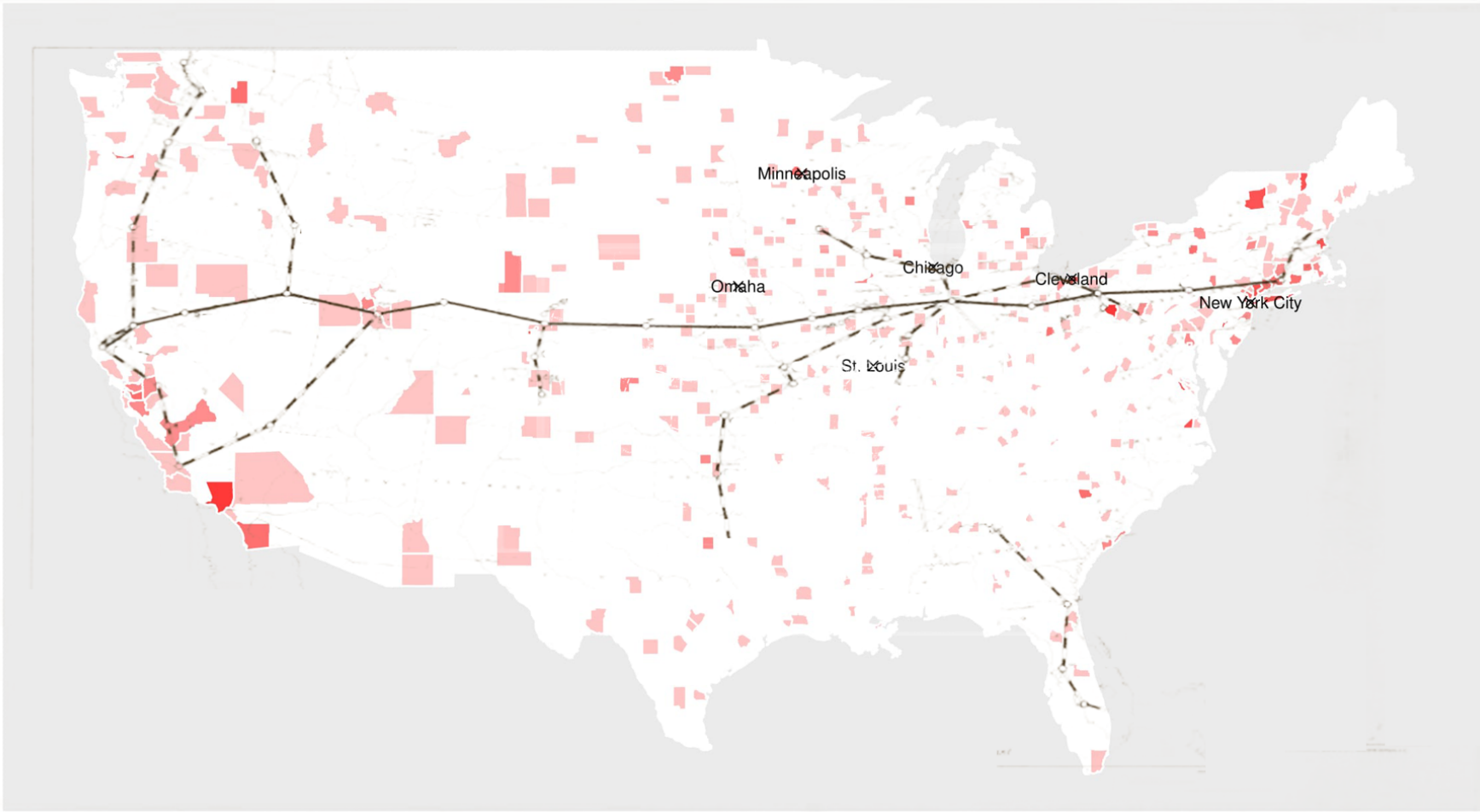
Little evidence of lobbying by *aircraft* companies before 1930

- Airmail contractors were initially mostly small, regional; A few exceptions (e.g. Ford Aircraft) but controlled by matching
- Colonial Airlines; National Air Transport; Varney Speed Lines

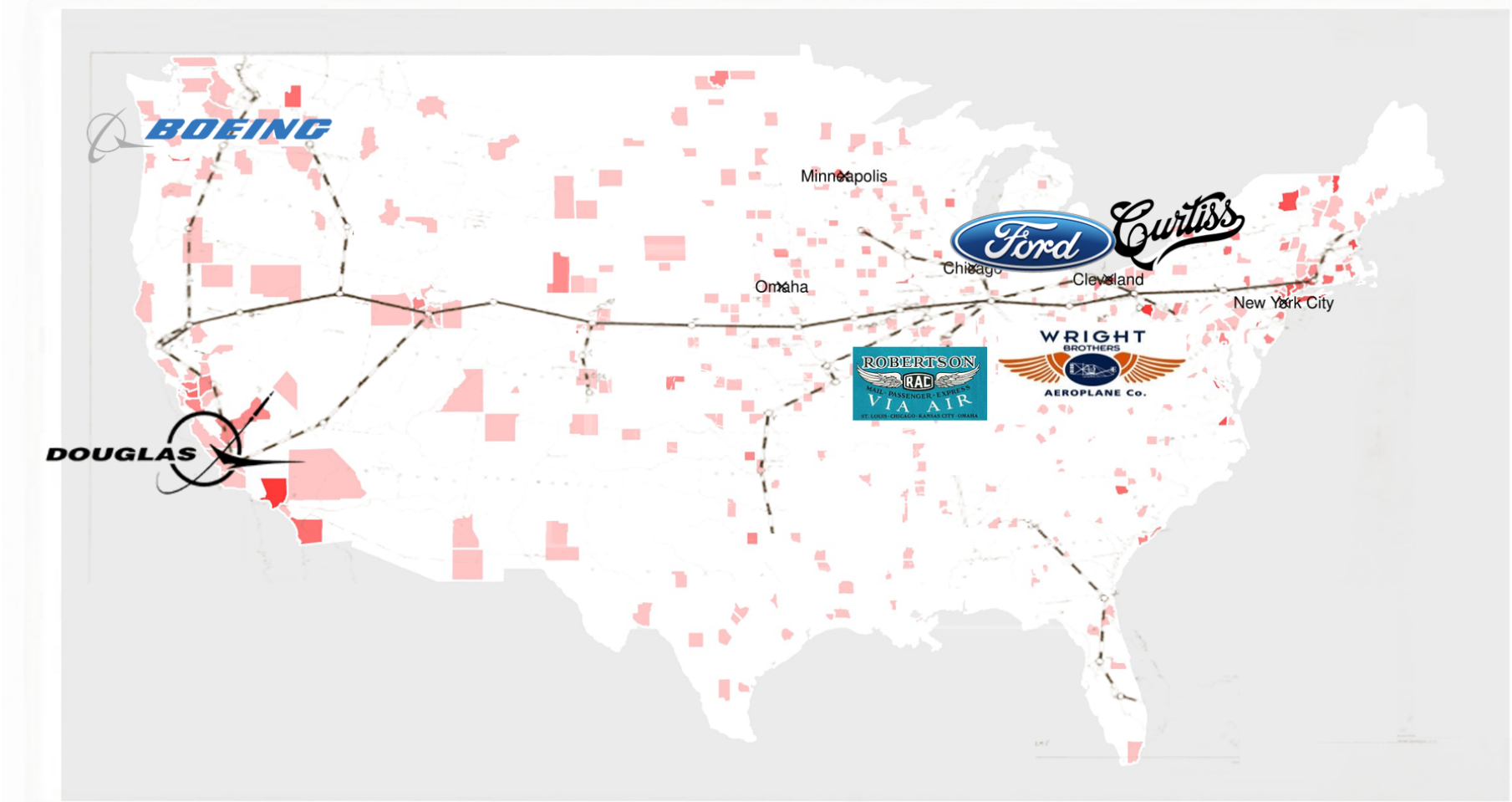
Route Openings: Temporal and Geographic Variation

May 15, 1918: First airmail from DC-Phila-NYC*
May 15, 1919: Chicago-Cleveland
July 1, 1919: Cleveland-NYC
May 15, 1920: Chicago-Omaha
August 16, 1920: Chicago-St. Louis*
September 10, 1920: Omaha-San Francisco
November 29, 1920: Chicago-Minneapolis*
*dropped in 1921
1921: government-run trunk route from East to West
1925: bids for private contractors on new routes (many)

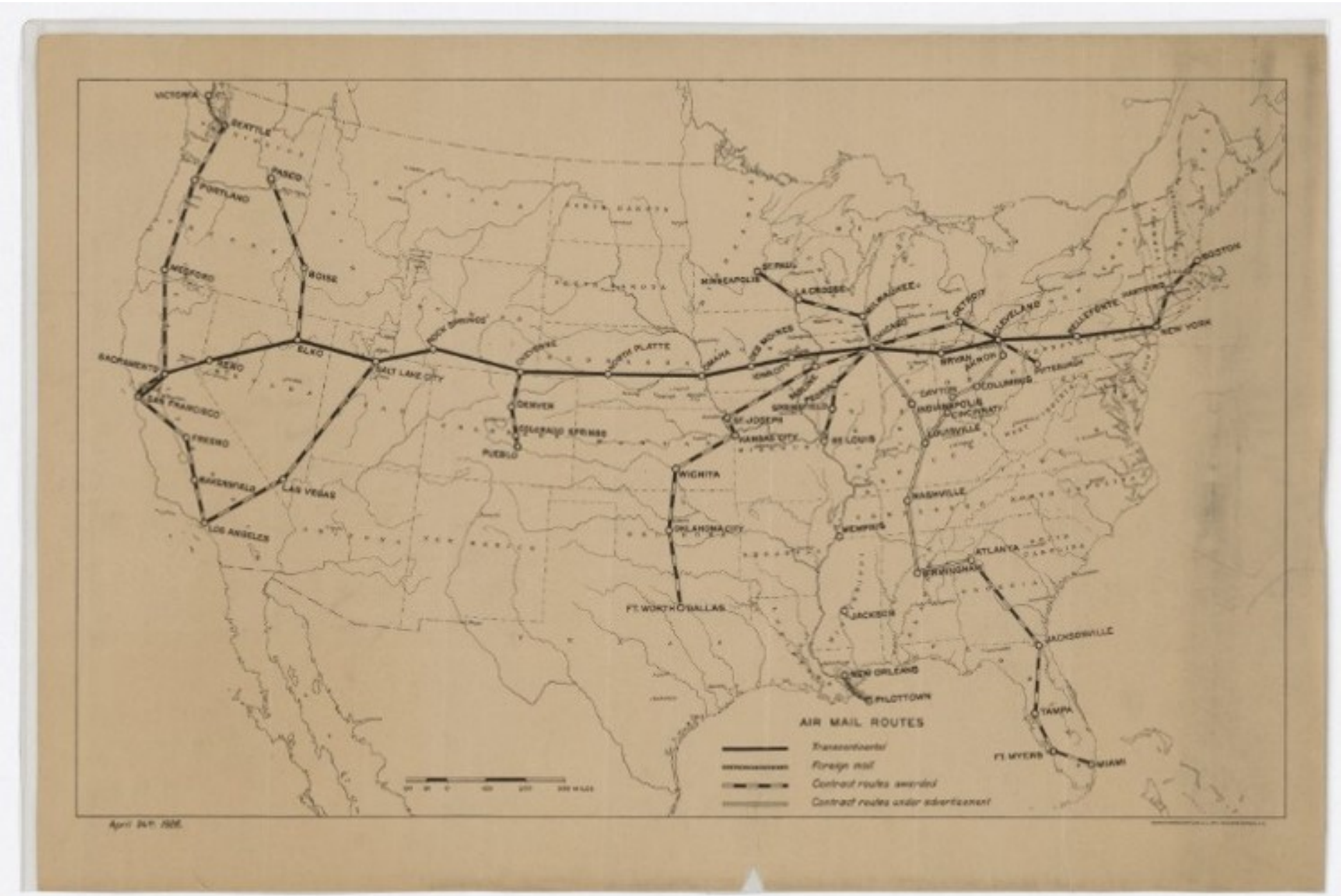
Examples of the Earliest Airmail Routes



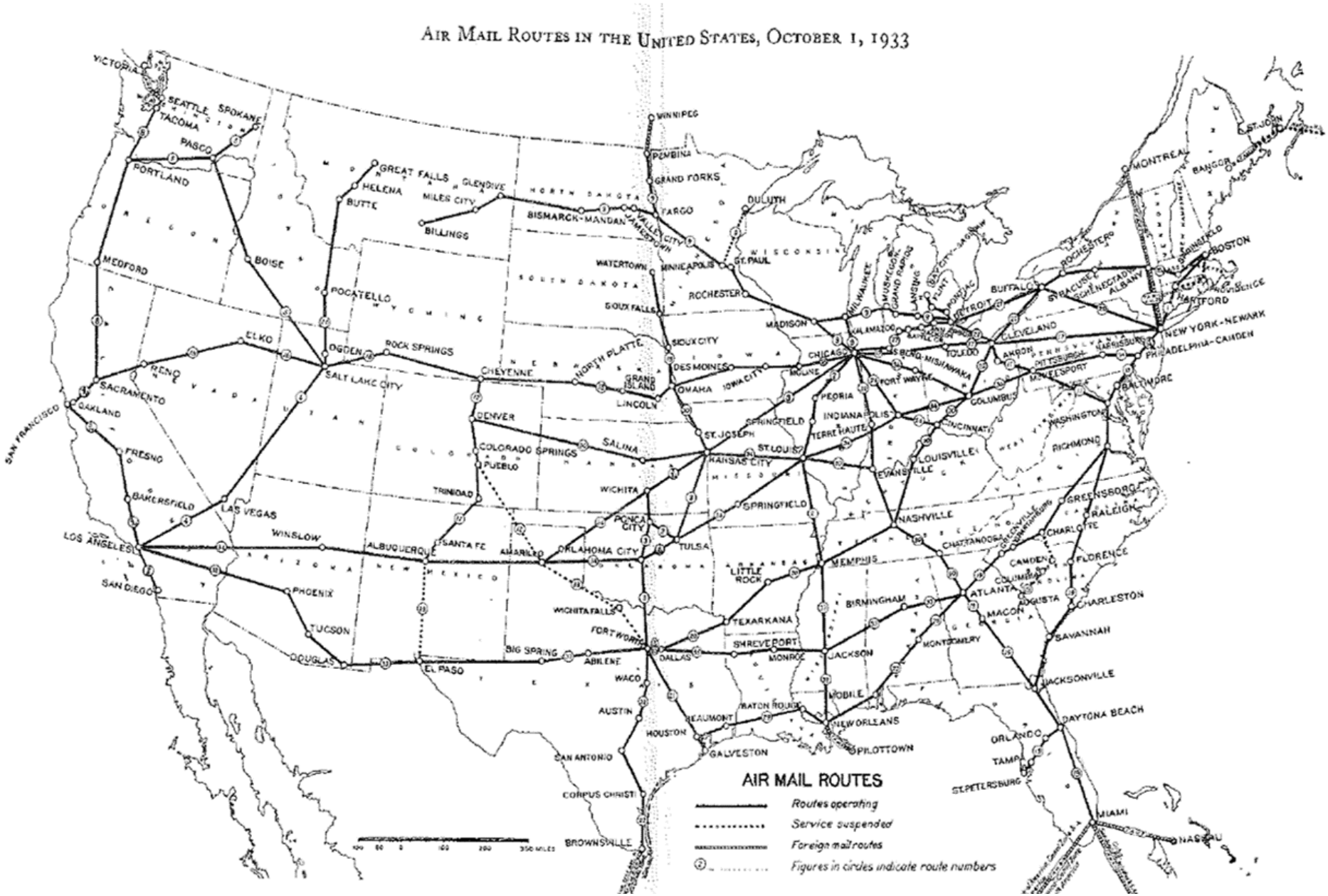
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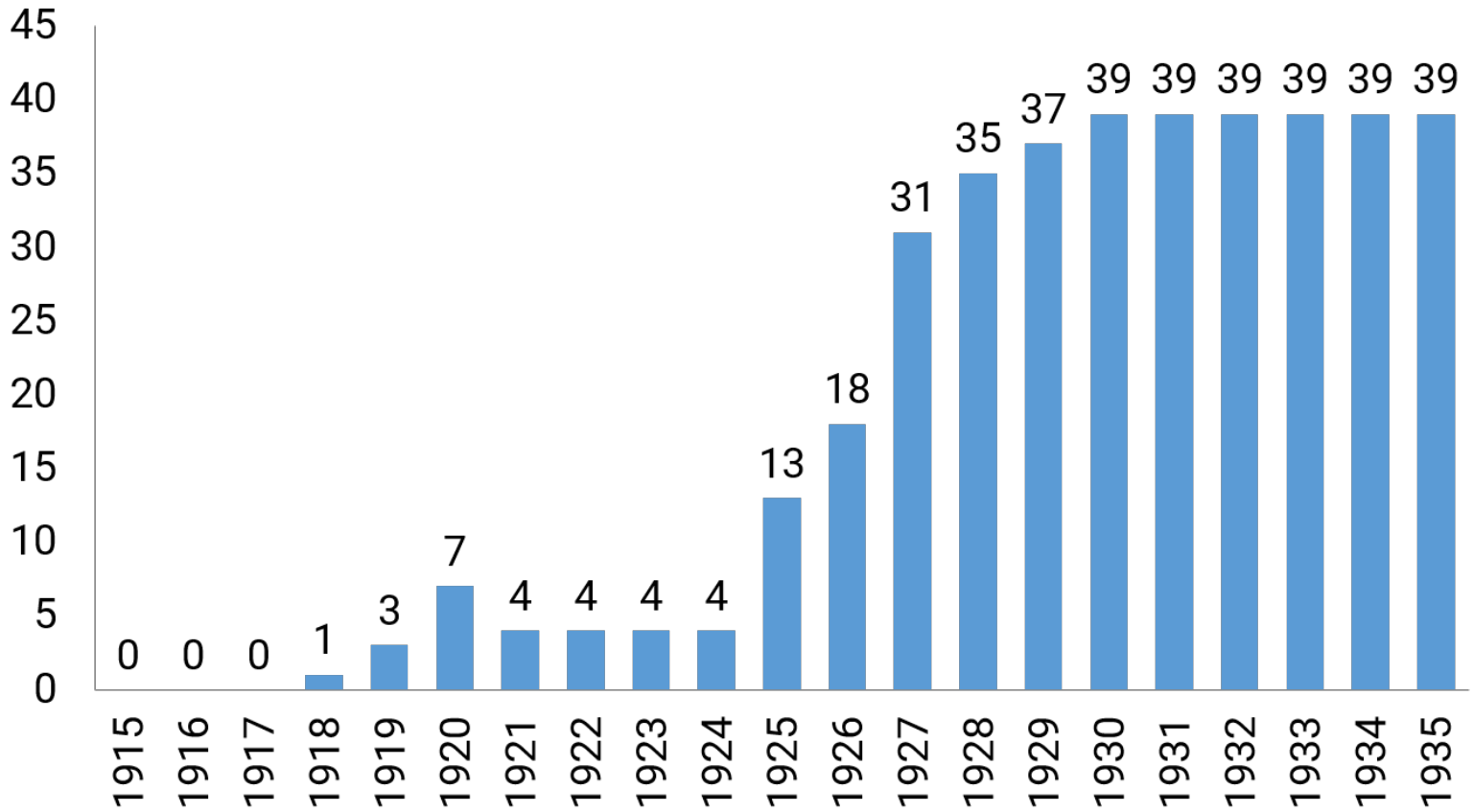
Expansion of U.S. Airmail Routes: 1926



Expansion of U.S. Airmail Routes: 1934



Number of US Airmail Routes 1915-1935



Population and Military Base Determine the Routes

	(1) Route Selection	(2)
Early Manufacturer	-0.145	-0.175
	(0.445)	(0.442)
Air Base	1.555***	1.481***
	(0.422)	(0.418)
Ln(Population)	1.198***	1.193***
	(0.378)	(0.370)
Ln(Manufacturing)	0.176	0.094
	(0.298)	(0.297)
Ln(Pre-1918 Non-air Patents)		0.078
		(0.153)
Ln(Pre-1918 Air Patents)		0.288
		(0.513)
Year Effect	YES	YES
Obs	29432	29432
Log Likelihood	-227.23	-226.61

Effect of Airmail on Aircraft Innovation

Opportunities for local inventors to improve on aircraft technology

- Expect an increase in aircraft patenting in treated counties.

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Effect of local opportunities on innovation quality

- Does local exposure lead to more radical innovation?
- Or more incremental innovation? (de-bugging existing tech)
- What is the impact on related and unrelated technology?

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Who leads innovation?

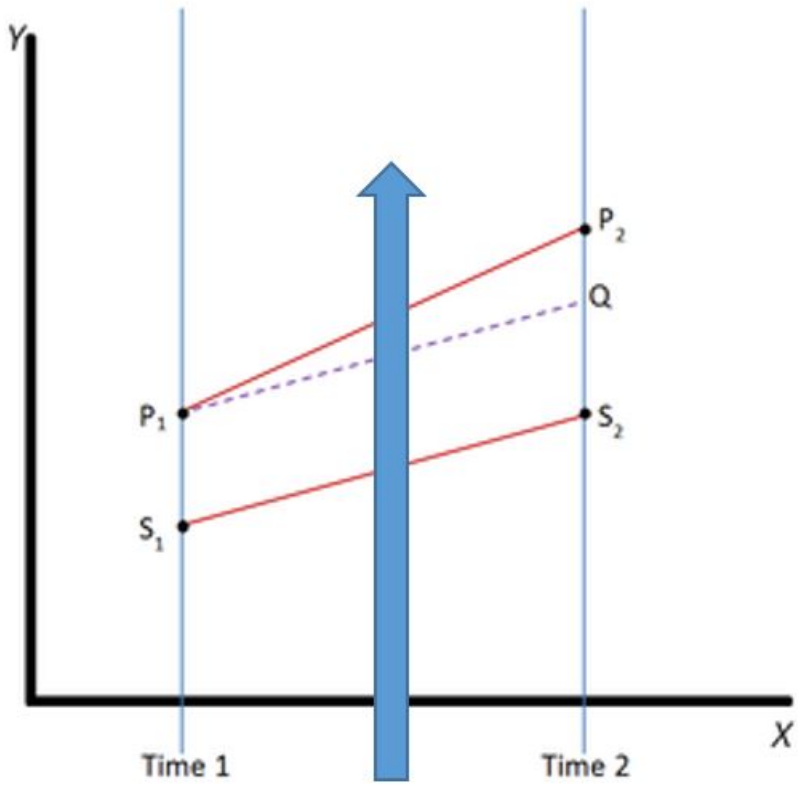
- What are the roles of local individuals and corporates?

Research Design: Difference-in-Differences

Aircraft Innovation

Treated County

Control County



Airmail Route Opening

Controls Construction:
Propensity Score Matching on

- Population, manufacturing capacity
- Airbase, incumbent aircraft company
- Aircraft/non-aircraft patenting

Data Collection: U.S. Patents between 1900-1940

Constructing Inventor Location Data from Google Patent OCR

- Inventor location scraped and fuzzy-matched to U.S. Address Dataset
- Filing date, grant date, international/US patent class, forward citations

Identifying Aircraft Patents

- Text: Word aircraft (or related word) in the title or main text
- Class: Aircraft-related (USC 244; IPC B64 and B21D 53/92).

County-year Analysis

- Patent Data aggregated based on the year of filing
- County-level variables: Population, manufacturing, etc.

Text Example: Brake control for aircraft landing wheels

UNITED STATES PATENT OFFICE

WALTER J. CARR, OF SAGINAW, MICHIGAN, ASSIGNOR, BY MESNE ASSIGNMENTS, OF ONE-HALF TO PARAMOUNT AIRCRAFT CORPORATION, A CORPORATION OF MICHIGAN, AND ONE-HALF TO GEORGE C. WILLCOX, OF SAGINAW, MICHIGAN

BRAKE CONTROL FOR AIRCRAFT LANDING WHEELS

Application filed October 13, 1928, Serial No. 312,253. Renewed February 9, 1931.

My invention relates to an improved mechanism for actuating the wheel brakes of aircraft. Heretofore the levers that control the wheel brakes have been mounted in such a position that their operation required the use of the pilot's free hand, the other hand being occupied with operating the control stick of the aircraft. In addition to that, it is necessary while landing an aeroplane or maneuvering a plane on the ground to be able to quickly regulate the engine throttle and one hand of the pilot should be free for that purpose.

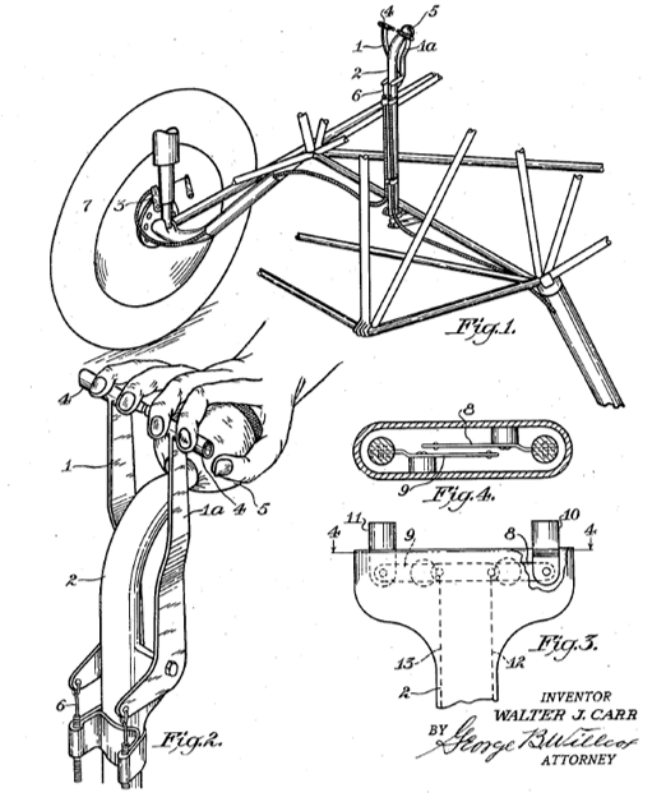
In order to simplify the pilot's task the wheel brake controls have heretofore been foot-operated, but since most aircraft have their rudder surfaces controlled by foot pedals this expedient is also awkward, especially when a change in the rudder setting and simultaneous application of brakes to one or both wheels becomes necessary.

The invention consists in a novel means control lever 2, there being one lever for each wheel brake 3. A finger piece 4 on each lever 1 can be grasped by one or two fingers of the piloting hand without removing from its operating position on the control handle 5.

When a finger piece, as 4, is pulled, an intermediate bellcrank 1 pivoted on the control stick pulls a cable 6 to operate the brake mechanism 3 of the corresponding wheel 7.

The scope of my invention is not limited to the precise arrangement of levers disclosed here, but it may as claimed embody various elements in combination for accomplishing the same purpose. For example, in Figs. 3 and 4 the control handle 5 is formed as a container within which is pivoted the system of brake-control levers 8, 9, that connect the finger pieces 10, 11 to the respective cables 12, 13.

Likewise, any other suitable brake-actuating devices may be employed without de-



Patent number US1825577A; filed October 13, 1928; by Walter J Carr; in Saginaw Michigan; aircraft patent

Class Example: Flying-Machine

UNITED STATES PATENT OFFICE.

HARRY C. GAMMETER, OF BRATENAHL, OHIO.

FLYING-MACHINE.

1,135,009. Specification of Letters Patent. Patented Apr. 13, 1915.

Application filed November 17, 1911. Serial No. 660,833.

CLASSIFICATIONS

U.S. Classification	244/22
International Classification	B64C33/00
Cooperative Classification	B64C33/00
European Classification	B64C33/00

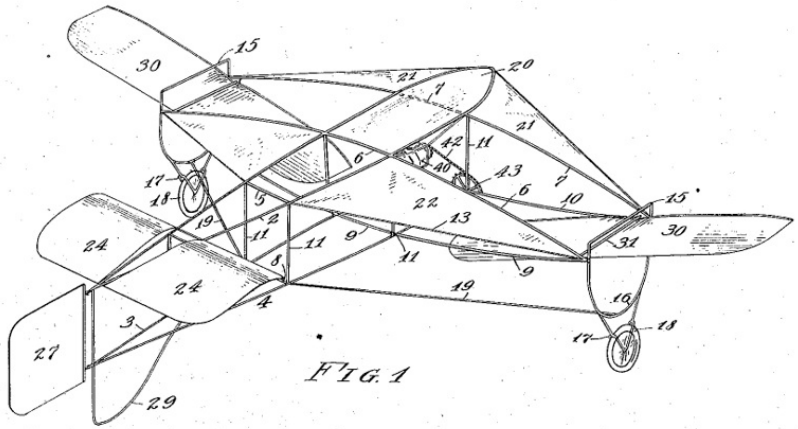
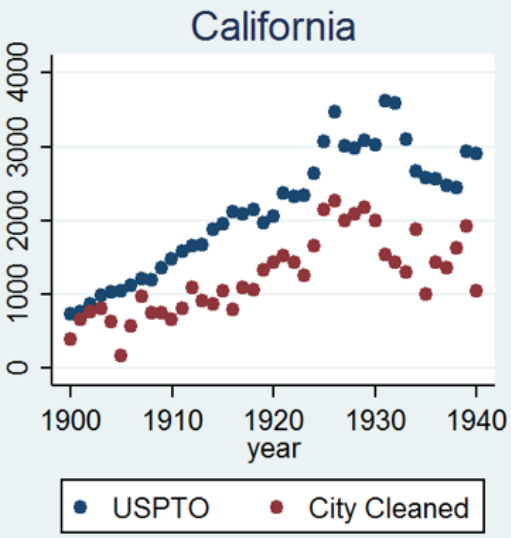
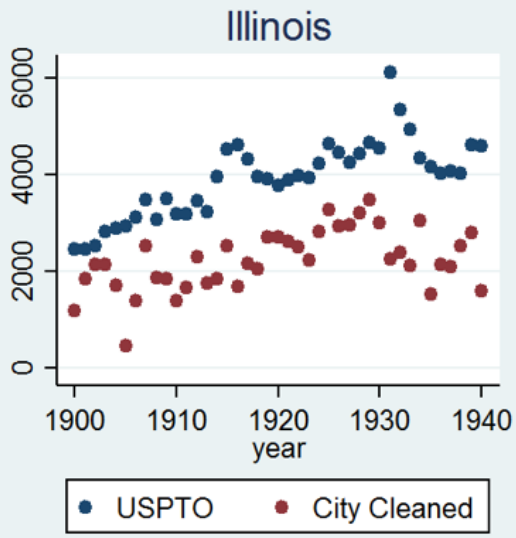
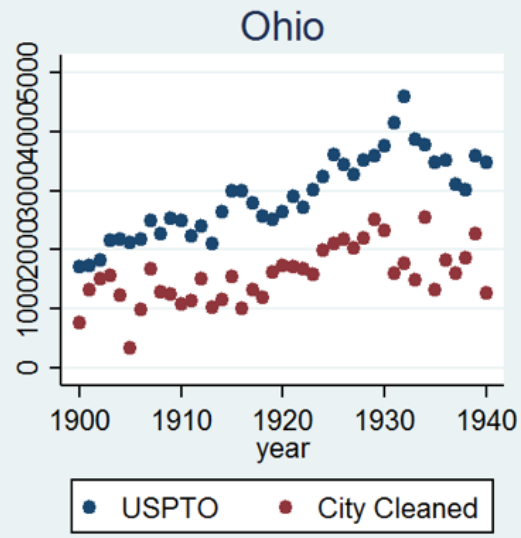


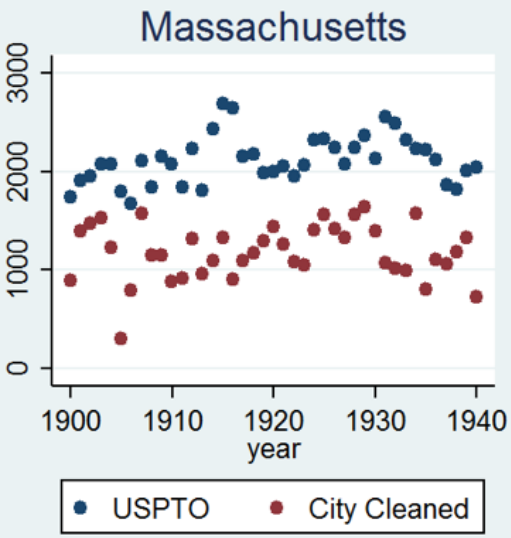
FIG. 1

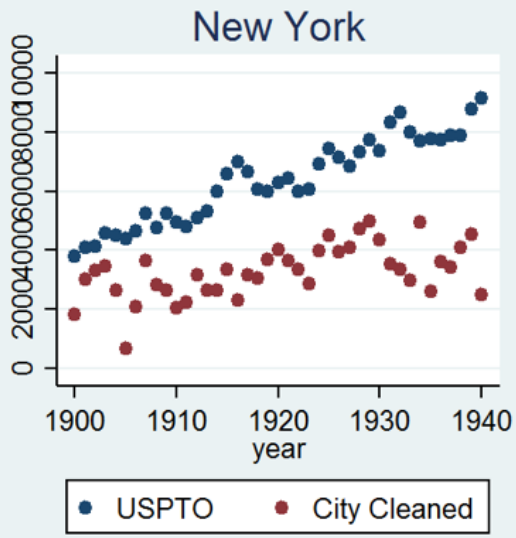
Visual Comparison of Our Data and USPTO

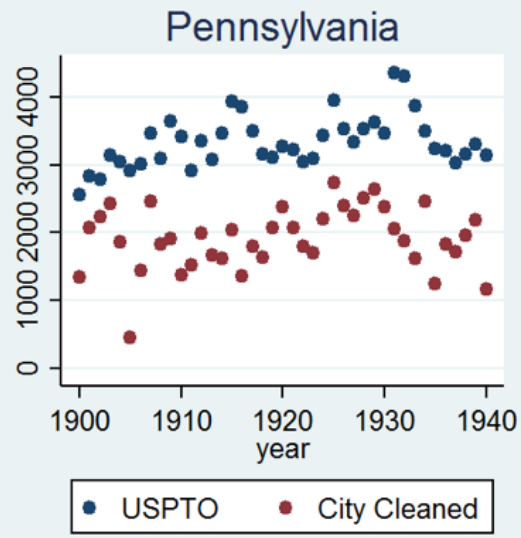












Econometric Specification

$$Innovation\ measure_{it} = \beta_0 + \beta_1 AirmailRoute_{it} + \beta_2 X_{it} + \delta_i + \mu_t + \epsilon_i t$$

$\boldsymbol{Innovation_{it}}$: count of patents or citations in county i in year t

- "aircraft patents" (many zeros, Poisson models)
- "non-aircraft patents" as placebo
- Forward citations, SD citations, citation distributions

$\boldsymbol{AirmailRoute_{it}}$: dummy =1 if airmail route in county i in year t
$\boldsymbol{X_{it}}$: County-year population from Fishback et al; includes interpolations
Data: county-year observations, 1915-1935

Summary Statistics (County-Year)

	Treated					Control				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
Year	714	1925.00	6.06	1915	1935	1743	1925.00	6.06	1915	1935
Aircraft Patents	714	1.50	3.47	0.00	31	1743	1.50	4.21	0.00	41.00
Non-Aircraft Patents	714	104.03	185.58	0.00	1135.00	1743	84.52	86.54	0.00	410.00
Avg. Forward Citations	714	1.39	4.28	0.00	64.00	1743	1.62	4.47	0.00	73.00
SD of Forward Citations	714	0.75	2.15	0.00	21.97	1743	0.93	3.54	0.00	53.74
Patents of Bottom 10% Cites	714	0.33	0.94	0.00	8.00	1743	0.40	1.50	0.00	15.00
Patents of Bottom 25% Cites	714	0.47	1.31	0.00	14.00	1743	0.52	1.66	0.00	15.00
Patents of Top 25% Cites	714	0.30	0.90	0.00	7.00	1743	0.35	1.13	0.00	12.00
Patents of Top 10% Cites	714	0.15	0.53	0.00	5.00	1743	0.13	0.52	0.00	5.00

Samples Balanced Across Demographics

Variable	Mean Treated	SD Treated	Mean Control	SD Control	T-Stats (P-value)
Controls Used in the Propensity Score Matching					
Total Population (1920)	342638.91	7.13E+04	263209.22	35806.18	1.00 (0.322)
Manufacturing Establishments (1920)	1019.53	236.83	818.95	128.31	0.74 (0.458)
Existence of Early Aircraft Manufacturers	0.32	0.08	0.3	0.05	0.23(0.819)
Existence of Army Airbases	0.32	0.08	0.31	0.05	0.15(0.879)
Pre-1918 Sum of Aircraft Patents	6.97	1.69	7.54	1.52	-0.25 (0.804)
Pre-1918 Sum of Non-Aircraft Patents	922.41	242.07	987.46	111.45	-0.24 (0.808)
Controls Not Used in the Propensity Score Matching					
Urban Population (1920)	311486.06	7.07E+04	221516.47	34954.97	1.14 (0.256)
Population Density (1920)	2103.08	964.49	811.1	238.59	1.30 (0.196)
Population in Schooling, 18-20 (1920)	2120.35	383.23	1758.66	225.75	0.81 (0.418)
Male Population, 18-44 (1920)	82451.32	17446.43	58614.59	8261.6	1.23 (0.219)
No. of Manufaturing Wage Earners (1920)	38171.65	9825.9	38467.17	5783.1	-0.03 (0.979)
Value of Manufacturing Output, 18-44 (1920)	2.93E+08	7.30E+07	2.66E+08	4.50E+07	0.31 (0.759)
Manufacutring Value Added, 18-44 (1920)	1.16E+08	3.30E+07	1.04E+08	1.70E+07	0.32 (0.751)
Bank Deposit (1920)	113034.7	25353.31	77147.06	8692.23	1.34 (0.183)

Notes: Cross-sectional differences between 34 treated counties and 83 matched counties

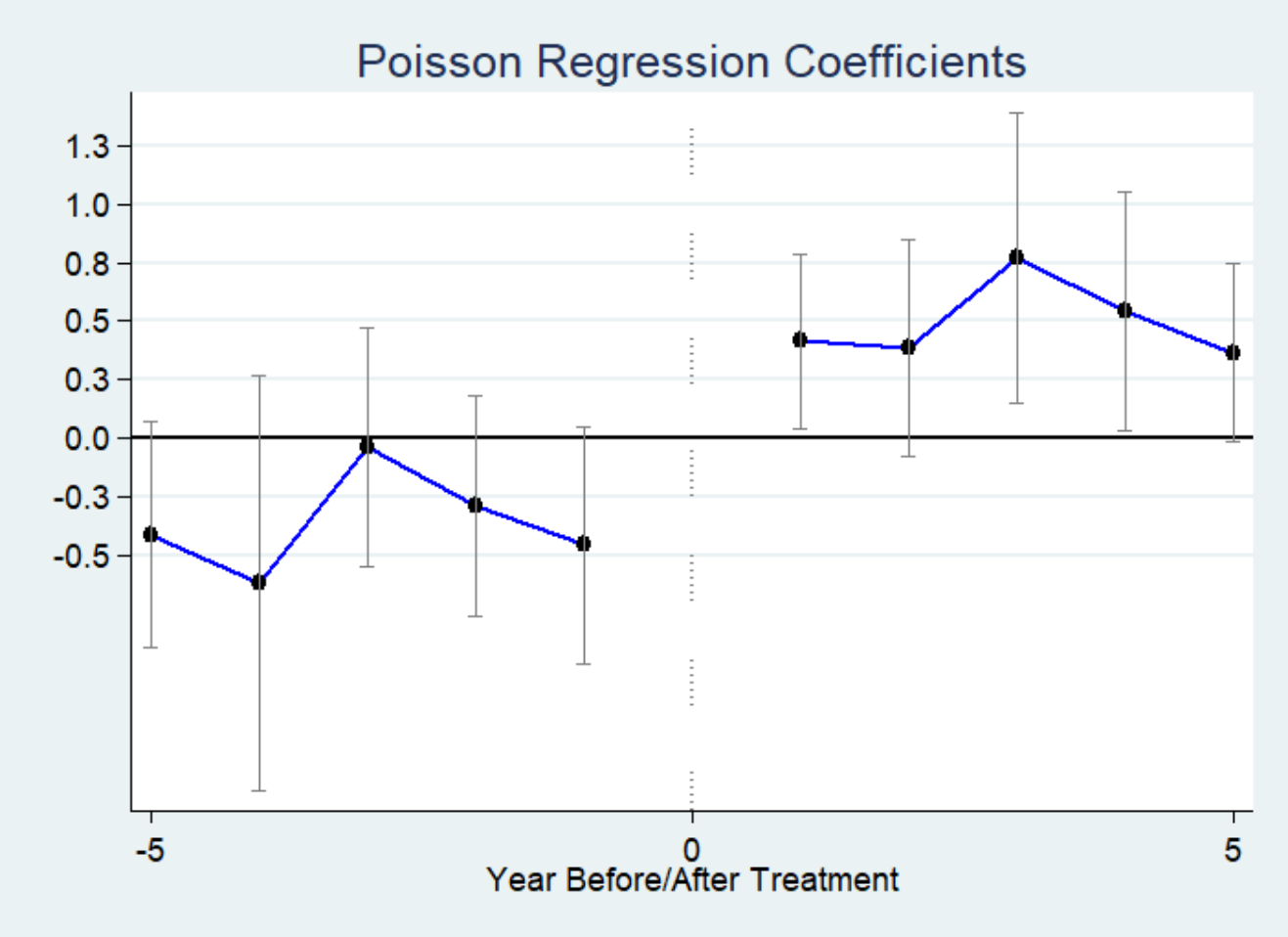
Aircraft Patents Increase Following Entry of Airmail

- Treated counties show a 93% increase in aircraft patenting, post-treatment; From about 1.5 to 2.9 patents.

	(1) Aircraft Patents 1915-1935	(2) Aircraft Patents 1915-1935	(3) Aircraft Patents 1915-1930	(4) Aircraft Patents Treated Counties Only 1915-1935	(5) Non-Aircraft Patents Only 1915-1935
Post-Entry	0.773***	0.658***	0.740***	0.459*	0.032
	(0.174)	(0.194)	(0.185)	(0.256)	(0.079)
Population(logged)		0.882**	1.694***	0.512	0.760***
		(0.387)	(0.466)	(0.422)	(0.162)
County FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Obs	1890	1890	1424	630	2415
Group	90	90	89	30	115
Log Likelihood	-1548.87	-1540.10	-1149.37	-653.09	-6773.59

Notes: Poisson regression coefficients with QML robust standard errors clustered at the county level in parentheses. Estimation weighted by propensity score weights. County FE, Year FE included in all models. * $p > 0.1$; ** $p > 0.05$; *** $p > 0.01$

Aircraft Patents Increase Following Entry of Airmail



Both High-impact and Low-impact Patents Increase

	(1)	(2)	(3)	(4)	(5)	(6)
	Patent Counts	Avg. Citations Per Patent	Count of Patents with Forward Citations in			
			Bottom 10%	Bottom 25%	Top 25%	Top 10%
Post-Entry	0.658***	0.114	0.727***	0.738***	0.517	0.845**
	(0.194)	(0.358)	(0.227)	(0.257)	(0.320)	(0.364)
Population(logged)	0.882**	0.164	0.820	0.545	0.992	1.066
	(0.387)	(0.788)	(0.551)	(0.531)	(0.694)	(1.005)
County FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs	1890	1764	1680	1680	1281	966
Group	90	84	80	80	61	46
Log Likelihood	-1540.10	-2665.35	-688.72	-835.35	-589.46	-326.95

Notes: Standard errors clustered at the county level in parentheses. * $p > 0.1$; ** $p > 0.05$; *** $p > 0.01$

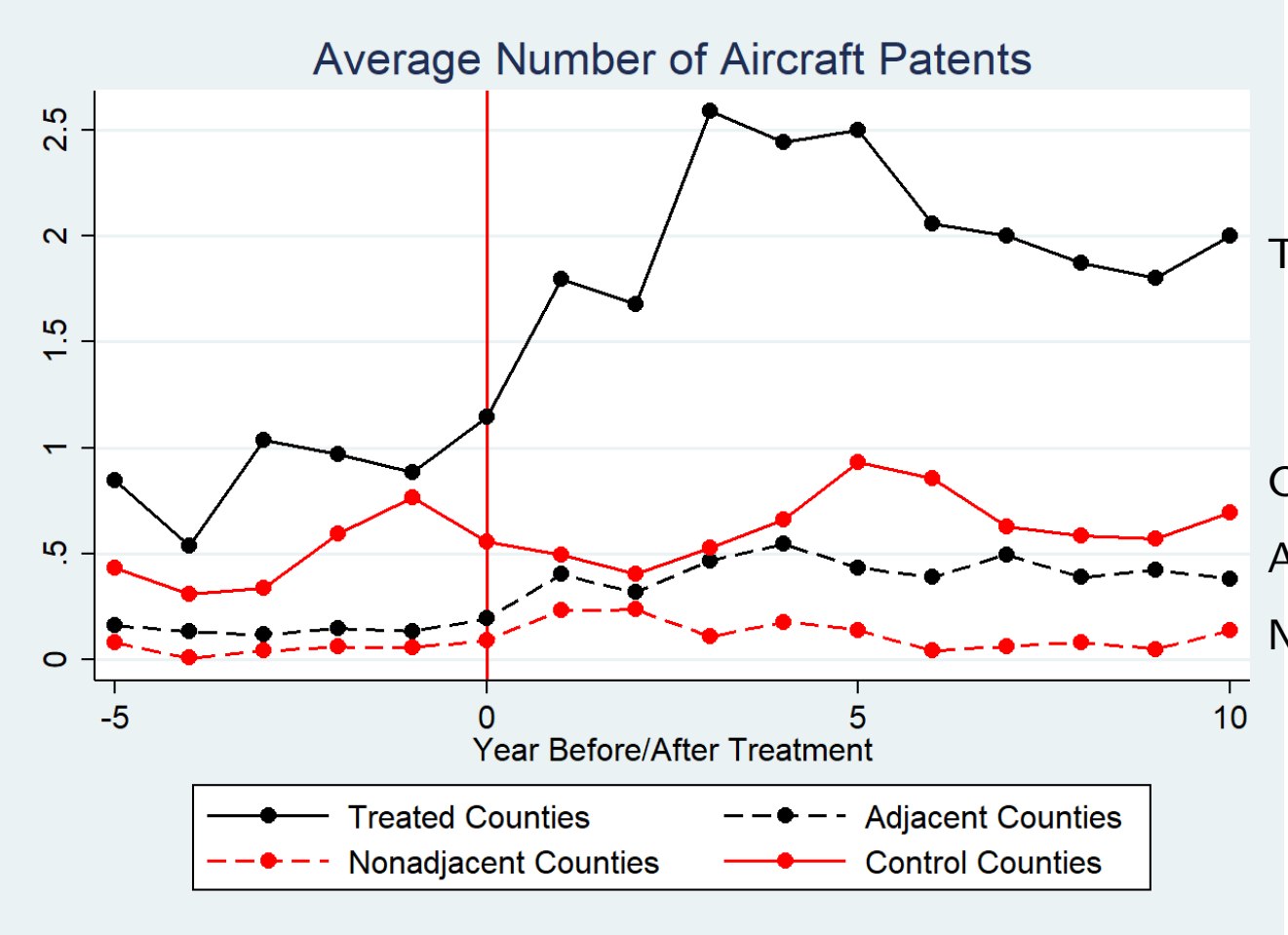
Little Evidence of Technology Spillovers

- Related technology defined as non-aircraft patents in technology subclasses that are listed together with aircraft-related subclasses in aicraft patents

	(1) Aircraft Patents 1915-1935	(2) Aircraft Patents 1915-1935	(3) Aircraft Related 1915-1935	(4) Aircraft Related 1915-1935	(5) Aircraft Unrelated 1915-1935	(6) Aircraft Unrelated 1915-1935
Post-Entry	0.658***		0.264**	0.139	0.131	0.035
	(0.194)		(0.104)	(0.094)	(0.085)	(0.071)
Post-Entry * Multiple Routes		0.721***				
		(0.203)				
Post-Entry * Single Route		0.253				
		(0.231)				
Population(logged)	0.882**	0.867**		0.850***		0.758***
	(0.387)	(0.398)		(0.154)		(0.152)
County FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs	1890	1890	2331	2331	2436	2436
Group	90	90	111	111	116	116
Log Likelihood	-1540.10	-1537.78	-2751.98	-2707.52	-6453.41	-6083.19

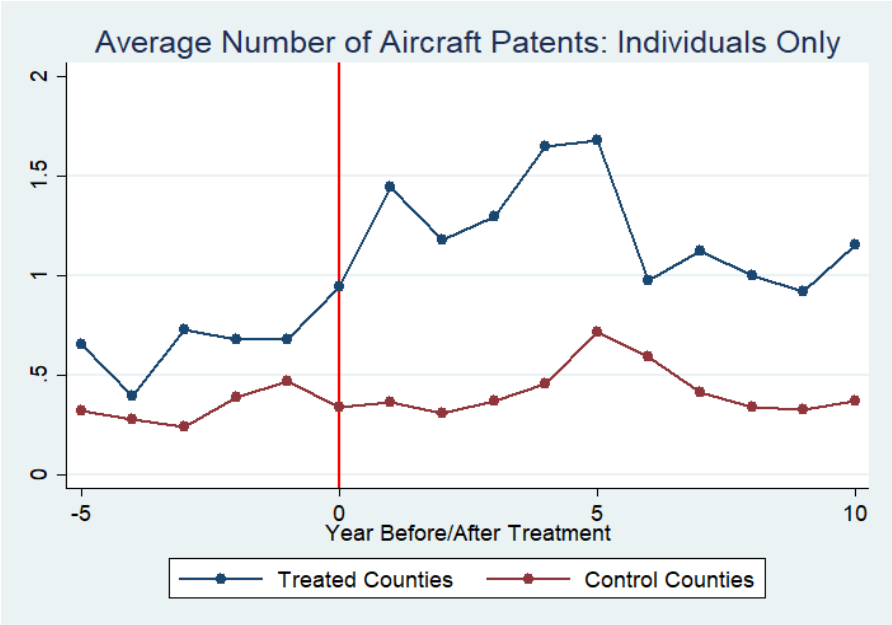
Notes: Standard errors clustered at the county level in parentheses. * $p > 0.1$; ** $p > 0.05$; *** $p > 0.01$

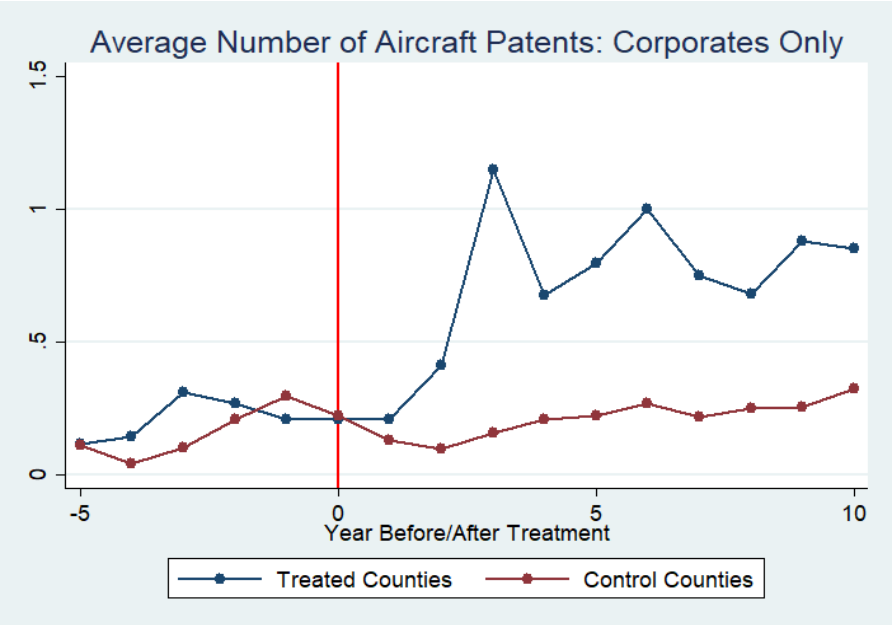
Suggestive Evidence of Geographical Spillovers



The Locus of Innovation: Individual vs. Corporates

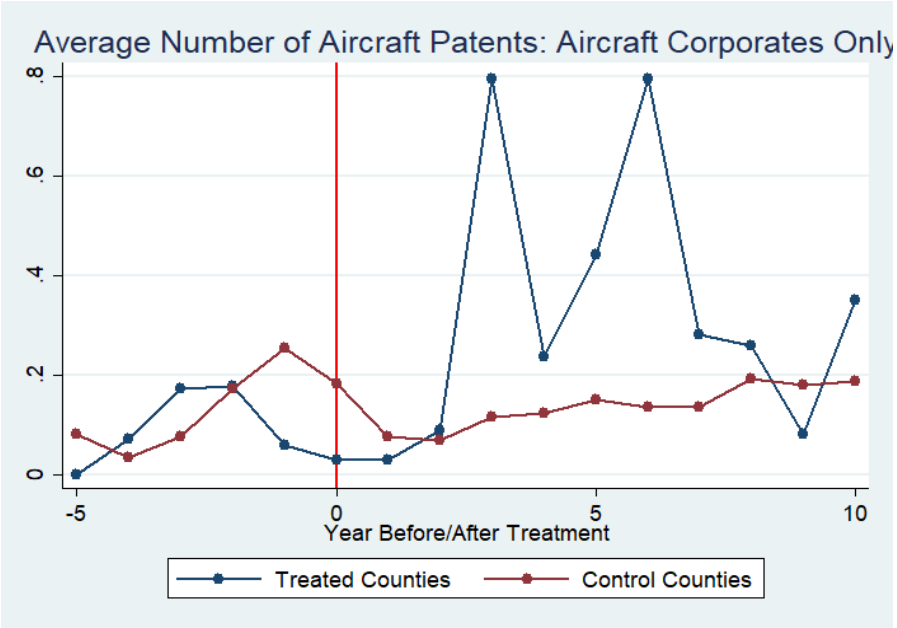
- Used assignee information to distinguish individual-assigned vs. corporate-assigned aircraft patents
- Individual patent filings increase first, followed by corporate patents

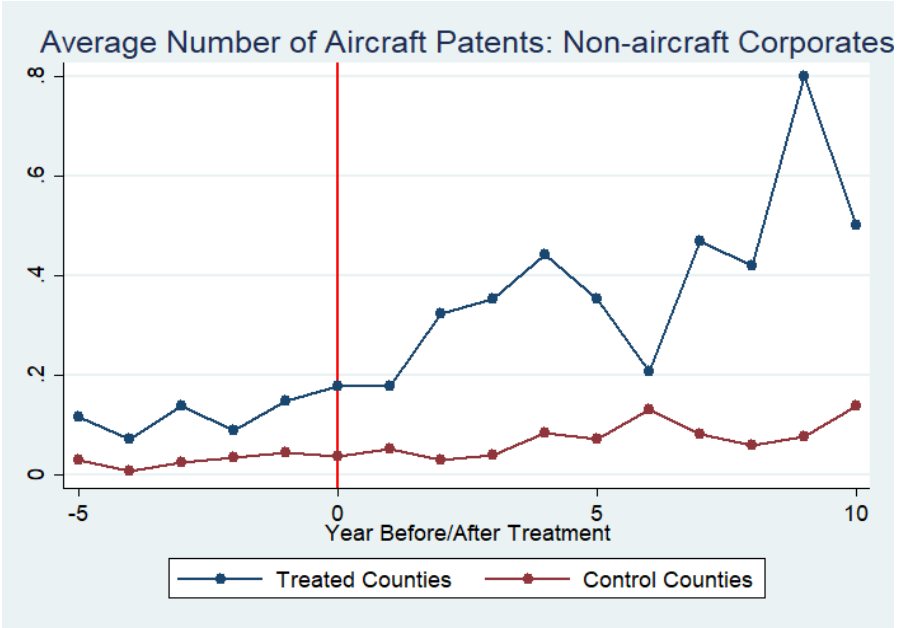




The Locus of Innovation: Aircraft vs. Non-Aircraft Corporates

- Used assignee names to distinguish aircraft company-assigned vs. non-aircraft company-assigned aircraft patents (e.g. Boeing Aircraft vs. Goodyear Tire)
- Aircraft company patents sharply increase at 3+ years; Followed by the rise of non-aircraft company patents





Contributions & Takeaways

1. Document **(unintended) bottom-up spillovers** from early US Airmail
   - Government initiative in the downstream →stimulate upstream innovation
   - Stimulate innovation by creating oupportunities for local inventors to use and tinker with new technology
   - A double-fold increase in aircraft-related innovations at a county level
2. Provide a **new dataset on historical patents** 1900-1940
   - Class, Assignee, Location; to be made public
   - Historical data provide us with opportunities to build upon and refine existing theory
3. Better understanding about the **evolution of a nascent industry**
4. More research needed on the role of the **government** to create bottom-up spillovers by **encouraging downstream activities** (of the private sector) in the R&D value chain