For Online Publication: Online Appendix A

Inventors and Firm Innovation: Evidence from the U.S. World War I Draft

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A.1 Conceptual Framework

The theories of human capital externalities explain how innovations and new ideas generated by knowledge producers or highly-skilled workers influence the productivity of firms. To show these spillovers can coexist with the law of diminishing returns, I develop a modified version of the model following Jones and Romer (2010) and Borjas and Doran (2015a). The production function for invention Y is modeled as an increasing function of the stock of ideas A, the stock of resources K such as buildings, land, and machinery, and the stock of inventors L. Suppose that the Cobb-Douglas production functions is given by

$$Y = A^{\phi} K^{\alpha} L^{1-\alpha} \tag{10}$$

where ϕ is the externalities elasticity for all firms that presents a percent increase in the stock of ideas is associated with a percent increase in invention. The stock of ideas is assumed to be proportional to the number of inventors and dependent on firms $A = L^{\gamma}$ where γ measures the firm-specific degree of increasing returns. A marginal product is then given by

$$\text{MPL} = (\gamma\phi + 1 - \alpha) K^{\alpha} L^{\gamma\phi-\alpha} \tag{11}$$

To analyze how the productivity responses to a supply shock, I show that[14]

$$d\text{logMPL} = \alpha d\text{log}K + (\gamma\phi - \alpha) d\text{log}L \tag{12}$$

In the short run, it is assumed that resources K are fixed, $d\text{log}K = 0$, and let $m = d\text{log}L$.

[14] See the mathematical appendix for more details.

The change in innovation rates following a supply shock of inventors is then given by

$$d\text{logMPL} = (\gamma\phi - \alpha)m \tag{13}$$

The equation (13) shows that spillover effects can coexist with competitive effects that are caused by the law of diminishing returns. This model of innovation rates demonstrates that spillovers will increase a firm's innovation rate as a result of increased innovations when the externality's elasticity ϕ is large, which leads to $\gamma\phi > \alpha$. On the other hand, the law of diminishing returns will act to decrease firms' innovations arising from the supply shock if the spillover effects are small $\gamma\phi < \alpha$. In the context of the WWI draft, losing inventors could either decrease innovation rates of firms when spillover effects come into play or increase innovation rates when competitors disappear following the law of diminishing returns. This model can also be used to explain the differential effects of the supply shock on invention among firms. In response to losing inventors, a firm would reduce productivity if the firm's degree of increasing returns to the stock of ideas is large γ, while they would not decrease inventions if a small degree of returns γ makes spillovers non-existent.

The degree to which human capital externalities come into play depends on the supply shock in three different spaces. Local externalities within a network of each space allows a generalizable model of the human capital externalities. The production function in equation (10) implies that the supply shock alters the productivity by the same proportion for all firms. It seems plausible, however, that a firm's productivity depends on different externalities in all three spaces. Specifically, the externalities may have a large influence on the firm's innovation rates when the firm loses their inventors who worked for the firm prior to the supply shock. For example, a supply shock of inventors in the same collaboration network would significantly reduce inventions of firms when those inventors lose that network. It is also possible that a supply shock that affects a particular area would have a strong effect on the productivity of firms at that location. Moreover, because patent applications can draw from many fields. For example, a supply shock of inventors in a field of chemistry would have a strong impact on inventions to firms in the chemistry field, but could also impact inventors within related fields.

To illustrate differential effects, I introduce local externalities as the number of efficiency units provided by the total invention workforce. Suppose there are N distinct networks and the generalized workforce is written as

$$L = (A_1^{\theta} L_1^{\beta} + \cdots + A_N^{\theta} L_N^{\beta})^{\frac{1}{\beta}} \tag{14}$$

where A_n is the stock of ideas in network n, L_n is the stock of invention workforce in network n, and θ is the local externality elasticity. Suppose that the stock of ideas is proportional to the size of invention workforce depending on firms and networks. It is then defined by $A_n = L_n^{\gamma\sigma}$ where γ is a firm-specific parameter and σ is a network-specific parameter that can vary for each of three spaces. These parameters are used to measure the network-specific spillovers for each firm. The model shows that the change in marginal product for a firm in network n as a result of a supply shock in network n is

$$d\text{logMPL}_n = (\gamma\phi + 1 - \alpha - \beta)m + (\gamma\sigma\theta + \beta - 1)m_n \tag{15}$$

where $d\log L = m$, $d\log L_n = m_n$, and resources K are fixed in the short run.

The supply shock is therefore measured by the percent change in the total supply of inventors and the percent change in the supply of inventors in network n. In the generalized model, the relative strengths of the total externalities elasticity ϕ, the local externalities elasticity θ in network n, and measures of the firm-specific γ and network-specific σ degree of returns to the stock of ideas will determine the impact of the supply shock in network n.

The model described above implies that the short-run impact of the supply shock on invention can be either positive of negative. Further, the model suggests that the supply shock of inventors differentially affects innovation rates of firms depending on the firm's characteristics and on which of the three distinct spaces is considered. The mixed evidence on the spillover effects in empirical studies can therefore be caused by the fact that the studies measure the conceptually different spillovers arising from distinct supply shocks.

To address this issue and test whether the theory is consistent with empirical evidence, I specifically measure the short-run impact of the supply shock in collaboration space, geographic space, and idea space on firm innovation rates. In this case, supply shocks are caused by the WWI draft during 1917-1918 that enlisted inventors into military service. I provide evidence that team members in collaboration space generate knowledge spillovers supporting the theory of human capital externalities, but other inventors outside the firm working on the same topics have a negative impact on firm's innovation rates supporting the law of diminishing returns in the space of ideas.

A.2 Data Description

Patent data

I use PATSTAT to create the firm panel data. I restrict data to "COMPANY" in an indicator of *psn_sector* from the database and "U.S." in *appln_auth*. I then build different measures of patent counts and variables as below.

Patent applications: I sum over the patent applications field by a firm each year.

Original patent applications: I create an indicator of new words in each patent title from *appln_title*. I assume any words contained in patent titles in 1900 as new words. Then, words that already appeared in previous patent titles are defined as non-novel. I define original patents applications containing at least one new word that had not already appeared in previous patent titles.

Patent citations: I sum over the patent citations by a firm each year using *nb_citing_docdb_fam*

Location: To find the location of a firm, I match patents from PATSTAT with the HistPAT database (Petralia et al., 2016). HistPAT provides the county-level geography of patents by the USPTO from 1790 to 1975. I calculate the number of the reported locations of each firm's patents between 1900 and 1916. The most frequently reported location is taken as a proxy for the location. The recent location is used if the number of the reported different locations is equal.

Year of experience: I define years of experience of a firm as years after a first patent application filed by the firm. For example, year of experience takes 1 in year 1913 if a first patent is filed in year 1913. Then, year of experience takes 0 before 1913 and is being added each year after 1913 (i.e., 1 in 1913, 2 in 1914, 3 in 1915, ...).

Inventor data

I use data from Doran and Yoon (2019) in which individual inventors from PATSTAT are merged into the complete 1920 U.S. Census with the full names of individuals. We implement a fuzzy matching procedure between all individual inventors from PATSTAT with 43 percent of the U.S. population with a unique first name, middle name, and last name combination between the ages of 18 and 80. The further details can be found in Doran and Yoon (2019).

WWI data

I use the platform FamilySearch for collecting records on the U.S. WWI draft registration and military service of individuals. I match the individual inventors merged in the census with records on FamilySearch. The matching is implemented as below.

1. Donal sample: I restrict inventor data to 121,027 male inventors who had at least one patent application before the draft, 1917.

2. Matching: I match the full name and birth year of inventors merged in the census with the digitized information on the full name and birth year from FamilySearch through the python coding. FamilySearch provides 30,165,145 United States World War I Draft Registration Cards (1917-1918) and 6,931,032 United States Veterans Administration Master Index (1917-1940).

3. Filtering: Similarity scores are computed and I keep 95 percent of matching scores.

Using this method, I find 67,342 inventors registered for the draft card and 1,783 inventors served in the military.

Supply shocks

Collaboration space: I use the information on patent applications from PATSTAT to identify which inventors file patent applications joint with which firms at which year. Inventors in collaboration space have patents with a firm before the draft (i.e., inventors working with the firm as a team member).

Geographic space: I use the county-level geography of firms matched with the HistPat database and individuals matched with the 1920 Census. Inventors in geographic space work in the same county where a firm is located.

Idea space: I use PATSTAT to assign patents to each industry. Specifically, I assign patents to 84 industries (two-digit NACE Rev. 2) via the International Patent Classification (IPC). Inventors in idea space have patents within a particular field in which a firm holds patents (i.e., inventors working in the same industry or working on the same topics in the space of idea).

A.3 Individual-level analysis

Table B.17 shows the summary statistics for the samples of native inventors who had at least one patent application between 1910 and 1916. Inventors who had served in the military were more productive in the number of patents prior to their service, even though their inventions substantially decreased during the WWI draft. However, inventors who served are used to measure the supply shocks and are, therefore, not included in the analysis sample. Since men who had been drafted and served were more likely to be registered during the first and second registrations, inventors who had served in the military were younger than inventors who did not serve. The age profile has a strong positive impact on innovation rates Bell et al. (2019b). Furthermore, I find little difference between the number of patents by inventors who served in the military before the WWI draft and that of patents of inventors who did not serve but registered between the ages of 21 and 30 during the war.

The supply shock in collaboration space is measured in a similar fashion. Individual i had collaborators who had one or more patent applications with inventor i for the pre-WWI period, 1910-1916. Let P_{iCs} be the number of pre-WWI patent applications per year by inventors who collaborated with individual i and served in the military, and let P_{iC} be the number of pre-WWI patents by collaborators of individual i. The collaboration-specific service rate at the individual level is then given as

$$S_{iC} = \frac{P_{iCs}}{P_{iC}} \tag{16}$$

The variable S_{iC} measures the supply shock inventor i faced when they lost their network of collaborators.

I measure the supply shock in geographic space using the information on the 1920 census merged into the patent data. A person observed in the 1920 census is assumed to have lived in the same place during the WWI draft. Let G be the county where inventor i lived, let P_{Gs} be the number of pre-WWI patents by inventors who registered and served in county G geographically close to inventor i, and let P_G be the number of pre-WWI patents by inventors in county G. The geographic-specific service rate is then given by

$$S_{iG} = \frac{P_{Gs}}{P_G} \tag{17}$$

The variable S_{iG} measures the size of the supply shock that inventor i, who had lived in county G, encountered because of the WWI draft.

Finally, I calculate the supply shock in idea space at the firm level using the field composition of individual i. Let $patent_{if}$ be the number of pre-WWI patent applications that inventor i had in field f and $patent_i$ be the total number of pre-WWI patents by inventor i. Then let P_{fs} be the number of pre-WWI patents in field f by inventors who registered and served, and let P_f be the number of pre-WWI patents in field f by all inventors. The field-specific service rate, calculated by the field composition of inventor i, is defined as

$$S_{iF} = \sum_f \frac{patent_{if}}{patent_i} \frac{P_{fs}}{P_f} \tag{18}$$

The variable S_{iF} measures the supply shock experienced by inventor i when they had lost their peers in a similar field.

I employ analogous difference-in-differences specifications to examine the impact of the supply shocks on the innovation rates of inventors who did not serve. Specifically, I use the following regression model:

$$Y_{it} = \beta_1(S_{iC} \times T_t) + \beta_2(S_{iG} \times T_t) + \beta_3(S_{iF} \times T_t) + \theta X_{it} + \gamma_i + \delta_{st} + \epsilon_{it} \tag{19}$$

where Y_{it} is the number of patents of inventor i in year t; S_{iC}, S_{iG}, and S_{iF} are personspecific supply shocks in collaboration space, geographic space, and idea space, respectively; and T_t is a dummy variable indicating WWI draft years 1917 and 1918. I include the quartic of age of inventor i in year t (X_{it}), individual fixed effects (γ_i), and state-by-year fixed effects (δ_{st}).

Using this regression model, I find large declines in the number of patent applications per year by inventors who did not serve when those inventors had lost their collaborators (Table B.18). The supply shock in idea space has a positive effect on the innovation rates of inventors who did not serve. Specifically, a supply shock that 10 percent of collaborators disappear–which is a 0.1 increase in the WWI service rate in collaborator space, weighted by their pre-WWI patents–decreases the number of patent applications per year by 0.003. Conversely, a 0.1 increase in the service rate in idea space increases the number of patents annually by 0.08. Given the dependent variable mean, when inventors lose 10 percent of their peers, a corresponding 2.2 percent decrease in innovation rates within collaboration space and a 5 percent increase in idea space occur.

I find that the supply shocks affect some inventors who had registered but did not serve and other inventors who neither registered nor served differently. For relatively young inventors, aged 18 and 45, who registered, the supply shock in a network of collaborators has an insignificant and small effect. Conversely, the supply shock in idea space has substantial positive effects on innovation rates. In particular, a 10 percent increase in the service rate in idea space results in a 9.5 percent increase in the number of patent applications per year by inventors who had registered but did not serve. Inventors who neither registered nor served do not benefit from the supply shock in idea space. Most of these inventors were aged 46 or older and experienced a large decline in innovation rates when their collaborators served in the military. Specifically, a 10 percent increase in the service rate in a network of collaboration decreases the number of patents by inventors who did not register or serve by 3.1 percent.

To address possible endogeneity issues, I employ the IV strategy using the instruments that rely on the age profile of inventors. Specifically, I create the analogous supply shocks at the individual level in each of the three spaces measured by draftable inventors.

Table B.19 reports the coefficients from the analogous first-stage regressions at the individual level. The regressions support the validity of the instruments that have a strong first stage. The estimated coefficients on the diagonal demonstrate that the instruments are substantially correlated with the supply shocks measured by inventors who served. The pairwise correlations among the three instruments range from 0.002 to 0.079. The multivariate F-test of excluded instruments demonstrates that the p-values are close to zero.

The IV estimates suggest that losing peers in collaboration spaces has a negative effect on patenting by inventors who did not serve, while the supply shock in idea space has a positive but less significant effect compared to the OSL estimates (Table B.20). Specifically, losing 10 percent of collaborators decreases the number of patent applications per year by 0.007, or 4.5 percent given the average number of patents.

The supply shock in collaboration space has a negative effect on the innovation rates of inventors aged 18 and 45 who had registered but did not serve. However, the supply shock in idea space has a strong positive impact on innovation rates. Specifically, a 10 percent supply shock in idea space increases patenting by inventors who had registered but did not serve by 6.9 percent. The supply shock in collaboration space has a significantly negative effect on the innovation rates of inventors who neither registered nor served and were aged 46 or above. A 10 percent supply shock in collaboration space decreases the number of patents by inventors who neither registered nor served by 8.4 percent. I also consider the reduced-form specifications and find that the results are robust to all outcomes reported in Table B.21.

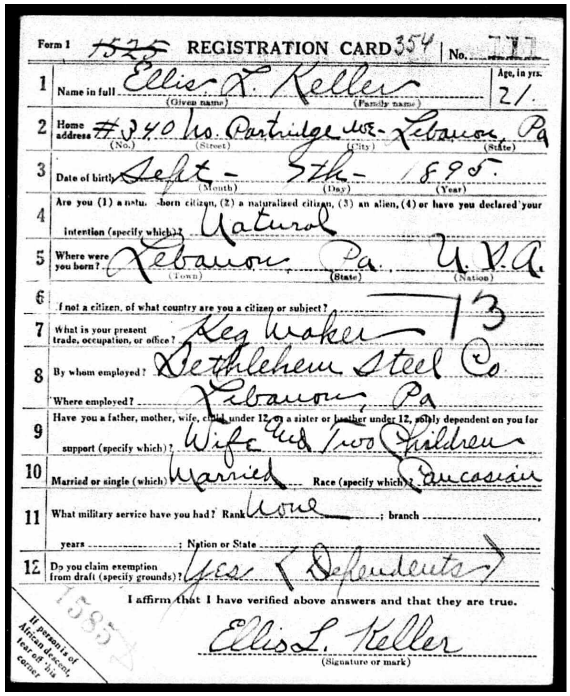
Figure A.1: WORLD WAR I LABOR FORCE

(a) Persons engaged in military, percentage of total labor force

(b) Persons engaged in military (thousands)

Notes: The figures show persons engaged in military across the years from administrative data (Kendrick, 1961).

Figure A.2: EXAMPLE OF DRAFT REGISTRATION CARD


Form 1 ~~1525~~ REGISTRATION CARD 354 No. 111

1 Name in full Ellis L. Keller (Given name) (Family name) Age, in yrs. 21.

2 Home address #340 No. Partridge Ave. Lebanon, Pa (No.) (Street) (City) (State)

3 Date of birth Sept - 5th - 1895 (Month) (Day) (Year)

4 Are you (1) a natural-born citizen, (2) a naturalized citizen, (3) an alien, (4) or have you declared your intention (specify which)? Natural

5 Where were you born? Lebanon Pa. U.S.A. (Town) (State) (Nation)

6 If not a citizen, of what country are you a citizen or subject? 13

7 What is your present trade, occupation, or office? Keg Maker

8 By whom employed? Bethlehem Steel Co. Where employed? Lebanon, Pa

9 Have you a father, mother, wife, child under 12, or a sister or brother under 12, solely dependent on you for support (specify which)? Wife and Two Children

10 Married or single (which) Married Race (specify which)? Caucasian

11 What military service have you had? Rank None ; branch years ; Nation or State

12 Do you claim exemption from draft (specify grounds)? Yes (Dependents)

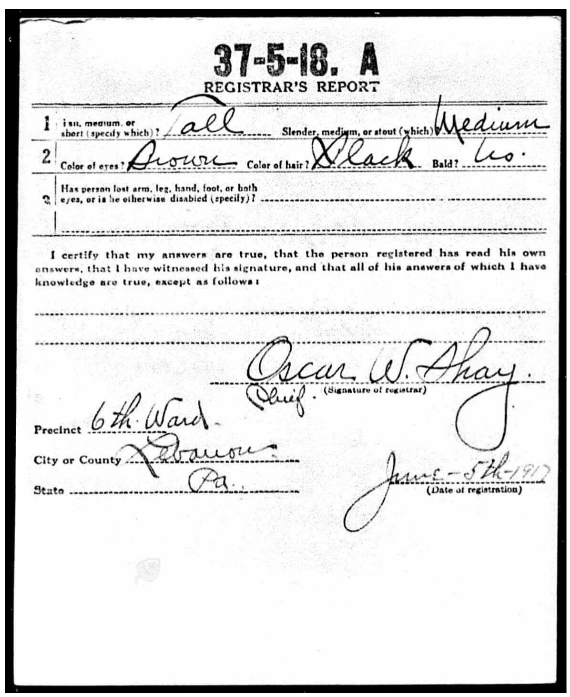
I affirm that I have verified above answers and that they are true.

Ellis L. Keller (Signature or mark)

If person is of African descent, tear off this corner.

1585

(a) Front of the draft registration card


37-5-18. A

REGISTRAR'S REPORT

1 Tall, medium, or short (specify which)? Tall Slender, medium, or stout (which)? Medium

2 Color of eyes? Brown Color of hair? Black Bald? No.

3 Has person lost arm, leg, hand, foot, or both eyes, or is he otherwise disabled (specify)?

I certify that my answers are true, that the person registered has read his own answers, that I have witnessed his signature, and that all of his answers of which I have knowledge are true, except as follows:

Oscar W. Shay. Chief. (Signature of registrar)

Precinct 6th Ward.

City or County Lebanon

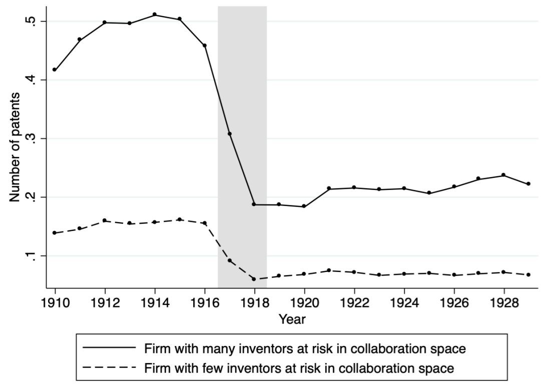
State Pa.

June - 5th - 1917 (Date of registration)

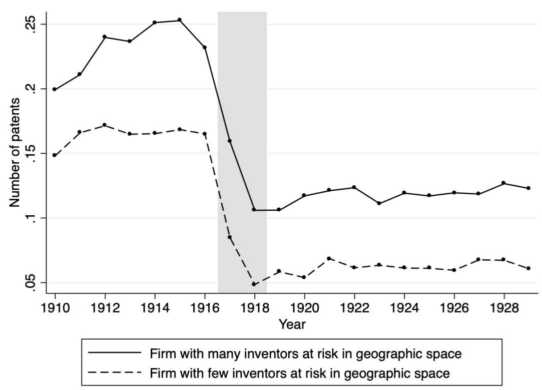
(b) Back of the draft registration card

Notes: This figure shows an example of a draft registration card that was registered in the first registration on June 5, 1917.

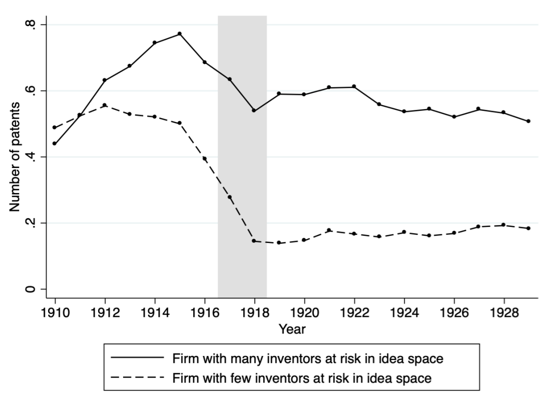
Figure A.3: IMPACT OF SUPPLY SHOCK ON INNOVATION RATES



(a) Collaboration space



(b) Geographic space



(c) Idea space

Notes: The figures show patent applications per year for firms likely to lose inventors and firms unlikely to lose inventors in each space, respectively. The sample consists of firms which had at least one patent application prior to the WWI draft and no patent application belonging to the arms industry, such as weapon, ammunition, and explosives. Firms with many inventors at risk had a portion of inventors of draftable age above the median, while firms with few inventors had a portion of inventors of draftable age equal to or below the median in each space, respectively. The outcome variable is the number of patent applications per year not relevant for the arms industry. The number of patent applications is winsorized at 10.

Table A.1: WORLD WAR I DRAFT

<table>
<tr><th>Register</th><th>Draft</th><th>Serve</th><th>Number</th><th colspan="3">Percent</th><th>Patent data</th></tr>
<tr><th>(1)</th><th>(2)</th><th>(3)</th><th>(4)</th><th>(5)</th><th>(6)</th><th>(7)</th><th>(8)</th></tr>
<tr><td>Y</td><td>Y</td><td>Y</td><td>2,566,748</td><td rowspan="2">58.66</td><td rowspan="2">11.6</td><td>91.33</td><td rowspan="2">Served inventor
(1,783)</td></tr>
<tr><td>Y</td><td>N</td><td>Y</td><td>243,548</td><td>8.67</td></tr>
<tr><td>Y</td><td>Y</td><td>N</td><td>367,200</td><td>-</td><td rowspan="2">88.4</td><td>1.52</td><td rowspan="2">Registered, but not served
(67,342)</td></tr>
<tr><td>Y</td><td>N</td><td>N</td><td>21,423,725</td><td>-</td><td>98.48</td></tr>
<tr><td>N</td><td>N</td><td>Y</td><td>1,980,876</td><td>41.34</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>N</td><td>N</td><td>N</td><td>25,314,807</td><td>-</td><td>-</td><td>-</td><td>Not registered, not served
(51,902)</td></tr>
</table>

Notes: Administrative data from U.S. Provost Marshal General (1919) provides the numbers in column (4). The numbers in parenthesis in column (8) present the number of inventors who had at least one patent application prior to the WWI draft.

Table A.2: IMPACT OF SUPPLY SHOCK ON INNOVATION RATES, OLS COEFFICIENTS

	Specification			
	(1)	(2)	(3)	(4)
Dependent variable: Patent applications per year				
A. Firms				
Supply shock in Collaboration space	-0.0271 (0.0175)	–	–	-0.0282 (0.0176)
Geographic space	–	0.0449 (0.0745)	–	0.0448 (0.0745)
Idea space	–	–	0.0953* (0.0574)	0.0963* (0.0575)
Dependent variable mean	0.1618			
Number of observations	261,279			
Number of firms	29,031			
B. More innovative firms				
Supply shock in Collaboration space	-0.0433 (0.0487)	–	–	-0.0463 (0.0491)
Geographic space	–	0.3347 (0.2687)	–	0.3380 (0.2689)
Idea space	–	–	0.2065* (0.1246)	0.2084* (0.1247)
Dependent variable mean	0.3481			
Number of observations	81,837			
Number of firms	9,093			
C. Less innovative firms				
Supply shock in Collaboration space	-0.0111 (0.0071)	–	–	-0.0105 (0.0071)
Geographic space	–	-0.0372 (0.0328)	–	-0.0366 (0.0327)
Idea space	–	–	-0.0661*** (0.0200)	-0.0658*** (0.0200)
Dependent variable mean	0.0768			
Number of observations	179,442			
Number of firms	19,938			

Notes: The sample consists of firms which had at least one patent application prior to the WWI draft and had no patent application relevant for the arms industry such as weapons, ammunition, and explosives. More innovative firms had pre-WWI patents above the median and less innovative firms had pre-WWI patents equal to or below the median. The outcome variable is the number of patent applications per year not relevant for the arms industry. The number of patent applications is winsorized at 10. Standard errors are clustered by firms. State-year fixed effects are included.

Table A.3: LONG-RUN IMPACT OF SUPPLY SHOCK ON INNOVATION RATES, REDUCED FORM

	Specification			
	(1)	(2)	(3)	(4)
Dependent variable: Patent applications per year				
A. Year: 1910-1929, Post-treatment years: 1917-1929				
Supply shock in Collaboration space	-0.0257*** (0.0051)	–	–	-0.0254*** (0.0051)
Geographic space	–	-0.1548*** (0.0340)	–	-0.1532*** (0.0339)
Idea space	–	–	0.0078 (0.0178)	0.0063 (0.0178)
Dependent variable mean	0.1618			
Number of observations	580,620			
Number of firms	29,031			
B. Year: 1910-1950, Post-treatment years: 1917-1950				
Supply shock in Collaboration space	-0.0311*** (0.0050)	–	–	-0.0316*** (0.0050)
Geographic space	–	-0.1857*** (0.0347)	–	-0.1827*** (0.0346)
Idea space	–	–	-0.0910*** (0.0134)	-0.0929*** (0.0134)
Dependent variable mean	0.1618			
Number of observations	1,190,271			
Number of firms	29,031			
C. Year: 1900-1950, Post-treatment years: 1917-1950				
Supply shock in Collaboration space	-0.0265*** (0.0033)	–	–	-0.0266*** (0.0033)
Geographic space	–	-0.1375*** (0.0232)	–	-0.1354*** (0.0231)
Idea space	–	–	-0.0315*** (0.0087)	-0.0330*** (0.0087)
Dependent variable mean	0.1444			
Number of observations	1,480,581			
Number of firms	29,031			

Notes: The sample consists of firms which had at least one patent application prior to the WWI draft and had no patent application relevant for the arms industry such as weapons, ammunition, and explosives. The outcome variable is the number of patent applications per year not relevant for the arms industry. The number of patent applications is winsorized at 10. Standard errors are clustered by firms.

Table A.4: IMPACT OF SUPPLY SHOCK ON INNOVATION RATES, PLACEBO WWI DRAFT YEARS

	Specification			
	(1)	(2)	(3)	(4)
Dependent variable: Patent applications per year				
A. Placebo pre-treatment years (1910) and post-treatment years (1911-1916)				
Supply shock in				
Collaboration space	-0.0279	–	–	-0.0259
	(0.0284)			(0.0288)
Geographic space	–	-0.0703	–	-0.0505
		(0.1174)		(0.1187)
Idea space	–	–	0.0073	0.0064
			(0.0648)	(0.0649)
B. Placebo pre-treatment years (1910-1911) and post-treatment years (1912-1916)				
Supply shock in				
Collaboration space	-0.0071	–	–	-0.0007
	(0.0241)			(0.0244)
Geographic space	–	-0.1393	–	-0.1384
		(0.1038)		(0.1054)
Idea space	–	–	0.0754	0.0753
			(0.0608)	(0.0608)
C. Placebo pre-treatment years (1910-1912) and post-treatment years (1913-1916)				
Supply shock in				
Collaboration space	-0.0120	–	–	-0.0089
	(0.0223)			(0.0225)
Geographic space	–	-0.0644	–	-0.0573
		(0.0983)		(0.0993)
Idea space	–	–	0.0666	0.0662
			(0.0601)	(0.0601)
D. Placebo pre-treatment years (1910-1913) and post-treatment years (1914-1916)				
Supply shock in				
Collaboration space	0.0278	–	–	0.0313
	(0.0220)			(0.0222)
Geographic space	–	-0.0357	–	-0.0590
		(0.0910)		(0.0920)
Idea space	–	–	0.0888	0.0899
			(0.0599)	(0.0599)

Notes: The sample consists of firms which had at least one patent application prior to the WWI draft. The outcome variable is the number of patent applications per year. The number of patent applications is winsorized at 10. Standard errors are clustered by firms.

Table A.5: IMPACT OF SUPPLY SHOCK ON INNOVATION RATES, REDUCED FORM, CONTROLLING FOR THE GOVERNMENT'S EFFECT

	Specification			
	(1)	(2)	(3)	(4)
Dependent variable: Patent applications per year				
A. Firms				
Supply shock in Collaboration space	-0.0219*** (0.0067)	–	–	-0.0215*** (0.0067)
Geographic space	–	-0.0611 (0.0430)	–	-0.0602 (0.0429)
Idea space	–	–	0.0590* (0.0343)	0.0579* (0.0343)
Dependent variable mean	0.1617			
Number of observations	260,901			
Number of firms	28,989			
B. More innovative firms				
Supply shock in Collaboration space	-0.0372* (0.0205)	–	–	-0.0351* (0.0205)
Geographic space	–	0.1413 (0.1444)	–	0.1383 (0.1444)
Idea space	–	–	0.1502* (0.0869)	0.1468* (0.0870)
Dependent variable mean	0.3484			
Number of observations	81,567			
Number of firms	9,063			
C. Less innovative firms				
Supply shock in Collaboration space	-0.0029 (0.0027)	–	–	-0.0030 (0.0027)
Geographic space	–	-0.0315* (0.0190)	–	-0.0310 (0.0190)
Idea space	–	–	-0.0423*** (0.0127)	-0.0424*** (0.0127)
Dependent variable mean	0.0768			
Number of observations	179,334			
Number of firms	19,926			

Notes: The sample consists of firms which had at least one patent application prior to the WWI draft and had no patent application relevant for the arms industry such as weapons, ammunition, and explosives and for which firms collaborated with the government. More innovative firms had pre-WWI patents above the median and less innovative firms had pre-WWI patents equal to or below the median. The outcome variable is the number of patent applications per year not relevant for the arms industry and the government. The number of patent applications is winsorized at 10. Standard errors are clustered by firms.

Table A.6: IMPACT OF SUPPLY SHOCK ON NEW INVENTORS, NEW FIRMS, AND INNOVATION AT THE INDUSTRY-LEVEL, REDUCED FORM

	Dependent variable		
	New inventors (1)	New firms (2)	Patents (3)
A. Year: 1910-1918, Post-treatment years: 1917-1918			
Supply shock × Post-treatment	471*	55*	0.2426
	(251)	(30)	(1.0670)
Dependent variable mean	190	26	4.7298
Number of observations	756	756	756
B. Year: 1910-1929, Post-treatment years: 1917-1929			
Supply shock × Post-treatment	1388*	113*	-0.2416
	(758)	(64)	(1.3223)
Dependent variable mean	190	26	4.7298
Number of observations	1,680	1,680	1,680
C. Year: 1900-1929, Post-treatment years: 1917-1929			
Supply shock × Post-treatment	1431*	120*	0.4187
	(773)	(67)	(1.3543)
Dependent variable mean	563	55	5.8460
Number of observations	2,520	2,520	2,520
D. Year: 1900-1950, Post-treatment years: 1917-1950			
Supply shock × Post-treatment	1254**	105*	0.4062
	(617)	(56)	(1.2525)
Dependent variable mean	563	55	5.8460
Number of observations	4,284	4,284	4,284
Number of industries	84	84	84

Notes: New inventors are those who patent for the first time in the industry, defined at the level of 84 industry classes in the PATSTAT database. New firms are new entrant firms which patent for the first time in the industry. The dependent variable of patents are the number of patent applications per year at the industry level, taken in natural logarithms. Standard errors are clustered by industries.

Table A.7: IMPACT OF SUPPLY SHOCK ON INNOVATION RATES, REDUCED FORM, HIGHLY INNOVATIVE FIRM

	Specification			
	(1)	(2)	(3)	(4)
Dependent variable: Patent applications per year				
A. Firms in the top 5 percentile of pre-WWI patents				
Supply shock in Collaboration space	-0.6461*** (0.1839)	–	–	-0.5824*** (0.1816)
Geographic space	–	1.6473 (2.0079)	–	1.1058 (1.9774)
Idea space	–	–	1.5834*** (0.3360)	1.4985*** (0.3362)
Dependent variable mean	1.9227			
Number of observations	12,447			
Number of firms	1,383			
B. Firms in the top 10 percentile of pre-WWI patents				
Supply shock in Collaboration space	-0.4037*** (0.1043)	–	–	-0.3666*** (0.1032)
Geographic space	–	0.5951 (0.9502)	–	0.4793 (0.9336)
Idea space	–	–	1.3563*** (0.2374)	1.3143*** (0.2374)
Dependent variable mean	1.2970			
Number of observations	26,397			
Number of firms	2,933			
C. Firms in the top 25 percentile of pre-WWI patents				
Supply shock in Collaboration space	-0.2066*** (0.0414)	–	–	-0.1909*** (0.0412)
Geographic space	–	0.3260 (0.3088)	–	0.2528 (0.3066)
Idea space	–	–	0.8679*** (0.1446)	0.8469*** (0.1445)
Dependent variable mean	0.6663			
Number of observations	73,314			
Number of firms	8,146			

Notes: The sample consists of firms which had at least one patent application prior to the WWI draft and had no patent application relevant for the arms industry such as weapons, ammunition, and explosives. The outcome variable is the number of patent applications per year not relevant for the arms industry. The number of patent applications is winsorized at 10. Standard errors are clustered by firms.

Table A.8: IMPACT OF SUPPLY SHOCK ON ORIGINAL PATENT APPLICATIONS, REDUCED FORM

	Specification			
	(1)	(2)	(3)	(4)
Dependent variable: Original patent applications per year				
A. Firms				
Supply shock in Collaboration space	0.0020 (0.0020)	–	–	0.0021 (0.0019)
Geographic space	–	0.0007 (0.0121)	–	0.0004 (0.0121)
Idea space	–	–	0.0112 (0.0089)	0.0113 (0.0089)
Dependent variable mean	0.0190			
Number of observations	261,279			
Number of firms	29,031			
B. More innovative firms				
Supply shock in Collaboration space	0.0037 (0.0059)	–	–	0.0040 (0.0059)
Geographic space	–	0.0309 (0.0376)	–	0.0313 (0.0377)
Idea space	–	–	0.0200 (0.0227)	0.0205 (0.0227)
Dependent variable mean	0.0403			
Number of observations	81,837			
Number of firms	9,093			
C. Less innovative firms				
Supply shock in Collaboration space	0.0025** (0.0011)	–	–	0.0025** (0.0011)
Geographic space	–	0.0005 (0.0097)	–	0.0003 (0.0096)
Idea space	–	–	-0.0002 (0.0051)	-0.0001 (0.0051)
Dependent variable mean	0.0093			
Number of observations	179,442			
Number of firms	19,938			

Notes: The sample consists of firms which had at least one patent application prior to the WWI draft and had no patent application relevant for the arms industry such as weapons, ammunition, and explosives. More innovative firms had pre-WWI patents above the median and less innovative firms had pre-WWI patents equal to or below the median. The outcome variable is the number of original patent applications per year defined as patents with new one/two/three word phrases in patent title that did not exist in previous patent titles. The number of patent applications is winsorized at 10. Standard errors are clustered by firms.

Table A.9: IMPACT OF SUPPLY SHOCK ON PATENT CITATIONS, REDUCED FORM

	Specification			
	(1)	(2)	(3)	(4)
Dependent variable: Patent citations per year				
A. Firms				
Supply shock in Collaboration space	-0.0360** (0.0157)	–	–	-0.0352** (0.0157)
Geographic space	–	-0.1424 (0.1068)	–	-0.1412 (0.1067)
Idea space	–	–	0.1035 (0.0861)	0.1017 (0.0860)
Dependent variable mean	0.2674			
Number of observations	261,279			
Number of firms	29,031			
B. More innovative firms				
Supply shock in Collaboration space	-0.0686 (0.0466)	–	–	-0.0635 (0.0465)
Geographic space	–	0.0979 (0.3720)	–	0.0921 (0.3720)
Idea space	–	–	0.3829* (0.2137)	0.3765* (0.2135)
Dependent variable mean	0.5610			
Number of observations	81,837			
Number of firms	9,093			
C. Less innovative firms				
Supply shock in Collaboration space	-0.0076 (0.0091)	–	–	-0.0082 (0.0091)
Geographic space	–	-0.1224** (0.0605)	–	-0.1208** (0.0601)
Idea space	–	–	-0.1713*** (0.0430)	-0.1716*** (0.0430)
Dependent variable mean	0.1335			
Number of observations	179,442			
Number of firms	19,938			

Notes: The sample consists of firms which had at least one patent application prior to the WWI draft and had no patent application relevant for the arms industry such as weapons, ammunition, and explosives. More innovative firms had pre-WWI patents above the median and less innovative firms had pre-WWI patents equal to or below the median. The outcome variable is the number of patent citations. The number of patent citations is winsorized at 20. Standard errors are clustered by firms.

Mathematical Appendix: Conceptual Framework

$$
\begin{aligned}
Y &= A^{\phi} K^{\alpha} L^{1-\alpha} \\
&\quad \text{Assume } A = L^{\gamma} \text{ where } \gamma \text{ is a firm-specific parameter.} \\
Y &= L^{\gamma\phi} K^{\alpha} L^{1-\alpha} = K^{\alpha} L^{\gamma\phi+1-\alpha} \\
\text{MPL} &= (\gamma\phi + 1 - \alpha) K^{\alpha} L^{\gamma\phi-\alpha} \\
\text{logMPL} &= \log(\gamma\phi + 1 - \alpha) + \alpha \text{log} K + (\gamma\phi - \alpha)\text{log} L \\
d\text{logMPL} &= \alpha d\text{log}K + (\gamma\phi - \alpha) d\text{log}L \\
&\quad \text{Assume } d\text{log}K = 0 \text{ in the short run and let } d\text{log}L = m \\
\Rightarrow \ d\text{logMPL} &= (\gamma\phi - \alpha) m \\
&\quad \text{Now, assume } L \text{ is given by} \\
L &= (A_1^{\theta} L_1^{\beta} + \cdots + A_N^{\theta} L_N^{\beta})^{\frac{1}{\beta}} \\
&\quad \text{Assume } A_n = L_n^{\gamma\sigma} \text{ where } \sigma \text{ is a network-specific parameter.} \\
L &= (L_1^{\gamma\sigma\theta+\beta} + \cdots + L_N^{\gamma\sigma\theta+\beta})^{\frac{1}{\beta}} \\
Y &= A^{\phi} K^{\alpha} L^{1-\alpha} = K^{\alpha} L^{\gamma\phi+1-\alpha} \\
&= K^{\alpha} (L_1^{\gamma\sigma\theta+\beta} + \cdots + L_N^{\gamma\sigma\theta+\beta})^{\frac{1}{\beta}(\gamma\phi+1-\alpha)} \\
\text{MPL}_n &= \frac{1}{\beta}(\gamma\phi + 1 - \alpha) K^{\alpha} (L_1^{\gamma\sigma\theta+\beta} + \cdots + L_N^{\gamma\sigma\theta+\beta})^{\frac{1}{\beta}(\gamma\phi+1-\alpha)-1} (\gamma\sigma\theta + \beta) L_n^{\gamma\sigma\theta+\beta-1} \\
\text{logMPL}_n &= \log\frac{1}{\beta}(\gamma\phi + 1 - \alpha) + \alpha\text{log}K + \left(\frac{1}{\beta}(\gamma\phi + 1 - \alpha) - 1\right)\text{log}L^{\beta} \\
&\quad + \log(\gamma\sigma\theta + \beta) + (\gamma\sigma\theta + \beta - 1)\text{log}L_n \\
&\quad \text{where } L^{\beta} = L_1^{\gamma\sigma\theta+\beta} + \cdots + L_N^{\gamma\sigma\theta+\beta} \\
d\text{logMPL}_n &= \alpha d\text{log}K + (\gamma\phi + 1 - \alpha - \beta) d\text{log}L + (\gamma\sigma\theta + \beta - 1) d\text{log}L_n \\
&\quad \text{Assume } d\text{log}K = 0 \text{ in the short run and let } d\text{log}L = m,\ d\text{log}L_n = m_n \\
\Rightarrow \ d\text{logMPL}_n &= (\gamma\phi + 1 - \alpha - \beta) m + (\gamma\sigma\theta + \beta - 1) m_n
\end{aligned}
$$