WHICH RESEARCH ORGANIZATION MODEL PROMOTES BREAKTHROUGH INNOVATION?

VALUE OF SIMULTANEOUS DISCOVERY-INVENTION RESEARCH ORIENTATION - SEMINAR - BETA - STRASBOURG

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Adæquate Consulting

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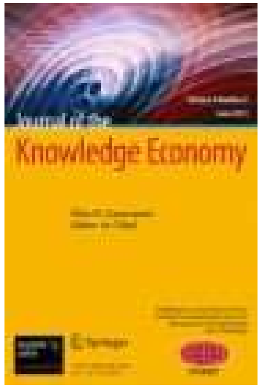
THE IMPACT OF RESEARCH

2016
Request from CEA corporate strategy Department

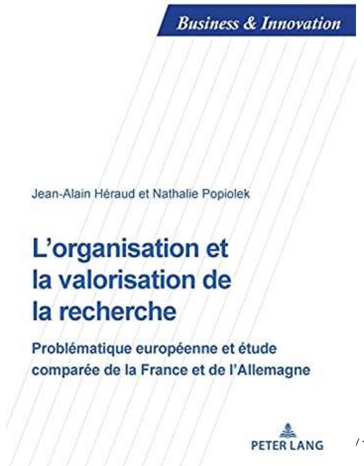
2017-2019
EARTO WG Impact



2017-2019
Interviews & Seminar

Coupling between science and industry to promote the impact

2019-2021
Book on the organization and valorization of research to go further in understanding the research and innovation system



2020-2021
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Tendance, Innovation and Breakthrough

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- Archambault, V., and Popiolek, N. Dir. 2020. Modèles et pratiques de couplage entre Sciences et industrie pour favoriser l'impact de la Recherche. Histoires de Sciences & Entreprises. Collective publication. Preface: A. Fert, Nobel Prize in Physics. Paris : Presses des Mines.
- Héraud, J.A. and Popiolek, N. 2021. L'organisation et la valorisation de la recherche - problématique européenne et étude comparée de la France et de l'Allemagne. P.I.E. PETER LANG SA, Éditions Scientifiques Internationales, collection Business and Innovation.
- Popiolek, N. 2021. "Which research organization model promotes breakthrough innovation?". R&D Management Conference 2021, 6th-8th July - Glasgow: Innovation in an Era of Disruption.
- Popiolek, N. 2019. « Mesure de l'impact de la recherche: Compte-rendu des entretiens réalisés entre juin et octobre 2018 ». Direction de la stratégie et des programmes. Rapport interne CEA.
- Taverdet-Popiolek, N. 2021. "Economic Footprint of a Large French Research and Technology Organisation in Europe: Deciphering a Simplified Model and Appraising the Results." Journal of the Knowledge Economy.

POSTULATES

Postulate 1: Research has a key role to play to support the transition to the "next world".

Postulate 2: Even if Research leads to a better understanding of the laws of nature, its ultimate purpose is innovation.

Postulate 3: Technological applications of research give humanity more freedom : thanks to an efficient and generalized vaccine, we could get out of the sacrificial dilemma "distancing or Covid-19"

Postulate 4: For the transition, we need breakthrough innovations arising from the exploration of new areas of knowledge.

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"Chance only favors prepared minds".

Pasteur (1854)

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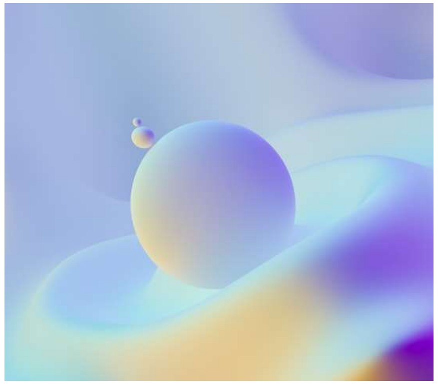
PRESENTATION PLAN



Perception of the innovation process

We are interested in breakthrough innovations

We look at the historical construction of an analytical framework to describe the innovation process at different periods during the past 30 years.

The dominant perception is insufficient to analyze the creative process in the fields of science and technology.

Our question and our methodology

We focus on the researchers' reasoning

To improve creativity, which coupling model between science and innovation?

Our approach is empirical. It is based on interviews with researchers from academic and industrial laboratories.

Our results

For a wide variety of fields of activity

We highlight in successful case studies the value of cross-fertilization between basic and applied research to explore new fields of knowledge.

It emerges the interest of considering the *simultaneous discovery-invention research orientation*.

This is particularly important for the design of public policies.

THE PERCEPTION OF INNOVATION PROCESS

THE HISTORICAL CONSTRUCTION OF AN ANALYTICAL FRAMEWORK

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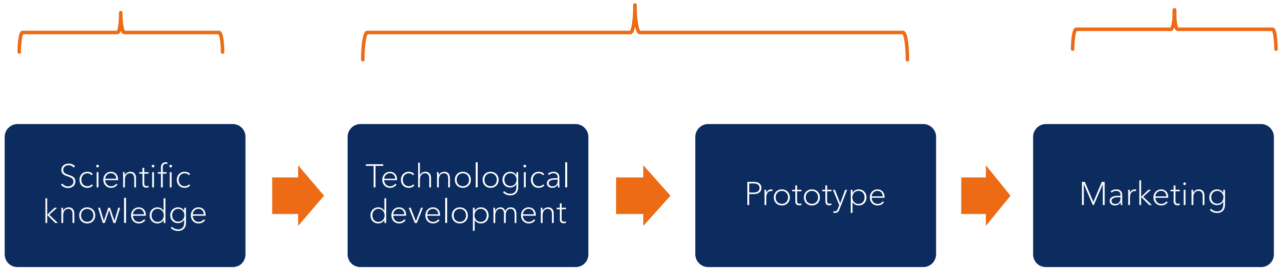
SCIENCE-PUSHED MODEL OF INNOVATION

- It expresses the idea that most innovations are the consequence of scientific discoveries - and related technological developments - that open the way to new economic applications.
- One of the issues with such a vision is that the process of creativity in Science & Technology (S&T) appears completely exogenous from a socio-economic point of view.
- There are fixation biases in each area of knowledge that hinder creativity for breakthrough innovation.

Creativity is considered separately in 3 different silos of knowledge.
This hinders the exploration of new fields of knowledge.



Schumpeter.1 in the beginning of the 20^{th} century

DEMAND-DRIVEN MODEL OF INNOVATION

- It expresses the idea that in most of the cases, innovations were introduced on the basis of market considerations, not triggered by scientific supply of knowledge.
- If the new economic good can be designed without developing a new technological system, it is better. If necessary, science can be driven by a firm in order to achieve the given economic goal.
- The issues with such a vision are that the process supposes the demand exists and it does not leave enough freedom for researchers to be creative.

In France, this vision led, from 2008 to the settlement of a policy favoring businesses such as the research tax credit policy (CIR) widely spread in recent years.

The innovator has more an economic vision than a technological passion.
There is little room for creativity in the field of S&T knowledge.

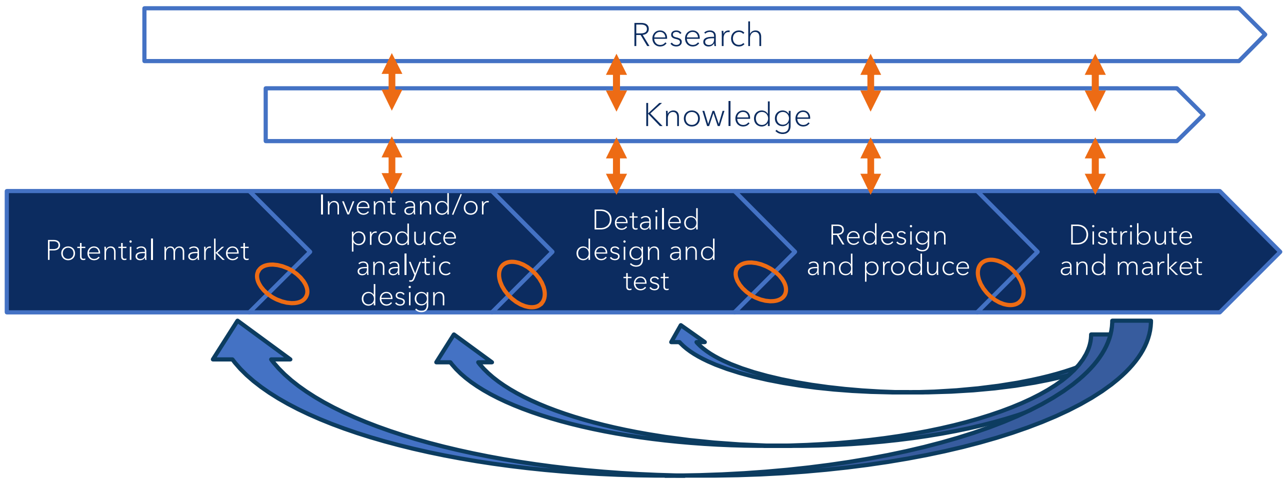
Market needs → Adaptation of existing technology → Prototype → Marketing

Schumpeter.2 after war and Jacob Schmookler ,1966

CHAIN-LINKED MODEL OF KNOWLEDGE CREATION AND INNOVATION

- It exhibits a lot of feedback loops between the different stages of the process going down from the first idea to the complete realization.
- The necessity to find a solution forces the involved actors to look for some information already available in the general stock of knowledge (books, data bases, individual skills, etc.), or to push the research in the relevant domain if no ready-to-use solution is available.
- This is interesting for incremental innovations.

Part of the creativity of the innovation process comes from the interactions.
But what about breakthrough innovation?



Kline & Rosenberg, 1986

SIMULTANEOUS DISCOVERY-INVENTION MODEL

- A third type of model was explored to better analyze the modalities of cooperation within public-private research projects.
- In echoes to Stokes (1997), Goldstein and Narayanamurti (2018) evoked: the *simultaneous discovery-invention (SDI) research orientation.*
- It is based on the scientists' commitment to addressing fundamental research questions through applied research.
- It is effective in the US Department of Energy's particular institutional context.
- Plantec, Cabanes *et al.* (2021) extend these results by showing its effectivity into a broader range of university-industry projects (in particular, for Collaborative Ph.D. projects through the CIFRE program in France).

Goldstein, A. P., Narayanamurti, V. 2018. Simultaneous pursuit of discovery and invention in the US Department of Energy. Research Policy, 47(8): 1505–1512.

Plantec, Q., Cabanes, B., Le Masson, P., Weil. B. 2021. "Market-pull or research-push? Effect of research orientations on university-industry collaborative Ph.D.". Projects' performances. Academy of Management Conference 2021, Jul. 2021, Philadelphia, United States.

Stokes, D. 1997. Pasteur's Quadrant. Basic science and technological innovation. Brookings Institution.

ROLE OF THE INDUSTRY IN THE EMERGENCE OF NEW SCIENTIFIC BREAKTHROUGHS

- Significant share of Nobel laureates (beyond the IBM and Bell Laboratories cases) benefited from their engagement with the industry for their scientific breakthrough discovery for which they were awarded the Nobel Prize.
- Econometric study shown that one-fifth of Nobel Prize laureates in the studied sample* were industry-inspired.
- For the last decades as more than 50% of laureates awarded in the 2010 – 2016 period were inspired by the industry for their breakthrough discoveries.

* Plantec, Q., Le Masson, P., Weil. B. 2021. "Another way to get the Nobel Prize: the role of the industry in the emergence of new scientific breakthroughs". R&D Management Conference, Jul. 2021. Glasgow. The United Kingdom.

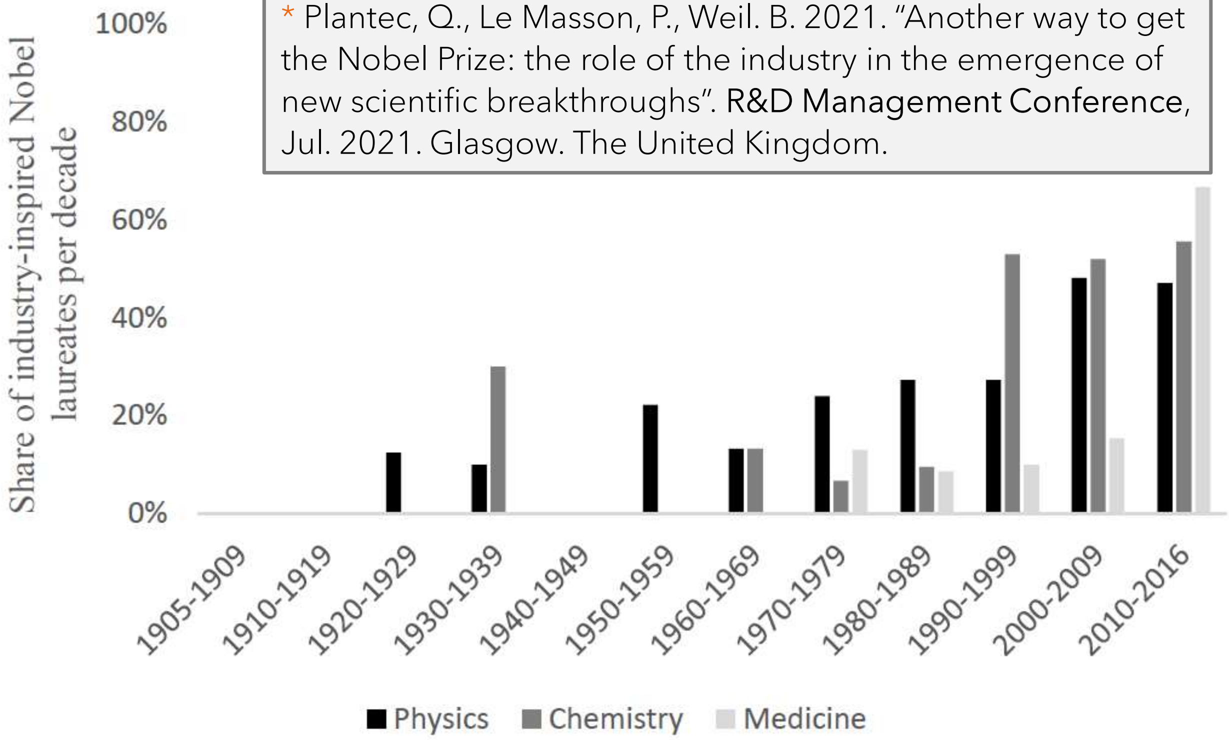
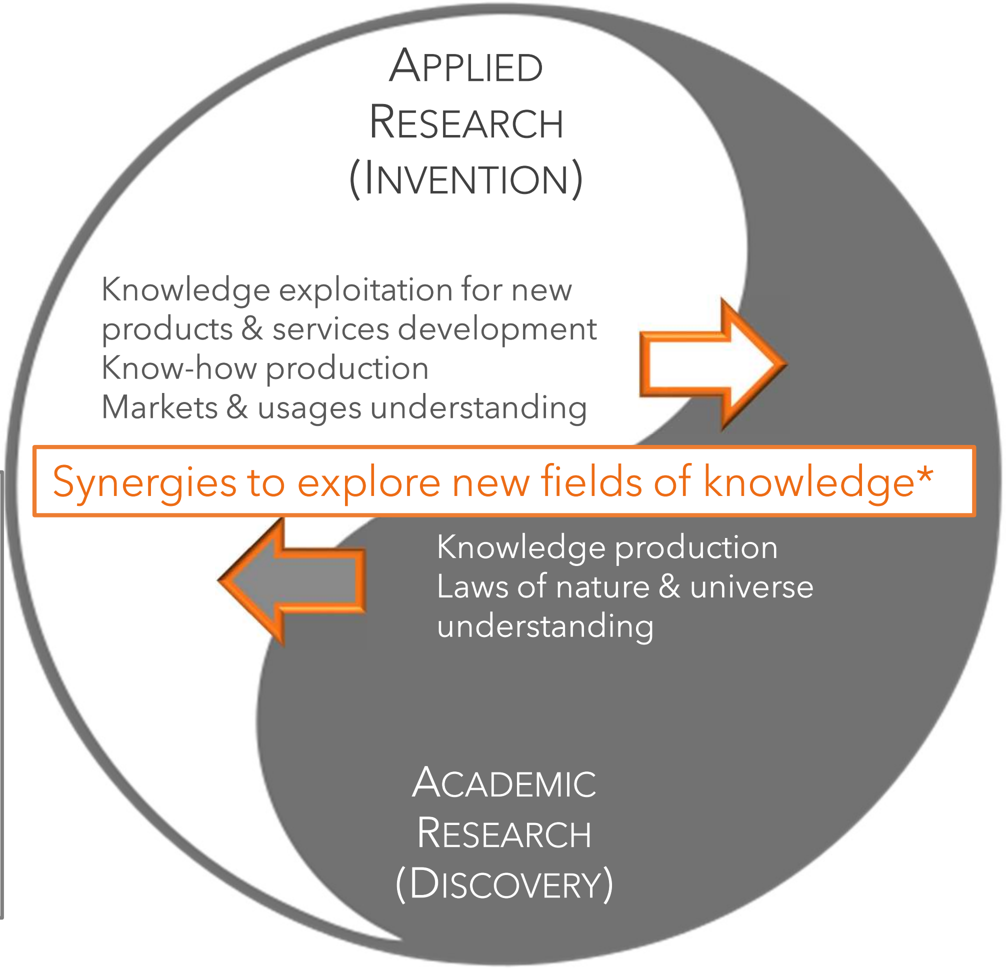


Figure: Evolution of share of industry-inspired Nobel laureates per decade and date of award and split by discipline *

Was it Galilee who made the telescope, or the telescope that made Galilee ?

OUR RESEARCH QUESTION

- We would like to reinforce the idea that researchers' creativity increases when they participate in *simultaneous discovery-invention research* projects.
- The fields of academic research (discovery) and applied research (invention) are independent but reinforce each other to explore new fields of knowledge.
- Within a public and private collaborative project, they constitute the Ying and Yang of the same entity.



* See for example the case study at STMicroelectronics:
Cabanes Benjamin, Le Masson Pascal, Weil Benoît, « Organiser la création de connaissance pour l'innovation de rupture. Des communautés aux sociétés proto-épistémiques d'experts », *Revue française de gestion*, 2020/3 (N° 288), p. 35-60.

See the research of Sarah Tung
Candidate at Strasbourg University and Lille Catholic University

We focused on the reasoning of researchers

FOCUS ON RESEARCHERS’ REASONING

(cf. Hatchuel *et al.*)

- How do researchers explore the unknown?
  - Public research organization (PROs) (basic science): the ability to ask new questions, to look in another direction, to get out the reality, to test new hypotheses… (see Poincaré or Einstein; Hadamard, 1945; Holton, 1981)
  - Industry (applied science): the ability to develop new skills, to invent new technologies and promote breakthrough innovations which are desirable for society...
- Why does collaboration help them to be more creative?

Hadamard J., 1945. *The psychology of invention in the mathematical field*, Princeton (N.J.), Princeton University Press.

Hatchuel A., Reich Y., Le Masson P., Weil B., Kazakçi A. O., 2013. “Beyond models and decisions: situating design though generative functions”, International Conference on Engineering Design, ICED’13, Séoul.

Holton G., 1981. *L’imagination scientifique*, Paris, Gallimard.

OUR METHODOLOGY

TO ADDRESS THESE QUESTIONS, WE INTERVIEWED RESEARCHERS

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INTERVIEWS WITH RESEARCHERS

- Successful collaboration experiences (with exploration of new fields of knowledge) were analyzed from semi-structured interviews with researchers from:
  - Public research organizations (PROs): CEA, CEA DAM, CEA Tech, Brgm, Cnrs, Ifpen, Inrae, Inserm, Paris-Saclay University;
  - Industrial R&D laboratories: Atos, Decathlon, TotalEnergies, Microsoft,Thales;
  - Association, R&D hub…

Bitard, P. 2020. « Quels partenariats pour une recherche à double impact ? » in : Archambault, V. et Popiolek, N., (Dir) (2020). *Histoires de sciences & entreprises*, Vol. 4 : *Séminaire « Favoriser l'impact de la recherche »*. Paris : Presses des Mines.

Le Masson, P. 2020. « Quels modèles pour une recherche à double impact ? » et « Quelles interactions entre recherche fondamentale et industrie », in : Archambault, V. et Popiolek, N., (Dir) (2020). *Histoires de sciences & entreprises*, Vol. 4 : *Séminaire « Favoriser l'impact de la recherche »*. Paris : Presses des Mines.

Popiolek, N. 2019. « Mesure de l'impact de la recherche: Compte-rendu des entretiens réalisés entre juin et octobre 2018 ». Direction de la stratégie et des programmes. Rapport interne CEA.

THE NOBEL PRIZE IN PHYSICS INTERVIEW

Fert, A. (2007). "The origin, development and future of spintronics." Nobel lecture, 2007. Stockholm.

BASIC SCIENCE - SOLIDS PHYSICS LABORATORY

He was exploring a new scientific concept: the spintronics that controls the movement of electrons by acting on their spin.

Fert was looking for an industry laboratory to test the new concept.

Albert Fert,
Nobel Prize in physics*

TECHNOLOGY - CENTRAL RESEARCH LABORATORY - THOMSON COMPANY

He was developing a new technology: Molecular Beam Epitaxy (MBE) allowing the deposit of ultra-thin layers of semiconductor materials

Friederich was seeking to push the MBE technology in original ways.

Alain Friederich
R&D engineer

- Fert could study magnetic multilayers and test his concept.
- Friederich expanded his range of technology by exploiting a new phenomenon that had never been observed or modeled before.

STRONG SCIENTIFIC IMPACT
The discovery of Giant Magnetoresistance in1988

STRONG SOCIO-ECONOMIC IMPACT
Breakthrough innovations for industry
(automotive, computers, mobile phones…)

* The interview was conducted in Thales offices by Pascal Le Masson and the author.

INSTRUMENTATION FOR BIG SCIENCE OR MILITARY EQUIPMENT

- Interviews with CEA researchers
  - Researchers in basic sciences who need state-of-the-art instruments transfer their knowledge to industry via specifications.
  - The RTO is not considered as an organization that only supplies research services but rather as one that asks for highly specified research services and technologies from companies: the supply-demand relationship is reversed.
  - Academic researchers (or military scientists) force industry to innovate by developing cutting-edge technologies.
  - This kind of collaboration leads to the development of instruments that is driving a compromise between the researcher's dream and achievable innovations.
  - This agile co-construction approach allows scientists and engineers to overcome their constraints and opens the door to significant innovations (e.g.: optics, electronics, deformable mirrors, etc.) which will subsequently spread in the consumer industry.
- There are economic spin-offs derived from high-technology purchases.

CO-DEVELOPMENT FOR HIGH PERFORMANCE COMPUTING

- Interviews with the head of the CEA's Very Large Computing Center (TGCC)
  - Supercomputers are yet another example of value creation thanks to the partnership between the CEA/DAM and Bull, an equipment supplier since the early 2000s.
  - The collaboration agreement was based on co-development, i.e. computer code structure development by the CEA/DAM and the machine structure developed by Bull.
  - This embedded research, innovation and development (RID) made it possible to optimize the results and success of the program.
  - Bull gained in economic standing and ATOS (which acquired Bull) has since become an international leader in the field.
- Partners can discuss any new requirements, operate new architectures and develop services to meet needs.

STRUCTURING AROUND SCIENTIFIC CHALLENGES

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- Interviews with IFPEN researchers
  - IFPEN's fundamental research is structured around nine scientific challenges which are organized to reflect the overall path followed by the R&I.
  - "The structuring of fundamental research around major scientific issues brings greater transparency vis-à-vis the outside". (Grégoire Allaire, Chairman of IFPEN's Scientific Board). It creates bridges between areas of expertise.
  - This scientific questioning can be shared with internal academic researchers as well as with industry.
  - This constructive approach has enabled IFPEN to initiate collaborations on fundamental research points with TotalEnergies, PSA, or EDF ... via CIFRE theses for example.

SCIENCE-BASED ON ANALOGICAL REASONING

- Interview with BRGM researchers
  - The BRGM is specialized in earth and environmental sciences (geothermal energy, carbon capture, and storage, wastewater management, etc.).
  - Geology is a science that describes and models geological objects, unlike physics that is based on laws. It works by analogies
  - The collaboration with the oil industry like the TotalEnergies partnership is particularly interesting because the company brings to researchers, data, and different analyzes of behavior and phenomena, that science would not otherwise have had access to.
- Such collaboration takes fundamental knowledge a step forward, while the industry gains a competitive advantage expertise-wise.

HEALTH RESEARCH

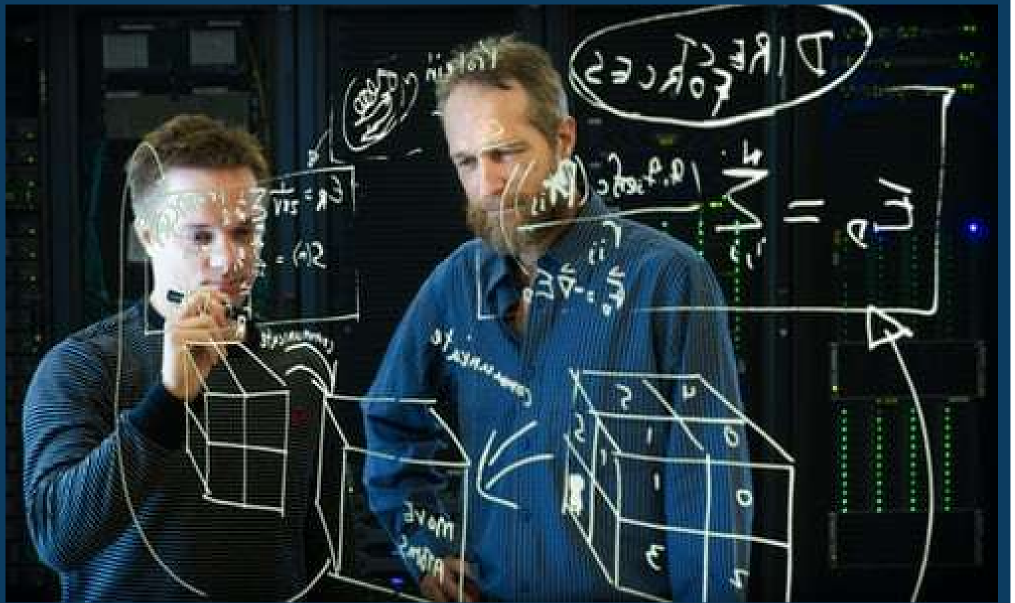
- Interview with INSERM researchers
  - The time-to-market is critical in particular to fight against epidemics (ex.: Ebola, Covid-19).
  - To shorten the deadline, researchers must get closer to patients and therefore look for solutions hand in hand with all the players located downstream in the value chain, such as the medical or pharmaceutical industries which are closest to the patients.
  - In a more generic way, not just in medical research, the place of end-users is crucial in research and innovation processes. It allows researchers to look in other directions.
  - This requires close collaboration between the upstream (academic research) and downstream (development, distribution) of the value chain.
- In this case, the objective to be achieved is the same.

ON THE INDUSTRY SIDE : HIGH TECHNOLOGY FIELDS

- Interview with a researcher from ATOS
  - In the quantum computing race scientists highlight the physical constraints that cannot be overcome and guide engineers towards the most promising innovative paths.
  - Atos has set up a scientific committee including a Nobel Prize (Serge Haroche) and a Fields Medal (Cédric Villani) for a quantum computing program named "Quantum".
  - Physicists helped Atos take the middle step of a quantum simulator before effectively getting to the quantum computer. And this simulator has found its market.
- Academic researchers bring fundamental knowledge that helps the industry be more realistic.

ON THE INDUSTRY SIDE : BIG DATA AND AI FIELDS

- Interviews with a researcher from Microsoft
  - In the field of big data and AI the collaboration between private companies and researchers in a wide variety of scientific disciplines (computer science but also medicine, archeology, etc.), leads to significant progress in the design of custom software applications.
- Academic researchers bring very useful fundamental knowledge that helps the industry solve problems and promote technological breakthroughs.



RESULTS FOR A WIDE RANGE OF ACTIVITIES

- Role of cross-fertilization between science and industry in the emergence of new knowledge fields
- Focus on the birth of collaborations
- The main obstacles

SIMULTANEOUS DISCOVERY-INVENTION RESEARCH ORIENTATION

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When the different areas of knowledge meet to work together while retaining their freedom and independence, a win-win process is set up.

New concepts, new phenomena that had never been observed or modeled before

Exploration of unknown

Exploitation of novelty

STRONG SCIENTIFIC IMPACT

Scientific knowledge

Technological knowledge

Innovation Marketing

BREAKTHROUGH INNOVATIONS

Exploitation of novelty

Exploration of unknown

New instruments (cryogenic electron microscope…), data processing, anomalies, understanding markets & usages (patients…)

THE VALUE OF INDEPENDENCE IN KNOWLEDGE STRUCTURES

- The collaborations we analyzed were neither the result of a "supply-demand" relationship (responding to industry demand) nor the result of chance ("serendipity").
- It was due to recognition, or even to joint construction, of an experience that could interest both parties but for different reasons (scientific progress for one, new technological possibilities for the other).
- We could illustrate with concrete examples, the value of independence in knowledge structures*.

* Hatchuel, A., Le Masson, P., Reich, Y., Subrahmanian, E., 2018. "Design theory: a foundation of a new paradigm for design science and engineering". Research in Engineering Design, Springer Verlag, 29 (1), pp.5-21.

THE BIRTH OF COLLABORATIONS

- We have observed that collaborations were built precisely:
  - to combine independent and complementary skills and knowledge
  - and to explore new areas of knowledge.

THE MAIN OBSTACLES AND WARNINGS

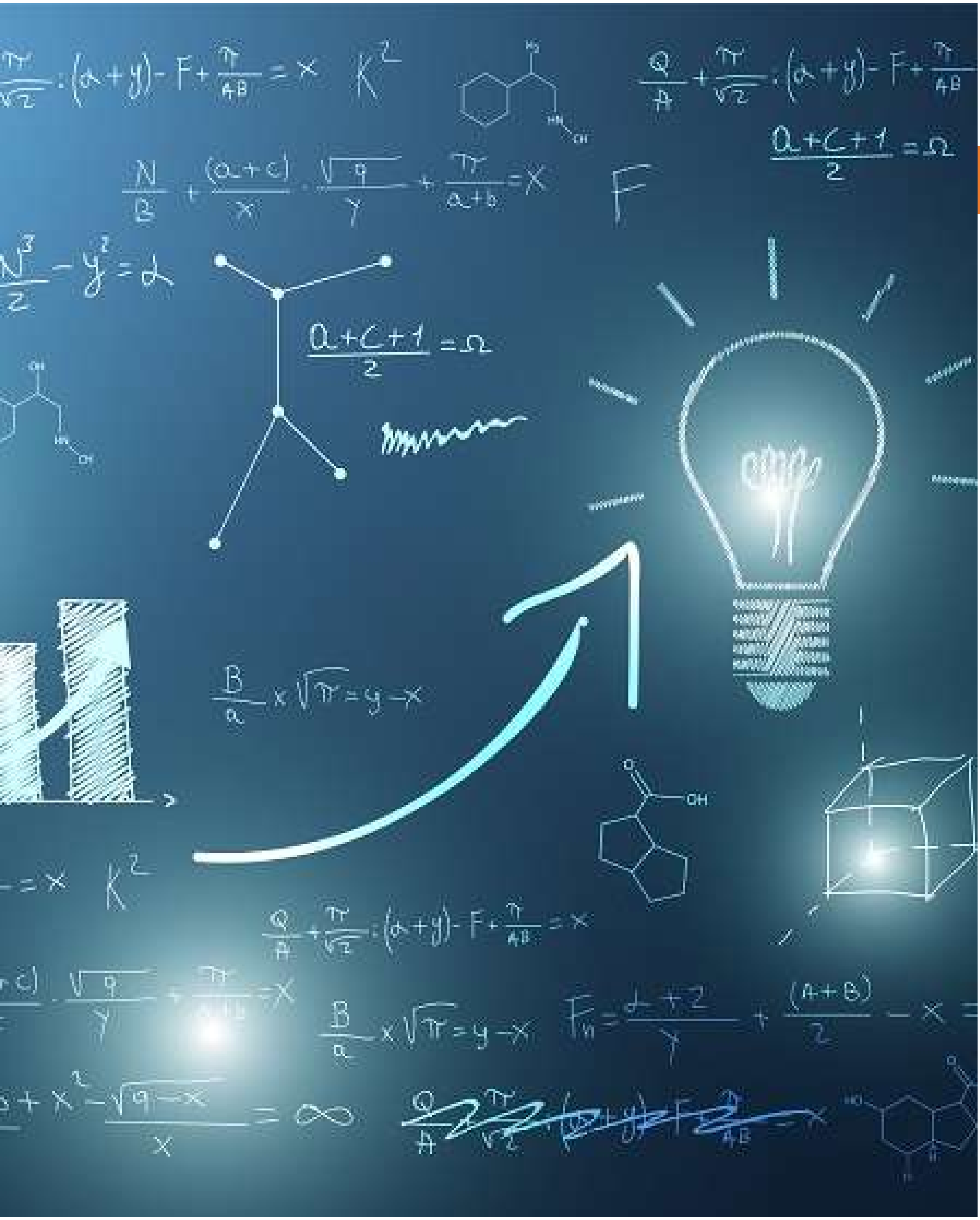
- The interviewees related successful collaborations that led double impact. But some collaborations have failed.
- Despite the benefits of synergies between science and industry, for bypassing fixation biases and promoting creativity, interviewees revealed several obstacles.

Warnings

- Moreover we must be concerned about the impact of technology on the environment and health: the planes (physical equations & engineering know-how) given us the freedom to fly ... but the aircraft traffic is noisy and emits CO_2.

Obstacles	Responses
Unsynchronized clocks between fundamental and applied research Funding of fundamental research and risk coverage Cultural gap Confidentiality and IPR issues…	• Invent new solidarities and forms of collegiality and give time to research
Inability to look outside the mainstream Inability to open new ways of thinking Unavoidable fixations and biases…	• Invent tools to assess the quality of exploration
Risk of mutual disempowerment in the face of the negative impacts of S&T Risk of unsustainable impact…	• Invent new forms of joint responsibility between science & industry

THIS HAS IMPLICATIONS ON RELATIONSHIP GOVERNANCE STRUCTURE



CONCLUSION

- What should be retained for
  - the design of research and innovation policies in line with the major challenges of the 21st century?
  - the management of research and innovation within RTOs and the industry?

CHANGE THE PERCEPTION OF THE INNOVATION PROCESS

- Linear thinking about the model of innovation is wrong.
- The relationships between fundamental research, applied research and industrial and commercial development are today extremely intertwined.
- Hence the strategic error at the state (or organization) level of systematically privileging application at the expense of the fundamental, with the implicit argument that the nation prefers economic development to the beauty of science and harmony.

INVEST IN FUNDAMENTAL SCIENCE

- In Germany, public research effort is largely directed towards basic research (without constraint).
- The Max Planck company, which in profit (2.4 billion euros in 2019 *), has recently had great success with two Nobel laureates in 2020 as well as two laureates in 2021.

  (* Domestic expenditure on research and development (GERD): Germany = € 110 billion; France = € 54bn)
- It is obvious that the impact of this research (in physics and chemistry) is also socio-economic

- Emmanuelle Charpentier et Jennifer Doudna (Chimie 2020): gene therapy.
- Benjamin List and David MacMillan (Chemistry, 2021): new pharmaceutical products and "greener" chemistry.
- Syukuro Manabe and Klaus Hasselmann (Physical, 2021): physical modeling of the Earth's climate and reliable prediction of global warming.

PROMOTE SIMULTANEOUS DISCOVERY-INVENTION RESEARCH MODEL

- Implement smart synergies between Science and Industry to create new knowledge and have both scientific and socio-economic impact
- On this point the German case is interesting.
  - In the Länder with prestigious universities, real clusters have been formed, encouraging interactions between actors.
  - The Fraunhofer network creates synergies between basic research and application areas (German companies invest in R&D without CIR: 2% of GDP in 2017 *vs.* 1.4% in France, in 2017).

PROMOTE SUSTAINABILITY-ORIENTED AND ETHIC INNOVATIONS

- Sustainability-oriented innovations (SOI) and ethic innovations should be considered as a priority to promote the post-Covid19 world.
- A world more respectful of the environment and in which we live healthier and with more freedom.
- Coupling science and industry to explore new areas of knowledge is a good thing but:
  - Are we sure that the impact of the innovations is for the common good?
  - Where to put the cursor between high-tech and low-tech (frugal innovation)?
- This raises the question of technological solutionism and ethics…

THANKS FOR YOUR ATTENTION !

QUESTIONS ?

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