Technology Differentiation and Firm Performance

Bruno Cassiman

Harvard Business School (visiting)

IESE Business School & KU Leuven (on leave)

Joint with

Sam Arts and **Jianan Hou** – KU Leuven

Innovation and Firm Performance

- Market power related to hard to imitate/substitute resources such as unique and proprietary technology

- Empirical work measuring Intangible Capital and relating to firm performance
  - Patents and R&D (Hall, Jaffe and Trajtenberg, 2005; Czarnitzki et al., 2006); Spillovers (Bloom et al. 2013); Scientific Publications (Simeth and Cincera, 2016); RQ (Knott, 2017); Innovation Topic (Bellstam et al. 2021)

- But do Technology Characteristics/Choices matter?
  - Empirical: Similarity, Relatedness, Complementarity (Ahuja and Katila, 2001; Cassiman et al. 2005, Makri et al. 2010)
  - Formal models: Firms differentiate their technology to minimize technology spillovers and competition in the product market (Kamien and Zang 2000, Aghion et al. 2005, Lin and Zhou, 2013

Characterizing Technology Portfolios

- Prior work relied on patent classification and citation as window on technology (Jaffe, 1989)
  - Limitations (Thompson Fox-kean 2005, Arts et al. 2018)
- US public firms dynamically matched to patents 1980-2015 (Arora et al, 2021 - Discern)
  - +/- 5,000 firms
  - +/- 1,5 million USPTO patents
- Patent portfolio of firm *i* in year *t* = all granted patents of firm *i* filed *t-5* to *t-1*
  - Moving 5 year window
  - n=+/-60,000

Characterizing Technology Portfolios

- Firms must provide a "fully written description of the invention … in such full, clear, concise, and exact terms …" in exchange for legal patent protection
    - Title, Abstract, and Claims

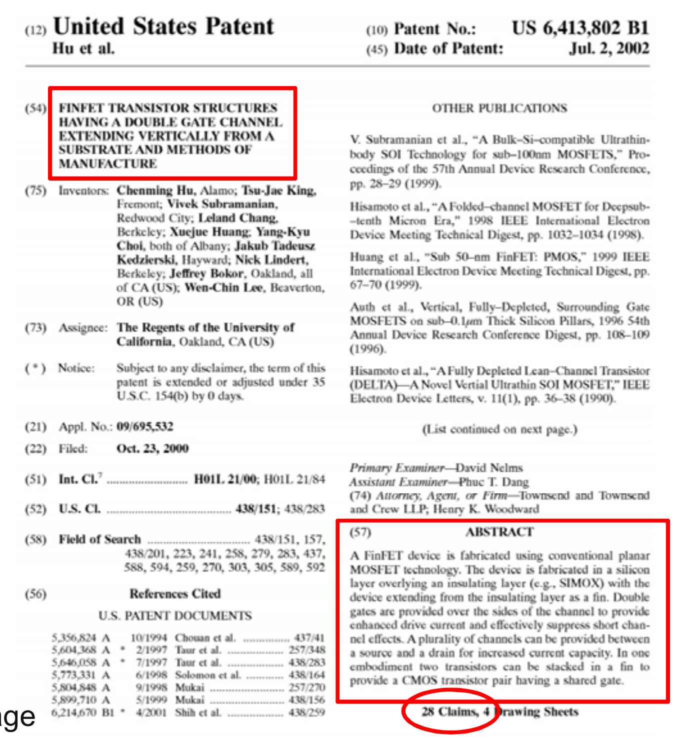
- Cleaned and stemmed technical keywords per patent (1,030,335 unique words) from Arts et al. 2021 (open access: https://zenodo.org/record/3515985)

- Technology portfolio firm *i* year *t*
    - vector of +/- 1 million dimensions
    - each dimension = one keyword
    - Value = share of patents in portfolio containing keyword

Pioneering Technologies

- New words (reuse)
  - FinFET (US6413802)
  - 3,238 patents reuse

- Arts, S., Hou, J., & Gomez, J. C. (2021). Natural language processing to identify the creation and impact of new technologies in patent text: Code, data, and new measures. *Research Policy*, 50(2), 104144.
- https://zenodo.org/record/3515985



(12) **United States Patent**
Hu et al.

(10) **Patent No.:** **US 6,413,802 B1**
(45) **Date of Patent:** **Jul. 2, 2002**

(54) **FINFET TRANSISTOR STRUCTURES HAVING A DOUBLE GATE CHANNEL EXTENDING VERTICALLY FROM A SUBSTRATE AND METHODS OF MANUFACTURE**

(75) Inventors: **Chenming Hu**, Alamo; **Tsu-Jae King**, Fremont; **Vivek Subramanian**, Redwood City; **Leland Chang**, Berkeley; **Xuejue Huang**; **Yang-Kyu Choi**, both of Albany; **Jakub Tadeusz Kedzierski**, Hayward; **Nick Lindert**, Berkeley; **Jeffrey Bokor**, Oakland, all of CA (US); **Wen-Chin Lee**, Beaverton, OR (US)

(73) Assignee: **The Regents of the University of California**, Oakland, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/695,532**

(22) Filed: **Oct. 23, 2000**

(51) **Int. Cl.**[7] **H01L 21/00**; H01L 21/84

(52) **U.S. Cl.** **438/151**; 438/283

(58) **Field of Search** 438/151, 157, 438/201, 223, 241, 258, 279, 283, 437, 588, 594, 259, 270, 303, 305, 589, 592

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,356,824	A		10/1994	Chouan et al.	437/41
5,604,368	A	*	2/1997	Taur et al.	257/348
5,646,058	A	*	7/1997	Taur et al.	438/283
5,773,331	A		6/1998	Solomon et al.	438/164
5,804,848	A		9/1998	Mukai	257/270
5,899,710	A		5/1999	Mukai	438/156
6,214,670	B1	*	4/2001	Shih et al.	438/259

OTHER PUBLICATIONS

V. Subramanian et al., "A Bulk–Si–compatible Ultrathin-body SOI Technology for sub–100nm MOSFETS," Proceedings of the 57th Annual Device Research Conference, pp. 28–29 (1999).

Hisamoto et al., "A Folded–channel MOSFET for Deepsub–tenth Micron Era," 1998 IEEE International Electron Device Meeting Technical Digest, pp. 1032–1034 (1998).

Huang et al., "Sub 50–nm FinFET: PMOS," 1999 IEEE International Electron Device Meeting Technical Digest, pp. 67–70 (1999).

Auth et al., Vertical, Fully–Depleted, Surrounding Gate MOSFETS on sub–0.1μm Thick Silicon Pillars, 1996 54th Annual Device Research Conference Digest, pp. 108–109 (1996).

Hisamoto et al., "A Fully Depleted Lean–Channel Transistor (DELTA)—A Novel Vertial Ultrathin SOI MOSFET," IEEE Electron Device Letters, v. 11(1), pp. 36–38 (1990).

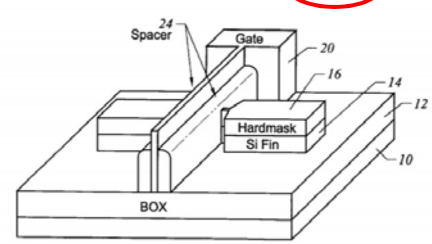
(List continued on next page.)

Primary Examiner—David Nelms
Assistant Examiner—Phuc T. Dang
(74) *Attorney, Agent, or Firm*—Townsend and Townsend and Crew LLP; Henry K. Woodward

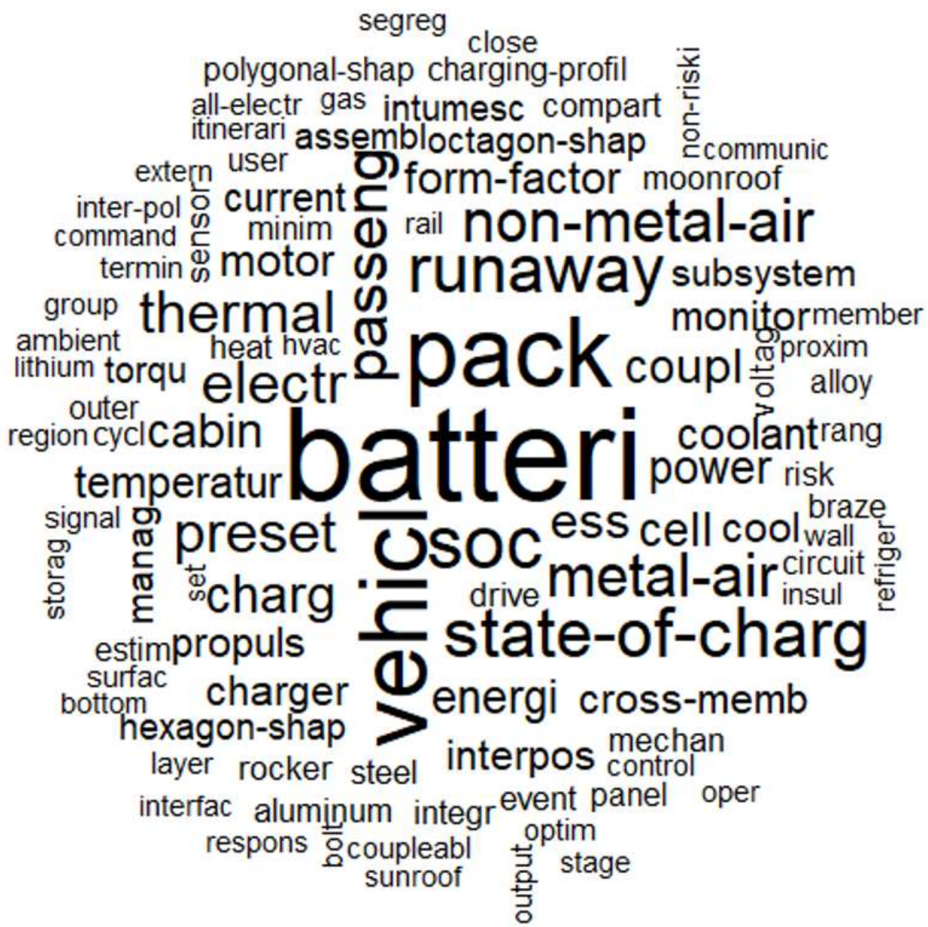
(57) **ABSTRACT**

A FinFET device is fabricated using conventional planar MOSFET technology. The device is fabricated in a silicon layer overlying an insulating layer (e.g., SIMOX) with the device extending from the insulating layer as a fin. Double gates are provided over the sides of the channel to provide enhanced drive current and effectively suppress short channel effects. A plurality of channels can be provided between a source and a drain for increased current capacity. In one embodiment two transistors can be stacked in a fin to provide a CMOS transistor pair having a shared gate.

28 Claims, 4 Drawing Sheets



Tesla


segreg
close
polygonal-shap
charging-profil
non-riski
all-electr
gas
intumesc
compart
itinerari
assembl
octagon-shap
communic
extern
user
form-factor
moonroof
inter-pol
current
rail
non-metal-air
command
sensor
minim
passeng
termin
motor
runaway
subsystem
group
thermal
monitor
member
ambient
heat
hvac
pack
proxim
lithium
torqu
voltag
electr
coupl
alloy
outer
region
cycl
cabin
batteri
coolant
rang
temperatur
power
risk
signal
braze
manag
preset
soc
ess
cell
cool
wall
storag
vehicl
refriger
circuit
set
charg
metal-air
drive
insul
estim
propuls
state-of-charg
surfac
charger
energi
cross-memb
bottom
hexagon-shap
mechan
interpos
layer
rocker
steel
control
interfac
aluminum
integr
event
panel
oper
respons
bolt
coupleabl
optim
sunroof
output
stage

Similarity between Firms

Data

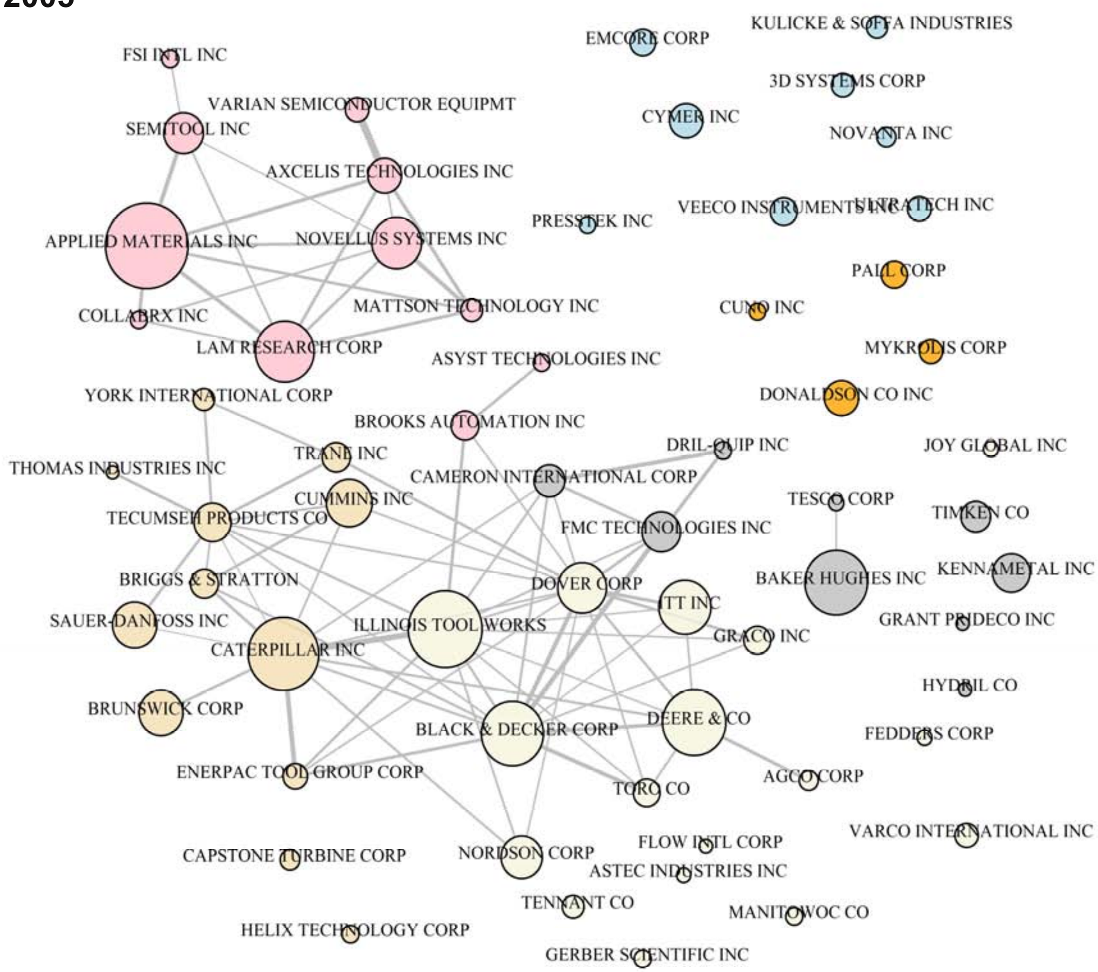
- Pairwise similarity between all firms for each year
  - +- 100 million pairs
- Cosine with TF-IDF
  - Keywords representative for firm i year t (e.g., *batteri* for Tesla or *herbicid* for Monsanto)
  - Keywords common across all firm i year t (e.g., *electr* or *drug*)
  - Higher weight for pioneering technology
- Correlation with traditional measures rather low

Most Similar Technology Portfolios

- IBM and Digital Equipment in 1994 (0.904)
- Baker Hughes and Schlumberger (both providing oil field services) in 2004 (0.906)
- AT&T and Sprint in 2006 (0.906)
- Alphabet (Google) and Altaba (Yahoo!) in 2009 (0.931)
- Texas Instruments and Freescale Semiconductor in 2012 (0.923).

Firms in Technology Space

Machinery Industry in 2005



Technology Differentiation Measure

- $Tech\ differentiation_{it} = 1 - \frac{1}{n-1} \sum_{j=1, j \neq i}^{n-1} tech\ similarity_{ijt}$

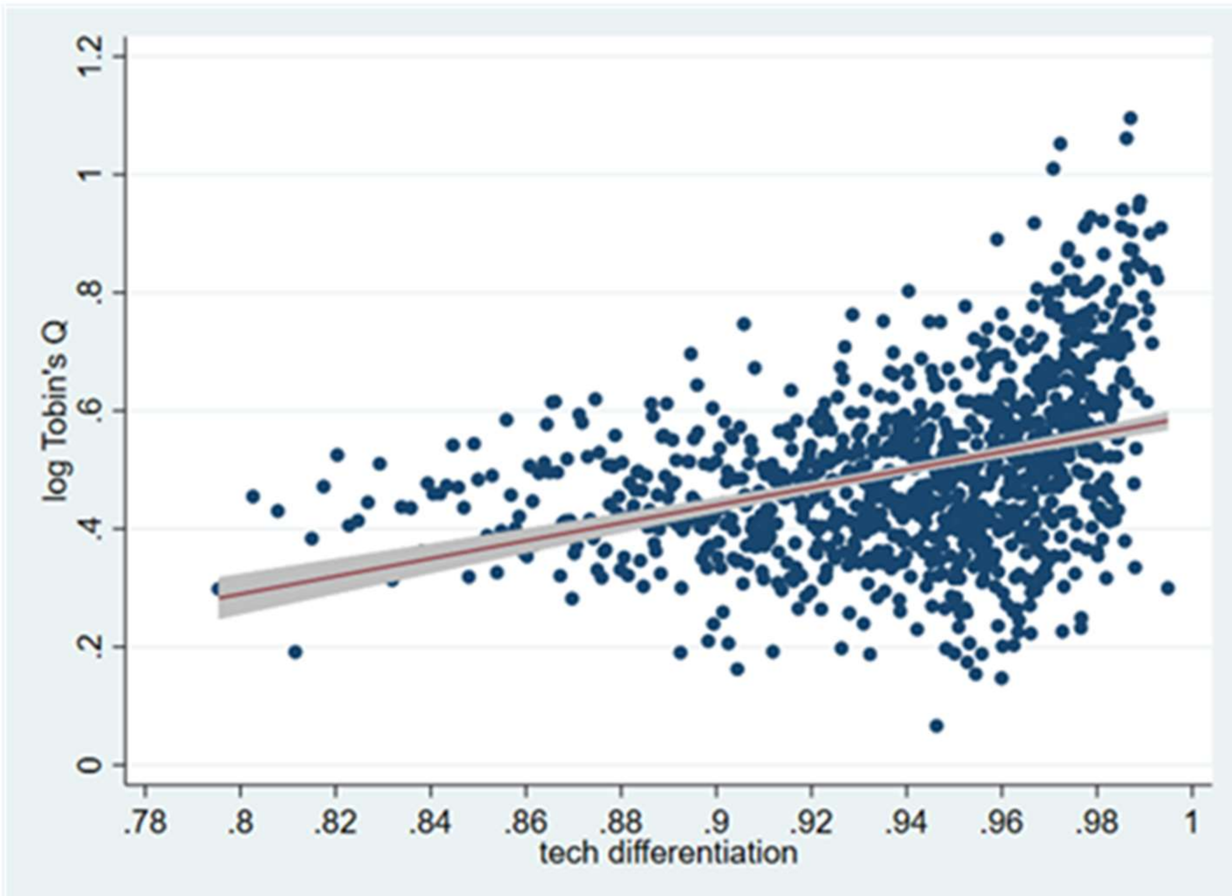
- Firms with more unique and less overlapping portfolio = more differentiated
  - New Technology (Keywords)
  - Higher TF-IDF (Specialize)
  - Move towards less Technologically Similar firms
  - Technologically Similar firms move away from focal firm

- Younger, smaller and more R&D intensive firms on average more differentiated

- Persistent high level of differentiation in their industry
  - Monsanto (agricultural production-crops)
  - Tesla (motor vehicles & passenger car bodies)
  - Gilead Sciences (biological products)
  - Universal Display Corporation and First solar (semiconductors & related devices)

- As a comparison, we also calculate tech differentiation using patent classes, subclasses and prior art citations
  - Correlation very low

Technology Differentiation and Firm Performance



Technology Differentiation and Firm Performance

Link to Compustat

- $Y_{it} = \alpha_i + \gamma_j + \delta_t + \beta_1 * tech\ differentiation_{it} + \beta_2 X_{it-1} + \varepsilon_{ijt}$
- Y_{it} = *Tobin's Q* (or *ROA)*
- α_i, γ_j, and δ_t capture firm, industry and year fixed effects
- X_{it-1} includes all control variables lagged by one year
  - *total assets*, *leverage*, *cash*, *asset tangibility*, *firm age,*
  - *R&D intensity, citation-weighted patents, tech specialization,*
  - *prod market competition*

Technology Differentiation and Firm Performance

	Tobin's Q				
	(1)	(2)	(3)	(4)	(5)
Tech differentiation	1.951***	3.469***			
	(0.416)	(0.552)			
Tech differentiation (class)			0.119		
			(0.151)		
				-0.031	
Tech differentiation (subclass)					
				(0.111)	
Tech differentiation (citation)					-0.025
					(0.082)
R&D intensity	0.837***	0.329***	0.315***	0.315***	0.315***
	(0.057)	(0.059)	(0.059)	(0.059)	(0.059)
Citation-weighted patents	0.106***	0.079***	0.050***	0.050***	0.050***
	(0.007)	(0.009)	(0.008)	(0.008)	(0.008)
Firm fixed effects	No	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
Other control variables	Yes	Yes	Yes	Yes	Yes
Number of observations	38,247	38,247	38,247	38,247	38,247
Number of firms	4,049	4,049	4,049	4,049	4,049
Within r2		0.159			
Between r2		0.076			
Overall r2	0.191	0.068			

Marginal Effects	(1)	(2)
Tech differentiation	7.3%	13.4%
R&D intensity	16.7%	6.3%
Citation weighted patents	24.2%	17.5%

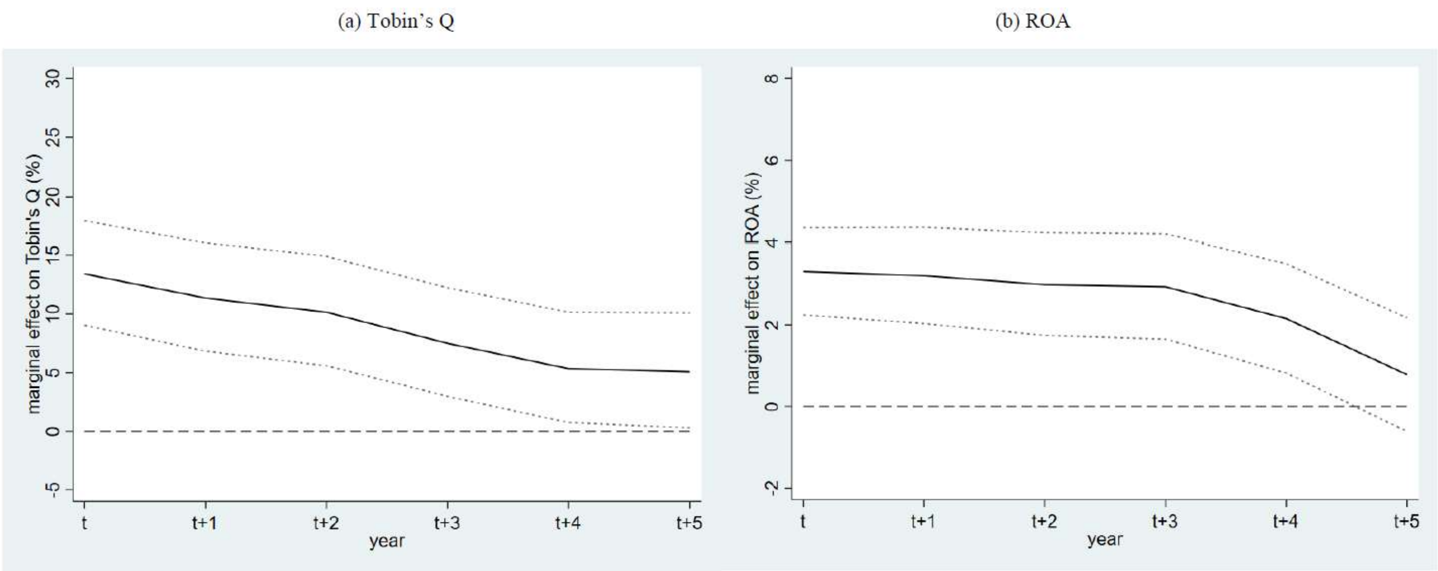
Robustness

	Tobin's Q								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tech differentiation	1.951***	1.627***	2.494***	3.028***	2.604***	2.194***	2.555***	1.804***	1.764***
	(0.416)	(0.457)	(0.594)	(0.477)	(0.490)	(0.574)	(0.486)	(0.548)	(0.637)
R&D intensity	0.837***	0.826***	0.313***	0.885***	0.890**	0.324***	0.854***	0.843***	0.302***
	(0.057)	(0.061)	(0.064)	(0.058)	(0.058)	(0.061)	(0.058)	(0.062)	(0.065)
Citation-weighted patents	0.106***	0.103***	0.073***	0.100***	0.096***	0.072***	0.102***	0.098***	0.071***
	(0.007)	(0.008)	(0.010)	(0.008)	(0.008)	(0.010)	(0.007)	(0.008)	(0.010)
Firm fixed effects	No	No	Yes	No	Yes	Yes	No	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
Industry*year	No	Yes	Yes	No	No	No	No	Yes	Yes
Subcategory fixed effects	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Subcategory*year	No	No	No	No	Yes	Yes	No	Yes	Yes
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	38,247	38,247	38,247	37,973	37,973	37,973	37,973	37,973	37,973
Number of firms	4,049	4,049	4,049	3,996	3,996	3,996	3,996	3,996	3,996
Within r2			0.244			0.196			0.272
Between r2			0.064			0.076			0.066
Overall r2	0.191	0.255	0.082	0.166	0.199	0.081	0.198	0.281	0.091
	Marginal effects (%)								
Tech differentiation	7.34	6.09	9.48	11.63	9.92	8.30	9.73	6.78	6.62
R&D intensity	16.68	16.43	5.94	17.66	17.77	6.14	17.01	16.77	5.70
Citation weighted patents	24.21	23.41	16.20	22.68	21.79	15.82	23.09	22.20	15.56

Technology Differentiation and Firm Performance

	ROA				
	(6)	(7)	(8)	(9)	(10)
Tech differentiation	1.082***	0.908***			
	(0.146)	(0.149)			
Tech differentiation (class)			0.027		
			(0.041)		
Tech differentiation (subclass)				-0.015	
				(0.030)	
Tech differentiation (citation)					0.017
					(0.036)
R&D intensity	-0.912***	-0.459***	-0.462***	-0.462***	-0.462***
	(0.033)	(0.037)	(0.037)	(0.037)	(0.037)
Citation-weighted patents	0.005**	0.009***	0.001	0.001	0.001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Firm fixed effects	No	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
Other control variables	Yes	Yes	Yes	Yes	Yes
Number of observations	38,375	38,375	38,375	38,375	38,375
Number of firms	4,049	4,049	4,049	4,049	4,049
Within r2		0.076	0.075	0.075	0.075
Between r2		0.407	0.411	0.411	0.411
Overall r2	0.466	0.318	0.326	0.325	0.325

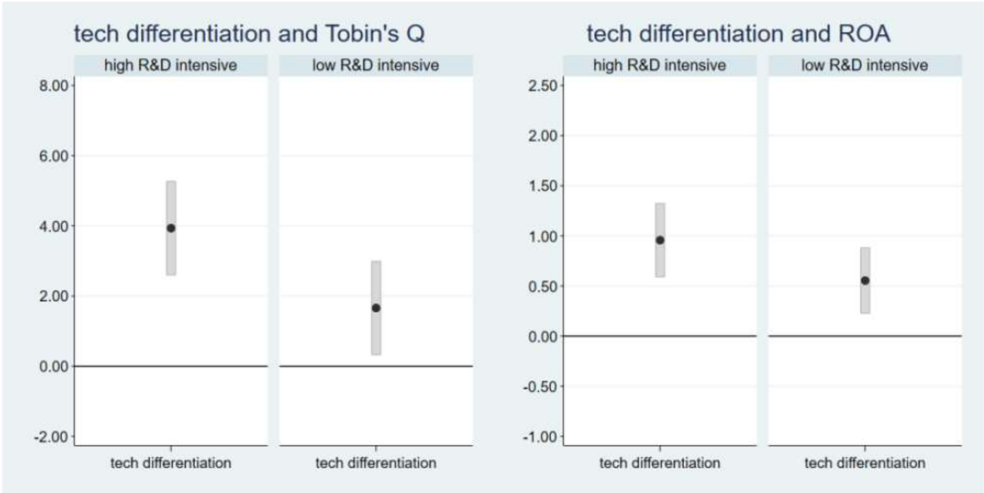
Technology differentiation and long-term firm performance



Notes: The graphs illustrate the marginal effects (in %) and the corresponding 95% confidence intervals of a one standard deviation increase in *tech differentiation* in year *t* on *Tobin's Q* and *ROA* measured in years *t* to *t+5*. Regression results can be found in Tables A.6 and A.7 in Appendix.

High versus Low R&D Intensive Industries

(a) Tobin's Q (b) ROA



Notes: The graphs illustrate estimated coefficients and the corresponding 95% confidence intervals of *tech differentiation* on *Tobin's Q* and *ROA* for samples split by the mean of *industry R&D intensity*. Regression results can be found in Table A.8 in Appendix.

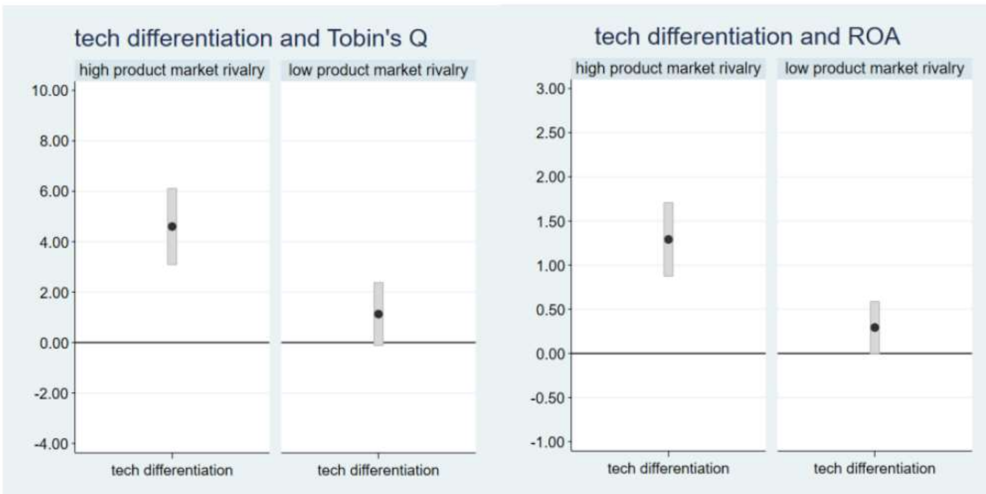
Marginal effect on Tobin's Q: 16% versus 6%

Marginal effect on ROA: 4% versus 2%

High versus Low Product Market Competition

(a) Tobin's Q

(b) ROA



Notes: The graphs illustrate estimated coefficients and the corresponding 95% confidence intervals of *tech differentiation* on *Tobin's Q* and *ROA* for samples split by the mean of *industry prod market competition*. Regression results can be found in Table A.8 in Appendix

Marginal effect on Tobin's Q: 18% versus 4%

Marginal effect on ROA: 5% versus 1%

Conclusion

- Firm's competitive advantage and performance relies on unique and differentiated technology
  - R&D intensive industries & industries strong product market rivalry
  - Differentiation of portfolio important relative to size (citation-weighted patents)
- Very different characterization of firm technology portfolios compared to prior approaches
  - Patent classification and patent citations
  - More strongly correlate with Tobin's Q and ROA
- Firm's competitive position and differentiation in technology space
  - Technological Similarity and Product Similarity are quite different
- New method (and open data) & New questions or revisit existing questions
  - Firm (Spillovers, Acquisition, Diversification,…)
  - Regional
  - Inventor
- Also works for firms with few patents, can presumably also be used for smaller (non-public) firms and startups