Patents that Match your Standards: Firm-level Evidence on Competition and Innovation

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[The views expressed herein are ours and should not be attributed to BdF]

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- The **ability to adapt** to the new technology frontier is **heterogeneous across firms** and depends on **past innovation choices**
- This has implications for **market structure**, **competition** and **(future) innovation**

Example: ITU Standard 2015, IMT-2020 5G protocol

- Date of release: 9 June 2015
- Key minimum specifications:
  - bandwidth to be at least 100 MHz
  - bandwidths up to 1 GHz are required for higher frequencies (above 6 GHz)
  - connection density is 1 million devices per square kilometer
  - downlink peak data rate of 20 Gb/s
  - uplink peak data rate of 10 Gb/s
  - target downlink user experienced data rate of 100 Mb/s
  - target uplink user experienced data rate of 50 Mb/s
- Which firms were ready to adapt and comply to the new standard?

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  2. how to measure firms' past innovation choices
  3. how to measure the proximity of the firm technology to the new frontier
- We use:
  1. data on **published standard documents** ← the new tech. frontier
  2. data on **firm-level patents** ← firms past innovation outcomes
  3. **textual analysis** to measure the **semantic proximity** of the firm' stock of **patents** to the newly published **standards** [!NOVELTY!] ← proximity to the frontier
- We cross this new measure with firm-level data (Compustat, Crisp, IBES)

Findings

1. Patent-level results

- Our **measure of proximity** to the technology frontier is **economically meaningful** as patents semantically closer to the new standards have higher **economic value**, are **more cited** and **renewed**

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- We exploit the exogeneity of the timing and content of the standard to show that **frontier firms**
  1. temporarily gain in terms of sales and market-shares
  2. temporarily increase R&D expenditure, in particular if they operate in a competitive market
- These results suggest that **the release of a new standard** can be interpreted as a **temporary competition shock** for frontier firms

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3. Industry-level results

- **Growth is higher** in industries with initial larger gap between leaders and laggards
- Growth is driven by frontier firms in the **short-run**, but by laggards in the **long-run**

Literature

1. The pros and cons of standardization (IO literature):

   Katz and Shapiro 1985; Farrell and Saloner 1985; Leland 1979; Rysman and Simcoe 2008; Lerner and Tirole 2015; Schmalensee 2009; Llanes and Poblete 2014; Spulber 2019; Bekkers et al. 2017; Baron and Pohlmann 2018

2. Innovation literature:

   - Real Effects: Arrow 1962; Romer 1990; Aghion and Howitt, 1992; Grossman and Helpman 1991; Aghion et al. 2005; Aghion and Griffith 2005
   - Financial Effects: Kogan et al. 2017, Pakes 1985, Nicholas 2008; Daniel et al. 1998; Mitchell and Stafford 2000

3. Text mining applied to semantic analysis of patents and standards

   Arts et al. 2018; Kuhn et al. 2020; Kelly et al. 2021; Argente et al. 2020; Bergeaud et al. 2017; Webb et al. 2018; Bloom et al. 2021; Brachtendorf et al. 2020

1. Data

1.1 Semantic Matching of Standards to Patents

- Goal: Calculation of a score between each patent and each standard that measures to what extent their content overlaps

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- Challenge: Large data volume and string processing
  - 24 mio patents (Google Patents Data)
  - 800,000 standard documents (Perinorm Data)

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- Challenge: Large data volume and string processing
  - 24 mio patents (Google Patents Data)
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- $Score(p, s)$ measures the proximity of patent p to standard s

	Mean	*SD*	*p1*	*p5*	*p25*	*p50*	*p75*	*p95*	*p99*	*N*
(A) Keyword matching sample										
Score	715.7	1,766.6	141.3	151.8	211.8	315.2	638.7	2,345.7	6,289.0	100M

1.2 Firm-level Data

- CRISP for stock market abnormal returns
- IBES for market expectation on future EPS
- COMPUSTAT for firms fundamentals: sales, market shares (defined at NAICS 3-digit level), R&D, CapX, Tobin's Q, market capitalization, leverage, age, industry markup
- Aggregation of **patent-to-standard scores** at the firm level:

$$Shock_{i,t} = \sum_{s \in S} \sum_{p \in P} Score(p, s)_{i,t}$$

	Mean	*SD*	*p1*	*p5*	*p25*	*p50*	*p75*	*p95*	*p99*	*N*
(A) Standardization Shock										
Shock	0.34	2.02	0.00	0.00	0.00	0.00	0.10	1.27	6.24	24,162
$\mathbb{I}[Shock > 0]$	0.48	0.49	0.00	0.00	0.00	0.00	1.00	1.00	1.00	24,162

2. Results

2.1 Patent-level Results

Is the score economically meaningful?

- For scores based on patents filed 1 year before the publication of each standard, consider this:

$$\log(\text{value}_i) = c + \alpha \log(1 + \text{score}_i) + \beta \log(1 + \text{cit}_i) + \gamma Z_i + \varepsilon_i$$

where *value$_i$* is the economic value of the patent from Kogan et al. 2017

	(1)	(2)	(3)	(4)	(5)	(6)
Score	0.0088***	0.0062***	0.0064***	0.0051***	0.0062***	0.0050***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Observations	1,165,487	1,165,487	1,165,462	1,165,462	1,163,913	1,163,913
R^2	0.05	0.06	0.10	0.11	0.13	0.14
Time	Yes	Yes	Yes	Yes	No	No
IPC	No	No	Yes	Yes	No	No
Time × IPC	No	No	No	No	Yes	Yes

- Since the mean patent is valued at 16.3 mio USD, patents with a positive score raise their value by 310,000-592,000 USD.

2.2 Firm-level Results

Is the release of new standard exogenous to the firm?
What are its implications for competition and innovation?

- For firms in the COMPUSTAT universe, consider the following:

$$Y_{i,t} = \alpha_i + \phi_{s,t} + \sum_{n=-12}^{N=16} \beta_n Shock_{i,t+n} + X'_{i,t-1}\eta + \varepsilon_{i,t}$$

where

- α_i is the firm FE
- $\phi_{s,t}$ is the Naics 3-digit FE interacted with a time FE
- $X_{i,t-1}$ controls for mkt cap, leverage, Q, dummy for tech. industries, age

- The distributed lead-lag model takes into account that different standards can be released in subsequent periods such that firms can receive multiple shocks throughout time

Exogeneity of the Shock

- Each standard is voted by an ad-hoc committee. If the committee approves it, the first version of the standard is circulated to sub-committees for comments

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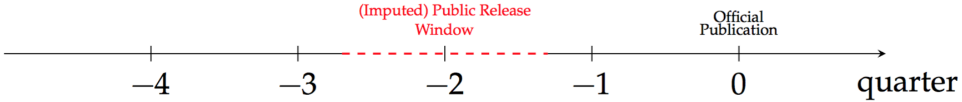
- Otherwise, the standard is revised and voted again
- Depending on the administrative procedure, the content of the new standard becomes public between 1.5 and 2.5 quarters before its official publication



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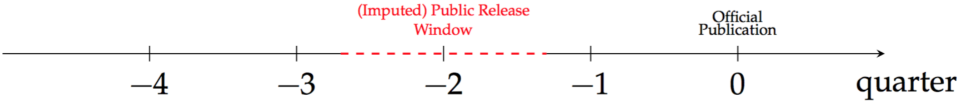
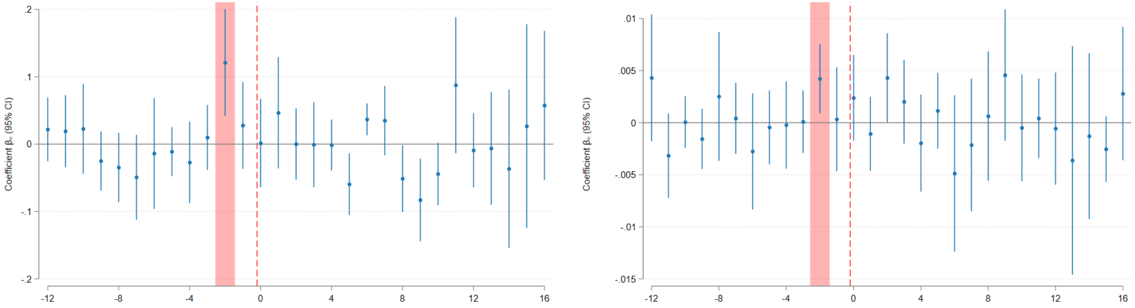


- **Market Efficiency Hypothesis:** if the timing and content of the standard are unexpected, financial markets should react at the moment of the information release

Exogeneity of the Shock

- Consider the following dependent variables:
  - the abnormal return over a NAICS3-industry portfolio, i.e. $ar_{i,t}^{NAICS3}$
  - the change in the 1-year EPS forecast from professional agencies, i.e. $\Delta\mathbb{E}[EPS_{i,t+4}] = \mathbb{E}[EPS_{i,t+4}|\mathbb{I}_t] - \mathbb{E}[EPS_{i,t+4}|\mathbb{I}_{t-1}]$

Figure: Standardization Shock and Financial Markets' Reaction

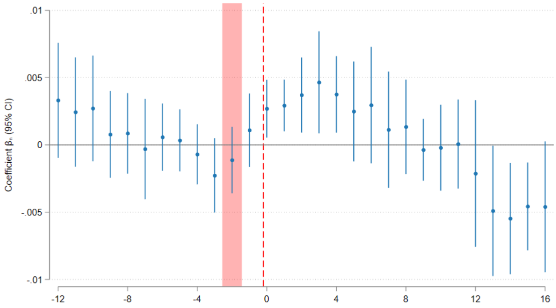


(a) ar^{NAICS3} (b) $\Delta\mathbb{E}(EPS)$

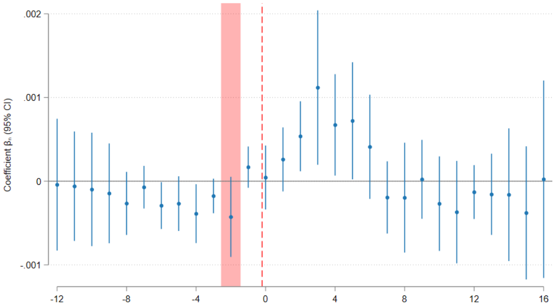
Sales & Market Shares

- Consider sales and market-shares (defined at the Naics 3-digit level) as dependent variables

Figure: Standardization Shock, Sales and Market Shares



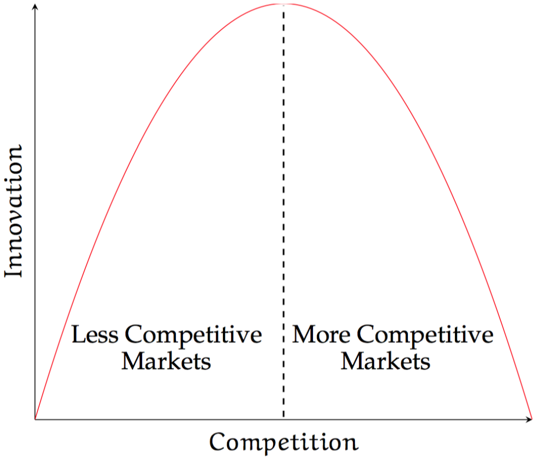
(a) Sales



(b) Market Share

Is it a competition shock?

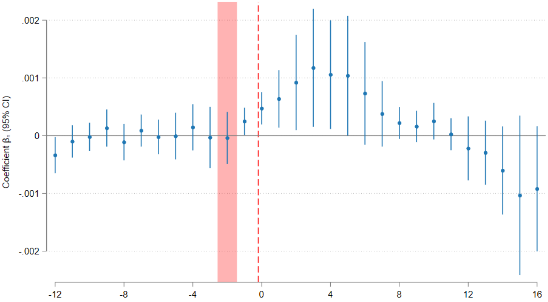
Figure: Aghion et al. 2005, Innovation vs. Competition



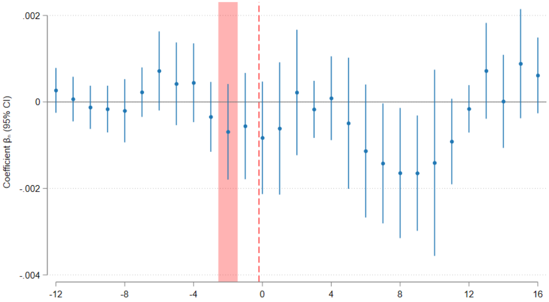
Is it a competition shock?

- Split Naics 3-digit industries in competitive and non-competitive according to their historical markup (De Loecker et al. 2020) and look at results for R&D

Figure: Standardization Shock and R&D



(a) R&D (Competitive Ind)



(b) R&D (Non-Competitive Ind)

Robustness Checks

- These results are robust
  - to different clustering methods:
    - firm-level clustering
    - industry-time double clustering
  - to sample selection:
    - results are not driven by frontier firms
    - results are not driven by listed firms only
  - when considering the intensive/extensive margin of the variable $Shock_{i,t}$
  - to different definitions of the variable $Shock_{i,t}$, i.e. they do not depend on our text analysis methodology

2.3 Industry-level Results

What are the sectoral implications of technology adoption in terms of growth? Is growth driven by leaders or followers in the long-run?

- Define as leaders (followers) those with $Shock_{i,t} > 0$ ($Shock_{i,t} = 0$)
- Aggregate variables at industry level and use same econometric model

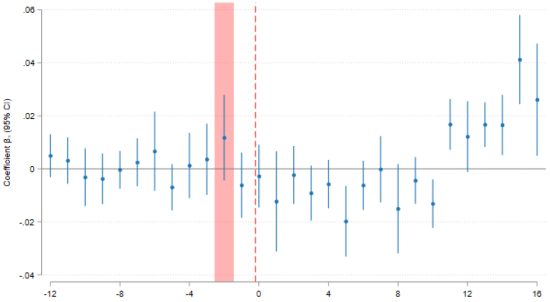
	Industry	*Leaders*	*Followers*
Mean Sectoral Growth Rate (%)	1.64	1.04	0.60
(1yr-Cumulative) Change in Growth (pp)	-0.03	0.08	-0.11
(4yr-Cumulative) Change in Growth (pp)	0.11	0.02	0.09

- Consistently with the step-by-step model of Aghion et al. (1997,2001)
  - **Short-run effect:** leaders try to **escape competition** by increasing R&D
  - **Long-run/Catching-up effect:** followers adapt, increase research effort and surpass leaders

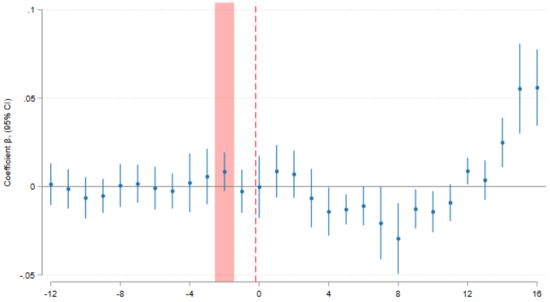
Followers explain sectoral growth in the long-run

- Consider the followers' share of industry aggregate sales and R&D expenditure

Figure: Sectoral Sales and R&D of Followers



(a) Market Share (Followers)



(b) R&D (Followers)

Conclusion

- This paper studies the implications of large-scale technology adoption at the firm level
- To do so, we introduce a new measure of proximity of firms to the technological frontier
- This measure is based on text analysis of patents and standard documents and expresses how much the content of the patents of a firm overlaps with the content of a new standard
- We find that when a new standard is released, firms closer to the new frontier
  - gain in sales and market shares
  - increase R&D expenditure, if they operate in a competitive industry
- We can interpret the release of a new standard as a competition shock in favor of frontier firms
- Effects are only temporary. Laggards catch up through higher innovation efforts. This explains sectoral growth in the long-run

Thank you!

Appendix

Linking patents to standards

- **Basic idea: look at keywords in the abstract of the patent and in the standard document**

1. Establish a list of all patent keywords with respective list of patent ids

keyword	patent id
air condit	41
aluminium	41,106
beef	2
electric	7,84,41,91,102
screw	3,9,17,38

2. Establish a list of all standard keywords with respective list of standard ids

keyword	standard id
air condit	B,M
aluminium	B
diameter	C
rubber	A,E,G,H,R,Z

Linking patents to standards

4. Find common keywords

keyword	patent id	standard id	idf
aluminium	41,106	B	0.2
air condit	41,65	B,M	0.5

5. For each keyword: Cartesian product of respective patent and standard ids

keyword	match	idf
aluminium	41-B	0.2
aluminium	106-B	0.2
air condit	41-B	0.5
air condit	41-M	0.5

6. Calculate score by adding up combinations of ids:

match	idf
41-B	0.7
41-M	0.5
106-B	0.2

Building up the score

Back

- Evaluation of importance of each keyword k via calculation of inverse document frequency (IDF) across all patents (N):

$$IDF\,(k) = 1 + \log\left(\frac{1+N}{1+N(k)}\right)$$

- For every patent $i \in \mathcal{P}$ and standard $j \in \mathcal{J}$, we extract
  - the set of k-grams $\mathcal{B}(i)$ for patent i
  - the set of k-grams $\mathcal{A}(j)$ for standard j
  - $n(k,i)$, i.e. the number of times k-gram k appears in $\mathcal{B}(i)$
  - $s(k)$, the length of k-gram k
- The final score from the matching of patent i to standard j is defined as

$$Score(i,j) = \sum_{k \in \mathcal{A}(j)} \sqrt{\left(\frac{n(k,i)}{|\mathcal{B}(i)|}\right)^{s(k)}} IDF(k)\left(|\mathcal{A}(j) \cap \mathcal{B}(i)|\right)$$