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ANOTHER WAY TO GET THE NOBEL PRIZE: THE ROLE OF THE INDUSTRY IN THE EMERGENCE OF NEW SCIENTIFIC BREAKTHROUGHS

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ABSTRACT: Since the 1980s, most industrial corporations cut-off their investments in fundamental research activities. While the benefits for scientists of interacting with the industry have been demonstrated many times, (1) how much scientific breakthroughs are still emerging, in modern science, from scientists engaged with the industry, and (2) how this would affect ex-post knowledge diffusion are yet to be documented. To do so, we explored the extent to which scientists from the quasi-complete cohort of Nobel laureates in Physics, Medicine, and Chemistry were engaged with industrial corporations for their breakthrough discoveries. We designed a unique dataset of their ties with the industry based on affiliations review of 84,423 academic papers and applicant review of 5,207 patent families. First, we showed that one-fifth of the studied cohort of Nobel laureate was engaged with the industry at the date of their breakthrough discovery. More importantly, this share is still increasing. During the last period of observation, more than one of two laureates belong to this category. Second, while those scientific discoveries were partly made possible thanks to those Nobel laureates' industrial partners, the laureates' subsequent knowledge was not bound to their initial sets of partners. Indeed, those laureates experienced similar knowledge diffusion-to-industry rates than other laureates but higher academic production rates and diffusion-to-academia rates. Finally, we claim that the extent to which scientific new knowledge still emerges in relation to industrial contexts in modern science has been under-evaluated and open rooms for further research.

This article aims at digging into the extent to which scientific breakthroughs still emerge from scientists engaged with the industry and the effects on subsequent scientists' knowledge diffusion rates towards both science and industry. Following the significant decrease of the industry contribution to fundamental science since the 1980s, management scholars contributed to a greater understanding of academic engagement with the industry, which can be defined as “*knowledge-related interactions by academic researchers with non-academic organisations, as distinct from teaching and commercialization*” (Perkmann, Salandra, Tartari, McKelvey, & Hughes, 2021). In particular, scholars reviewed individual motives, characteristics and institutional effects associated with academic engagement (see. Perkmann et al., 2013, 2021 for comprehensive literature review). While the literature remains fragmented, it has been repeatedly demonstrated that academic engagement is widely practiced (eg. Cohen, Nelson, & Walsh, 2002) and is associated with a positive effects on research productivity (eg. Bikard, Vakili, & Teodoridis, 2019). This literature is of crucial interest to explore the relationship

between academic engagement and scientific breakthrough discoveries because we have “*only tentative evidence on the effect of engagement on [...] the potential for breakthroughs increases.*” (Perkmann et al., 2021).

While the role of the industry in the early emergence of scientific breakthroughs has been documented through questionnaires or case studies (e.g. D’Este & Patel, 2007; Evans, 2010; Narayanamurti & Odumosu, 2016; Stokes, 1997), the “*backward link*” (D’Este & Perkmann, 2011: 330) of being engaged with the industry on fundamental research activities — particularly for breakthrough discoveries — is still underappreciated (Perkmann et al., 2021) and contentious (Murray, 2010). On the one hand, some scholars claimed that engaged academics might suffer from publications restrictions or additional delays to contribute to open-science due to secrecy and patenting activities (Blumenthal, Causino, Campbell, & Louis, 1996; Czarnitzki, Grimpe, & Toole, 2015). On the other hand, the industry may also be a valuable source of skills, materials, equipment, resources, and ideas to fuel fundamental research (eg. Ankrah, Burgess, Grimshaw, & Shaw, 2013; Banal-Estañol, Jofre-Bonet, & Lawson, 2015; D’Este & Perkmann, 2011; Gulbrandsen & Smeby, 2005; Lee, 2000; Mansfield, 1995; Siegel, Waldman, & A. Link, 2003). Scientific activities performed in industrial contexts also conduct researchers to be more interested in the “*usage*” of their fundamental breakthroughs, a phenomenon that has been associated with higher research performances in specific contexts, in relation with the Pasteur Quadrant (Goldstein & Narayanamurti, 2018; Narayanamurti & Odumosu, 2016; Stokes, 1997; Tijssen, 2018). Furthermore, industry-university interactions may also conduct more efficient specialization between researchers and their industrial partners, particularly for scientific breakthroughs with commercial potential, with positive effects on follow-on research and researchers’ performances (Bikard et al., 2019).

Hence, due to the structural changes in the science-industry ecosystem (i.e. withdrawal of leading firms on fundamental research activities and the development of open-innovation), as well as the need to disentangle both adverse and positive effects of academic engagement with the industry on academics’ research activities, **(1) to what extent scientific breakthroughs are still emerging from academics engaged with the industry** and **(2) how this would affect knowledge diffusion of those**

academics, are yet to be documented. Here, we take a step towards filling these gaps by assessing the magnitude and evolution of academic engagement with the industry in relation to new scientific discoveries from scientists awarded with the Nobel Prize. We also explored the effects of such an engagement with the industry on the follow-on (future) laureate knowledge diffusion towards academia and the industry. We acknowledged that in the long run, Nobel laureates constituted an adequate proxy of fundamental scientific activities evolution and, can help us better understand modern science dynamics (Jones, 2009).

1. CONCEPTUAL BACKGROUND

In this section, we derive assumptions on the relation between academic engagement and scientific breakthroughs and its effects on subsequent academics' knowledge diffusion. As it is a short paper, we only provide our different assumptions.

1.1. Academic engagement and scientific breakthroughs

Hypothesis 1: a significant share of Nobel laureates (beyond the well-known 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.

1.2. Academic engagement and post-discovery performances:

Hypothesis 2.a / b : Nobel laureates who benefited from their engagement with the industry for their scientific breakthroughs are suffering from a negative (b. positive) effect on their ex-post publication performances (number and quality).

Hypothesis 3.a / b. Nobel laureates who benefited from their engagement with the industry for their scientific breakthroughs are (b. not) shifting their research towards a more applied orientation, with then an increase of the research diffusion to industry rate.

2. METHODOLOGY & DATA

2.1. Identification of Nobel laureates who benefited from their engagement with the industry for their scientific breakthroughs

In order to identify the Nobel laureates that have been engaged with the industry and benefited from those interactions for their breakthrough discoveries, we developed a dedicated method. To do so, we used Li et al. (2019) public dataset that comprising of an extensive list of 89,311 academic papers written by 92.4% of all the Nobel laureates in Chemistry, Medicine and Physics between 1900 and 2016. They also provided the identification of the specific scientific paper (ie. *Prize Paper*) that led each laureate to be awarded the Nobel Prize. We called *Period 0*, the period between the first academic paper of a given laureate and his/her Prize Paper; *Period 1*, the period between his/her Prize Paper, and the Nobel award¹.

Hence, we consider the potential interactions with the industry that the laureate may have experienced before or at the date of the Prize Paper publication (i.e. *Period 0*). We designed a unique dataset that relied on a review of laureates' ties with the industry based (1) on a careful examination of authors' affiliations and funding organizations of all papers written by Nobel laureates as well as (2) a review of all assignee organizations of patents filed by laureates. Previous research showed that affiliations of authors of academic papers or patent's assignee organizations could be used as a proxy to measure ties with the industry and, therefore, academic engagement (eg. Abramo et al., 2009, 2010; Arora et al., 2018; Arts & Veugelers, 2020; Calvert & Patel, 2003; Tijssen, 2012).

Here, we called ***industry-inspired researchers the laureates that had ties with the industry before or at the date of their breakthrough discoveries***. The procedure is summarized in **Figure 1** below. All publication's data are finally gathered at the laureate level for each period (panel structure) and normalized.

¹ The period post-Prize has been excluded to avoid issues related to distortions of the results following the fact that the laureate become more famous and can received additional solicitations and can be diverted from research.

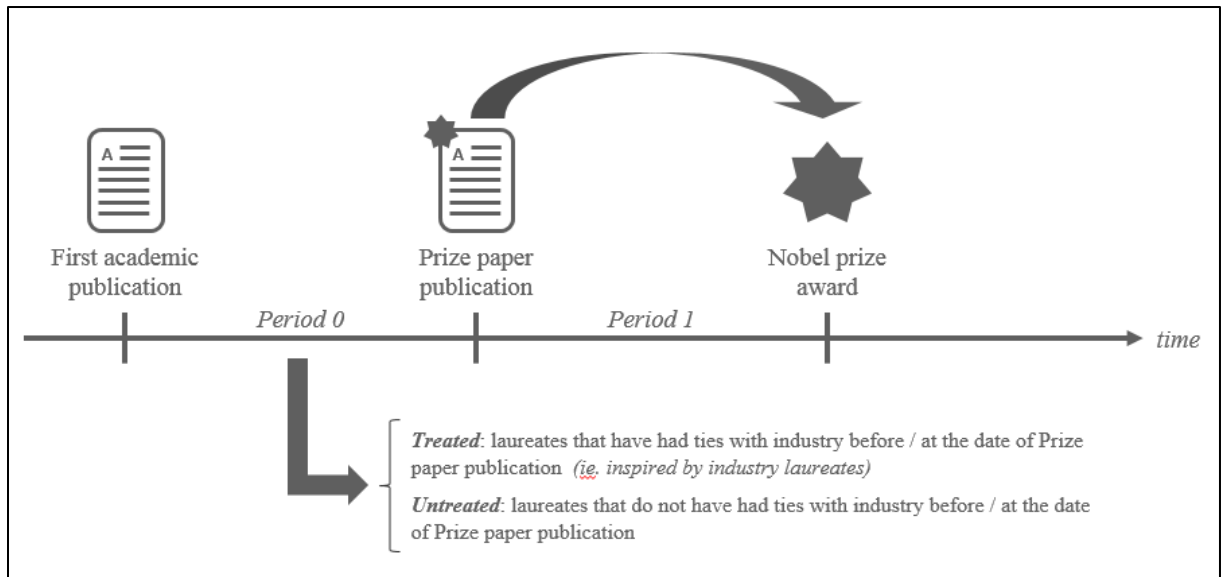


Figure 1 – Treated Nobel laureate identification process

2.2. Patent of Nobel laureates and ties with the industry analysis

Previous literature showed that patents filed by academics could help to define ties with the industry, in particular by analyzing the applicant of the patent (e.g. Balconi, Breschi, & Lissoni, 2004; Balconi & Laboranti, 2006; Crescenzi, Filippetti, & Iammarino, 2017). Here, we collected data from the PATSTAT database², and we looked for patents filed by inventors with exact similar names and surnames than those from the list of Nobel laureates' academic publications. To control for the issue of reduplicated names, we adopted a conservative approach with cross-checked on Wikipedia, Nobel.org and in the academic publication's affiliations of the laureates or its co-authors. The final dataset comprises 5,219 patent families, including 3,001 filled for company applicants and 2,394 filled for the university-like applicants.

² Spring 2019 version

2.3. Nobel laureates' research orientation

To proxy research orientation towards basic or applied research, we explored how the industry relies on laureate's academic papers when filing patents. Hence, scholars have extensively used this proxy of Scientific Non-Patent Literature (SNPL): academic papers that are cited by the inventor or the examiner of a given patent application in order to demonstrate the newness of the invention, since the seminal work of Narin, Hamilton, & Olivastro (1997). Here, we relied on the Marx & Fuegi (2020) dataset, who conducted an in-depth analysis to disentangle citations to academic papers in patents filled in the USPTO, OEB, and through the PCT procedure. After crossing the database on Nobel laureates' publications and SSNPL, we showed that 13,935 academic papers wrote by Nobel Prize laureates in our sample are cited in 68,361 specific patent applications. All SNPL data are finally gathered at the laureate level for each period (panel structure) and normalized.

3. EXPLORING THE COHORTS OF NOBEL LAUREATES THAT WERE INSPIRED BY INDUSTRY

In this section, in relation to *Hypothesis 1*, we explored the extent to which some Nobel laureates were inspired by the industry for their fundamental discovery.

We computed in **Table 1** the number of Nobel Prize's laureates with ties with the industry before the publication of their prize paper, split by channel and discipline.

	Nbr. Nobel Prize's laureates (share of the cohort)	Nbr. Nobel Prize's laureates (share of the cohort by discipline)		
		Physics	Chemistry	Medicine
Nbr. laureates affiliated to a University-type organization who published academic papers with industry affiliated co-authors before publishing its Nobel paper (CI Pub.)	55 11%	16 9%	24 15%	15 8%
Nbr. laureates directly affiliated to an Industry-type organization and who published academic papers before publishing its Nobel paper (IA Pub.)	52 10%	29 16%	14 9%	9 5%
Nbr. laureates registered as inventor for an Industry-type organization who filled patents before publishing their Nobel papers (IA pat.)	38 7%	19 11%	14 9%	5 3%
Nbr. laureates inspired by industry before publishing their Nobel papers	108 21%	47 26%	40 26%	21 11%

Note: for example, 16 Nobel laureates in Physics published at least one academic paper before (or at the date) of their Prize Paper publication by being affiliated to a University-type organization while at least one co-author was affiliated to the industry in this paper. It represents 9% of the whole cohort of Nobel laureates in Physics. A given Nobel laureate can be involved in more than one channel.

Table 1 – Treated Nobel laureates split by ties with industry types and disciplines

We also analyzed the evolution through time of the share and number of industry-inspired Nobel laureates across the sample's whole cohort of laureates. We reviewed the share of Nobel laureates that had ties with industry before their prize paper based on the date of award per decade basis (**Figure 2**) and by analyzing the split per discipline (**Figure 3**).

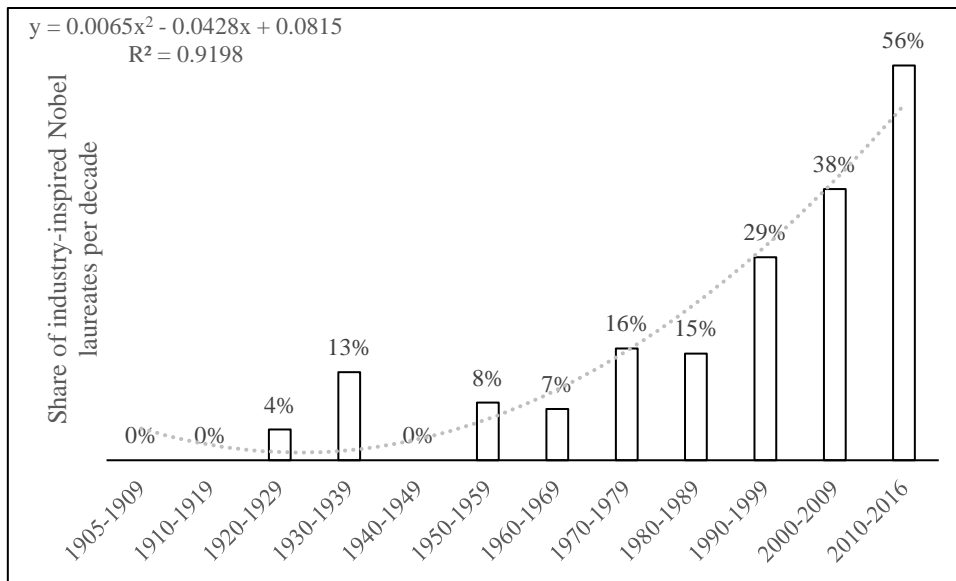


Figure 2 – Evolution of share of industry-inspired Nobel laureates per decade by date of award

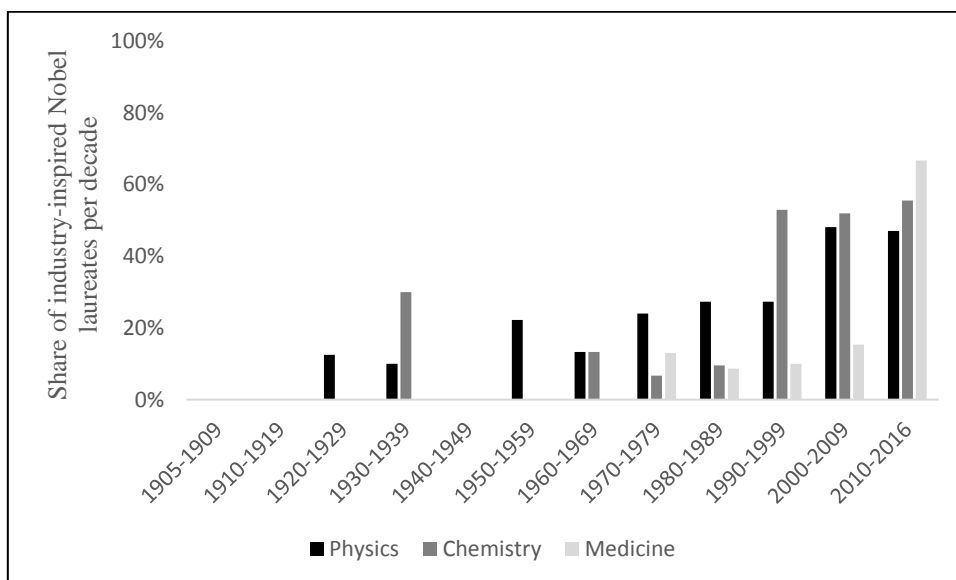


Figure 3 – Evolution of share of industry-inspired Nobel laureates per decade and date of award and split by discipline

Hence, our results confirmed *Hypothesis 1*, as we demonstrated that **one-fifth** of Nobel Prize laureates in the sample were industry-inspired. Our results are robust in particular 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.

4. INDUSTRY INSPIRATION EFFECTS ON NOBEL LAUREATES' ACADEMIC FOLLOW-ON RESEARCH

4.1. Variables and descriptive statistics

To test *Hypothesis 2* and *Hypothesis 3*, our objective is to define if during the period following the publication of the Prize paper by a given laureate, being inspired by the industry during period 0 conduct to significant differences in terms of follow-on academic performances and orientations of research with those that were non-engaged. Our data set is a panel with two periods: period 0 and period 1 (**Figure 1**). Therefore, we used a Difference-in-Difference (D-i-D) model. The D-i-D variable is a dummy equal to 1 during the tested period, here the period 1 and for treated laureate only, and 0 otherwise. The variables definitions are reported in **Table 2**.

Variable	Definition
Nbr. academic publications	Total number of academic papers published by the laureate in a given period.
Nbr. academic publications - Scholarly citations weighted	Total number of academic papers published by the laureate in a given period, weighted by the number of follow-on received academic citations.
Nbr. academic publications - SNPL citations weighted	Total number of academic papers published by the laureate in a given period, weighted by the number of follow-on citations of those papers in patents.
Nbr. patent families	Total number of patent families filled by the laureate in a given period.
Nbr. patent families - Patent citations weighted	Total number of patent families filled by the laureate in a given period weighted by the number of follow-on citations by other patents.
Nbr. industry partners	Total number of distinct industrial company that interacted with the laureate in a given period.
Period	A dummy variable equal to 0 the period before the publication of the Nobel's paper of the laureate and 1 the period
Period duration	Count of the number of distinct years for a given period of the laureate.
Born year	Date of birth of the laureate.
US-born laureates	A dummy variable equal to 1 if the laureate is born in the US, 0 otherwise.
Female laureate	A dummy variable equal to 1 if the laureate is a female, 0 otherwise.
Chemistry Nobel	A dummy variable equal to 1 if the laureate was awarded with the Chemistry Nobel prize, 0 otherwise.
Medicine Nobel	A dummy variable equal to 1 if the laureate was awarded with the Medicine Nobel prize, 0 otherwise.
Physics Nobel	A dummy variable equal to 1 if the laureate was awarded with the Physics Nobel prize, 0 otherwise.
Age at Nobel's paper publication	The age of the Nobel laureate when he or she published the Nobel's paper.
Age at Nobel Prize winning	The age of the Nobel laureate when he or she was awarded with the Nobel prize.
Treated	A dummy variable equal to 1 if the laureate was industry-inspired before the publication of its Nobel's paper, 0 otherwise
Difference-in-difference	A dummy variable equal to 1 if the laureate was industry-inspired before the publication of its Nobel's paper and during the period after the publication of the Nobel's paper of the laureate and before being awarded with the Nobel prize (i.e. period 0).

Table 2 – Variable definition

4.2. Estimation

Formally, we used the following regression equation to estimate the effect of inspiration by the industry on the cohort of laureates, with Y_i a given Dependent Variable for laureate I and X_i a vector of controls variables:

$$Y_i = f(\beta_1 DiD_i + \beta_2 treated_i + \beta_3 period_i + \alpha X_i + \varepsilon_i)$$

Since the Dependence Variables of our models are a count of scores (non-negative integers), ranging from 0 to many, we used a Negative Binomial Regression (NBR) as a means of estimation and by controlling for period exposure (e.g. Baba, Shichijo, & Sedita, 2009; Zucker & Darby, 1996). Then, the results of the estimation are reported in **Table 3**.

	DV = Nbr. academic publications	DV = Nbr. academic publication - Scholarly citations weighted	DV = Nbr. academic publications - SNPL citations weighted	DV = Nbr. patent families	DV = Nbr. patent publications - Patent citations weighted	DV = Nbr. industry partners
	(1-1)	(1-2)	(1-3)	(1-4)	(1-5)	(1-6)
Difference-in-difference treated vs. untreated (0/1)	0.312*** (0.109)	0.660*** (0.133)	1.021*** (0.386)	-0.507 (0.438)	-1.765*** (0.546)	-16.26*** (0.205)
Treatment	0.281*** (0.0966)	-0.211 (0.144)	-0.542* (0.309)	2.421*** (0.433)	3.634*** (0.711)	17.61*** (0.161)
Period	0.557*** (0.0576)	0.0833 (0.0801)	0.105 (0.352)	1.643*** (0.353)	3.084*** (0.369)	16.77*** (0.161)
Born year	0.0154*** (0.00173)	0.0331*** (0.00342)	0.0824*** (0.00530)	0.0509*** (0.00966)	0.0998*** (0.0156)	0.0350*** (0.00375)
US-born laureate	-0.210*** (0.0802)	-0.168* (0.0966)	-0.284 (0.264)	-0.192 (0.345)	-0.217 (0.359)	-0.318** (0.124)
Female laureate	-0.563*** (0.165)	-0.600*** (0.155)	-1.284*** (0.367)	-0.101 (0.942)	-1.316 (0.862)	-0.913** (0.377)
Chemistry Nobel	0.692*** (0.101)	0.290** (0.134)	1.564*** (0.272)	0.661* (0.362)	0.774 (0.490)	0.0534 (0.150)
Medicine Nobel	0.397*** (0.0994)	0.410*** (0.123)	1.955*** (0.342)	0.427 (0.382)	1.099* (0.563)	-0.129 (0.175)
Age at Nobel's paper pub.	0.00478 (0.00597)	0.00931 (0.00750)	0.0550*** (0.0145)	-0.00401 (0.0210)	0.0826*** (0.0239)	0.00369 (0.01000)
Age at Nobel Prize winning	-0.00154 (0.00373)	-0.0171*** (0.00496)	-0.0227* (0.0123)	0.0591*** (0.0165)	0.00768 (0.0206)	0.0102 (0.00695)
Constant	-33.23*** (3.371)	-66.15*** (6.573)	-164.3*** (9.813)	-107.3*** (18.94)	-204.1*** (30.87)	-87.89*** (7.382)
Exposure – time period	Yes	Yes	Yes	Yes	Yes	Yes
Log-pseudolikelihood	-1021.9801	-1121.1657	-913.46381	-623.8026	-480.60184	-845.77287
Wald chi-squared	468.46***	281.93***	482.11***	220.98***	211.84***	575.87***
Nbr. treated	108	108	108	108	108	108
Nbr. laureates	518	518	518	518	518	518
Observations	1,004	1,004	1,004	1,004	1,004	1,004

Robust errors clustered to laureate id in parentheses, * p<0.1, ** p<0.05, *** p<0.01

Table 3 – Negative Binomial Regression

Based on our regression, our D-i-D model showed that the effect of being inspired by the industry has a significant impact on the career trajectory of those Nobel Prize laureates. Indeed, the D-i-D estimator in each model indicates the magnitude of this effect on DV by taking into account ex-ante

Nobel laureate career trends and the set of controls. Nevertheless, our key objective to answer *Hypothesis 2* and *Hypothesis 3* is to compare industry-inspired laureates vs. other laureates in period 1. Then, we need to test if $\beta_1 + \beta_2 \neq 0$ which would mean that industry's inspiration for Paper Prize conduct laureates to come up with different estimated mean for a given dependent variable. The results are presented in **Table 4**.

<i>Chi-squared test:</i> $\beta_1 + \beta_2 = 0$	DV = Nbr. Academic publications	DV = Nbr. academic publication - Scholarly citations weighted	DV = Nbr. academic publications - SNPL citations weighted	DV = Nbr. patent families	DV = Nbr. patent families - Patent citations weighted	DV = Nbr. industry partners
	(1-1)	(1-2)	(1-3)	(1-4)	(1-5)	(1-6)
$\beta_1 + \beta_2$	0.593	0.449	0.480	1.914	1.869	1.346
Chi-squared	22.87	8.99	3.49	26.14	17.11	51.94
Prob > chi-squared	0.0000	0.0027	0.0618	0.0000	0.0000	0.0000
Status	Reject	Reject	Accept	Reject	Reject	Reject

Acceptance or rejection decision is based on a 5% confidence intervals ratio.

Table 4 – Mean difference test estimation of DV in period 1

First, we showed that regarding *Hypothesis 2*, industry-inspired laureates for their Prize paper have a premium in terms of follow-on academic papers. On the one hand, they publish more papers in period 1 that they would have done without industry inspiration and more papers than their peers. On the other hand, those results stand by taking into account the quality of the publications. Hence, we accept *Hypothesis 2.b* and reject *Hypothesis 2.a*. Second, we showed that regarding *Hypothesis 3*, industry-inspired laureates have been prone to a greater orientation towards applied research than they would have done without being engaged with the industry in Period 0. Nevertheless, there are no significant differences between the orientations towards applications than their peers who were not engaged in period 0. Then we reject *Hypothesis 3.a* and accept *Hypothesis 3.b*.

Finally, models 1-4, 1-5 and 1-6 showed that the non-industry-inspired laureates in period 1 are catching up with the industry-inspired laureates in terms of the number of patent families filled in period 2, associated impacts measured by patent citations, and number of distinct industrial partners. Nevertheless, industry-inspired laureates still get a premium regarding the rest of the cohorts in terms of direct industrial impact through patent filling and the number of their industry partners.

5. DISCUSSION

This research's primary motivations were to explore the relation between academic engagement and scientific breakthroughs, which ultimately shed light on the industry's role in the early emergence of new radical scientific knowledge.

First, our essential contribution is to establish that despite the significant cut-off of corporate laboratories on fundamental research from the 1980s, the share of industry-inspired laureates to be awarded is mainly increasing. The industry has inspired more than one of two laureates for their breakthrough discoveries in the last observation period. We demonstrated that this phenomenon is discipline-dependent: more laureates are industry-inspired in Physics and Chemistry than in Medicine, even if we recently observed a catch-up phase. Finally, while The Bell Laboratories or IBM are well known for concentrating many Nobel laureates, many other industrial companies had influenced Nobel laureates. Second, we showed that despite that industry-inspired Nobel laureates' scientific breakthroughs were partly made possible thanks to their industrial partners, their subsequent knowledge was not bound to these initial sets of partners. Those laureates experienced similar knowledge diffusion-to-industry rates than other laureates but higher academic production rates and diffusion-to-academia rates. It also means this industry-inspiration do not lead to a more remarkable shift towards applied research than their Nobel laureates' peers.

Our findings contribute to the literature on academic engagement. While it was previously showed that academic engagement is widely practiced across all disciplines (Cohen et al., 2002; Hughes et al., 2016), we bring evidence that (1) it constitutes a reality also for the most incredible scientific advances

in modern science and (2) academic engagement is becoming more and more practiced by scientists who made major scientific breakthroughs. Our results regarding the comparison of academic performances and post-Prize Paper behaviors between industry-inspired laureates and non-industry inspired ones also complement previous literature findings. Hence, first, we noticed that industry-inspired laureates published a higher number of articles in period 0 than their peers, which echoes the finding that academics with more publications are more prone to be engaged with industry (e.g. Gulbrandsen & Smeby, 2005; Tartari, Perkmann, & Salter, 2014). We also found that industry-inspired laureates published more follow-on papers than their peers, even when considering the quality of those publications. It matches with a robust line of works claiming that one consequence of academic engagement is an increase in the number of publications (e.g. Blumenthal et al., 1996; Gulbrandsen & Smeby, 2005; Hottenrott & Lawson, 2017). The quality of those publications remained unclear, but our finding showed that for star scientists it has a positive effect, which is aligned with Bikard et al. (2019) and Hottenrott & Lawson's (2017) findings on non-star scientists. Finally, we also contributed to the literature by demonstrating that industry-inspired laureates did not have a more excellent orientation towards applied research than their non-industry-inspired peers. In contrast, it has been highlighted as a common drawback of academic engagements (e.g. Blumenthal et al., 1996). It seems that those Nobel laureates were able to maintain their orientation towards basic research by continuously be engaged with their industrial partners, including for commercialization activities measured through filled patents or for collaborative research projects (co-publications).

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