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i3 Institut interdisciplinaire de l'innovation

Centre de Recherche en Gestion
École Polytechnique ParisTech

« *Out of the dusty labs* ». Really ?

GE, Bell Labs and the myth of isolated research (1900 – 1950)

Sylvain Lenfle

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CAUTION WORK IN PROGRESS

The evolution of US corporate research : an overview (Hounshell, 1996; Mowery, 2009)

1. Tremendous growth of corporate research from 1900 to 1940 with emblematic successes (Tungsten filament lamp at GE; Vacuum tubes at BL; Nylon at DuPont). From 50 labs in 1913 to 2000 in 1940
2. Amplified after WWII by the explosion of military spendings (*cold war science*) : 11 000 labs in 1970. Emblematic sucesses : transistor and defence/space megaprojects (Atlas/Titan, Polaris, Apollo…)
3. Doubts began in late 60's – early 70's (project Hindsight, 1969). Different factors (push to more « fundamental » R, economic crisis of the 70's, Japanese competition based on NPD performance, recentering on core competencies) leads to a *research bloodbath* in the early 90's.
4. Growth of « open innovation » (Powell, 1996 ; Chesbrough, 2003). Biotech and ICT as paradigmatic cases.

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Consequences

1. More D and less R (Arora & al, 2018).

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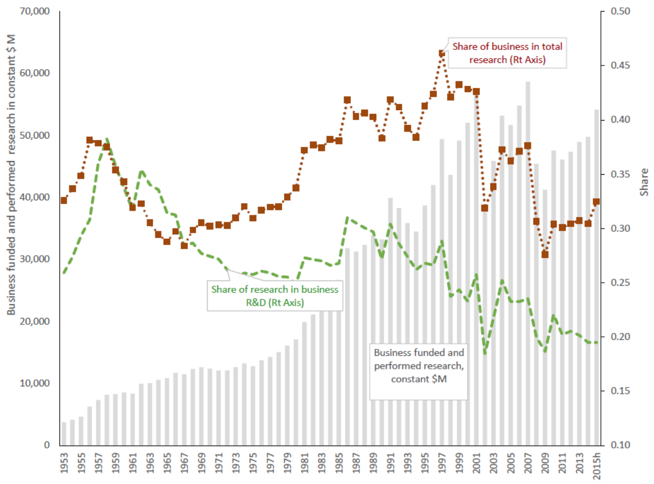
More « D » and less « R »

(Arora & al, 2017 & 2018)



Business funded and performed research in the United States, 1953-2015, NSF S&E Indicators

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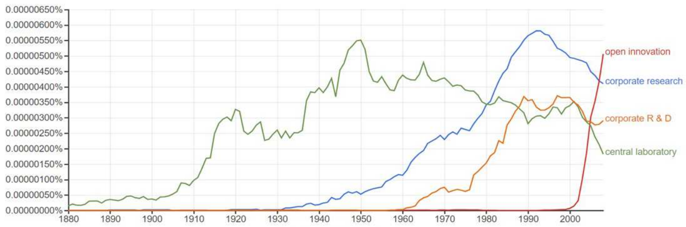
2. A decline in the academic interest for *CR* in favor of networks, Open Innovation, IUC, etc. *CR* almost disappeared from handbooks and academic journals (*to be confirmed*)



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Consequences

1. More D and less R (Arora & al, 2018).

2. A decline in the academic interest for *CR* in favor of networks, Open Innovation, IUC, etc. *CR* almost disappeared from handbooks and academic journals (*to be confirmed*)

3. A « popular » (but ingrained) view of *CR* as « dusty labs » or « ivory tower », and investing in CR a « stategy of hope », particularly in the 50-60's (Roussel & al, 1991)

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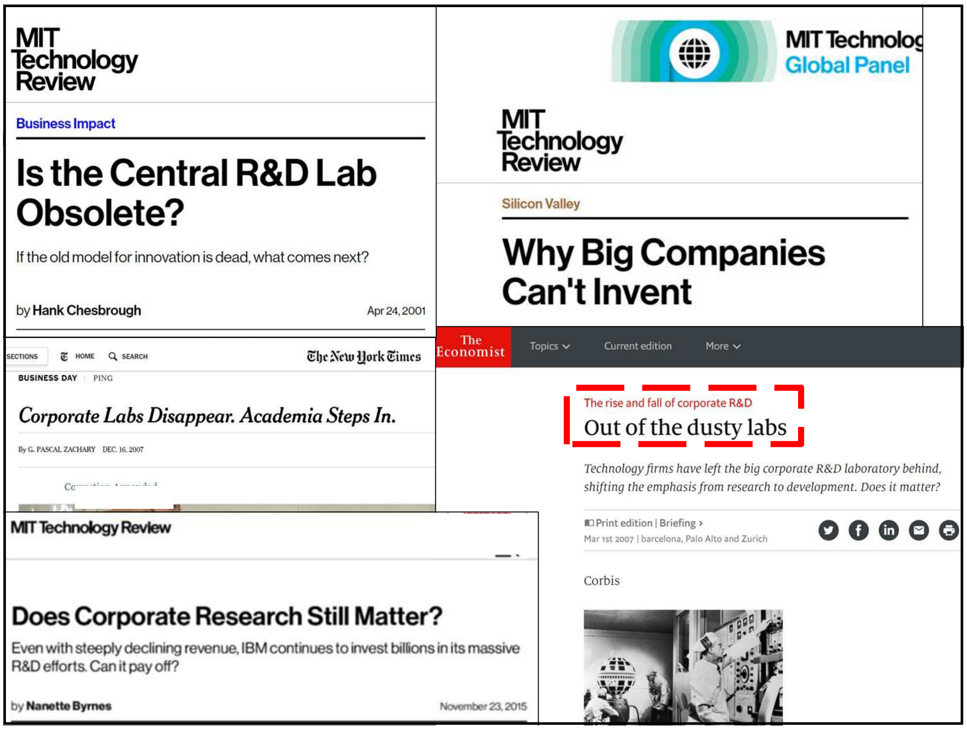

… that pervades academic literature.
Ex : First to Sixth R&D Generations (Nobelius, IJPM, 2004).

R&D Generations	Context	Process Characteristics
First generation	Black hole demand (1950 to mid- 1960s)	R&D as ivory tower, technology-push oriented, seen as an overhead cost, having little or no interaction with the rest of the company or overall strategy. Focus on scientific breakthroughs.
Second generati…	…rket shares battle …mid-1960s to …)	R&D as business, market-pull oriented, and strategy-driven from the business side, all under the umbrella of project management and the internal customer concept.
Third generation	…efforts (mid-1970s to mid-1980s)	R&D as portfolio, moving away from individual projects view, and with linkages to both business and corporate strategies. Risk-reward and similar methods guide the overall investments.
Fourth generation	Time-based struggle (early 1980s to mid-1990s)	R&D as integrative activity, learning from and with customers, moving away from a product focus to a total concept focus, where activities are conducted in parallel by cross-functional teams.
Fifth generation	Systems integration	R&D as network, focusing on collaboration within a wider system – involving competitors, suppliers, distributors, etc. The ability to control…

Does this really exist ?

=> Going back to the historical roots of corporate research at GE and Bell Labs

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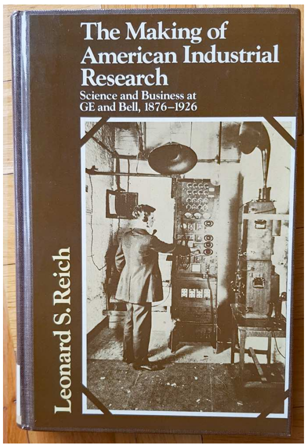
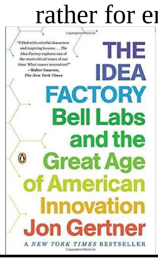
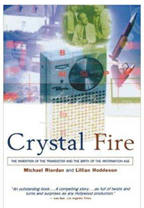
Methodology : historical analysis

We rely on the historiography of industrial research in the US.

- Reich's classic (1983) on the early history of research at GE & Bell
- History of Bell Labs in general (Lipartito, 2009 ; Gertner, 2012) ;
- History of the transistor (see Lenfle & Petitgirard , 2020)
- We did not look for exhaustiveness (see Reich), rather for emblematic cases







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Industrial Research

« *Industrial laboratories*

✓ *set apart from production facilities,*

✓ *staffed by people trained in science and advanced engineering who work toward deeper understandings of corporate-related science and technology,*

✓ *and who are organized to keep them somewhat insulated from immediate demands yet responsive to long-term company needs (p. 3)* »

⇒ General engineering labs are out of the scope.

⇒ A classic form of organization in the 20's.

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GE and the ductile tungsten filament : Research as a strategic asset

- GE was engaged in « *a race with the europeans* [and Westinghouse] *to develop controlling method of metal-filament fabrication* » (p. 77) => creation of a research lab in 1902 under W. Whitney (MIT / PhD chemistry, Leipzig).

- Intense work on incandescent light (1905 -1912) led by W. Coolidge (hired 1906 : MIT / Leipzig / MIT)
  - 13 processes studied in parallel
  - Crisis in 1907 : no process, 40% spending cut, external patent purchase.
  - W. Coolidge 1907 shifts from chemical to mechanical treatments of tungsten => integrated design process (including the plants) => ductile tungsten filament in 1912.
  - Huge commercial success and légitimization of industrial research at GE

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Ductile-tungsten lamps quickly took over the profitable American lighting market, as their share rose from 25% in 1911 to 71% in 1914. The profit margin on these lamps was considerably higher than that on most other GE products. It ranged from 50% to 200% of costs, on lamp sales of $21 million in 1913, $36 million in 1917, and $58 million in 1920. Profits on incandescent lamps reached over $30 million annually during the 1920s, a figure which the *New York Times* calculated to be a 30% return on investment. Up until the Second World War, incandescent lamps brought the company one-third to two-thirds of its annual profit, although they represented only one-sixth of its sales.[59]

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Enter Irving Langmuir

- Training : Columbia / PhD, Göttingen / SIoT / GE in 1909.
- An approach opposed to the « edisonian style » of W. Coolidge =>
  - Langmuir starts with theoretical analysis and the design of conceptual models that will help to solve sets of problems. First in ductile tungsten filament
  - Always work on topic interesting scientifically and for GE, « *and took great pain to make his work available to engineers* » (p. 123)
  - On different fields : light bulbs, radio, vaccum tubes, etc.
- <u>Results:</u>
  - Incandescent gas filled lamps in 1913 and the associated lineage (*Lamp Vacuum Committee* created in 1912 => GE market share raises to 87% in 1939.
  - 63 patents for GE
  - Diversification in vacuum tubes electronics for radio, X-ray and medicine, chemistry, etc
  - Nobel prize in chemistry for Langmuir in 1932.

blacken. Langmuir set out not to solve these problems directly, but to understand the basic principles of lamp operation. He wanted to determine what reactions went on inside the bulbs and how variations in temperature and pressure affected them. With the help of three assistants, including a skilled toolmaker, he studied the dissociation of gases near the filament and the transfer of heat from it; the transportation of molecules between the filament, envelope space, and glass bulb; and the buildup of electrical charge within the lamp. His research took him into the general study of electrical discharge in gases and vacuum.[68] Langmuir undertook this study to gain a general understanding of the physical processes inside the lamp, not only to improve it. Indeed, he himself later claimed that "nearly all those experiments would have seemed quite useless, or even foolish, to a man who was making a direct and logical attack on the problem of improving tungsten lamps."[69]

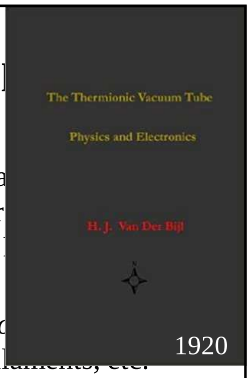
Whether dealing with his own research or reviewing that of others, Langmuir always looked for applications. He not only suggested applications to others, but sometimes appropriated ideas from their work to acquire patents of his own.[80] He understood that properly posed questions often yielded results that could lead the researcher beyond the original problem, whether the problem had at first been formulated in terms of science or technology. As Whitney emphasized, chance favored the prepared mind; and Langmuir let few chances to find new explanations or new ap-

Research as « *House of magic* » Chicago World Fair, 1933.

ATT and the transcontinental link

- Central problem at ATT = signal amplification, particularly for long-distance communication (but also radio) => creation of research branch in engineering department in 1911 and Purchase of Lee de Forest *Audion* Patent in 1913.
- « *F. Jewett put H. D. Arnold in charge of a* <u>*team attack*</u> *on the physics and engineering of the triode* » (p. 162) => work on gases, filaments, etc.
- But most importantly : « « *Arnod and H.J van der Bijl, a Leipzig physicist Ph.D., and fellow Milikan protégé, undertook theoretical studies of electron emission and transmission in the tubes. Based on this work, van der Bijl developed a methodology of vaccum-tube design, introducing a number of functional constants such as the amplification factor (μ), grid constant (γ), and energy-level factor. These constants depended on element shape and configuration, filament emissivity, and plate and grid voltage.* <u>***As a contemporary noted, « Van der Bijl put the electron tube on a fundamental mathematical basis »***</u> *» (p. 163)*

ATT and the transcontinental l



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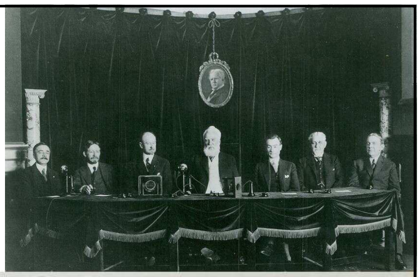
> « *It is interesting to note how sharply this pursuit of theory and mathematics contrasted with the company's approach to development under Hayes. Jewett, Arnold, and the new laboratory researchers recognized the importance of* ***<u>taking a step « back » from the technology</u>*** *to a level of understanding based on theoretical and mathematical considerations* » (p. 171-172)

January 25, 1915 : « *Mr. Watson – Come here – I want to see you* »



The effort was a spectacular success. On January 25, 1915, Alexander Graham Bell spoke from New York to his erstwhile assistant Thomas Watson in San Francisco, thus inaugurating coast-to-coast service. Even though extensive work remained to be done, the Research Branch had, in the short span of little more than two years, entered a new area of physical research, developed theory and application together, and created a functional, predictable electronic device along with circuits for its use. As part of the development process, the Research Branch had also devised quantity manufacture methods for the triode. During 1915 it stepped up in-house production, supplying the Bell System with over 3,200 for use in long-distance service.[37]

Technological theories

(Chap. 8 p. 205, <u>a must read</u>)

- Technological theories (TT) are « *conceptual and mathematical construct that described the behavior of particular types of technology. TT could be used directly or, with experience, codified for further development and design (…) i.e. became design methodologies – technologies in themselves* » => irrelevance of the basic/applied research distinction.

- Indeed TT were « *Analyses of man-made devices , often based on idealization of their structures and functions. <u>In doing so the researchers usually discarded the programs and even the conceptual bases of the scientific disciplines, but they did so on practical rather than on metaphysical bases</u>* » (p. 206) ~ double impact research (Le Masson & Weil, 2016 ; Plantec & al, 2019)

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« *One radio researcher, looking back over the development of signal modulation theory in the lab between 1913 and 1915, noted: « Perhaps no piece of apparatus was ever built for the Bell System that was more pratical or useful than this theory… Latent in this theory were many many inventions » »*

~ TT as conceptual model (Le Masson & al., 2014)

In the same vein Van der Bijl work leads to the design of « *system of tube description and a methodology of design* » (p. 208) that allows engineer to avoid « *to be led in possibly but rather fruitless bypaths* » (ibid).

Fast forward : the transistor case
(based on Lenfle & Petitgirard, 2020)

- Continuation of the strategic research on signal amplification : the « beyond vacuum tubes » question appears in the mid-30's.
- December 16th, 1947 : demonstration of a working point-contact « transistor » at Bell Labs by J. Bardeen & W. Brattain
  - A technical breakthrough
  - Leading to « Junction transistor » (1948) …and others !
  - Opening the « Silicon Valley » and the « Information age »
- A scientific breakthrough : 1956 Nobel Prize in Physics for Shockley, Bardeen & Brattain.

- Here again we find the importance of « *taking a step back from the technology* », particularly for the Junction Transistor.

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Designing the transistors

- **Point contact transistor :**
  - A breakthrough without a theoretical understanding
  - Far from « structure to structure » replacement of VT
  - An industrial nightmare !!!
- **Junction transistor**
  - Start with the frantic theoretical work of W. Shockley in Dec. 47 / Jan. 48 => whereas PCT was an exprimental process, JCT design starts with theory.
  - 2 years of R&D : working April, 12, 1950 / Announced summer, 1951.
    - In particular on the metallurgy of germanium : « *good p-n junction prepared by sparks & teal by changing the doping of the melt in germanium crystal grower by « pill dropping » and subsequent double doping to make n-p-n structures* » (in Shockley, 1976)
  - Publication of Shockley's classic *Electron and holes in semiconductors with application to transistor electronics* (nov. 1950) ~ bible of the Silicon Valley

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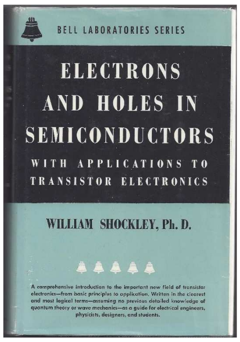
Designing the transistors



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> *"It was like picking up the phone and talking to god. He was absolutely the most important person on semiconductor electronics. Getting that job meant you will definitely be playing in the big league".*
>
> R. Noyce (Intel co-founder) on Shockley's call for a job interview (in Reid, *The Chip*, 2001, p. 87).

Science and corporate strategy at GE & Bell Labs

- In both case not a single trace of « *Ivory towers* » or « *strategy of hope* »
- Rather a tightly supervised and carefully designed research program to solve strategic problems
  - **At GE (W. Withney)** : creating new products on existing markets / protecting position through patents / exploring new domains
    - Research is a profit center financed by the divisions
  - **At Bell (M. Kelly)** : work on the generic question of signal amplification to improve the performance of the complex Bell System (first Audion, then Semiconductors) and fight alternative technologies (radio)

=> ***Both cases*** : multi-disciplinary research labs, closely integrated in the all firm, and which emphasized the development of *technological theories* (i.e. conceptual models) adressing a broad range of mainly practical issues

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The Bell Labs under Mervin J. Kelly

- Tight supervision of M. Kelly,
  - Setting the direction of research for the group (cf. Shockley, 1976)
  - Creation of the multi-disciplinary SC Group in 1945
  - Always anticipating the next problem to accelerate innovation (BL internal organization, physical design of the labs, link with the divisions; e.g. Kelly 1943 & 1950)
  - ⇒ A carefully orchestrated innovation process from « basic research » to fundamental development, production, etc.

« *Here was the lab strengh, « continuous operation » from research to application. Though personnel were free to pursue fundamental work, the labs was not set up « separate and apart » from daily operations of « commercial design and economic consideration », as were other research entities. Research and development department were in « close proximity », and information flowed between them casually and informally. The research worker served as a consultant to the development engineer, and researchers had a good understanding of the field operations of the apparatus they are working on* ». K. Lipartito, 2009, p. 144

Conclusion (1)

An original research model combining (Le Masson & Weil, 2016 ; Plantec & al. 2019)

- Wide exploration within a vision
- Structure/process and freedom
- Generic laws *AND* pratical applications…
- … that raises nex scientific questions (*double impact*)

=> It questions the relevance of the Basic / Applied Research distinction (Narayanamurti & Odumosu, 2016)

« *It is frequently said that having a more-or-less specific practical goal in mind will degrade the quality of research. I do not believe that this is necessarily the case and to make my point in this lecture I have chosen my examples of the new physics of semiconductors from research projects which were very definitely motivated by practical considerations.* » (W. Shockley Nobel Lecture, 1956).
=> « *Respect for scientific aspects of practical problems* » (1974)

From practical problems to science

« *Arnold's breakthrough came when, taking account of the more general theory, he achieved and understanding of the emission and transportation of electrons between a negatively charged filament and a positively charged plate. His assumption that this process could take place in a vacuum – by no means the commonly held scientific opinion of the day – proved crucial in the analysis and greatly acceleratd ATT development of the device* » (p. 210)

Frequently experiences « *revealed serious conceptual problems, forcing workers to re-evaluate the related science. For example, an unexpected success in sealing glass to metal caused W. Housekeeper to reconsider the chemistry of adhesion and to make a mathematical analysis of seal stress* » (p. 211) ~ double-impact again

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Conclusion (2)

« *These laboratories are (…) organized on a strictly business basis, and the work conducted in them is directed to no other purpose that improving and extending and conducting in a more economical way the service which we render to the punlic. (…) The criterion which we apply to the work conducted in theses labs is that of practical utility. Unless the work promises pratical results it is not undertaken, and unless as a whole the work yields practical results it cannot and should not be continued.* ***The practical question is « Does this kind of research pay?*** » »

JJ. Carty, ATT chief engineer 1924 (p. 193)

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Conclusion (2)

"The current skepticism about basic research in industry imagines a world of detached corportate laboratory that existed only for a moment in a much longer history of successful balancing of the commitment to the long term with the need for a commercial payoff. This historical misperception perpetuates the error that basic research is a luxury firms cannot afford. Reducing the scope of innovation in this way is a recipe for reducing innovation, period ».

K. Lipartito, 2009, p. 153-154

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sylvain.lenfle@lecnam.net
http://www.sylvainlenfle.fr

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