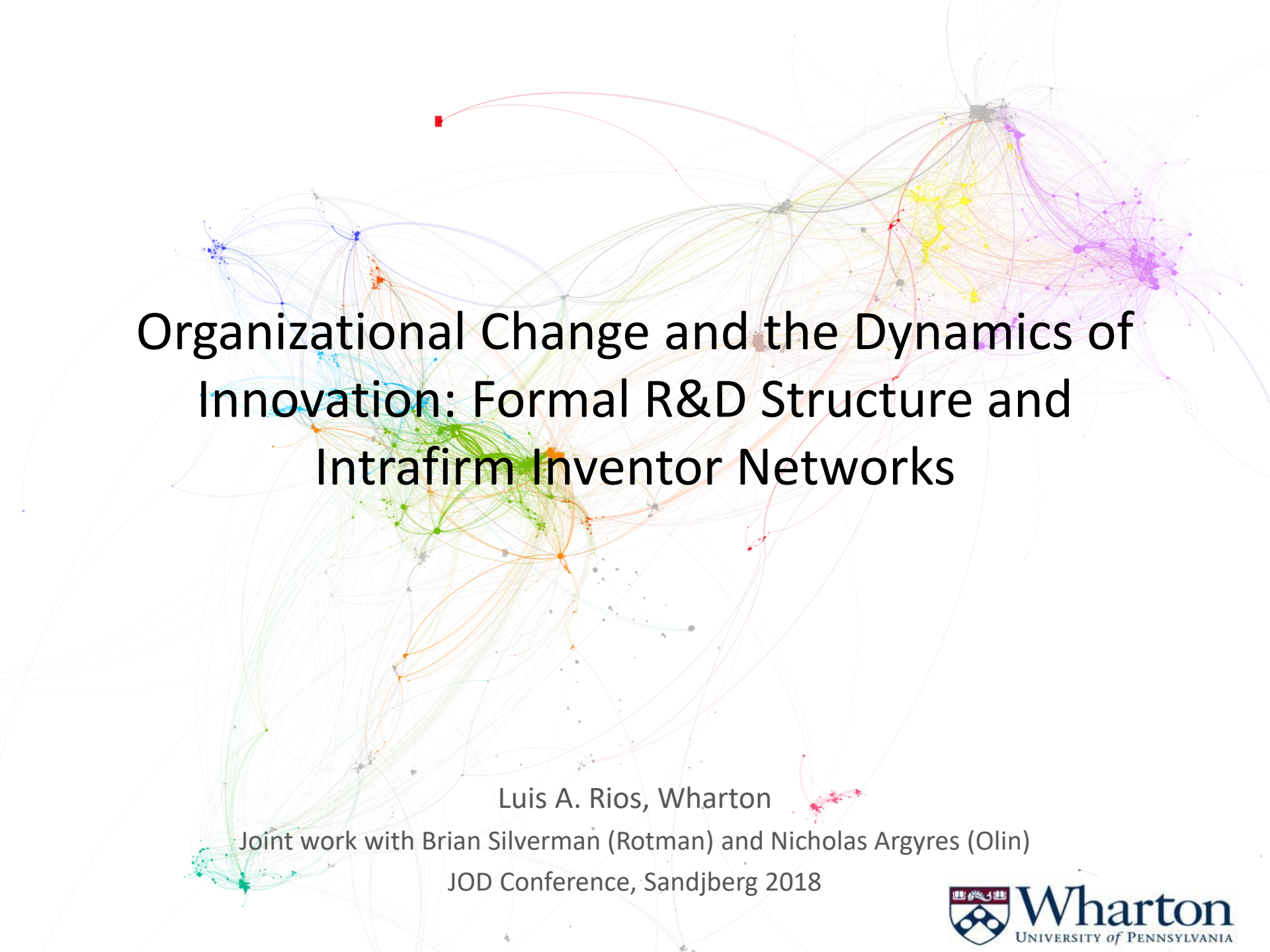

Organizational Change and the Dynamics of Innovation: Formal R&D Structure and Intrafirm Inventor Networks

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Joint work with Brian Silverman (Rotman) and Nicholas Argyres (Olin)

JOD Conference, Sandjberg 2018

Wharton
University of Pennsylvania

Org Structure and Innovation: What we know/don't know

The organization of R&D is a key determinant of innovation (Kay 1988; Teece 1996)

Firm structure and R&D outcomes:

- Argyres & Silverman (*SMJ* 2004): Relationship between centralization of R&D and the type of innovative outcomes. Centralized=broader search, more impact.

- Arora, Belenzon & Rios (*SMJ* 2014): Centralization (decentralization) interacts with external sourcing, both relate to the type of innovative and performance outcomes. Centralized=more scientific, and yield more patents per $

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→ **In *steady-state*, R&D structure shown to be associated with patterns of innovation**

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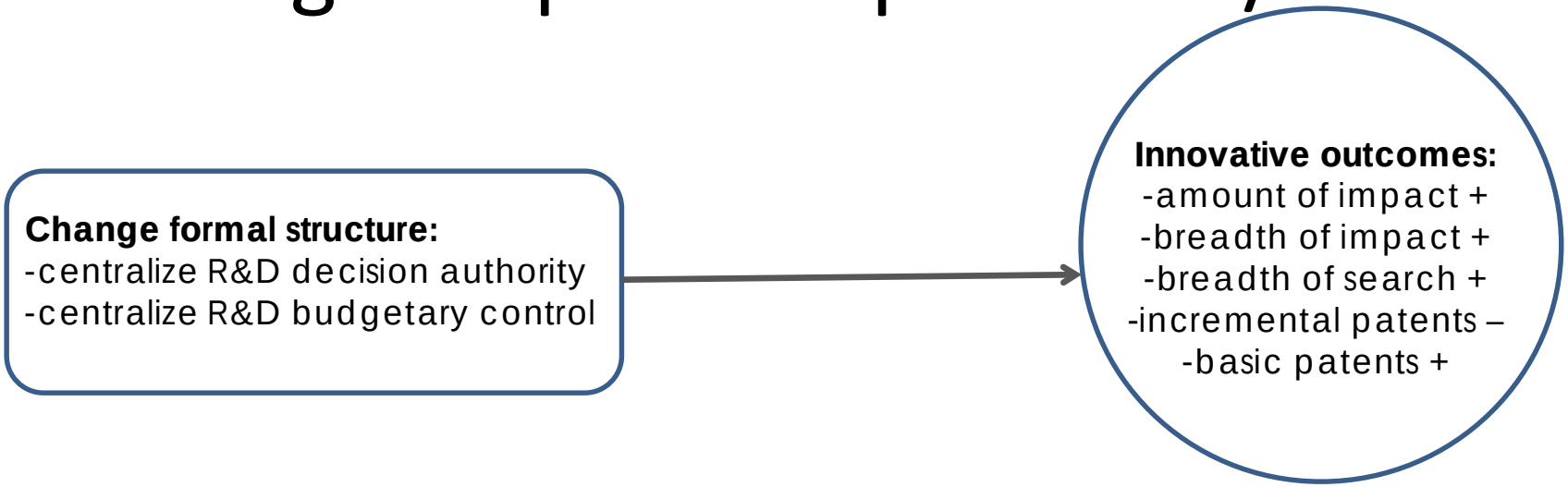
→ **In *steady-state*, R&D structure shown to be associated with patterns of innovation**

Broad Research Question: So… if formal R&D structure is changed, do innovative outcomes change? If so, how fast, how much, and through what channels?

- These are key questions for managers, if they want to purposely change the types of innovations produced
- There has been very little work exploring the dynamics of change in the organization of R&D

If organizations were mechanistic, we might expect simple cause/effect



Extrapolating from steady-state findings, tempting to assume that changing formal structure would have predictable outcomes. ***But***…

But the social nature of a firm may dampen response to formal levers

"Strategy and structure call forth and mold organizational capabilities, but **what an organization can do well has something of a life of its own**."

Richard Nelson (1991)

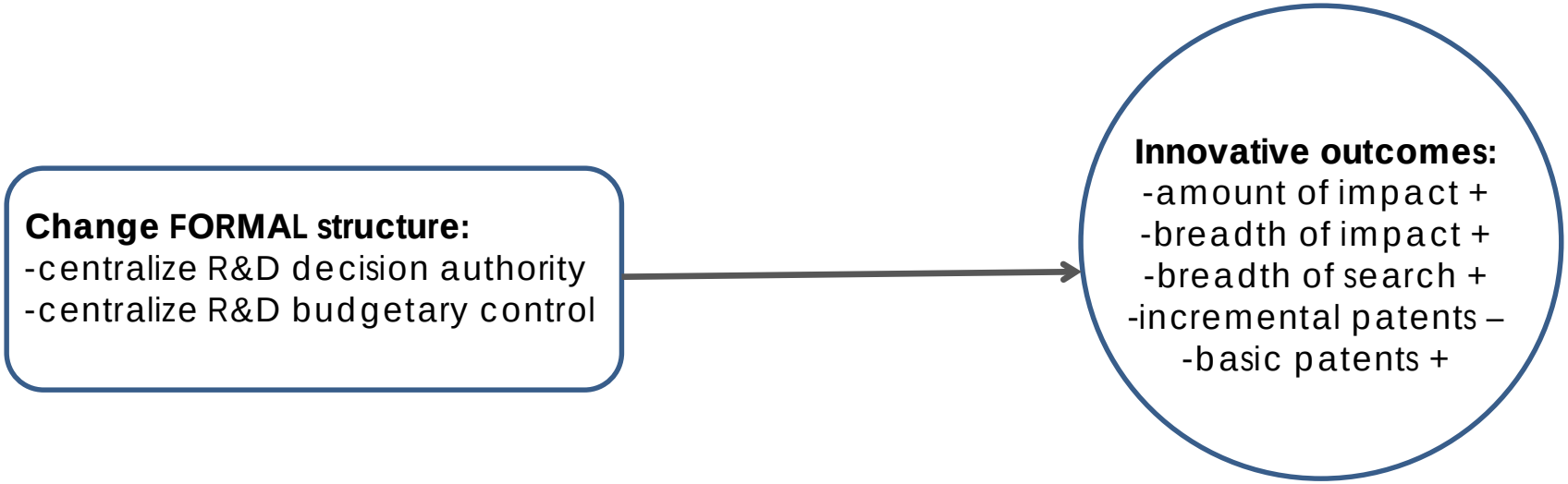
Social network structure likely matters

- Reagans & Zuckerman *(OrgSci 2001):* Social structure of team explains innovative productivity variance
- Nerkar & Paruchuri *(MS 2005):* Position of inventor in intrafirm co-invention network influences subsequent outcomes

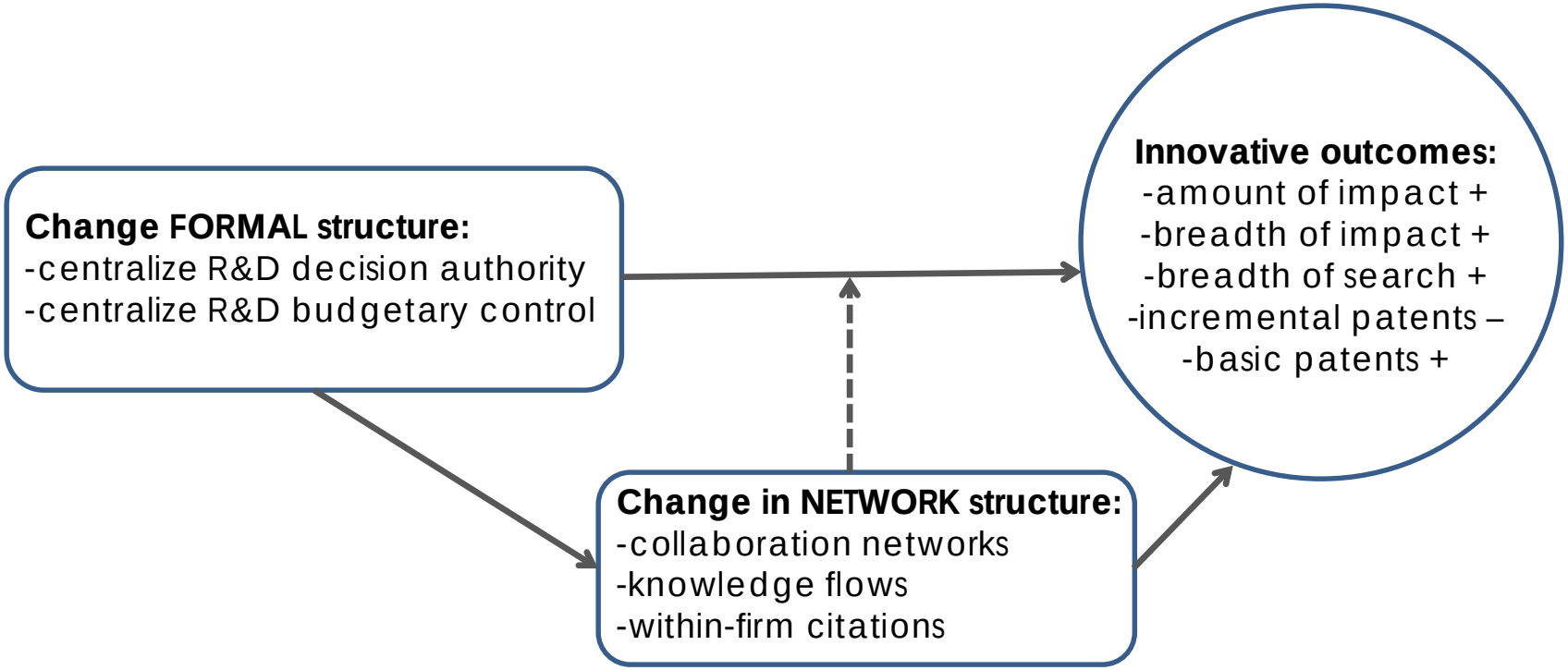
Informal organization influences innovative outcomes

- Nickerson & Zenger *(OrgSci 2002)*; Zenger, Lazzarini & Poppo *(AiSM 2002):* Discrete changes in formal organization structures spark slower, more continuous changes to informal organization

Our specific research questions:



Our specific research questions:



What we do

Use information on discrete changes to the R&D structure undertaken by 12 very large firms

Show the direct effect of these changes on patent-based measures of innovation

Explore a possible mechanism underlying this shift: the relationship between formal R&D structure and the co-patenting and citation networks within each firm.

We propose that this approach can help us infer the extent to which changes in formal organizational structure can affect innovation by influencing patterns of collaboration among the firm's inventors.

Finally, we examine the time lag between implementation of discrete formal change and subsequent changes in network topology. This is an important question, which speaks to the ability of firms to use technology as a respond to competitive threats.

Hypotheses: centralization and patent output

Placing R&D budget control higher on the hierarchy encourages research that is less tied to the needs of divisions (Hounshell & Smith, 1988), and which is more likely to serve the firm more broadly (Argyres & Silverman, 2004). Thus:

- H1a: R&D centralization (decentralization) leads to an increase (decrease) in the **impact** of a firm's patents

- H1b: R&D centralization (decentralization) leads to an increase (decrease) in the **breadth** of technological search of a firm's patents

Hypothesis: centralization and network structure

Centralized R&D manager might actively connect inventors to cross-pollinate innovation. Also, higher incentives to develop technologies that help the whole firm (not just division), should increase collaboration among formerly disconnected inventors. Thus:

– H2: R&D centralization (decentralization) leads to an increase (decrease) in the **cohesiveness** of the firm's ***co-patenting and citation*** network

Hypothesis: network structure and patent output

More cohesive inventor networks should stimulate the diffusion of ideas better (Fleming, Ming & Chen, 2007). As more fundamental innovations tend to emerge from a synthesis of ideas from more disparate technological realms (Nelson & Winter, 1982). Thus:

- H3a: More (less) **cohesive inventor networks** should result in innovations with greater and broader (narrower) innovative impact.
- H3b: More (less) **cohesive inventor networks** should result in innovations with greater and broader (narrower) technological search.

Empirical question: rate of organizational change

Finally, we propose that there is not enough theory to formulate a clear prediction regarding the **lags** we might expect to see between implementation of formal organization change and the ensuing network structure change. Thus, rather than formulate a hypothesis, we leave this as an empirical exploration.

Empirics

Data - What do we need to test this?

- Formal R&D structure – to identify changers vs. non-changers
- Co-author and citation network properties
- Innovative outcomes

Data - What do we need to test this?

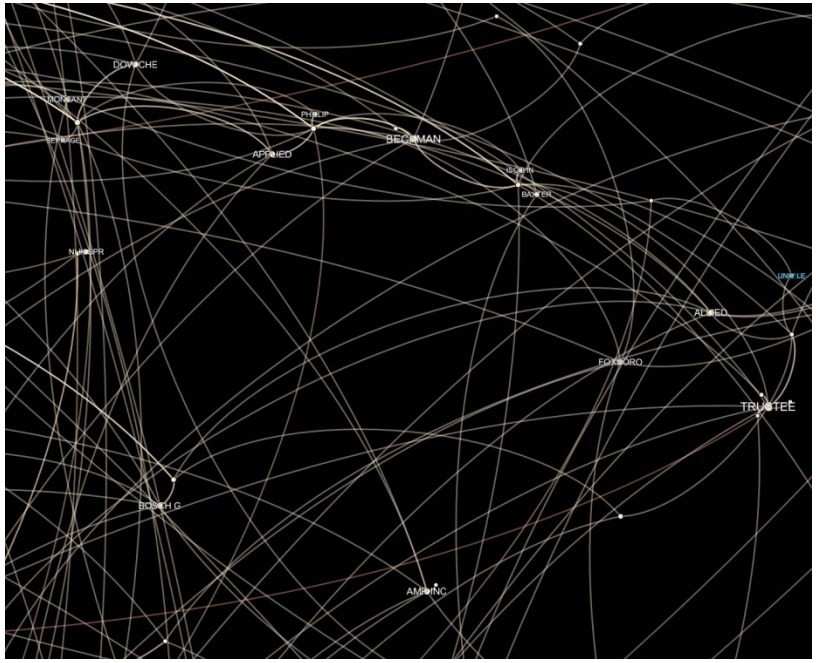
- Formal R&D structure – to identify changers vs. non-changers
  - IRI/CIMS 1990-1998 [ultimately, 12 “changers” and 48 control firms]
    - Annual breakdown of corporate vs. business unit funding
  - Detailed information on extent and timing of substantive changes to decision authority

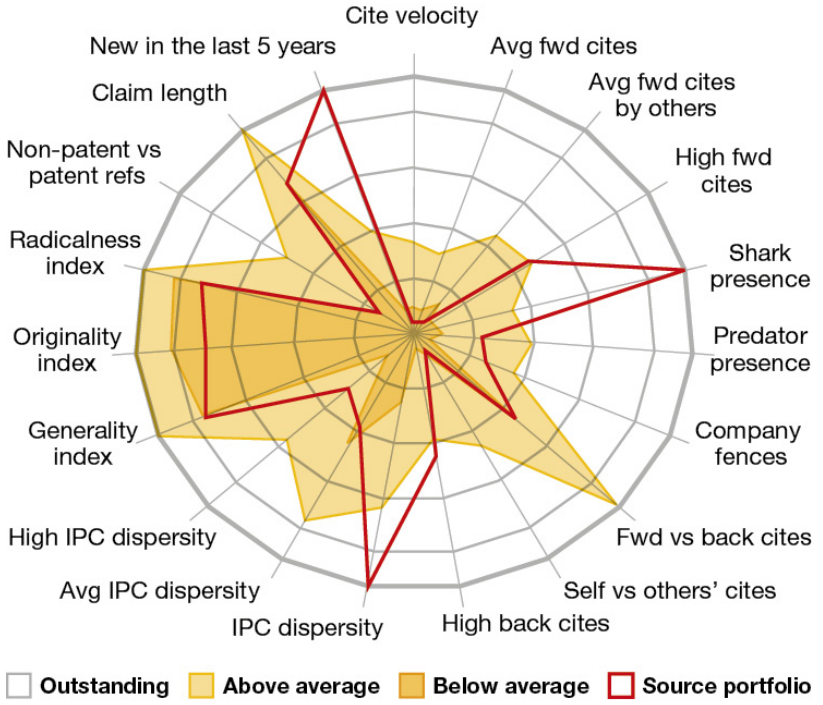
- Co-author and citation network properties
  - Patent ownership and bibliometric dataset constructed by matching EPO’s PATSTAT, USPTO, Bureau VanDjik’s ORBIS database, Lee Fleming's Berkeley data project, and NBER dataset

- Innovative outcomes
  - PATSTAT bibliometrics: patent counts, citations, originality, generality, co-patenting, self-citations.

Data

The patent dataset allows us to dynamically track each firm inventor and patent. For example, who collaborates or cites, when, and what kind of patents they generate.

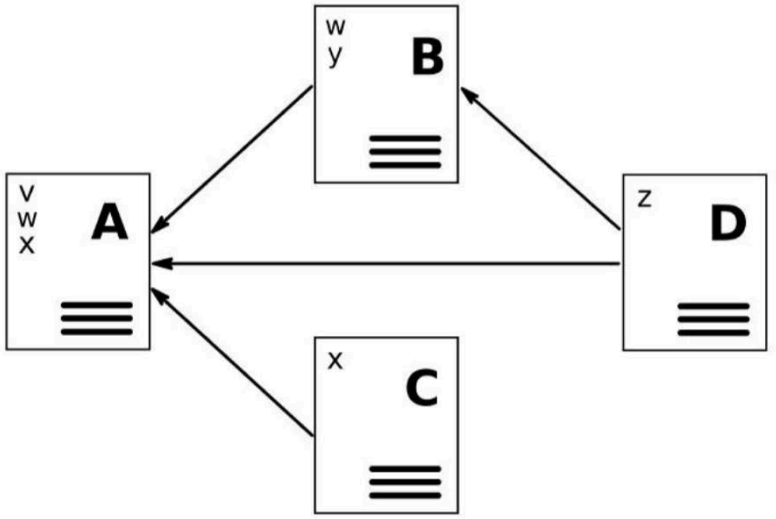




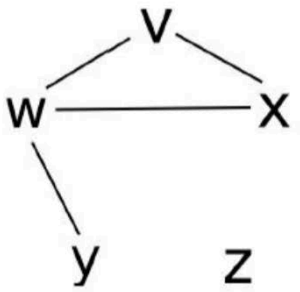
Citation and co-invention networks

Co-inventors (name appears in same patent application). Non-directional tie.

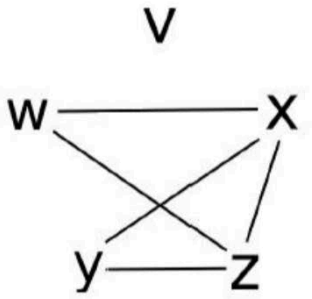
Citations (tie exists between two non-collaborating inventors if their patents cite a common third). Non-directional tie.



(a) Patent citations



(b) Co-authorship



(c) Co-citation

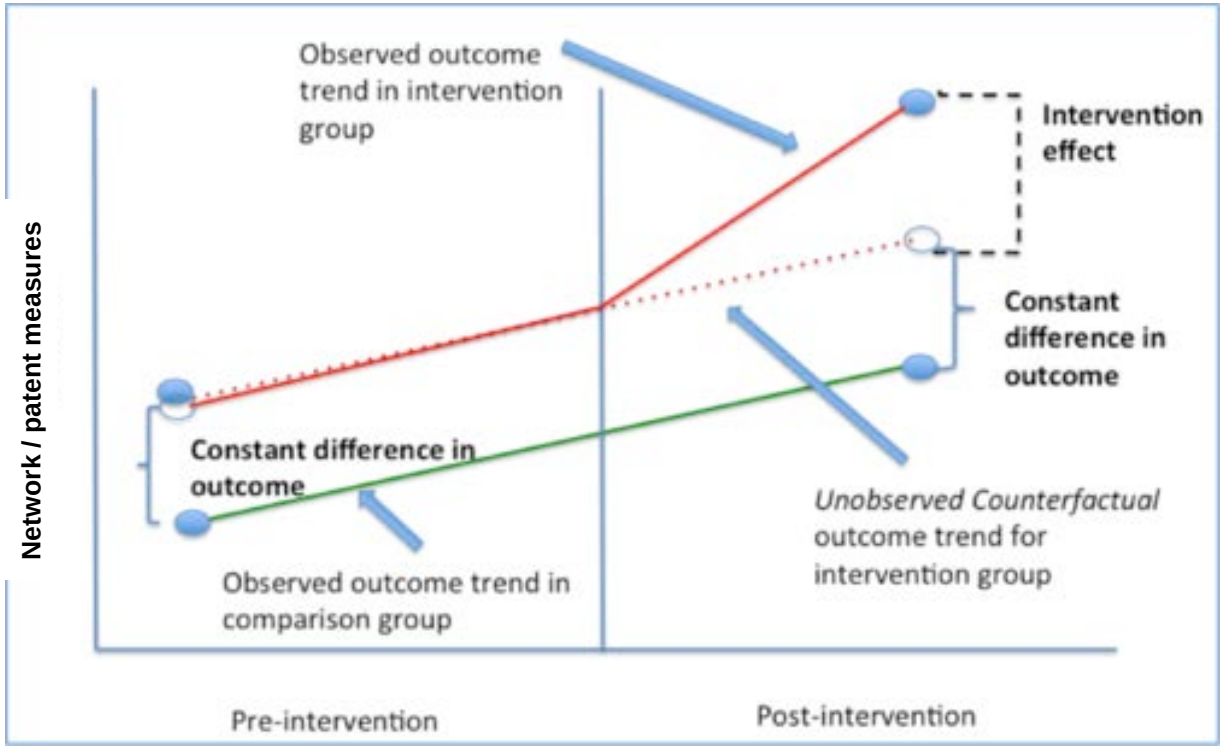
Figure 1: Network construction from a set of patents. (a) Citations (arrows) between four patents (A, B, C, and D). The authors of a patent are listed in the top-left corner. (b) Co-authorship, and (c) author co-citation networks derived from the network of patents in panel (a).

The logic of differences-in-differences estimation

Without context, a single firm's changes are hard to interpret

A reference group solves the problem….

While introducing a new problem: finding adequate "controls"



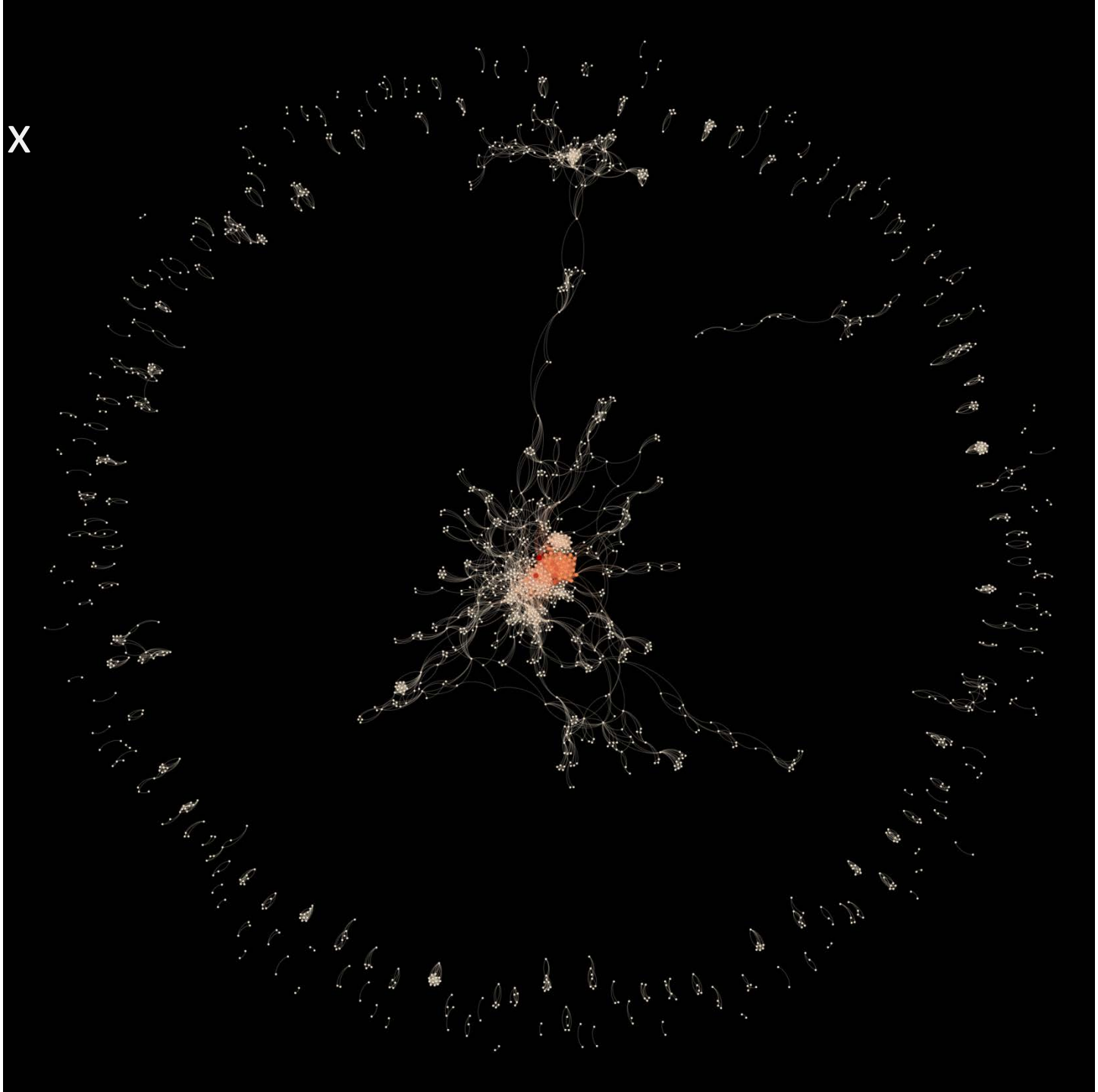
The key assumption: the two groups would have same trends if not for the treatment

Red = control group
Green= treatment group

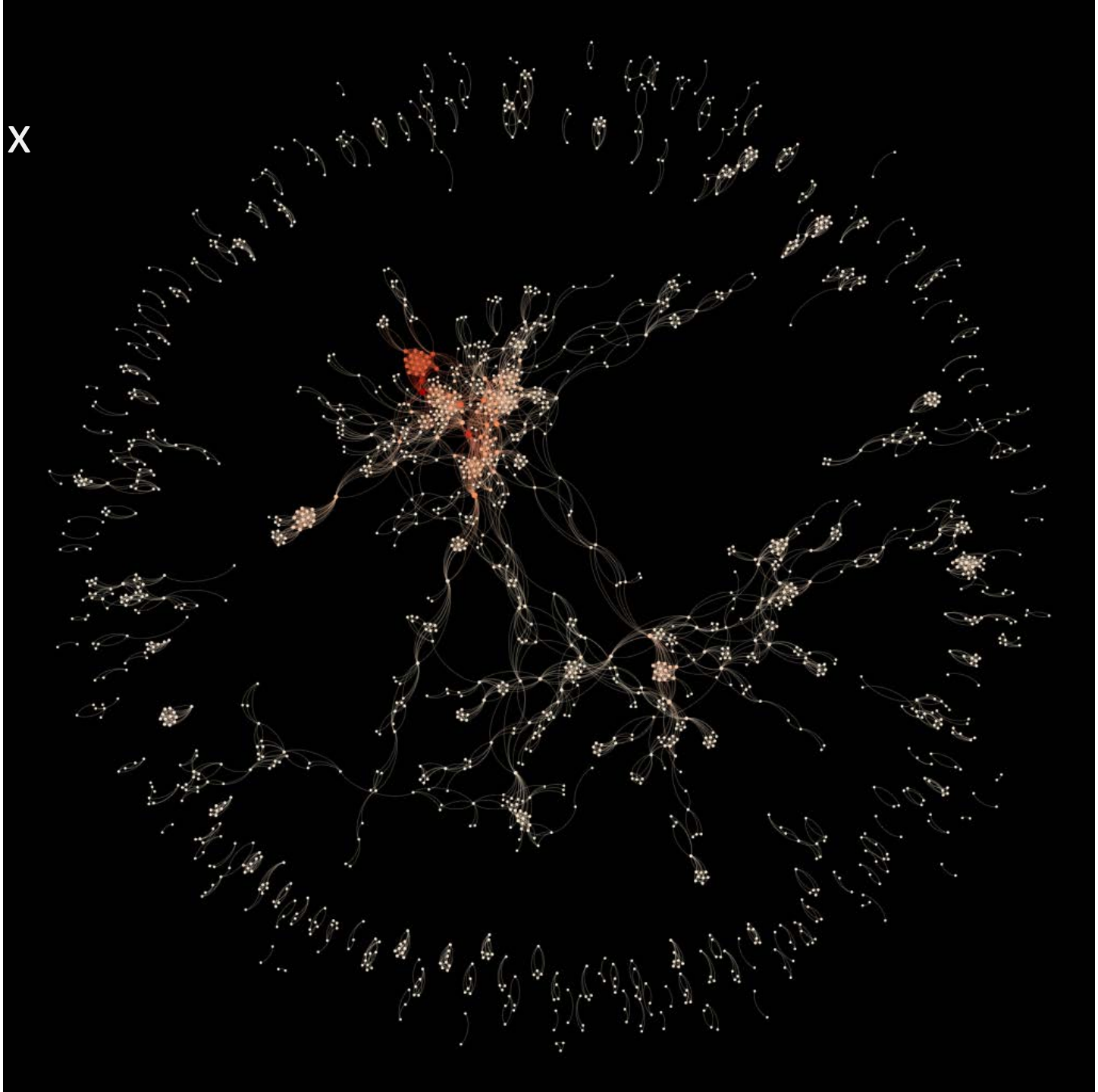
Our solution: Use industry peers

- Create aggregated measures for every firm in the treated firms' industries
- This requires mapping and calculating whole network measures for 48 "control" firms, for 16 years which are the top peer firms in the industry of each focal firm
- This results in almost 1,000 firm-year full network snapshots

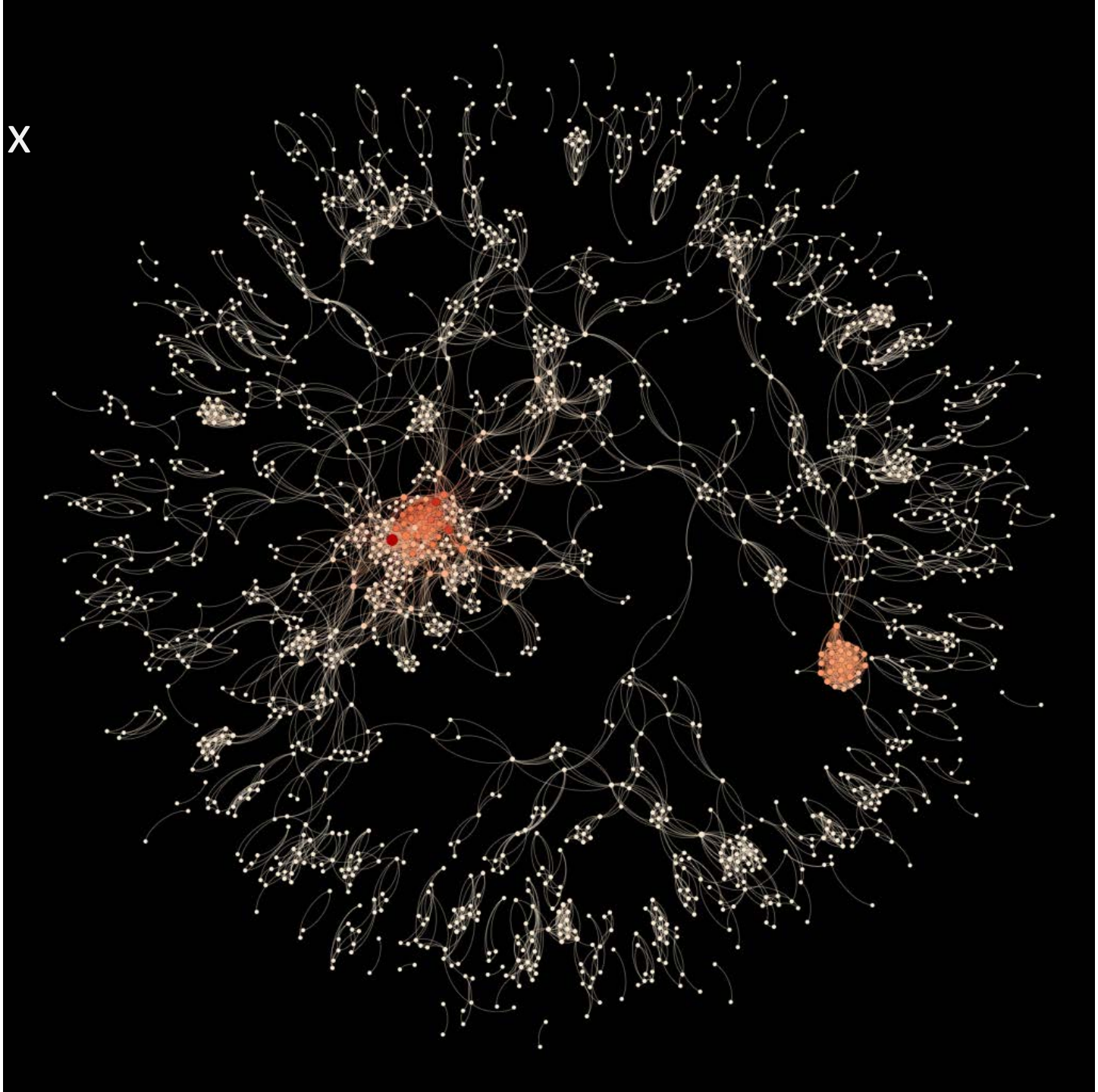
Firm X



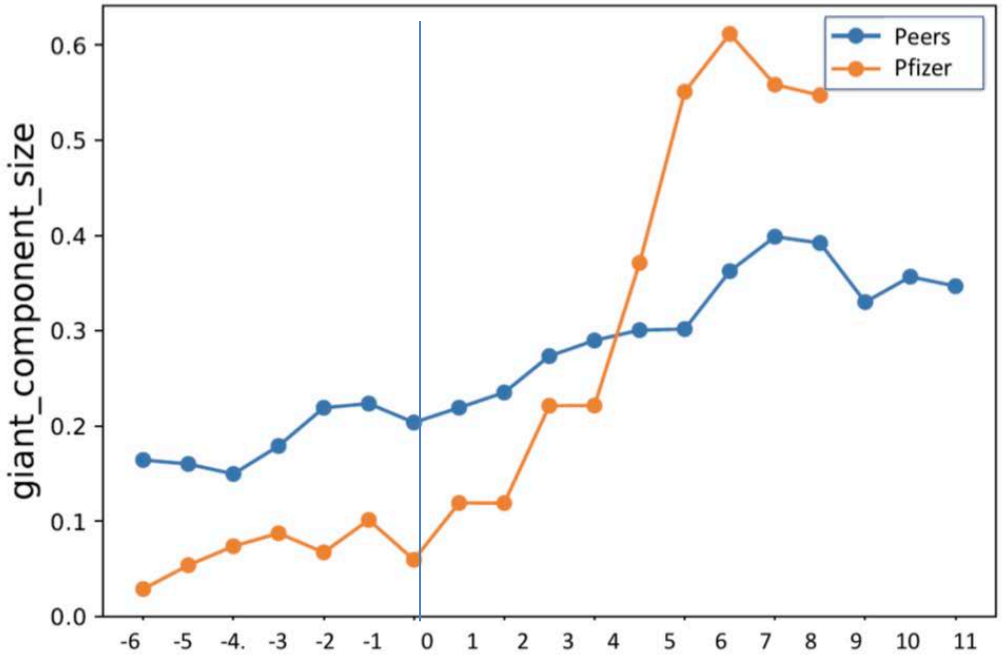
Firm X

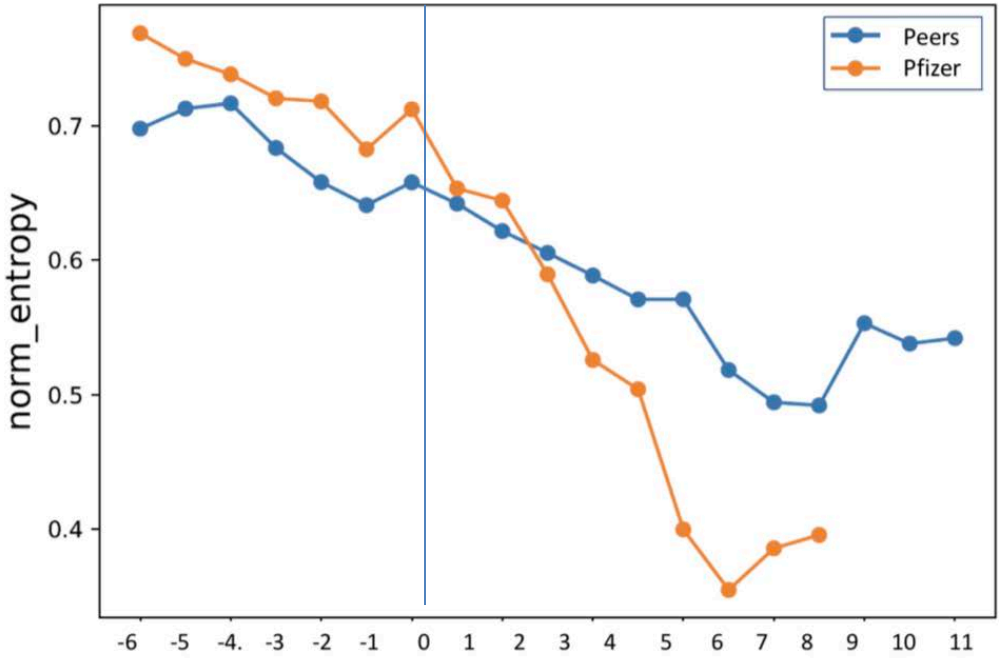


Firm X



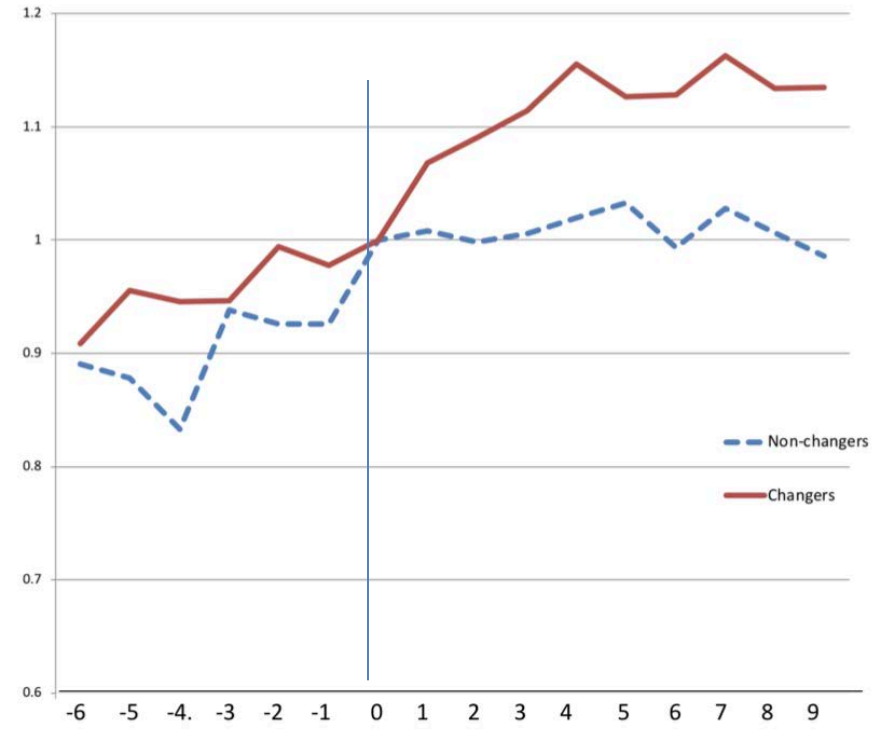
Findings



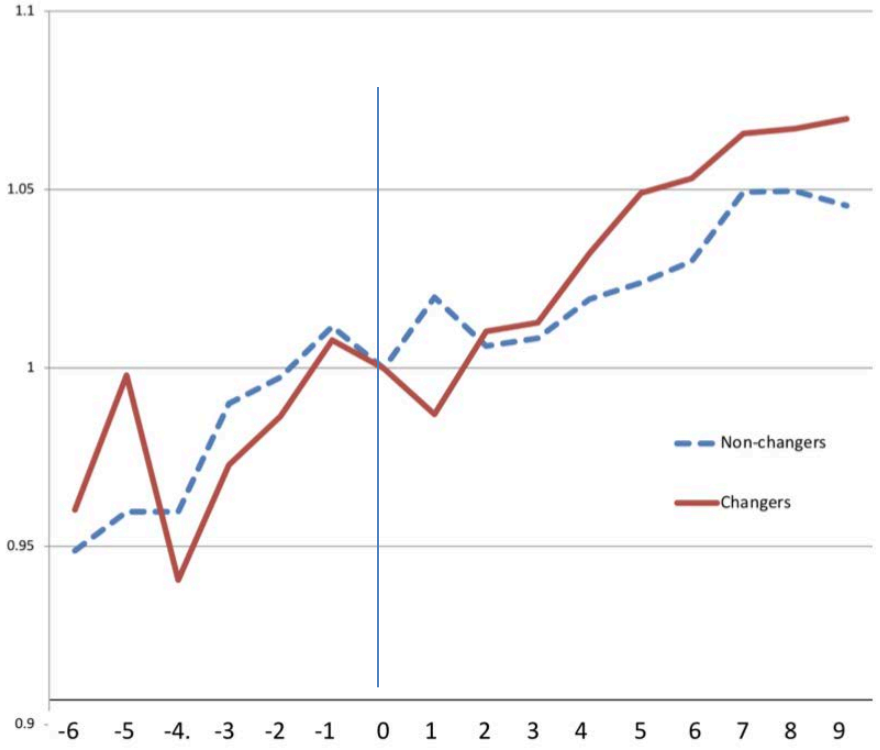


Non-parametric evidence: co-authorship network measures vs. averages for industry peers. Pre and post centralization of focal firm

Parametric evidence: co-authorship network measures vs. averages for industry peers. Pre and post centralization of focal firm



Average Patent generality for treated vs. control group



Average Patent originality for treated vs. control group

H1: Centralization impact on patent characteristics

(firm-level analysis)

	Change = centralization			Change = decentralization		
	(1)	(2)	(3)	(4)	(5)	(6)
	Originality	Generality	Scope	Originality	Generality	Scope
Change*After	0.018**	0.040**	0.14	-0.014	0.013	-0.32
	(0.008)	(0.016)	(0.400)	(0.042)	(0.013)	(0.329)
# Patent families	0.001	-0.021	-0.004	0.019	0.007	0.13
	(0.006)	(0.013)	(0.212)	(0.015)	(0.027)	(0.193)
Average patent family size	0.002	-0.003	0.14**	0.002	-0.005**	0.12**
	(0.001)	(0.003)	(0.065)	(0.001)	(0.003)	(0.053)
Sales	-0.003	-0.005	-0.10	-0.003	-0.008	-0.063
	(0.003)	(0.008)	(0.162)	(0.003)	(0.008)	(0.171)
Assets	0.017***	0.005	-0.22	0.011*	0.010	-0.43
	(0.004)	(0.012)	(0.257)	(0.006)	(0.015)	(0.279)
Employees	-0.030***	-0.001	0.80	-0.026**	-0.020	1.16*
	(0.009)	(0.020)	(0.637)	(0.011)	(0.024)	(0.607)
R&D expenditure	-0.010**	-0.019*	-0.031	-0.006	-0.026	0.11
	(0.005)	(0.011)	(0.412)	(0.006)	(0.016)	(0.445)
Avg tech classes	0.002***	0.002	0.049	0.001	-0.002	0.040
	(0.001)	(0.001)	(0.036)	(0.001)	(0.002)	(0.040)
Avg references to publications	0.001***	0.001***	0.021	0.001***	0.001***	0.021*
	(0.000)	(0.000)	(0.012)	(0.000)	(0.000)	(0.012)
Avg # inventors	0.005	0.016	-0.30	-0.013	-0.010	-0.25
	(0.008)	(0.015)	(0.377)	(0.016)	(0.027)	(0.344)
Observations	562	561	519	524	522	485
R-squared	0.87	0.77	0.32	0.79	0.69	0.33
Adjusted R-squared	0.85	0.74	0.21	0.76	0.64	0.20

Notes: OLS regression. Standard errors clustered by firm are provided in parentheses. Models 1-3 compare firms that centralize their R&D function to those that do not change. Models 4-6 compare firms that decentralize their R&D function to those that do not change. All models include firm, industry and year fixed effects. Consequently, the main effects for Change and After are not included in the estimation.

H1: Centralization impact on patent characteristics

(patent-level analysis)

	Change = Centralization			Change = Decentralization		
	(1)	(2)	(3)	(4)	(5)	(6)
	Originality	Generality	Scope	Originality	Generality	Scope
Change*After	0.032***	0.050***	0.23**	-0.005	-0.030***	-0.26***
	(0.004)	(0.011)	(0.086)	(0.012)	(0.005)	(0.093)
# Patent families	0.003	-0.024**	-0.20***	-0.005	-0.033***	-0.24***
	(0.003)	(0.011)	(0.054)	(0.004)	(0.010)	(0.061)
Patent family size	0.006***	0.002	0.025**	0.003***	0.002	0.031***
	(0.002)	(0.002)	(0.012)	(0.001)	(0.001)	(0.008)
Sales	-0.002	-0.007	0.006	-0.005	-0.016	-0.052
	(0.007)	(0.015)	(0.129)	(0.008)	(0.016)	(0.100)
Assets	0.019***	0.041**	0.040	0.011	0.043***	0.11
	(0.006)	(0.016)	(0.211)	(0.007)	(0.015)	(0.112)
Employees	-0.012*	-0.064***	0.064	-0.009	-0.049***	-0.071
	(0.006)	(0.016)	(0.165)	(0.008)	(0.016)	(0.146)
R&D expenditure	-0.017***	-0.002	-0.071	-0.007	0.0047	-0.054
	(0.006)	(0.010)	(0.102)	(0.005)	(0.011)	(0.083)
Tech classes	0.002***	0.004***	0.017***	0.002**	0.003**	0.016***
	(0.000)	(0.001)	(0.006)	(0.001)	(0.001)	(0.005)
References to publications	0.001***	0.001***	0.010***	0.001***	0.001***	0.006***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
# inventors	-0.001	0.000	-0.002	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.003)	(0.000)	(0.000)	(0.002)
Observations	157890	124930	266703	110696	88041	190108
R-squared	0.10	0.11	0.14	0.16	0.22	0.19
Adjusted R-squared	0.098	0.11	0.14	0.16	0.22	0.19

Notes: OLS regression. Standard errors clustered by firm are provided in parentheses. Models 1-3 compare firms that centralize their R&D function to those that do not change. Models 4-6 compare firms that decentralize their R&D function to those that do not change. All models include firm, industry and year fixed effects. Consequently, the main effects for Change and After are not included in the estimation.

H2: Centralization impact on network structure

	Change = Centralize				Change = Decentralize			
	Co-author network		Citation network		Co-author network		Citation network	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Giant	Entropy	Giant	Entropy	Giant	Entropy	Giant	Entropy
Change*After	0.12***	-0.075***	-0.012	0.020	0.046	-0.015	-0.016	0.038
	(0.033)	(0.026)	(0.026)	(0.021)	(0.112)	(0.080)	(0.028)	(0.024)
# Patent families	0.043	-0.008	0.043	-0.031	0.047*	-0.023	0.051	-0.037
	(0.032)	(0.023)	(0.032)	(0.027)	(0.027)	(0.021)	(0.036)	(0.030)
Patent family size	0.000	-0.000	0.003	-0.002	0.001	-0.001	0.002	-0.001
	(0.006)	(0.004)	(0.005)	(0.004)	(0.007)	(0.005)	(0.005)	(0.004)
Sales	0.023	-0.023	-0.014	0.011	0.028	-0.027	-0.014	0.012
	(0.028)	(0.019)	(0.022)	(0.021)	(0.027)	(0.019)	(0.024)	(0.022)
Assets	0.013	-0.002	0.022	-0.023	0.006	0.005	0.021	-0.024
	(0.020)	(0.013)	(0.031)	(0.028)	(0.021)	(0.013)	(0.032)	(0.030)
Employees	-0.017	0.014	-0.050*	0.053**	-0.016	-0.000	-0.037	0.042
	(0.048)	(0.039)	(0.029)	(0.021)	(0.044)	(0.038)	(0.038)	(0.028)
R&D expenditure	-0.067**	0.045**	0.019	-0.017	-0.067**	0.046**	0.016	-0.015
	(0.028)	(0.019)	(0.023)	(0.021)	(0.030)	(0.019)	(0.022)	(0.021)
Avg tech classes	0.006**	-0.003	0.002	-0.001	0.007**	-0.004**	0.003	-0.002
	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
Avg references to publications	0.001*	-0.001	-0.001	0.001	0.001*	-0.001	-0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Avg # inventors	0.017	-0.054	-0.042	0.014	0.013	-0.044	-0.049	0.017
	(0.047)	(0.032)	(0.031)	(0.026)	(0.041)	(0.028)	(0.032)	(0.027)
Observations	563	563	335	335	555	555	300	300
R-squared	0.75	0.81	0.80	0.77	0.74	0.79	0.80	0.77
Adjusted R-squared	0.72	0.78	0.75	0.71	0.69	0.75	0.74	0.70

Notes: OLS regression. Standard errors clustered by firm are provided in parentheses. Models 1-4 compare firms that centralize their R&D function to those that do not change. Models 5-8 compare firms that decentralize their R&D function to those that do not change. All models include firm, industry and year fixed effects. Consequently, the main effects for Change and After are not included in the estimation.

	Change = Centralize				Change = Decentralize			
	Co-author network		Citation network		Co-author network		Citation network	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Giant	Entropy	Giant	Entropy	Giant	Entropy	Giant	Entropy
Change*Year1After	0.082	-0.050	-0.043**	0.031*	0.065	-0.059**	-0.058**	0.037
	(0.067)	(0.037)	(0.019)	(0.015)	(0.041)	(0.029)	(0.026)	(0.023)
Change*Year2After	0.047	-0.036	-0.022	0.013	0.039	-0.031	0.056**	-0.029
	(0.054)	(0.032)	(0.023)	(0.020)	(0.062)	(0.049)	(0.026)	(0.023)
Change*Year3After	0.061	-0.026	-0.043	0.040*	-0.009	-0.036	0.002	-0.004
	(0.038)	(0.029)	(0.029)	(0.024)	(0.073)	(0.041)	(0.017)	(0.015)
Change*Year4After	0.039	-0.042	0.034	-0.018	0.077*	-0.071*	0.004	-0.000
	(0.056)	(0.045)	(0.047)	(0.040)	(0.045)	(0.039)	(0.027)	(0.020)
Change*Year5After	0.11*	-0.063	0.033	-0.004	0.013	-0.033	-0.012	0.015
	(0.059)	(0.038)	(0.042)	(0.034)	(0.055)	(0.047)	(0.035)	(0.032)
Change*Year6After	0.16**	-0.090**	-0.003	0.022	0.11**	-0.10***	-0.015	0.029
	(0.064)	(0.044)	(0.045)	(0.037)	(0.048)	(0.038)	(0.031)	(0.026)
Change*Year7After	0.21***	-0.12***	-0.028	0.036	0.018	-0.053	0.011	0.006
	(0.066)	(0.044)	(0.039)	(0.029)	(0.077)	(0.056)	(0.032)	(0.026)
Change*Year8After	0.14*	-0.092*	-0.019	0.030	-0.003	-0.052	0.030	-0.009
	(0.077)	(0.047)	(0.030)	(0.022)	(0.070)	(0.040)	(0.042)	(0.028)
Change*Year9After	0.26***	-0.15***	-0.017	0.027	-0.028	-0.030	-0.012	0.020
	(0.055)	(0.031)	(0.028)	(0.020)	(0.085)	(0.065)	(0.041)	(0.033)
# Patent families	0.046	-0.010	0.043	-0.031	0.047*	-0.023	0.052	-0.038
	(0.032)	(0.023)	(0.032)	(0.028)	(0.027)	(0.021)	(0.037)	(0.031)
Patent family size	0.000	-0.001	0.003	-0.002	0.002	-0.001	0.003	-0.001
	(0.007)	(0.004)	(0.004)	(0.004)	(0.008)	(0.005)	(0.005)	(0.004)
Sales	0.023	-0.023	-0.015	0.012	0.029	-0.028	-0.014	0.012
	(0.028)	(0.019)	(0.023)	(0.021)	(0.028)	(0.019)	(0.024)	(0.022)
Assets	0.012	-0.001	0.025	-0.025	0.007	0.004	0.019	-0.022
	(0.020)	(0.013)	(0.031)	(0.028)	(0.020)	(0.012)	(0.033)	(0.030)
Employees	-0.016	0.013	-0.047	0.051**	-0.014	-0.000	-0.044	0.042
	(0.047)	(0.039)	(0.030)	(0.022)	(0.044)	(0.038)	(0.040)	(0.031)
R&D expenditure	-0.066**	0.045**	0.019	-0.017	-0.073**	0.049**	0.022	-0.020
	(0.028)	(0.019)	(0.022)	(0.021)	(0.029)	(0.019)	(0.025)	(0.023)
Avg tech classes	0.0055*	-0.003	0.002	-0.001	0.008**	-0.005**	0.002	-0.001
	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)
Avg references to publications	0.001*	-0.001	-0.001	0.001	0.001	-0.001	-0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Avg # inventors	0.020	-0.056*	-0.046	0.017	0.013	-0.044	-0.053	0.016
	(0.047)	(0.032)	(0.031)	(0.026)	(0.041)	(0.029)	(0.033)	(0.029)
Observations	563	563	335	335	526	526	300	300
R-squared	0.76	0.81	0.80	0.77	0.74	0.79	0.81	0.78
Adjusted R-squared	0.72	0.79	0.75	0.71	0.69	0.75	0.74	0.69

Change in network entropy and giant over time

	Change = centralization			Change = decentralization		
	(1)	(2)	(3)	(4)	(5)	(6)
	Originality	Generality	Scope	Originality	Generality	Scope
Change*Year1After	-0.009	0.017	0.057	0.009	-0.002	1.07
	(0.014)	(0.017)	(0.513)	(0.015)	(0.023)	(0.898)
Change*Year2After	0.006	0.030	0.37	-0.041**	-0.090**	0.38
	(0.010)	(0.022)	(0.468)	(0.016)	(0.044)	(0.621)
Change*Year3After	0.011	0.026	0.40	0.014	-0.046*	1.06**
	(0.010)	(0.018)	(0.401)	(0.033)	(0.023)	(0.472)
Change*Year4After	0.024***	0.056**	0.30	0.004	0.030*	-0.63
	(0.007)	(0.021)	(0.727)	(0.025)	(0.017)	(0.628)
Change*Year5After	0.026**	0.027	-1.28**	0.006	0.033	1.28
	(0.011)	(0.022)	(0.494)	(0.024)	(0.033)	(0.785)
Change*Year6After	0.026	0.057***	0.36	-0.019	-0.003	0.12
	(0.018)	(0.021)	(0.957)	(0.021)	(0.018)	(0.944)
Change*Year7After	0.024*	0.048**	1.04	0.008	0.004	1.27*
	(0.014)	(0.021)	(0.974)	(0.039)	(0.034)	(0.674)
Change*Year8After	0.029**	0.045**	0.74	-0.006	-0.024	0.27
	(0.013)	(0.022)	(0.722)	(0.023)	(0.024)	(0.806)
Change*Year9After	0.029**	0.053**	-0.31	0.006	-0.072*	-0.24
	(0.013)	(0.021)	(0.473)	(0.023)	(0.042)	(0.760)
# Patent families	0.001	-0.021	-0.043	0.018	0.006	0.058
	(0.006)	(0.013)	(0.217)	(0.015)	(0.026)	(0.178)
Avg patent family size	0.002	-0.003	0.14**	0.002	-0.005*	0.12**
	(0.001)	(0.003)	(0.066)	(0.001)	(0.003)	(0.054)
Sales	-0.003	-0.006	-0.094	-0.003	-0.006	-0.065
	(0.003)	(0.008)	(0.166)	(0.003)	(0.008)	(0.182)
Assets	0.017***	0.005	-0.26	0.011**	0.012	-0.45
	(0.005)	(0.013)	(0.255)	(0.005)	(0.015)	(0.275)
Employees	-0.030***	-0.000	0.82	-0.026**	-0.017	1.19*
	(0.009)	(0.020)	(0.637)	(0.012)	(0.024)	(0.621)
R&D expenditure	-0.010**	-0.019*	-0.018	-0.006	-0.032*	0.13
	(0.005)	(0.011)	(0.413)	(0.006)	(0.016)	(0.451)
Avg tech classes	0.002***	0.002	0.049	0.001	-0.002	0.034
	(0.001)	(0.001)	(0.036)	(0.001)	(0.002)	(0.039)
Avg references to publications	0.001***	0.001***	0.021*	0.001***	0.001***	0.021*
	(0.000)	(0.000)	(0.012)	(0.000)	(0.000)	(0.012)
Avg # inventors	0.005	0.016	-0.24	-0.011	-0.008	-0.18
	(0.008)	(0.016)	(0.384)	(0.015)	(0.025)	(0.358)
Observations	562	561	519	524	522	485
R-squared	0.87	0.77	0.33	0.80	0.71	0.34
Adjusted R-squared	0.85	0.73	0.21	0.76	0.65	0.19

Change in search and impact over time

Relationship between network structure and innovation

(patent-level analysis)

	(1) Originality	(2) Generality	(3) Scope	(4) Originality	(5) Generality	(6) Scope
Giant	0.019***	0.026***	-0.29***			
	(0.006)	(0.008)	(0.042)			
Entropy				-0.037***	-0.064***	0.20***
				(0.010)	(0.013)	(0.070)
# Patent families	-0.000	-0.023***	-0.10***	-0.000	-0.024***	-0.13***
	(0.002)	(0.002)	(0.013)	(0.002)	(0.002)	(0.013)
Patent family size	0.004***	0.002***	0.20***	0.004***	0.002***	0.20***
	(0.001)	(0.001)	(0.004)	(0.001)	(0.001)	(0.004)
Sales	0.005	0.008*	-0.027	0.005	0.009*	-0.021
	(0.004)	(0.005)	(0.025)	(0.004)	(0.005)	(0.025)
Assets	0.022***	0.042***	0.13***	0.023***	0.043***	0.13***
	(0.004)	(0.005)	(0.026)	(0.004)	(0.005)	(0.026)
Employees	-0.018***	-0.073***	0.10***	-0.018***	-0.073***	0.10***
	(0.003)	(0.005)	(0.025)	(0.003)	(0.005)	(0.025)
R&D expenditure	-0.019***	-0.010***	-0.20***	-0.020***	-0.010***	-0.19***
	(0.002)	(0.003)	(0.017)	(0.002)	(0.003)	(0.017)
Tech classes	0.001***	0.003***	0.017***	0.001***	0.003***	0.017***
	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.002)
References to publications	0.001***	0.001***	0.006***	0.001***	0.001***	0.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
# inventors	-0.000	0.000	0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
Observations	154554	122504	160063	154554	122504	160063
R-squared	0.15	0.18	0.19	0.15	0.18	0.19
Adjusted R-squared	0.15	0.18	0.19	0.15	0.18	0.19

Notes: OLS regression. Standard errors clustered by firm are provided in parentheses. All models include firm, industry and year fixed effects. Consequently, the main effects for Change and After are not included in the estimation.