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Scientist's Industry Engagement and the Research Agenda: Evidence From Germany

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Scientist's industry engagement and the research agenda: Evidence from Germany

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Abstract

We investigate the impact of industry engagement on the direction of academic science. We apply the framework of the research agenda to assess to which extent industry engagement shifts the costs and benefits of pursuing and adopting research topics. Our empirical analysis, based on a survey of German scientists, shows that scientists who engage more with industry are more likely to incorporate commercial considerations in selecting a research topic, and are less likely select a topic for its potential to contribute to ongoing scientific discussions. They are also more likely to consider industry an important sponsor to explore new research topics. In this way, too much emphasis on engagement might alter the direction of scientific progress towards industrially relevant research areas.

Keywords: Industry-science links, Industry engagement, research agenda

JEL Classification: I23, O33

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1 Introduction

Industry-university engagement is now a prominent part of the scientific profession. Engaging with industry demonstrates the relevance of academic knowledge for the private sector, and hence, society (D'Este & Patel 2007; Etzkowitz & Leydesdorff 2000; Mowery *et al.* 2015; Perkmann *et al.* 2013, 2021; Perkmann & Walsh 2007). Its positive impact on innovation is well-documented (Adams 1990; Cohen *et al.* 2002; Hall *et al.* 2003; Mansfield 1991). Consequently, universities and public sponsors increasingly encourage scientists to engage with industry, and private sector funding is gaining importance as a source of science funding (Hornbostel 2001; Perkmann *et al.* 2021).

It is important to understand how this industry orientation affects the production and diffusion of scientific research. The literature on the impact of academic engagement (see Perkmann *et al.* 2013, 2021, for reviews of this literature) mainly finds that industry-university engagement is beneficial for scientific progress due to complementarities between industry and science, division of labour, and knowledge spillovers from firms. However, increased linkages between science and industry funding have been shown to hamper the open disclosure of research results (Blumenthal *et al.* 1996b; Czarnitzki *et al.* 2015a,b; Walsh *et al.* 2007).

Yet, industry engagement might have a more subtle influence on the direction of scientific research. Engaging with industry and, in particular, incorporating engagement in incentive systems, might cause scientists to spend more time working on topics with high industry interest or with strong commercial potential (Bianchini *et al.* 2016; Jensen *et al.* 2010; Pavitt 2001; Owen-Smith & Powell 2002; Perkmann & Walsh 2009; Thursby *et al.* 2007). For instance, a survey of U.S. faculty members found that industry funding leads scientists to consider commercial potential as a requirement for choosing research topics (Blumenthal *et al.* 1996a). Likewise, scientists who engage in academic patenting may shift their research focus to topics that are of commercial interest (Azoulay *et al.* 2009).

In this article, we investigate the impact of industry engagement on the research agenda. The research agenda encompasses the set of research aims that characterizes a scientist (Carayol 2003), and defines the scope of research topics that she might choose to investigate. At its core, the research agenda presents an allocation problem: resources – especially time – being scarce, scientists must strategically balance the expected costs and benefits of pursuing a given research topic (Bianchini *et al.* 2016; Jensen *et al.* 2010; Ziman 1987). Each topic carries a particular risk of failure, opportunity cost, and a potential scientific impact (Dasgupta & David 1994; Merton 1957; Nelson 1959; Peirce 1967). We argue that engaging with industry affects the research agenda in two ways. On the one hand, engaging with the scientific and technological challenges faced by industry can act as a source of renewal, inspiring researchers to pursue new and exciting scientific questions (Perkmann & Walsh 2009; Rosenberg & Steinmueller 2013). On the other hand, engaging with industry might also work as a catalyst for the continuation of existing research, as industry partners may have access to cutting-edge research infrastructure (Rosenberg & Nelson 1994; Rosenberg 2000). However, scientists might then use their expertise for more narrow and applied problems that might be less relevant for the scientific community (Cohen *et al.* 2002; Lee 2000).

This framework allows us to study how industry engagement affects the direction of research in ways that are more nuanced than productivity effects. Based on a survey of German scientists ($n = 1,331$), our empirical analysis investigates whether scientists that engage with industry are more prone to consider industry relevance when deciding to continue existing research lines, or to explore new research topics, and whether this consideration comes at a trade-off in terms of potential for scientific contribution.

Our results indicate that scientists who engage more with industry are more likely to take industry relevance into account when deciding on which new research topics to adopt. Concretely, we find that a 10 percent point increase in industry funding associates with a 4% increase in the probability that the scientists consider potential for knowledge transfer when deciding on whether or not to pursue a certain topic, and a 8.3% increase in the probability that they consider industry an important source of funding for new research topics. We also show that an increased focus on industry considerations poses a partial trade-off to scientific interests. Specifically, we find that scientists with more industry funding are less likely to pursue research because it is of interest for the scientific community. At the same time, we do not find such trade-off when considering science as a funder of new research topics.

Our findings contribute to understanding how the relation between science and industry affects science. Our research indicates that scientists who engage with industry apply different criteria when deciding to pursue or not to pursue a research topic. Our findings imply that policy makers and university leaders should consider these potential unexpected consequences when considering to introduce engagement in funding and evaluation schemes.

The remainder of this paper is structured as follows: section 2 develops the research agenda framework, section 3 introduces the data source and methodology. Section 4 presents the results. Section 5 concludes.

2 Conceptual framework

2.1 The research agenda

We propose to study the effects of industry engagement on the direction of science through researchers' agendas. Formally defined, a research agenda reflects "the research aims that the agents set for themselves" (Carayol 2003, p. 902). It represents an abstract knowledge space that is shaped by the scientist's abilities and preferences for potential topics and methodologies. Scientists need to balance their agendas in terms of the expected risks and rewards of the topics they choose to pursue. This is an allocation problem: how should scientists select the problems on which to spend their scarce resources—in terms of time, energy, and research funds—given that each topic carries a certain level of potential utility and risk (Peirce 1967). Even though the freedom to pursue interesting research topics is a primary motivation for scientists (Merton 1973), scientists face incentives and reward structures that also make this a strategic decision. Ziman (1987) refers to this allocation issue as "the problem of choices": "A scientist who makes a poor choice of research problems can never hope to produce valuable research results; a scientist who chooses good problems may not succeed in solving them, but at least stay in the game" (p. 93). In the context of Open Science, individuals are rewarded when they claim priority on new pieces of knowledge (Merton 1957; Dasgupta & David 1994). To be successful, scientists thus need to design a research agenda with maximimal potential for impactful contributions, considering at the same time that each topic carries a different impact.

The potential reward of pursuing a topic, however, needs to be balanced against its riskiness. Science is a inherently uncertain activity with a low rate of success (Nelson 1959). Not all research topics are equally risky, though: success is likely easier to obtain in well established research areas, and in areas where the scientist already has a high level of expertise. A well-formed research agenda thus typically consists of a set of interlinked topics that generates economics of scope. This specialization is a natural consequence of the Open Science reward system: specialization increases the chance of claiming priority since knowledge production and diffusion goes hand by hand (Carayol & Dalle 2007; Price 1984). Established scientists are hence relatively inelastic in terms of research area (Myers 2020).

On the other hand, exploring new areas is likely more risky, but might also lead to more novel findings (Myers 2020) or breakthrough results (Uzzi *et al.* 2013). When deciding on how to develop their research portfolio, scientists thus face a fundamental choice. Either they can continue to do research in a topic they are already familiar with, or they can decide to start working on a new topic. In other words, scientists need to strike a balance between topics that exploit their comparative advantage and topics that explore new ideas.

2.2 The research agenda and industry engagement

We then argue that industry engagement leads to changes in scientist's research agendas by changing the opportunity cost of exploring and exploiting industrially relevant topics. To see this, it is key that exploring and exploiting ideas require different incentive systems: the higher uncertainty of exploration needs to be offset with a long-term reward system and tolerance for early failure (Azoulay *et al.* 2011; Manso 2011), and the traditional science funding system is biased against radical novelty (Braun 1998; Li 2017; Boudreau *et al.* 2016). Therefore, the possibility of funding exploration through industry sponsors can allow scientists to engage in exploration more easily, compared to being restrained to science sponsors. Similarly, interacting with industry can lead to new opportunities for scientific exploration (Banal-Estañol *et al.* 2018; Gulbrandsen & Smeby 2005; Perkmann & Walsh 2009). Concerning exploitation, we argue that industry's different goals, combined with the increasing importance of technology transfer, leads engaging scientists to adapt their agenda to industry needs. Below, we describe how characteristics of open and commercial science interact with these needs.

2.2.1 Engagement and exploitation

Our first hypothesis is that scientists who increase their engagement with industry shift their ongoing research lines towards industrial research goals. Open and commercial science fundamentally differ in their goal. Open science, generally, rewards and aims at advancing scientific knowledge (Merton 1957; Dasgupta & David 1994). This knowledge is not necessarily oriented towards specific applications but aims at providing a better understanding of the world. To that end, a large part of public science funding is distributed through open-ended grant programs that prioritize scientific quality and freedom of intellectual enquiry (Li & Agha 2015). Over time, public authorities have played an increasing role in directing scientific efforts towards specific goals (Myers 2020; Dasgupta & David 1994), areas where private investment is lacking (Sampat 2012; Fabbri *et al.* 2018), or social value is high (Bhattacharya & Packalen 2011). Scientists respond to changes in funding priorities by shifting their agendas to areas where more resources are available.

In order to be of value for industry, science must be useful and applicable for the goals of the firm (Bikard *et al.* 2019; Stephan 2010). Pavitt (1998, p 795) summarizes the goal of open science as "codify[ing] theories and models that explain and predict natural reality" while commercial science aims to "design and develop produceable and useful artefacts". Achieving these goals makes commercial science more applied and goal-oriented than open science. At the same time, engaging in science allows firms to generate new technologies more efficiently (Fleming & Sorenson 2004), and collaborating with scientific experts allows firms to do so at lower risk (Pavitt 1998; Carayol 2003).[1] Compared to open science, this focus on usefulness and applicability limits the range of topics that are potentially of interest for a firm. There is often a trade-off between scientific and industrial relevance (Lam & de Campos 2015).

Because of that, industry engagement means to define research areas of common interest which are large enough to ensure mutual benefits. This is partially realized through search processes that match firms with scientists with relevant research agendas (Mindruta 2013; Banal-Estañol *et al.* 2018). At the same time, scientists can still be stimulated to come to favour industrially relevant topics, within the bounds of their research agendas. Engage-

[1]Commercial science can also serve strategic purposes: firms in some sectors, such as tobacco alcohol, sugar, and mining, use science sponsorship to establish research areas benefiting the firm's legal and regulatory situations, or to lend scientific credibility to priority areas Fabbri *et al.* (2018).

ment might allow the scientist to access new research infrastructure, that can bring new scientific opportunities which allow scientists to investigate topics that they were not able to investigate before (Price 1984; Freedman *et al.* 2015; Furman & Stern 2011; Furman *et al.* 2012; Helmers & Overman 2017; Murray *et al.* 2016; Rosenberg 1992; Williams 2013; Yaqub 2017). Obtaining access to materials, data, and more broadly speaking, research infrastructure are also a key driver of industry engagement (Perkmann & Walsh 2009; Perkmann *et al.* 2013; Rosenberg & Steinmueller 2013). Knowledge spillovers from industry to science might also spark new avenues for continuing research. Bikard *et al.* (2019) support this idea by demonstrating how industry collaboration can be a source of academic specialization by enhancing the scientist's productivity and line of research. Scientists able to combine applied purpose and scientific contributions ("Pasteur"-related scientists) tend to benefit the most of university-industry collaborations in terms of scientific publications. Lastly, the prospect of securing a steady stream of research funding through industry engagement might also drive scientists to strategically work on topics of higher industrial interest.

Hypothesis 1 *Engaging with industry leads scientists to continue ongoing research lines (exploitation) in order to solve industrial problems.*

2.2.2 Engagement and Exploration

A second dimension in which open and commercial science differ is their stance towards novelty. Competitive science funding is notoriously biased against novelty.[2] Various explanations have been put forward for this, including power dynamics within scientific fields and competitive considerations (Braun 1998), the added risk of funding novel research topics for science sponsors (Myers 2020), but also review panel's limited ability to appraise too novel research topics because of bounded rationality (Boudreau *et al.* 2016; Criscuolo *et al.* 2017; Li 2017).

Regardless of which of these factors is most important, scientists can only rely to a limited extend on competitive science funding to pursue truly novel ideas. Compared to

[2] Other biases than novelty exist. Banal-Estañol *et al.* (2019) finds, for instance, that proposals put forward by more diverse researcher teams are evaluated more harshly. It should be noted, however, that competitively funded research still appears to be more novel than research funded through block funding Wang *et al.* (2018). A more general source of bias can be found in the Matthew effect, where past research success is an important driver of access to resources (Bol *et al.* 2018)

this, commercial science is more strongly driven by technological opportunities, which can allow more space for innovative ideas. Several studies have concluded that industry-funded scientists develop more innovative ideas (Behrens & Gray 2001; Salandra 2018). Corporate science is also more interdisciplinary in the sense that industrial problems do not necessarily fit within disciplinary boundaries, and that industry is more open to drawing on a wide range of fields and technical knowledge in order to solve them (Pavitt 1998). Consequently, industrial problems might provide an opportunity to explore a new area of interest for the scientist.

At the same time, engaging with industry might also lead scientists to explore novel lines of research. Engagement generates knowledge spillovers and inspires new research by exposing scientists to new issues, perspectives, and approaches (Banal-Estañol *et al.* 2015; Gulbrandsen & Smeby 2005; Perkmann & Walsh 2009). Examples from many fields show that the challenges posed by technological bottlenecks can inspire scientific investigations and breakthroughs later on (Mowery & Rosenberg 1999; Rosenberg & Steinmueller 2013; Vincenti 1990). The relative difficulty of exploring novel research topics with public science funding, and the relative openness of industry towards novelty combined with the potential for knowledge spillovers, leads us to hypothesize that scientists that engage with industry are more likely to explore new research topics that speak to industrial problems:

Hypothesis 2 *Engaging with industry expands the scientist's research agendas towards new topics with industrial relevance.*

3 Data and Methodology

3.1 Data sources

We base our analysis on an online survey of higher education professors in Germany in 2011, that asked about their research activities in 2008-2010. The survey was commissioned by the German federal ministry for Research and Innovation and carried out by the Leibniz-Center for European Economic Research (ZEW) in Mannheim. The survey collected information on 2,435 professors and had a response rate of 27%.[3] Considering

[3] The survey is further described in EFI (2012).

the lesser importance of industry funding in social science and humanities, we focus on responses from professors active in the natural sciences, engineering, and medicine. We also focus on professors employed in doctorate-conferring institutions, omitting more practically oriented universities of applied sciences (*Fachhochschulen*) and other types of higher education institutions. After removing incomplete observations and data cleaning, we have a final sample of 1,331 responses.

The German context is especially interesting for this analysis, as Germany experienced an extraordinary rise in industry funding. According to the OECD's Main Science and Technology Indicators, the share of Higher Education R&D financed by the business sector rose from 9.14% in 1995 to 13.83% in 2016, an increase of 51%. In 2016, Germany showed the highest share among OECD countries. For comparison, the OECD average in 2016 is 5.83% (OECD 2019).

3.2 Variables

In this section we describe the variables used in the analysis. See Table 4 in the Appendix for variable descriptions. Table 1 provides summary statistics.

3.2.1 Outcomes: the research agenda

Our dependent variables concern the research agenda. Specifically, we estimate to what extent industry engagement leads scientists to include research topics in their agendas for reasons of industrial relevance. In that framework, we differentiate between topics that continue the scientist's main research lines (exploitation), and new topics (exploration). To do that, we need to measure how scientists decide which topic to investigate. We make use of two survey questions.[4]

Exploitation To assess considerations for exploitation, we draw on a question that asks about scientist's selection criteria for choosing a research theme. The survey proposed 10 possible reasons.[5] To answer our research question, we select among these the items most closely related to industry and science. We consider scientists' exploitation activities

[4]Items were rated on a 5-point scale. For ease of interpretation, we built new variables that take value 1 if the item was rated important or very important and value 0 otherwise.

[5]These include personal interest, contributing to discussions in the scientific community, institutional interests, funding opportunities, collaboration possibilities, and fit with general public interest.

Table 1: Summary statistics

	Mean	S.D.	Min	Max
Outcomes				
Exploitation: Industry	0.17	0.37	0.00	1.00
Exploitation: Science	0.85	0.36	0.00	1.00
Exploration: Industry	0.16	0.37	0.00	1.00
Exploration: Science	0.76	0.43	0.00	1.00
Funding				
% industry funding	9.13	16.05	0.00	100.00
% government funding	19.92	23.01	0.00	100.00
% science funding	58.32	32.26	0.00	100.00
Exploration with basic funds	0.44	0.50	0.00	1.00
TPF not relevant	0.33	0.47	0.00	1.00
Controls				
Career age	11.45	7.93	0.00	42.00
Female	0.11	0.32	0.00	1.00
Patent experience	0.05	0.22	0.00	1.00
Teaching hours	8.56	3.61	0.00	50.00
Field				
Biology	0.14	0.35	0.00	1.00
Chemistry & Pharma	0.15	0.36	0.00	1.00
Engineering	0.21	0.41	0.00	1.00
Mathematics & C.S.	0.12	0.32	0.00	1.00
Medicine	0.19	0.39	0.00	1.00
Physics & geology	0.20	0.40	0.00	1.00

Notes: $n = 1,331$

to be industry-oriented if they indicate to select research topics based on the criterion that they will allow them to engage in knowledge and technology transfer in the future (*Exploitation: Industry*). Of course, selecting research topics for their knowledge transfer potential can be perfectly complementary to contributing to scientific knowledge based. The implications of our study for scientific knowledge development as a whole depend strongly on to what extent engagement and knowledge production constitute a trade-off or a source of complementarity. To test this, we construct a second measure that indicates whether or not scientists choose topics in order to contribute to discussions in the scientific community (*Exploitation: Science*). Table 1 shows that a strong majority of respondents develops topics to contribute to science (85%). Exploitation along industry potential by 17% of respondents. Of those that consider industry potential an important motivation for topic choice, 83% also consider scientific discussion as an important selection criterion.

Exploration To delineate scientists' considerations in exploring new research topics, we make us of a question that asks which funding sources are important channels for new research topics, assuming that a new topic is closer to the interests of a sponsor when it is a more important funding channel.[6] We consider scientists as exploring research with industry (*Exploration: Industry*) when they indicate that industry is a highly relevant funding source for new research topics. Likewise, we consider scientists to explore research in a direction highly relevant for science (*Exploration: Science*) when they indicate that funding by the German Science Foundation is a highly relevant source. 16% of respondents indicates that firms are an important source, and 76% indicates that science funders are important. Compared to exploitation, the overlap between the two is less strong: 68% of those who consider industry funding to be important for exploration also consider science funding important.[7]

3.2.2 Variable of interest: industry engagement

Our variable of interest is the degree up to which the scientist engages with industry. Industry engagement is a broad concept that captures various channels through which scientists interact with industry, outside of the direct commercialization of research results through patenting and academic entrepreneurship (Perkmann *et al.* 2013, 2021). The degree to which academics engage with industry is commonly summarized through the share of a scientist's research funding that stems from industry (Blumenthal *et al.* 1996b; Czarnitzki *et al.* 2015a,b; Gulbrandsen & Smeby 2005; Hottenrott & Lawson 2014, 2017; Louis *et al.* 2001). In the survey, respondents were asked to specify which share of external research stems from industry. On average, respondents reported to have 9% of their external research portfolio funded by industry. 42% of respondents report any funding from industry, and the average funding share of a respondent with industry funding is 22%.

3.2.3 Control variables

Other funding sources Beyond industry engagement, scientists might be influenced by the composition of their broader funding portfolio. We therefore control for the share of external funding drawn from science funders and government sources. Their respective

[6] The question offers 8 funding channels, including basic university funding, project funding by the German Science Foundation, programs coordinated by the German Science foundation, science foundations, funding from the federal or local government, industry, European programs, or others.

[7] 18% considers neither to be particularly important, and rely more on government, European, or other sources for funding new research themes.

amounts represent between 58% and 20% of the researcher's funding portfolio on average.[8] Likewise, we control for the possibility that some scientists might have access to more institutional funds than others, and might be able to use those funds for research purposes. Institutional funds might be a particularly attractive source for funding for exploring new and risky research topics. We capture this through a variable that indicates whether basic funding is an important or very important source of funding for new research topics. This is the case for 44% of scientists (*Exploration with basic funds*).

Fit with third party funders Scientist's decisions to explore certain research topics also depends on the fit between it and the interests of potential sponsors. Scientists working in fields with less interest from third-party sponsors might need to adjust their research agendas in particular ways in order to secure funding. We control for this possibility through the survey question "*How important are the following reasons for forgoing the (further) attraction of external research funds?*". We consider scientists to have poor fit between their research theme and third party sponsors when they indicate "*Thematic requirements of potential third-party funders are not interesting*" as an important or very important reason not to pursue funding. This is the case for 33% of respondents (*TPF not relevant*).

Personal characteristics Scientist's industry engagement and agenda-setting also varies along personal characteristics. We first control for life cycle effects. These affect industry engagement (Abreu & Grinevich 2013; Aschhoff & Grimpe 2014; Bekkers & Bodas Freitas 2008; Boardman & Ponomariov 2009; D'Este & Patel 2007; Haeussler & Colyvas 2011; Lawson *et al.* 2019; Link *et al.* 2017), but also affect research in a broader sense (Stephan & Levin 1992). We capture life cycle effects through the scientist's career age, the years since the scientist was first appointed professor, on average 11 years. We also control for gender, as women are less likely to engage with industry (Abreu & Grinevich 2013; Azagra-Caro 2007; Boardman & Corley 2008; D'Este *et al.* 2019; Giuliani *et al.* 2010; Lawson *et al.* 2019). 11% of the sample consists of female scientists.

Research characteristics Scientist's choice of research topics can also be influenced by prior experience in commercialization, and by the degree to which the scientist's research

[8] Science funding includes funding by the German Science foundation or other science foundations. Government funding includes funding by the German federal or local governments. We categorize funding by the European Commission as 'other', as it can be government or science funding depending on the specific funding program.

outputs are suited for use in applied contexts (Aschhoff & Grimpe 2014; Lawson *et al.* 2019). We capture both through a variable which indicates whether the scientist was listed on at least one patent application at the German national patent office in the two years before the survey. This was the case for 5% of respondents. We also control for scientist's teaching load through the average number of lecture hours per week. On average, scientists in the sample lecture 8.6 hours per week.

University characteristics Institutional characteristics are important drivers of research choices and industry engagement. On the one hand, scientists in more reputable institutes might have more access to both scientific and industry funding opportunities, and might also be more successful in attracting science funding when more institutional support resources are available, leading them to be less reliant on external funding. On the other hand, industry engagement is sensitive to local department culture and peer behaviour (Aschhoff & Grimpe 2014; Bercovitz & Feldman 2006; Perkmann *et al.* 2013, 2021). To control for both factors, we include a set of university dummies in the main specification. As we mainly rely on binary outcome models, this limits our effective sample to those where at least two scientists are observed in each institution, of which at least one positive and negative outcome need to be observed. The dataset contains responses from 74 institutions. The median number of responses per institution is 15, up to a maximum of 49.

Discipline Lastly, we control for scientific discipline, as the antecedents and consequences of industry engagement are highly field-dependent (Bekkers & Bodas Freitas 2008; Cohen *et al.* 2020; Boardman & Corley 2008; Lee & Bozeman 2005). We distinguish the fields of biology (14% of the sample), chemistry and pharmaceuticals (15%), engineering (21%), mathematical and computer sciences (12%), medicine (19%), and physics and geosciences (20%).

3.3 Specification

We investigate the effect of industry engagement on agenda-setting through a series of regression models. As the outcome variables are binary, we specify Probit models.[9] The

[9] The outcomes of this analysis do not depend on the choice of model. Logit models and Linear Probability Models yield highly similar results.

outcome variables are whether or not the scientist exploits or explores research topics along scientific or industry norms (*Exploitation* or *exploration*; *science* or *industry*). The variable of interest is the share of industry funding in the scientists' third party funding. We further control for other funding sources, personal characteristics, research characteristics, and institute specificities. We cluster standard errors by institution to account for within-institute autocorrelation.

The causal interpretation of our results is challenged by our limited ability to control for scientist's preferences and abilities. Regarding preferences, scientists can sort into institutions with different research focus and funding opportunities along their preferences for research themes and academic engagement. Scientists with higher ability, too can sort into more reputable institutions, where more funding is available and topic choices are less constrained. In ideal circumstances, we would have access to a panel of scientists. Then, we could account for self-selection by exploiting exogenous variation in the demand for scientists, or in local funding opportunities. However, the cross-sectional nature of our data limits possible sources of exogenous variation to the geographic dimension, which co-varies along with institutional characteristics. This can lead the effect of funding on research topic choice to be overestimated.

In the absence of a reasonable source of exogenous variation, we make use of recent advances in structural econometrics that allow for identification in the absence of valid instruments. Lewbel (2012) shows that, under minimal assumptions, heteroscedasticity in the first stage—in our application, the reduced-form correlates of the share of industry funding—can be used to generate valid instruments. These can then be used in a standard two-stage least squares setting. As a robustness check, we test whether the results of the Probit model hold when we apply this estimator.[10]

[10]Note that we have to apply a Linear Probability Model in order to apply this estimator. Whereas the Probit specification might be preferred to avoid out-of-bounds predictions, the estimated coefficients of the Linear Probability Model are in practice virtually indistinguishable from the average marginal effects estimated by the Probit model (Angrist & Pischke 2008, p. 105-106).

4 Results

4.1 Main Results

Table 2 provides the main results. Columns (1) and (2) report the relation between industry funding and exploitation in the direction of science and industry; columns (3) and (4) report the same relationship for exploration.

In line with hypothesis 1, column (1) shows that scientists who are more strongly funded by industry are more likely to expand their main research lines in accordance with industry, that is, to consider technology transfer an important factor when deciding to work on a given topic. The coefficient of industry funding is statistically significant ($p < 0.01$) and large: a 10 percentage point increase in the share of industry funding relates to an average 4% increase in the probability of exploiting in the direction industry. Compared to a scientist not funded by industry, the average industry-funded scientist (who draws 22% of their external funds from industry) has a 8.8 percentage point higher probability of exploiting their expertise in a way relevant for industry - or 1.6 times the probability for the sample without industry funding (5.4%).

Column (2) shows that this re-orientation towards topics with relevance for knowledge transfer comes also reduces scientific relevance: scientists that are more intensely funded by industry are less likely to select research topics based on scientific debate ($p < 0.05$). The marginal effect, however, is only half that of previous model (-1.7 percentage points for 10 percentage point increase in industry funding). The average share of industry funding generates an approximately 5 percentage point probability drop in probability compared to that of non-industry-funded scientists (a 3.7 percentage point decrease compared to a base probability of 88%).

Industry engagement, thus, has two effects on exploitation in the research agenda: it orientates the agenda towards knowledge transfer, and shifts it away from ongoing discussions in the scientific community. The former effect is strong, the latter relatively weak. In that sense, industry engagement does impose a trade-off on the direction of science: whereas it generates more knowledge transfer, with positive impacts on innovation, more industry engagement might also lead scientists to focus more on topics that they can valorize through knowledge transfer. To a lesser extent, this also means a shift away from topics of scientific

Table 2: Industry funding relates to exploitation and exploration with industry

	Exploitation		Exploration	
	(1) Industry	(2) Science	(3) Industry	(4) Science
% industry funding	0.022***	-0.008**	0.044***	-0.001
	(0.004)	(0.004)	(0.004)	(0.003)
% government funding	0.001	0.001	0.005	-0.001
	(0.003)	(0.003)	(0.003)	(0.002)
% science funding	-0.010***	0.002	-0.006**	0.011***
	(0.002)	(0.003)	(0.002)	(0.002)
Exploration with basic funds	-0.093	0.241***	-0.125	-0.652***
	(0.112)	(0.085)	(0.104)	(0.105)
TPF not relevant	-0.201*	0.016	-0.257**	-0.122
	(0.111)	(0.104)	(0.123)	(0.086)
Career age	0.011*	-0.005	0.005	0.005
	(0.007)	(0.006)	(0.008)	(0.006)
Female	0.127	0.402**	-0.183	0.102
	(0.189)	(0.186)	(0.222)	(0.126)
Patent experience	0.800***	0.111	0.283	-0.223
	(0.224)	(0.175)	(0.209)	(0.207)
Teaching hours	-0.004	-0.019	0.013	-0.025**
	(0.013)	(0.015)	(0.014)	(0.012)
Biology	0.155	0.070	0.023	-0.207*
	(0.210)	(0.188)	(0.241)	(0.124)
Chemistry & Pharma	0.153	-0.307*	0.182	-0.147
	(0.171)	(0.168)	(0.237)	(0.160)
Engineering	0.454***	-0.341*	0.259	-0.060
	(0.171)	(0.180)	(0.192)	(0.157)
Mathematics & C.S.	0.202	0.032	0.058	-0.279*
	(0.216)	(0.170)	(0.273)	(0.160)
Medicine	-0.137	-0.266**	0.514**	-0.401***
	(0.180)	(0.135)	(0.229)	(0.150)
Constant	-1.338***	1.774***	-2.019***	1.079***
	(0.211)	(0.309)	(0.297)	(0.236)
University F.E.	YES	YES	YES	YES
Observations	1262	1245	1154	1302
Pseudo R-Squared	0.284	0.093	0.358	0.150
Avg. Mfx.				
% industry funding	0.403%	-0.169%	0.831%	-0.038%
% government funding	0.018%	0.020%	0.087%	-0.021%
% science funding	-0.187%	0.054%	-0.110%	0.318%

Notes: Probit regression with university and field fixed effects (not reported). Standard errors clustered by university in parentheses.
***(,**,*): $p < 0.01(,p < 0.05,p < 0.1)$

interest. This dynamic implies a possible dual impact of industry engagement. A sanguine interpretation of our findings might be that the impact of engagement on the research agenda is small in fields where commercial and scientific usefulness overlap; especially for those scientists active in Pasteur's Quadrant (Stokes 2011) there might not be a trade-off at all. At the same time, this trade-off exists for scientists outside of Pasteur's Quadrant, where increasing commercial usefulness implies diminishing scientific relevance.

The control variables in models (1) and (2) are in expected patterns. Those who draw more intensely on science funders, and those who consider third party funders not relevant are less likely to adopt topics in the direction of industry. The probability of adopting topics in line with industry increases with career age (Bekkers & Bodas Freitas 2008; Boardman & Ponomariov 2009; D'Este & Patel 2007; Haeussler & Colyvas 2011; Link *et al.* 2017). Female scientists are more likely to align their research agenda with scientific discussions, in line with the notion that women engage less with industry (Azagra-Caro 2007; Boardman & Corley 2008; Giuliani *et al.* 2010). Patenting experience relates to more consideration of knowledge transfer in the selection of topics to pursue. Engineers are more likely to adopt topics in line with industry, and less in line with scientific discussion, albeit weakly significantly, compared to the reference category (physics & geology). The latter is also true for scientists in chemistry & pharma and in medicine.

Columns (3) and (4) of Table 2 study the relationship between industry funding and exploration with funding from industry or science. Compared to models (1) and (2), these results are explicitly about expanding the agenda towards new research topics. Column (3) shows the impact on funding new research topics from industry. Raising industry funding by 10 percentage points increases the probability that the scientist considers industry an important potential funding source for new research topics with 8.3 percentage points ($p < 0.01$). Compared to a scientist without industry funding, the average industry funded scientist thus has a 18.3% higher probability of considering industry an important funder of new research topics, or a six-fold increase in probability. The stronger effect of industry engagement on exploration, as compared to exploitation, is likely a result of scientific funder's reluctance to fund novel ideas (Boudreau *et al.* 2016; Braun 1998; Criscuolo *et al.* 2017; Link *et al.* 2017). Scientists with the social networks and experience to potentially draw on industry funding for new ideas might find this option more convenient than trying to win competitive grants for their ideas, especially when the ideas are risky, or in areas where the scientist has less of a proven track record (Azoulay *et al.* 2011). In contrast to exploitation, we do not find that this effect represents a trade-off with science funders: column (4) shows no significant relation between industry funding and the probability that the scientist considers science funders important sponsors to explore new research ideas.

In terms of control variables, columns (3) and (4) show that scientists who are more intensely funded by science funders tend to rely on the latter to explore new research topics, and less on industry. Column (3) shows that the share of public funds moderates the adoption of new industrial relevant topics. Those who are able to explore new topics with basic funding rely less on science funders, and those who consider third party funders not relevant for their research are less likely to rely on industry funding. Scientists who have high amounts of teaching also rely less on science sponsors, suggesting that the portfolio of activites might also influence the research strategies pursued. In terms of field differences, scientists in biology, mathematics & computer science, and medicine are less reliant on science for funding of new topics. The first two, however, are not correspondingly more reliant on industry, whereas scientists in medicine are.

4.2 Robustness check: instrumenting industry funding

Table 3 replicates the findings of Table 2, while instrumenting the share of industry funds through instruments à la Lewbel (2012). The results confirm the key findings from Table 2, with robust coefficients of the effect of industry funding. Only the coefficent of exploitation with science becomes only significicant at $p < 0.10$, compared to $p < 0.05$ in Table 2. The effect sizes are in the same range as the ones found in the Probit regression.[11] Concerning the instruments, the Kleibergen Paap Weak Identification Test rejects the null hypothesis of weak instruments at conventional Stock-Yogo critical values, and the Hansen J statistic is only significant in column (2), indicating that the model's overidentifying restrictions are valid in the other three models. On the whole, the alternative specification leads us to conclude that the effects observed in Table 2 are not driven by selection effects.

[11] The coefficients of 2-Stage Least Squares (2SLS) instruments can be directly interpreted as semi-elasticities on the probability of exploiting of exploring with science or industry.

Table 3: 2SLS estimates of effect of industry funding on research agenda

	Exploitation		Exploration	
	(1) Industry	(2) Science	(3) Industry	(4) Science
% industry funding	0.006***	-0.002*	0.010***	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
% government funding	0.000	0.000	0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
% science funding	-0.002***	0.000	-0.001***	0.003***
	(0.000)	(0.001)	(0.000)	(0.001)
Exploration with basic funds	-0.015	0.048***	-0.020	-0.167***
	(0.019)	(0.017)	(0.015)	(0.026)
TPF not relevant	-0.034*	0.002	-0.038**	-0.037
	(0.019)	(0.021)	(0.017)	(0.023)
Career age	0.002*	-0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.002)
Female	0.020	0.067**	-0.031	0.022
	(0.030)	(0.026)	(0.026)	(0.031)
Patent experience	0.180***	0.031	0.055	-0.061
	(0.058)	(0.041)	(0.053)	(0.067)
Teaching hours	-0.001	-0.005	0.003	-0.008**
	(0.002)	(0.004)	(0.002)	(0.003)
Biology	0.028	0.010	0.011	-0.054**
	(0.027)	(0.029)	(0.023)	(0.027)
Chemistry & Pharma	0.020	-0.060*	0.007	-0.026
	(0.026)	(0.033)	(0.029)	(0.041)
Engineering	0.128***	-0.072**	0.064**	-0.002
	(0.040)	(0.037)	(0.031)	(0.039)
Mathematics & C.S.	0.030	0.005	0.018	-0.064
	(0.033)	(0.028)	(0.032)	(0.042)
Medicine	-0.036	-0.055**	0.058*	-0.106***
	(0.025)	(0.027)	(0.033)	(0.038)
University F.E.	YES	YES	YES	YES
Observations	1331	1331	1331	1331
R-Squared	0.182	0.041	0.300	0.109
Kleibergen-Paap Weak id test	143.7	143.7	143.7	143.7
Hansen J stat(p-value)	15.9(0.196)	22.1(0.037)	16.0(0.191)	12.4(0.411)

Notes: 2SLS with heteroskedasticity based instruments (Lewbel 2012). University and field fixed effects partialled out. Standard errors clustered by university in parentheses.
***(,**,*): $p < 0.01$(,$p < 0.05$,$p < 0.1$)

5 Conclusion

We study the impact of academic engagement on the research agenda. By taking the perspective of the research agenda (Carayol 2003), we contribute to understanding the long-term impact of increasing academic engagement on the production of scientific knowledge, and, in particular, on the direction of science. Our analysis shows that scientists who engage more with industry are more likely to consider potential for technology transfer in their research topic choices, and are more likely to turn to industry to fund novel ideas. At the same time, they – to a limited degree – consider to a lesser extent how much a topic could contribute to discussions in the scientific community. Our results suggest that increasing attention for academic engagement might lead science to evolve in a different direction: towards topics with more potential for knowledge transfer and commercialisation and away from topics that advance ongoing scientific discussions. Particularly radically new topics are more likely to depend on industry funding. At the same time, we show that the trade-off in terms of relevance for science or industry is relatively limited, and is focused on exploitation. Explorative research topics become more relevant for industry in the light of academic engagement, but not less relevant for science. A probably explanation for the absence of a trade-off in exploration would be the nature of science-funded projects. Science sponsors mainly act through grants, that generally do not condition on particular outcomes, such as publications (Azoulay & Li 2020). Different levels of tolerance for failures (or taste to explore risky topics) among scientists may imply distinct strategies to renew the agenda and which on average shows no detrimental impact on exploring new topics with public grants. The perception of change among new topics is also probably lower than among the topics composing the core of the scientific agenda.

The implications of our study depend on, on the one hand, whether synergies exist between what is useful for industry and what is useful for science. The more these synergies exist, the more a push for engagement resembles an activation of Pasteur-like research topics (Stokes 2011). If that is predominantly the case, scientific distortions in the light of engagement, will be minimal, and the benefits of engagement for innovation will likely outweigh them. However, these synergies do not exist for all research topics, fields, or scientists, so for some more engagement will imply a trade-off between industrial and scientific relevance. For how many fields and scientists this is the case would be an interesting future research topics. On the other hand, previous studies might underestimate the importance of industry as a source of renewal. An optimistic interpretation of the finding that engaging scientists rely more on industry to fund new research topics is that industry funding can serve as a complementary funding channel to science funding. That option might help scientists to bypass novelty-related biases of science funders for those topics where there is mutual scientific and industrial interest.

The main policy implication of our study is that policy makers and university leaders should be mindful of the incentives they create when integrating engagement with industry in job definitions, performance evaluations, and funding. Too much focus on engagement might create distortions in the direction of science for research areas that have less direct industrial relevance. In that light, it remains essential to maintain a sufficiently large share of basic science funding for safeguarding the free evolution of science.

Our study is not without limitations and opens a range of questions for future research. The context of our study, Germany, places particular importance on industry funding. The size of our sample also limits our ability to consider variations between and within fields in the relation between funding and topic selection. Future research should consider the heterogeneous impact of industry engagement on the scientific agenda depending on its prior match with industrial relevance. Similarly, different industries collaborate with academia because of different reasons (Pavitt 1998). Like field characteristics, industry specificities are also likely to affect the mode of industry engagement and its impact on the direction of science (D'Este *et al.* 2019; Pavitt 1998). Furthermore, our results hint there might be different strategies to integrate the tensions inherent to industry engagement in the research agenda. Further research should explore with more fine-grained measures how research agendas shift in the light of academic engagement. The magnitude of change and the strategies to manage such risks are likely to differ over the career age and the organizational structures that scientists work in.

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Appendix

Table 4: Variable definitions

Variable	Definition	Unit
Dependent Variables		
Exploitation		
With Industry	1 if "potential for knowledge transfer" is important or very important criterion for selection and development of research topic, 0 otherwise	0/1
With Science	1 if 'discussion in scientific community' is important, or very important criterion for selection and development of research topic, 0 otherwise	0/1
Exploration		0/1
With Industry	1 if industry is important or very important funding channel for new research topics, 0 otherwise	0/1
With Science	1 if project funding from German Science Foundation or programs coordinated by German Science Foundation are important or very important funding channel for new research topics, 0 otherwise	0/1
Independent Variables		
% industry funding	Share of external research funding stemming from industry, average 2008-2010	%
Control Variables		
% government funding	Share of external research funding stemming from local or federal governments, average 2008-2010	%
% science funding	Share of external research funding stemming from German Science Foundation or other science foundations, average 2008-2010	%
TPF not relevant	1 if "Thematic requirements of potential third-party funders are not interesting" is important or very important reason for not seeking external research funds, 0 otherwise	0/1
Career age	Years since first appointment as professor	#
Female	1 if scientist is female, 0 otherwise	0/1
Patent experience	1 if scientist was listed as inventor on at least 1 German National Patent Office in 2008-2010 before the survey	0/1
Teaching hours	Average teaching hours per semester, 2008-2010	#
Exploration with base funds	1 if basic funding is at least a somewhat relevant funding channel for new research topics, 0 otherwise	0/1
Field	Set of field indicators, distinguishing biology; chemistry and pharmacy; engineering; mathematical sciences; medicine; and physics and geosciences	0/1

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