RESEACH INFRASTRUCTURES AND TECHNOLOGICAL LEARNING: TRACKING THE IMPACTS

Workshop RI-PATHS, DESY

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OUTLINE

- Conceptual framework
- How to use procurement and other firm-level data
- Case studies (structured narratives)
- Survey data (statistical tools, Bayesian Networks)
- Company accounts (dif-in-dif econometrics)
- Patents and innovations (non-linear econometrics)
- Start-ups and corporate spin-offs
- Product spin-offs
- Lessons learned for data taking and research design
- Further reading

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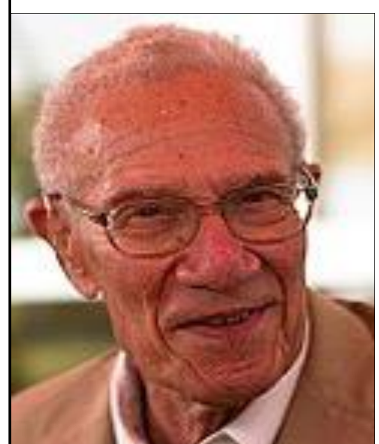
CONCEPTUAL FRAMEWORK (1)

ARROW (1962) vs SOLOW (1997)

Continuos Learning	Discontinuos Innovation
«Learning is the product of experience. Learning can only take place through the attempt to solve a problem and therefore only takes place during activity[…] (L)earning associated with repetition of essentially the same problem is subject to sharply diminishing returns»	«A new theory that combines learning by doing (identifying it with the concept of "continuous improvement") with a separate process of discrete "innovations"»
Progress = Improvement (=Learning by doing)	**Progress = Innovation + Improvement**
 Arrow, "The economic implications of learning by doing." *The review of economic studies* (1962). Nobel Prize 1972	 Solow, *Learning from" learning by doing": lessons for economic growth*. Stanford University Press, 1997. Nobel Prize 1987

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CONCEPTUAL FRAMEWORK (2)

- The analytical issues involved in estimating the technological impact of Ris include two aspects:
  1. how to identify and measure spillover effects
  2. how to value them
- If the R&D cost is fully internalized by the firm, and it is then repaid by the procurement contract, there is no identifiable first-round externality
- This does not bar second-round effects from occurring
- Innovation spilling over the scope of the initial procurement contract can be attributed to the knowledge acquired on the job
- A CBA of a RI should look at the social profits generated by the spillovers
- A possible approach is to look at the company's return on sales
- With j being the number of companies benefiting from technological spillovers over time $\mathcal{T}$, Π_{jt} their *incremental* shadow profits (i.e. profits at shadow prices) directly imputable to the spillover effect, and given the discount factor, the present value of technological learning externalities is expressed as:

$$TE = \sum_{j=1}^{J} \sum_{t=0}^{\mathcal{T}} \frac{1}{(1+SDR)^t} \cdot \Pi_{jt} = \sum_{j=1}^{J} \sum_{t=0}^{\mathcal{T}} \frac{1}{(1+SDR)^t} \cdot (\Delta r_{jt} - \Delta c_{jt})$$

- the last term is the difference between incremental revenues D*r* and costs D*c* for firm *j* over years *1,…t,…* $\mathcal{T}$
- If costs decrease thanks to innovation, then profits increase

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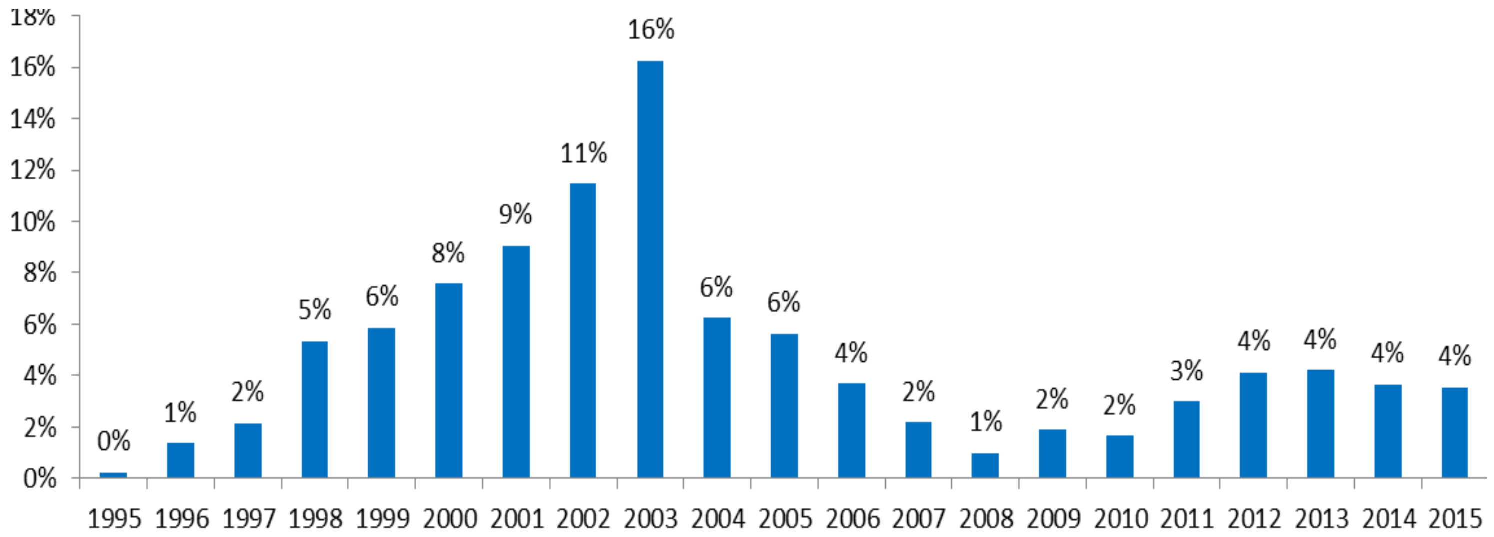
PROCUREMENT DATA: CERN* (1)

*Period: 1995 – 2015; Orders > 10,000 CHF (about 8,500 Euro)

4,204 suppliers from 47 countries
65% low tech; 35% high tech
33,414 orders
4.3 Billion CHF of expenditure

Volume of the orders by year %



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RI PATHS
Research Infrastructure impAct Assessment paTHwayS

PROCUREMENT DATA (2) : DIFFERENT METHODS

Surveys and Bayesian Networks → **Case studies** → Benefits to first-tier suppliers and along the value chain:

- Innovation benefits (new products, services)
- Learning benefits (use new technologies, quality processes)
- Market benefits (reputation, new customers, increasing sales)

Balance sheet data (before-after comparison) → Positive impact on high tech suppliers' profitability, differently gauged

Key mechanisms:

- The way how CERN interacts with its suppliers
- The type and volume of orders

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CASE STUDIES (1)

- 28 illustrative case studies were assembled by CSIL and CERN (Sirtori et al 2019)
- Face-to-face conversations based on a semi-structured interview template
- Questions about:

1. the company
2. collaboration with CERN
3. impact of this collaboration

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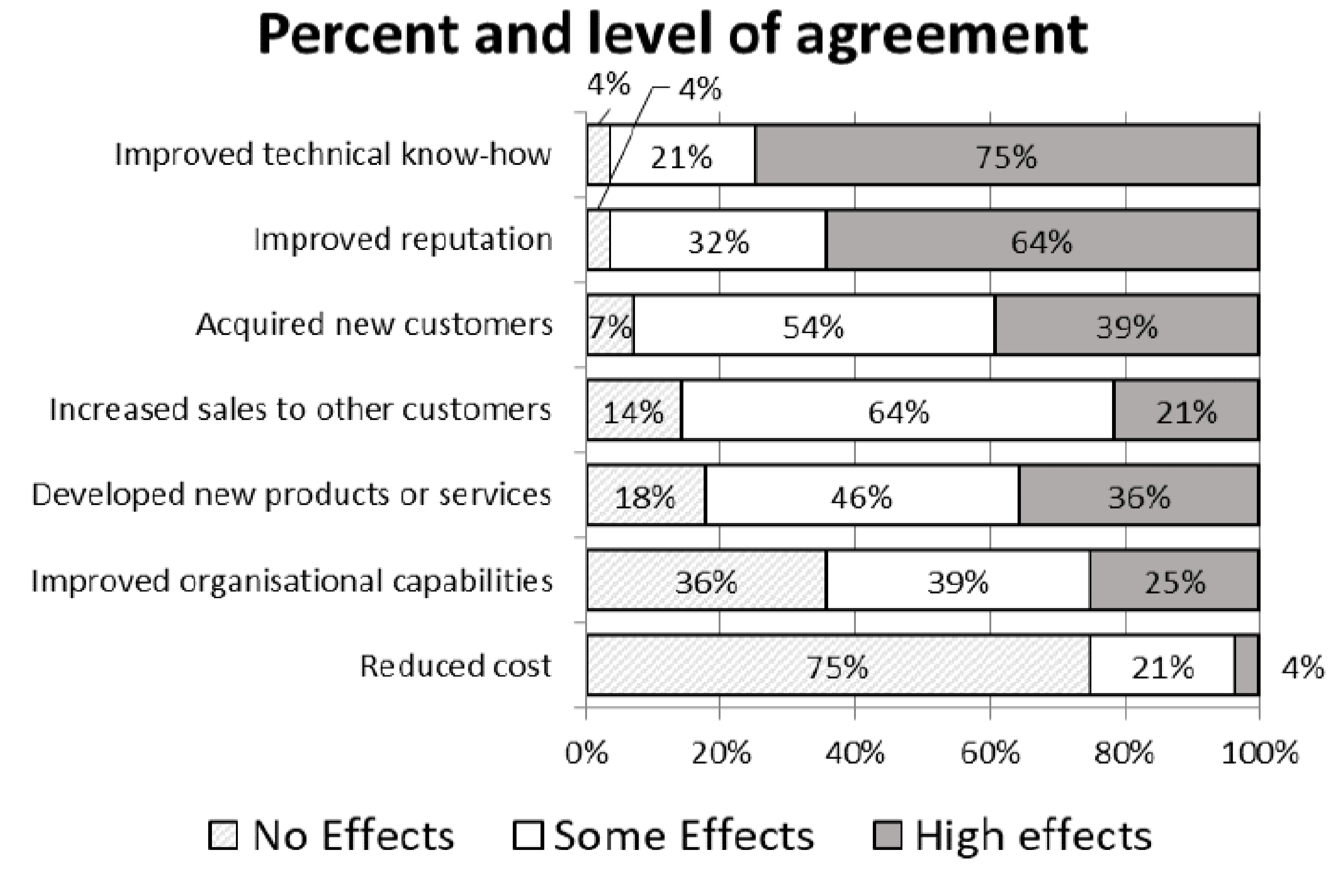
CASE STUDIES (2)



Source: authors' analysis of company survey and face-to-face interviews

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CASE STUDIES (3)

Markets	Technology innovation level: Existing	Modified	New
New	Market development - new clients (0.0%)	Market extension - partial diversification (14.8%)	Diversification (7.4%)
Expanded	Market expansion - remerchandising (3.7%)	Market expansion - improved product (29.6%)	Partial diversification - new product line (14.8%)
Existing	Market penetration - advantage over competitors (0.0%)	Product extension - added value (25.9%)	Replacement - new product development (3.7%)

Notes: Percentage of the number of responses. Source: authors' elaboration on interviews

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CASE STUDIES (4)

RI PATHS
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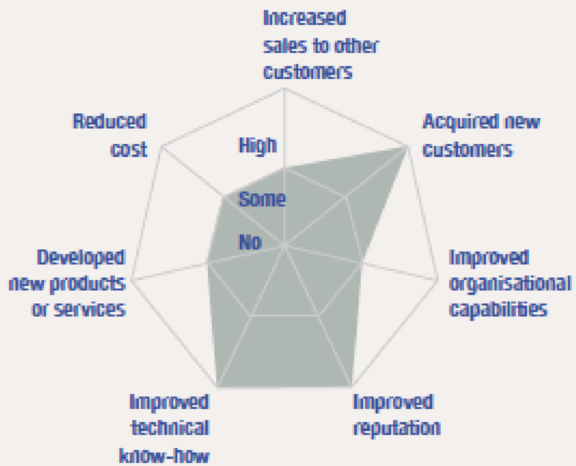
PERCEIVED BENEFITS GAINED THANKS TO CERN



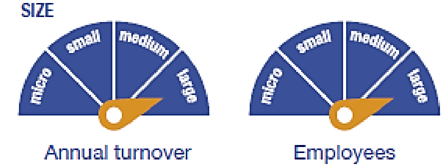
BiLFINGER

YEAR OF FOUNDATION
1824

LOCATION
Würzburg, Germany

APPLICATION DOMAIN
Science, energy, specialized engineering

SIZE



CERN-RELATED MARKET OR INNOVATION BENEFITS FOR BILFINGER NOELL

MARKET	EXISTING	MODIFIED	NEW
NEW	Market development (New clients)	Market extension through partial diversification	Diversification
EXPANDED	Market expansion through re-merchandising	Market expansion through improved product	Partial diversification through new product line
EXISTING	Market penetration through advantage over competitors	Product extension through added value	Replacement through new product development
	TECHNOLOGY INNOVATION LEVEL		

- Three main areas of business: magnet technology, nuclear technology, and service and assembly.
- Development of large superconducting magnets for research into high-energy physics and nuclear fusion

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SURVEY DATA (1): ECONOMIC UTILITY RATIOS AND OUTPUT MULTIPLIERS IN THE LITERATURE

Organization	Method	Average values	Source
CERN	Survey of firms	3	Schmied (1977)
CERN	Survey	1.2	Schmied (1982)
CERN	Survey	3	Bianchi-Streit et al. (1984)
European Space Agency	Survey of firms	3	Brendle et al. (1980)
European Space Agency	Survey	1.5–1.6	Schmied (1982)
European Space Agency	Survey	4.5	Danish Agency for Science (2008)
NASA Space Programmes	Input–Output model	2.1	Bezdek and Wendling (1992)
National Institute of Nuclear Physics	Input–Output model	2–2.7	Salina (2006)
John Innes Centre, UK	**Input–Output model**	**3.03**	**DTZ (2009)**

Source: Florio et al (2016) based on cited sources.

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SURVEY DATA (2)

- **Hypothesis 1:** The level of innovation and the value of orders shape the relationship between CERN and its suppliers. Specifically, the larger and the more innovative the order, the more likely the CERN and its suppliers are to establish relational governance as a remedy for contract incompleteness, agents' opportunism, and suboptimal investments on both sides.
- **Hypothesis 2:** The relational governance of procurement is positively related to innovation outcomes for the suppliers of largescale science centers.
- **Hypothesis 3:** Innovation and market penetration by the large-scale science centers' suppliers are likely to impact positively on their performance.
- **Hypothesis 4:** In the case of relational governance of procurement, the innovation and market outcomes are not confined solely to first-tier suppliers but spread to second-tier suppliers as well.

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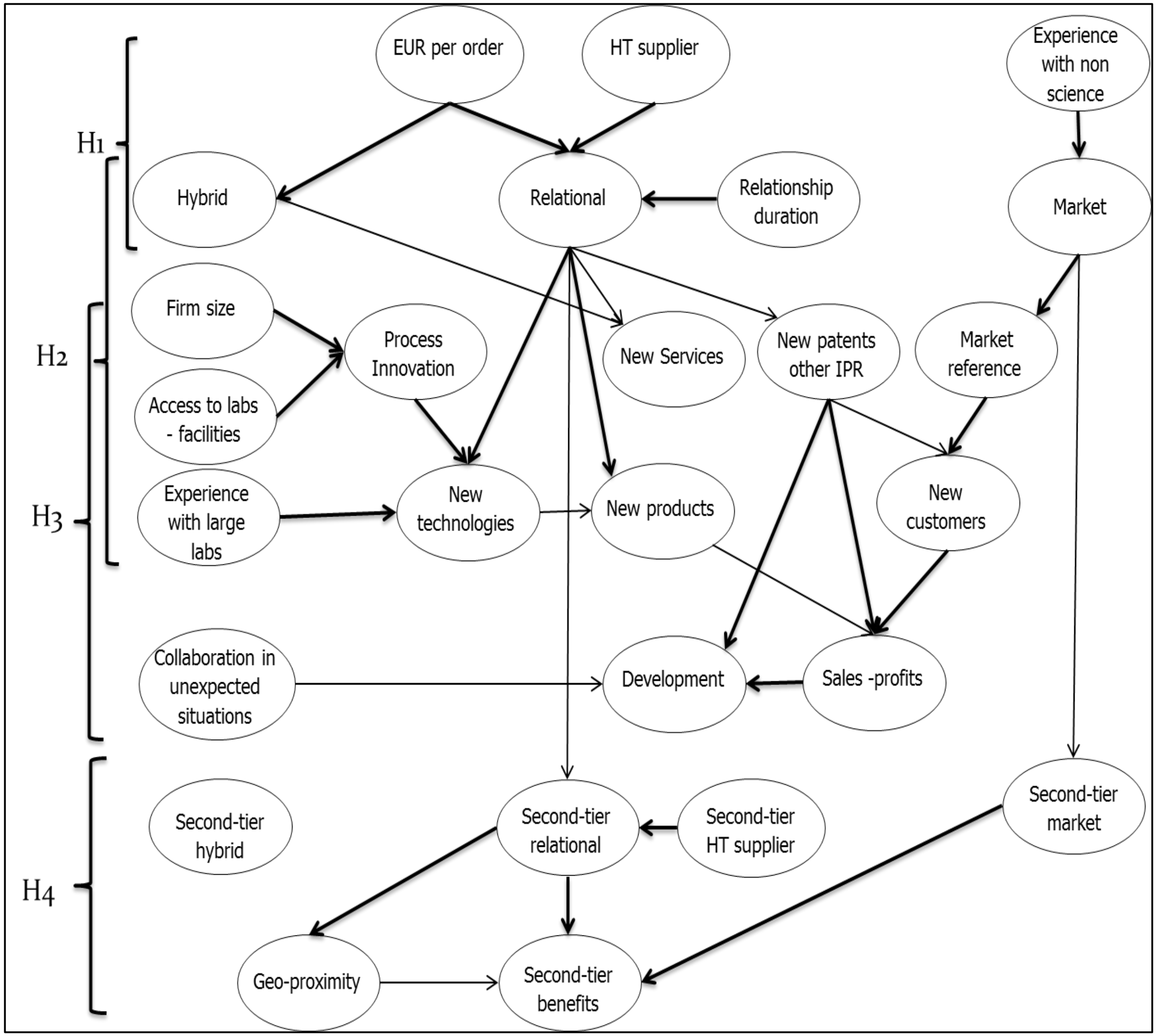
SURVEY DATA: BAYESIAN NETWORKS (3)



- **Findings:**
- This study (Florio et al 2018) provides empirical evidence about the **various types of benefits** accruing to companies involved in a procurement relationship with CERN:
  - Innovation benefits
  - Learning benefits
  - Market benefits
- **Key mechanisms** which explain the type and size of benefits enjoyed are:
  - The way how CERN interacts with its suppliers
  - The type and volume of orders
- Procurement relationships based solely on **market and prices mechanisms are not creating and generating innovation and generate spillovers**

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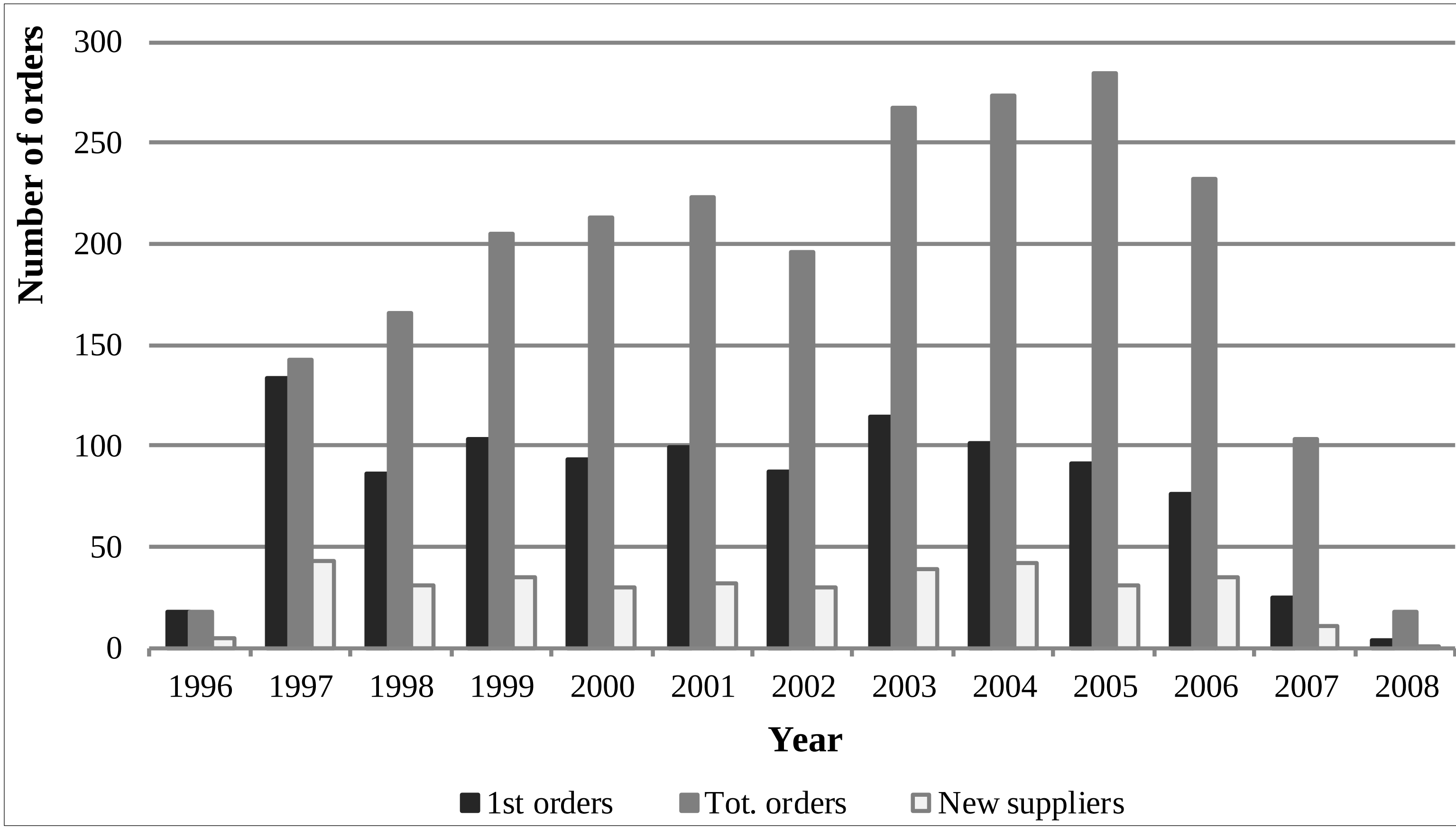
PROCUREMENT DATA: ECONOMETRICS (1)



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FIRM PERFORMANCE FROM COMPANY ACCOUNTS: LOGICAL CHAIN OF IMPACTS (2)

Procurement event

R&D

(Patents)

Productivity

Sales/Profitability

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FIRM PERFORMANCE FROM COMPANY ACCOUNTS (3)

Structural model (system of simultaneous equations):

$$\begin{cases} \Delta R\&D_{jt} = \beta_1 CERN_{jt} + Size'_{jt}\gamma_1 + \theta_1 \Delta GDP_{ct} + \omega_1 \Delta CPI_{ct} + \sigma_s + \eta_t + \rho_c + u_{jt} \\ \Delta Patents_{jt} = \beta_2 R\&D_{it} + Size'_{jt}\gamma_2 + \theta_2 \Delta GDP_{ct} + \sigma_s + \eta_t + \rho_c + e_{jt} \\ \Delta Productivity_{jt} = \beta_3 \Delta patents_{jt} + Size'_{jt}\gamma_3 + \theta_3 \Delta GDP_{ct} + \omega_3 \Delta CPI_{ct} + \sigma_s + \eta_t + \rho_c + \varepsilon_{jt} \\ \Delta Performance_{jt}^{EBIT} = \beta_4 \Delta Productivity_{jt} + Size'_{jt}\gamma_4 + \theta_4 \Delta GDP_{ct} + \omega_4 \Delta CPI_{ct} + \sigma_s + \eta_t + \rho_c + \epsilon_{jt} \end{cases}$$

- $\Delta R\&D_{jt}$: proxied by yearly change of intangible fixed assets per employee
- $CERN_{jt}$: dummy variable that takes value 0 before the first order is received and 1 hereafter
- $\Delta Size'_{jt}$: vector including information on yearly change of assets and number of employees
- $\Delta Productivity_{jt}$: proxied by early change of sales per employee
- $\Delta Patents_{jt}$: number of patents filed by company j in year t
- $\Delta Performance_{jt}^{EBIT}$: yearly change of variable of economic performance considered, where EBIT is the Operating Revenue and earnings before interest and taxes margin

- ΔGDP_{ct}: yearly percentage change of GDP in the firm's country c
- ΔCPI_{ct}: yearly percentage change in that country's CPI (Consumer Price Index)
- η_t: denotes time-fixed effects
- σ_s and ρ_c: time-invariant unobservable industry- and country- specific fixed effects respectively
- u_{jt}, e_{jt}, ε_{jt}, and ϵ_{jt}: random errors terms of each equation

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FIRM PERFORMANCE FROM COMPANY ACCOUNTS (4)

- **Findings:** The coefficients obtained from the estimation of the system highlight the direct effect of procurement on R&D investments as well as its mediated impact on company innovation output: Castelnovo et al (2018) find a positive effect on firm performance for high-tech suppliers, for non high-tech there is often no significant effect.

	(1) FULL SAMPLE	(2) HIGH-TECH	(3) NON HIGH-TECH
ΔR&D (dependent variable) controls non reported			
CERN	0.668***	1.256***	-0.250
ΔPatents (dependent variable) controls non reported			
ΔR&D	7.446***	3.956***	-0.102***
ΔProductivity (dependent variable) controls non reported			
ΔPatents	2848.6***	2535.5***	2815.7***
ΔRevenues (or EBIT or EBIT margin: dependent variables) controls non reported			
ΔProductivity	209.6***	221.2***	211.7***

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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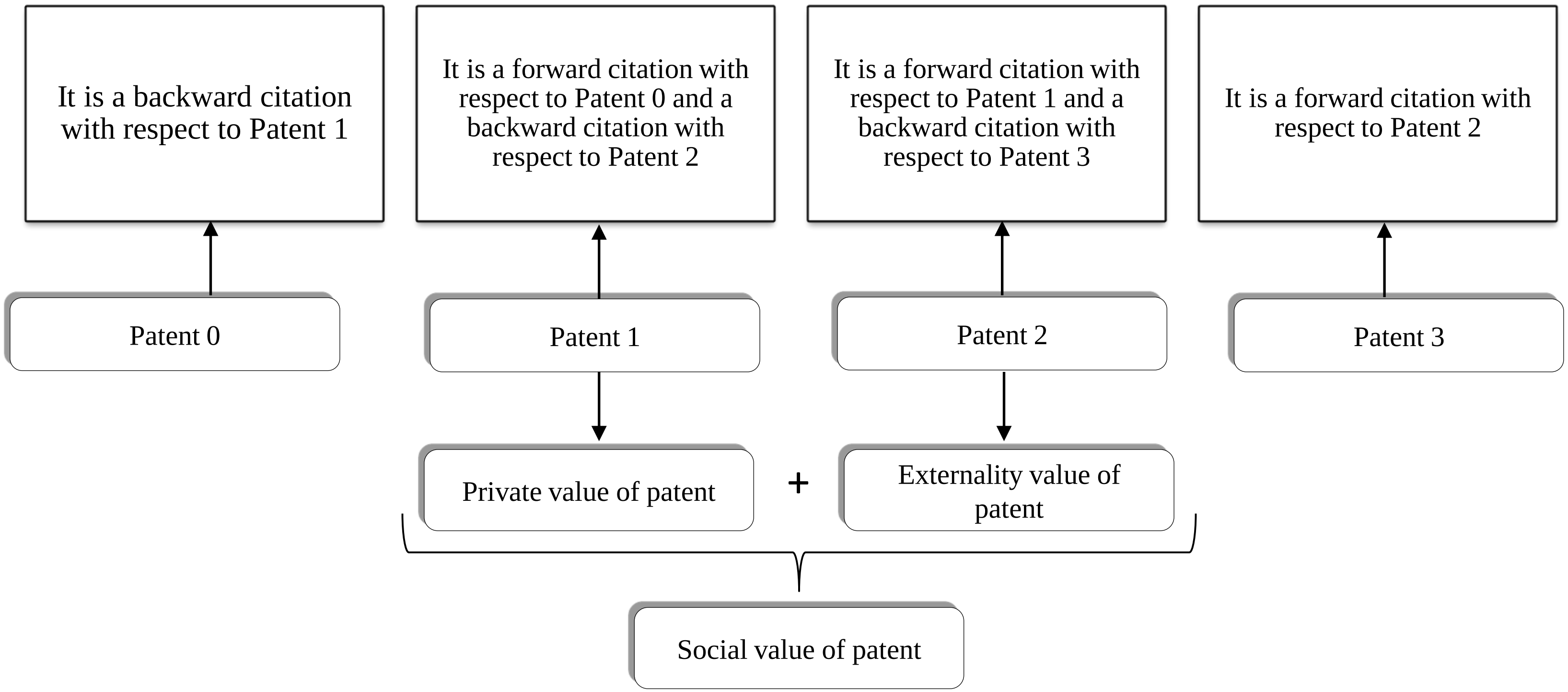
PATENTS AND INNOVATIONS (1):

THE SOCIAL VALUE OF PATENTS



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PATENTS AND INNOVATIONS (2): AVERAGE PATENT VALUES BY COUNTRY AND INDUSTRY

Country	Average patent value (EUR thousands)	Median patent value (EUR thousands)
Technological area		
Pharmaceuticals, cosmetics	5,260	605
Macromolecular chemistry, polymers	3,980	449
Space technology weapons	3,854	414
Environmental technology	3,250	354
Biotechnology	3,134	336
Semiconductor	2,555	284
Telecommunications	2,331	247
Electrical devices, engineering, energy	1,938	211
Country		
Denmark	2,947	300
Germany	2,958	305
Spain	3,029	307
France	2,922	293
Hungary	3,647	408
Italy	3,007	297
The Netherlands	2,788	285
United Kingdom	3,355	332

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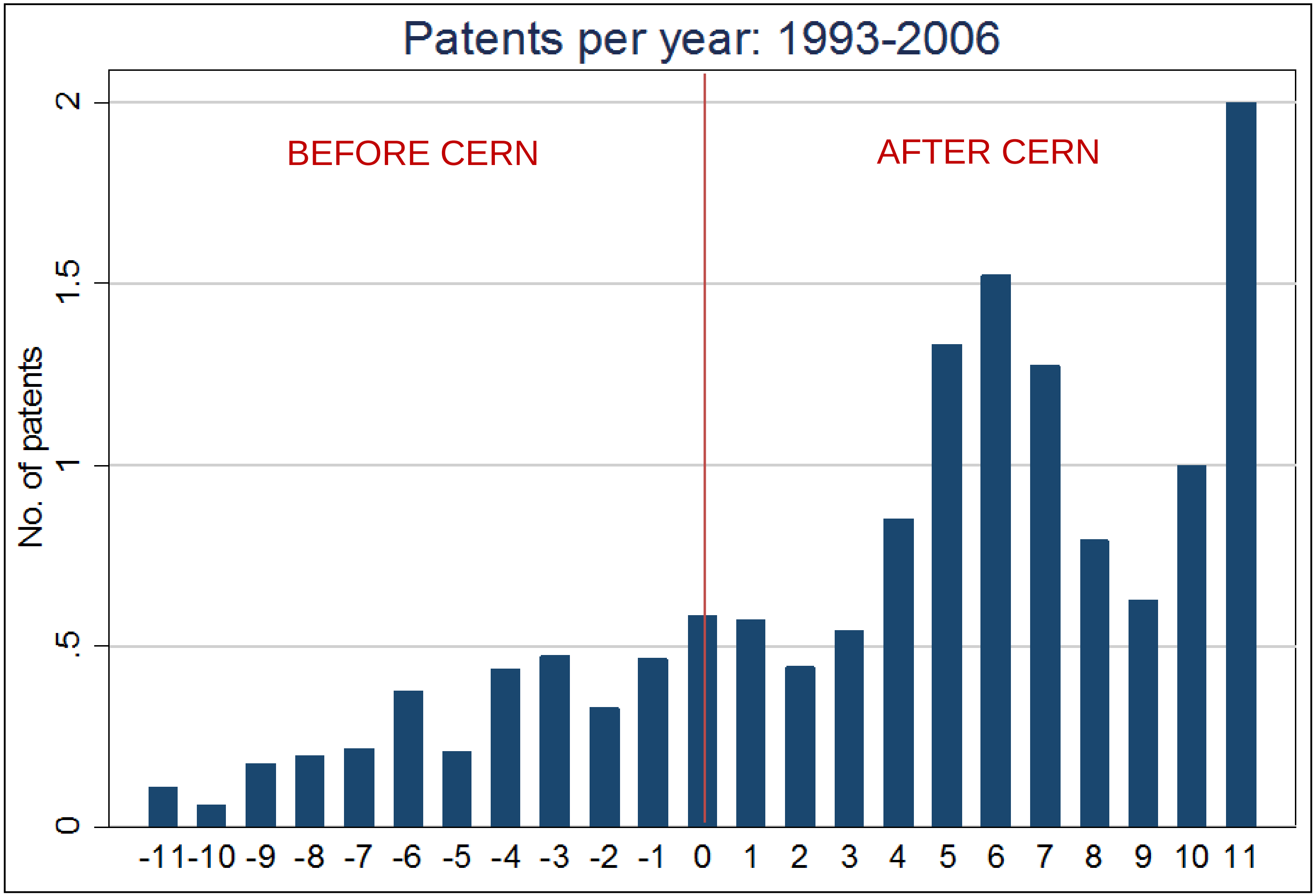
PATENTS AND INNOVATIONS (3) : GESTATION LAGS



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PATENTS AND INNOVATIONS: GESTATION LAGS (4)

RI PATHS
Research Infrastructure impact Assessment paTHwayS

- CERN has effect on innovation, but it takes time to build
- The gestation lag is up to year 5-8 from the first procurement event
- This finding is different from the mainstream literature about the gestation lag from R&D to patents (much shorter lag) and points to technological breakthroughs that need time and experience to build an adequate absorption capacity by the firm
- Lag between procurement and innovation is likely due to the difficulty to translate science into commercial applications

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PATENTS AND INNOVATIONS:

DATASET FOR ECONOMETRIC ANALYSES (5)

- 1296 firms have collaborated with CERN at the construction of LHC between 1995-2008 (Focus on orders >10,000 CHF)
- Balance sheet data, info on patenting activity & on the nature of procurement over the 1993-2006 time period available only for 830 firms.
- Sample starts in 1993 to observe the transition from not-yet-supplier to suppliers
- Sample ends in 2006 and not in 2008 to have some firms that in 2006 are not yet suppliers (i.e. these act as a control group)

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PATENTS AND INNOVATIONS:

DATASET FOR SURVIVAL ANALYSIS (6)

- For survival analysis we keep 692 firms out of 830
- This yields a sample of 9688 observations to be used in survival analysis
- Excluded companies have filed patents before 1993 or after 2006. These firms have been removed because we want to observe the transition from not-patenting to patenting status

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PATENTS AND INNOVATIONS:

THE COX PROPORTIONAL HAZARD MODEL (7)

We are interested in estimating the "Hazard function":

$$h(t|X_i) = h_0(t)\exp(\beta_1 X_{i1} + \ ... + \ \beta_n X_n)$$

Main Explanatory variable

- Dummy variable capturing the beginning of the procurement relationship

Control variables

- Firm-level controls:
  - -size
  - -technological intensity of the order received
  - -total amount of the orders received
- % of contributions to CERN of the Member States where the firm is located
- sector and country dummies

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PATENTS AND INNOVATIONS: COX-PH MODEL (8)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7	k=8	k=9
CERN(k)	0.034	0.043	0.046*	0.054**	0.067***	0.080***	0.088***	0.071**	-0.009	0.034
	(0.028)	(0.032)	(0.024)	(0.023)	(0.024)	(0.025)	(0.029)	(0.033)	(0.047)	(0.052)
High Tech	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ln(Order CHF)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Size controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
% Contribution	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Cox proportional hazard model for start of patenting activity; * $p<0.1$, ** $p<0.05$, *** $p<0.01$
Notes: Robust Std. Err. in parentheses

Note: CERN (K=0) represents the impact of CERN procurement in the year in which the company becomes a CERN supplier

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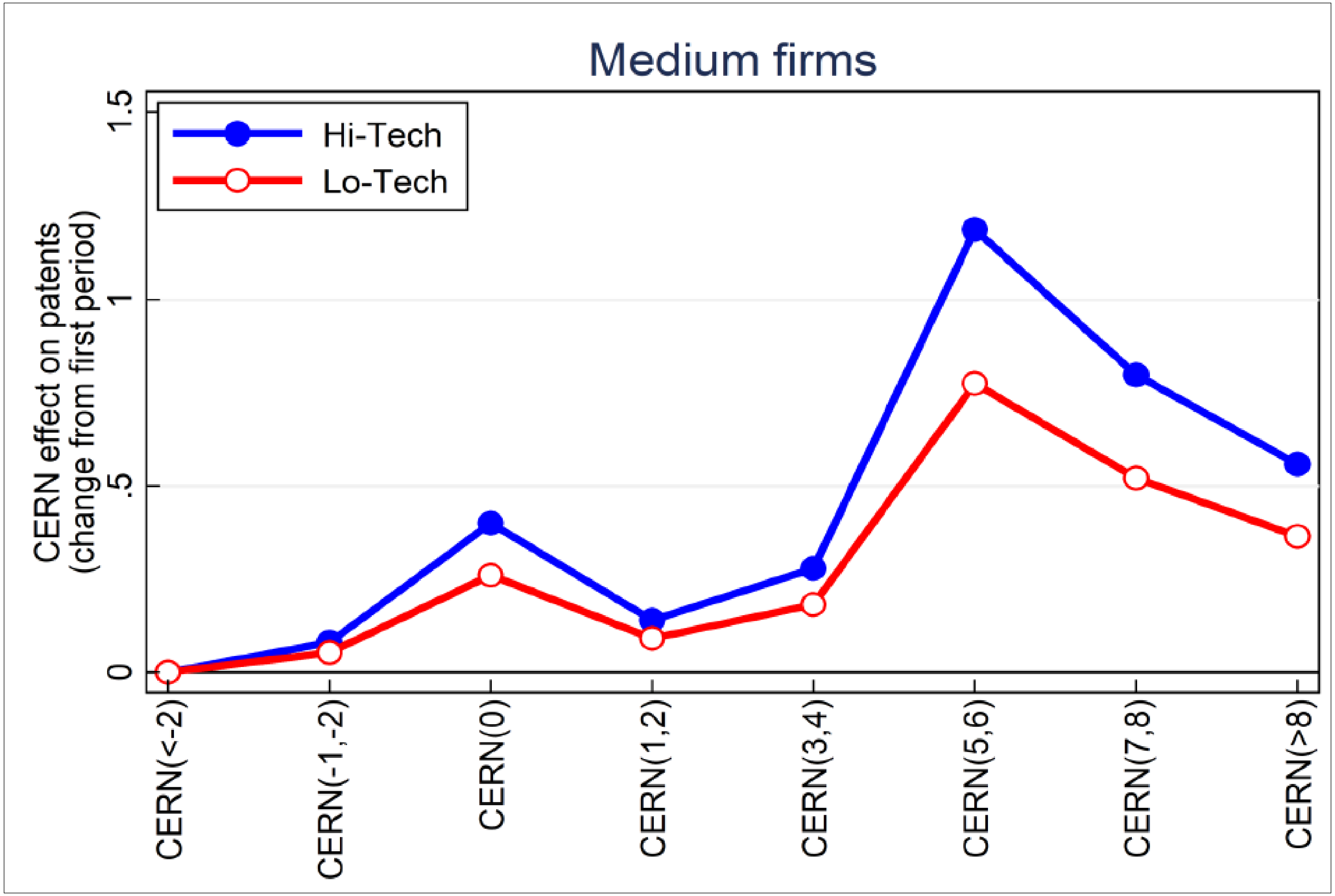
PATENTS AND INNOVATIONS: VARIATION IN THE YEARLY NUMBER OF PATENTS FILED* (9)

* Fitted values, count data model



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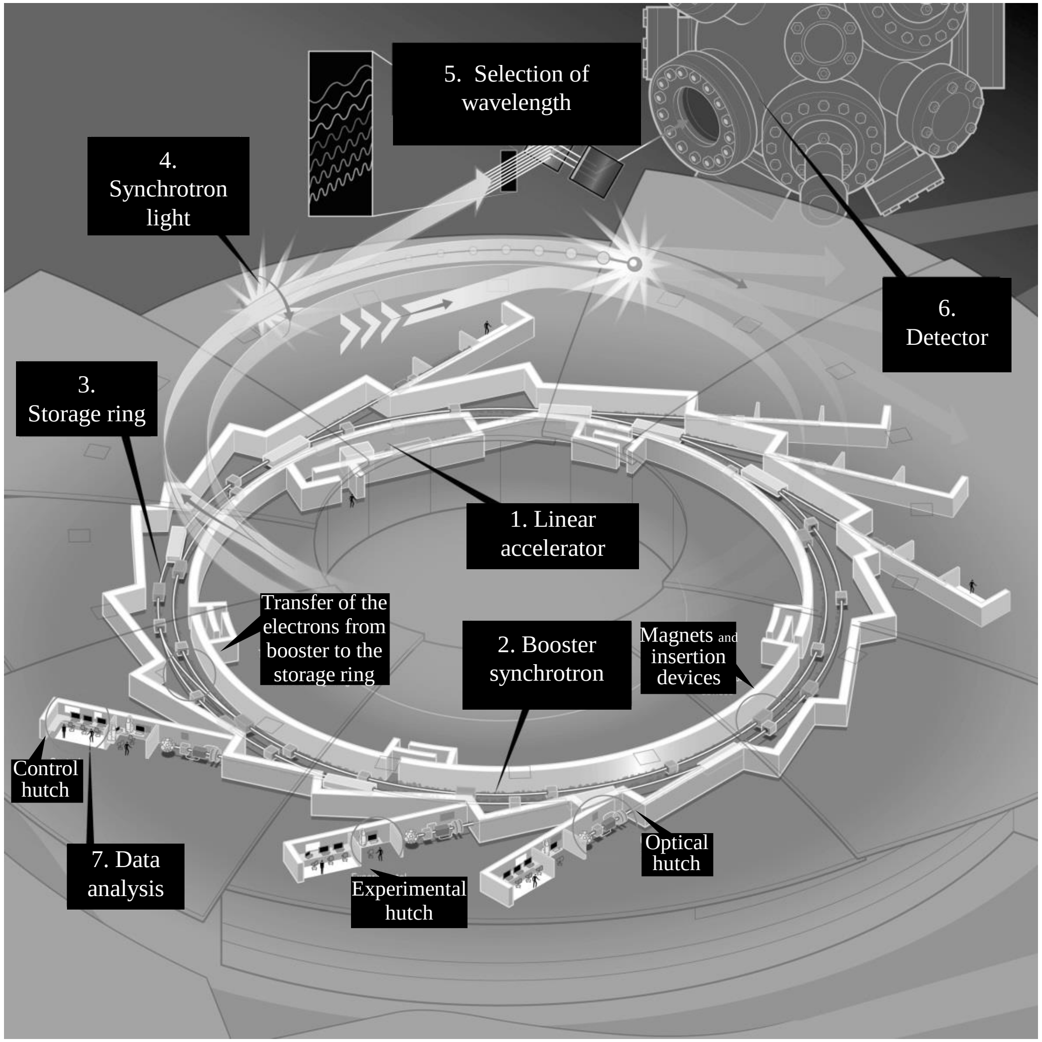
TRACKING INNOVATIONS (1): ALBA SYNCHROTRON



ALBA (Cerdanyola del Vallès, Barcelon) is a synchrotron light source, based on combination of a linear accelerator of electrons and a booster placed in the same 270 m perimeter tunnel as the storage ring. The x-rays emitted by the 3 Gev electon beam allow to study the atomic structure of matter mainly for biosciences, condensed matter, materials science research.

Sources: Courtesy of ©ALBA Synchrotron, own adaptation, https://www.cells.es/en

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TRACKING INNOVATIONS (2)

- A synchrotron light source: Experiments using the beamlines can be classified by scientific fields:
  - chemistry
  - advanced materials
  - nanotechnology
  - pharmaceutical
  - health products
  - environment
  - automotive and aerospace
  - energy
  - cultural heritage
- Except for the very small share of beam time allocated to proprietary research, the vast majority will generate experimental data, supporting publications in scholarly journals in different domains.
- For example in recent years, almost 200 publications in scholarly journals per year are tracked by the ALBA Scientific Division
- Every year 200-300 experimental teams
- Are publications followed by innovations?

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TRACKING INNOVATIONS (3)

Evaluate the economic impact of the knowledge created by ALBA (or similar SLs):

Minimalist approach

- would be to evaluate the citation impact of the ALBA-related literature (more than 700 articles by the end of 2018)
- this would miss the innovation impact

Promising strategy

- would be a periodical survey of external users, as it is highly likely that they will track the applications of their published research
- At ALBA, around 30 percent of the applicants for beam time declare on the online application form that they are already aware of the possible interest of industry for the results of their experiment
    1. some academic teams have already established some linkages with corporate R&D at the time of the application or will create such linkages with industry soon after the experimental data are available, or after publication of the results
    2. thousands of articles will be published, based on the scientific services provided by ALBA
    3. regular survey of the authors can reveal whether they are aware of product or process innovations related to such literature
    4. estimating the value of such innovations pointing to shadow profits
- For the small share of industrial users a similar survey after some years may reveal the contribution of experiments with the SL to their R&D and innovations

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TRACKING INNOVATIONS (4)

Shortcut strategy

- Any SL such as ALBA could point to the identification of a threshold value of innovation benefits against costs

$$NPV_{RI} = [SC + HC + TE + AR + CU] + B_n - [K + L_s + L_o + OP + EXT]$$

- Benefits to scientific users measured by:
  - *SC*: impact of publications
  - *HC*: ECRs in the experimental teams
  - *TE*: technological learning
  - *CU*: users of cultural goods
- Costs of capital, scientific and operative labor, other operative expenditures, and negative externalities $(K + L_s + L_o + OP + EXT)$ are also qualitatively similar
- The main difference between the LHC and ALBA, or between an RI for basic science and one for applied research more in general, potentially lies in two terms:
  - B_n: the nonuse benefits, which include the WTP of citizens for just knowing that LHC and ALBA make certain research;
  - *AR*: the benefits of innovations deriving from services provided
- $B_n = 0$ for ALBA, then $NPV_{RI} > 0$ if $AR > [K + L_s + L_o + OP + EXT] - [SC + HC + CU]$. As all the terms on the right side of this disequation can be determined, the minimum value of *AR* leading to $NPV = 0$ can be determined as $min(AR) = [K + L_s + L_o + OP + EXT] - [SC + HC + CU]$.

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TRACKING INNOVATIONS (5)

- Taking stock of all the ALBA-related literature as N_t at any given time *t*,
  the NPV test is passed if the average paper generates an economic value of innovations in terms of shadow profits > min(AR)/(N_t)
- Perhaps most scientific publications may not generate innovations and profits at time *t*, but some of them will lead to innovations and their economic value may be estimated
- It would be possible to focus on a subsample of the ALBA-related literature and conservatively test whether the measurable cumulated benefits are greater than the required min (AR) value per published paper times the number of papers:

$$\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=0}^{T} s_t \mathbb{E}(\Pi_{ijt}) > \left(\frac{minAR}{N_t}\right) N_t$$

- where j are companies (*j* = 1 … *J*) and i their innovations (*i* = 1 … *I*) (products, services, and technologies), and *t* is the time
- This would require an adequate economic impact-monitoring mechanism over time, beyond simply counting papers and citations by each beamline

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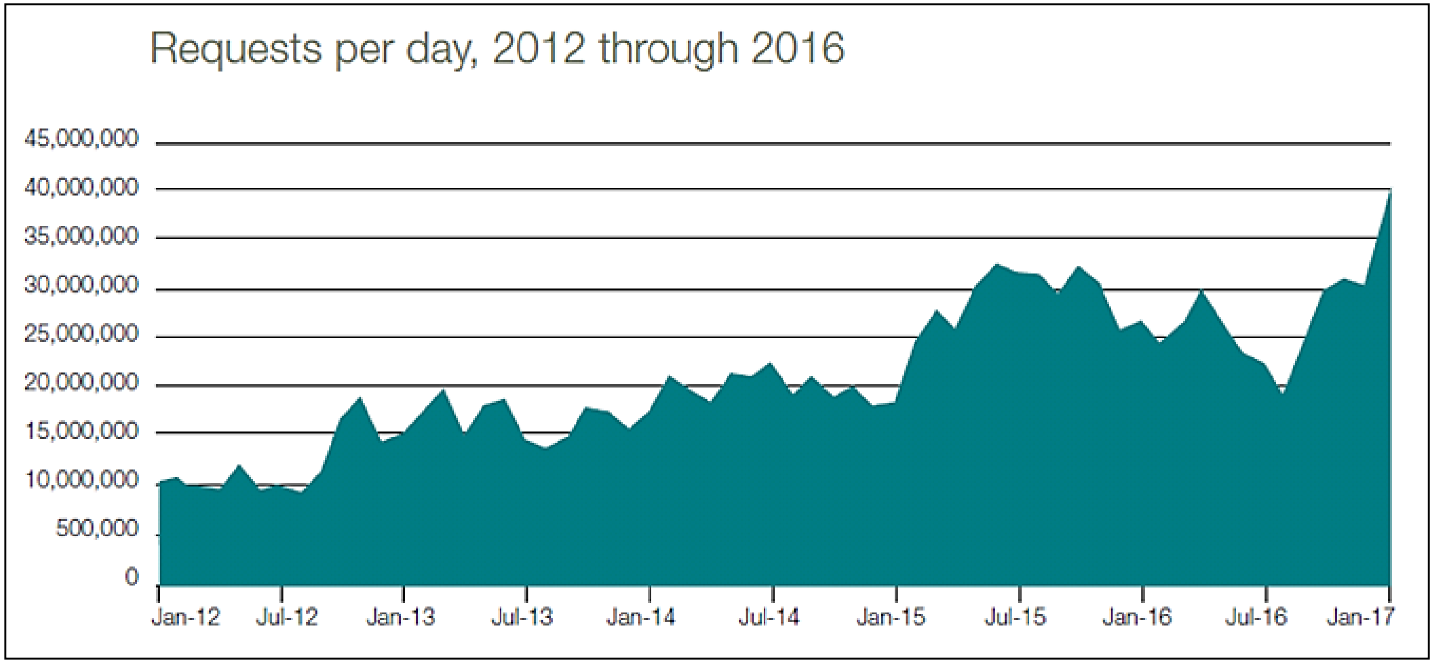
TRACKING INNOVATIONS (6): EMBL-EBI



- EMBL-EBI databases usage (2017): 3.2 million unique IP addresses accesses to EMBL-EBI websites are recorded *every month*.
- These users have potential access, *inter alia*, to 42,529 genomes of different species and strains: to 2.2 million gene expression assays; to 71 million protein sequences; to 125,463 macromolecular structures.
- **Source:** Courtesy of ©EMBL, from EMBL Annual Report 2016.

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TRACKING INNOVATIONS (6)

- A practical example on the implementation of a data-mining approach for patents citing biodata is Bousfield et al. (2016).
- This strategy, while informative, is constrained by the fact that NPL references are unsystematic and, importantly, by the fact that many innovations are not patented

Bousfield, D., McEntyre, J., Velankar, S., Papadatos, G., Bateman, A., Cochrane, G., … and Blomberg, N. 2016. *Patterns of Database Citation in Articles and Patents Indicate Long-Term Scientific and Industry Value of Biological Data Resources*. F1000Research, 5: ELIXIR-160. https://f1000research.com/articles/5-160/v1. Access date: March 19, 2019.

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START UPS AND CORPORATE SPIN OFFS (1)

The ex ante estimation of this benefit involves:

1. Forecasting the *number* of KT activities, start-ups, and/or spin-offs expected to be created by the RI during the entire reference period
2. Establishing the *expected lifetime and survival rate* of start-ups and spin-offs (when the RI contributes to increasing the life expectancy of start-ups, the expected increase in their survival rate must be estimated)
3. Estimating the expected *shadow profit* generated by start-ups and spin-offs created by the RI

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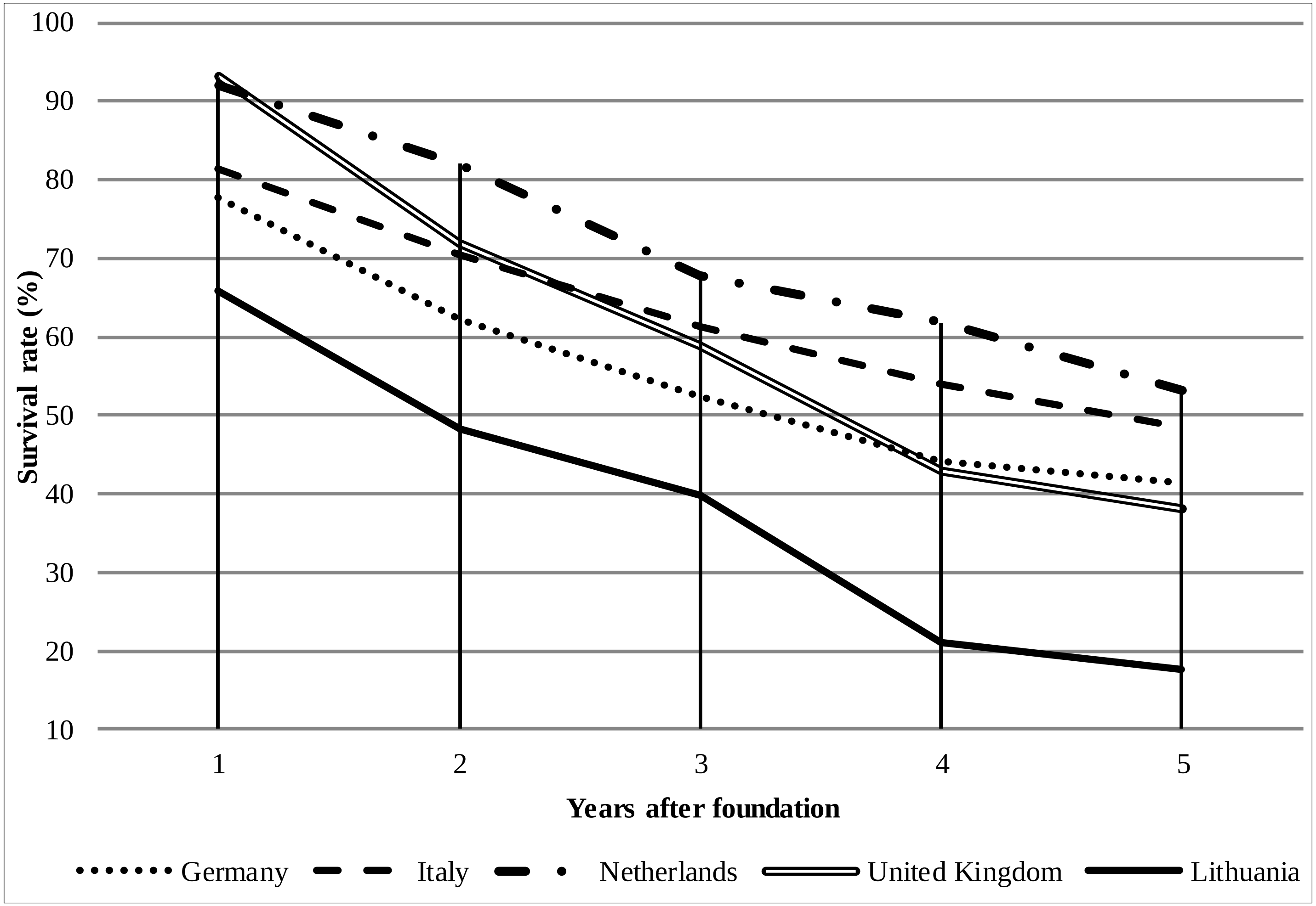
START UPS AND CORPORATE SPIN OFFS (2)



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PRODUCT SPIN OFFS (1)

- NASA (2018b, 6) reports the most recent cases in such sectors as health and medicine, transportation, public safety, consumer goods, energy and environment, IT, and industrial productivity
- These spin-offs are defined as follows:

  "A commercialized product incorporating NASA technology or expertise that benefits the public. These include products or processes that:

  - designed for NASA use, to NASA specifications, and then commercialized;
  - developed as a result of a NASA-funded agreement or know-how gained during collaboration with NASA;
  - developed through Small Business Innovation Research or Small Business Technology Transfer contracts with NASA;
  - incorporate NASA technology in their manufacturing process;
  - receive significant contributions in design or testing from NASA laboratory personnel or facilities;
  - successful entrepreneurial endeavors by ex-NASA employees whose technical expertise was developed while employed by the Agency;
  - commercialized as a result of a NASA patent license or waiver;
  - developed using data or software made available by NASA"

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PRODUCT SPIN OFFS (2)

- Since 1976, NASA's Spinoff publication has featured nearly 2,000 NASA technologies-turned-commercial-products. There's more space in your life than you think!
- spinoff.nasa.gov

"PRECISION COFFEEMAKER ADAPTS BREWS TO BEANS, TASTE"

One student's NASA experience with cutting-edge, autonomous robotic vehicles has informed the creation of one of the world's most sophisticated coffee machines. […] It was his work on one such class of control systems—proportional-integral-derivative (PID) controllers—that laid the foundation for the key component in Blossom's coffeemakers. […] The Blossom One Brewer draws heavily on Blossom Chief Engineer Matt Walliser's four summer internships at NASA's Ames Research Center, where he learned to work with the kinds of technology that enable the coffeemaker to hold brew temperatures steady and synchronize brewing with recipes stored in the cloud

https://spinoff.nasa.gov/Spinoff2016/cg_2.html

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LESSONS LEARNED

- Tracking innovations (systematically)
- Estimating their economic value (seriously)
- In-depth case studies to detect causal mechanisms
- Well designed surveys to firms for statistical analysis (subjective evidence)
- Company accounts and treatment econometrics (objective evidence, if possible)
- Tracking patents (with citations backwards and forwards)
- Monitoring start ups and corporate spin offs
- Monitoring product spin offs
- Hire external experts as independent evaluators
- Publish results in peer reviewed economic journals

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THANK YOU

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