The relationship between university-industry interactions and university scientific productivity: evidence from China

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Abstract This paper proposes an inter-temporal conceptual model to examine the effect of different types of university-industry (U-I) interaction – contract research and intellectual property (IP) transfer – on university scientific productivity. Based on the empirical analysis of 59 Chinese research-intensive universities from 2010 to 2015, this paper finds that contract research commissioned by industry has an inverted U-shaped effect on university research whereas IP transfer has a negative effect on university scientific productivity. University internal R&D intensity will weaken the effect of university-industry interaction on university scientific productivity. Past university scientific production influences positively current academic engagement with industry (contract research) as well as academic commercialization (IP transfer).

1. Introduction

Universities are organizations that perform a crucial role in society as producers and transmitters of knowledge. In recent years, often on the initiative of policy-makers, the discussion about whether universities can encompass a third mission of fostering links with industry and facilitating technology transfer, has received great attention. Among these discussions, one of the essential issues are the impacts of industry involvement on universities. In light of the growing trend to promote university interactions with industry by policy makers, this issue is considerable important for science and technology policy. If increasing university-industry interactions was found to be detrimental to the accumulation of openly accessible knowledge, policies aimed at promoting academic engagement and

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commercialization would risk sacrificing the long-term benefits of scientific inquiry for short-term economic benefits (Dosi et al., 2006; Perkmann and Walsh, 2009). While some emphasize the university may benefit from industrial interactions and U-I interactions have positive effects on researcher productivity (Perkmann et al., 2013; Banal-Estanol et al., 2015; Muscio et al., 2017; Zhang and Wang, 2017; Chen et al., 2017; Tseng et al., 2018), others express concerns that a heavy involvement with industry have negative effects on the academic research, whereas U-I interactions distract attention from the fundamental research, and concentrating on the applied research which meet the needs of the industry (Calderini et al., 2007; Breschi et al., 2008; De Fuentes and Dutrenit, 2012; Aguiar-Diaz et al., 2015). Despite its considerable importance, there is far from a consensus among the academic community about this issue.

Previous research has investigated this issue by studying university–industry interactions primarily focusing on academic commercialization[2] such as patenting, licensing or participation in spin-off companies. While valuable in its own right, this research does not tell us how academic engagement[3] such as joint research or contract research affect the research productivity of academics and how different ways of interacting with industry affect the research output of academics (Perkmann and Walsh, 2009; Aguiar-Diaz et al., 2015). This aspect would seem crucial in light of recent evidence on the multi-channel nature of university–industry interactions. Academic engagement represents an important way in which academic knowledge is transferred into the industrial domain; many companies consider it significantly more valuable than licensing university patents (Perkmann et al., 2013). The purpose of this paper is to focus on this different varieties of channels through which university researchers interact with industry and their mechanisms and effects on academics' research.

Four contributions are made to the existing literature in this paper. First, focusing on the contract research and intellectual property transfer, this study offers a conceptual framework that explain how academic engagement and commercialization influence university scientific productivity differently whereas the knowledge of academic engagement remains relatively fragmented and tentative, given the fact that academic engagement is not a new phenomenon and represents an important way for academic

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[2] Academic engagement defines as knowledge-related collaboration by academic researchers with industry. These interactions include formal activities such as collaborative research, contract research, and consulting, as well as informal activities like providing ad hoc advice and networking with practitioners (D'Este and Patel,2007; Perkmann and Walsh, 2009; Perkmann et al., 2013)

[3] Commercialization of academic knowledge normally involves the patenting and licensing of inventions as well as academic entrepreneurship (De Fuentes and Dutrenit, 2012; Perkmann et al., 2013; Aguiar-Diaz et al., 2015).

research to contribute to economy and society.

Second, exiting studies about U-I interactions are mostly based on cross-sectional data and therefore pose limitations in terms of inferring causal relationships between variables. It is unclear whether research performance is enhanced by U-I interactions, or U-I interactions is a mere consequence of high research performance. Utilizing a panel dataset covers 59 Chinese research-intensive universities from 2010 to 2015, this study deploys both qualitative explanation and quantitative evidence to explain the inter-temporal relationship between U-I interactions and university scientific productivity.

Third, this study offers initial clues about how university internal R&D affect the efficiency of U-interactions, since the attention-based theory (Laursen and Salter, 2006) suggests that ideas are produced both internally and externally and the substitution effect between internal R&D and open innovation, and greater attention to internal R&D will lower researchers' attention for external sources which leads to the lower university scientific productivity.

Finally, the studies related with university-industry interaction mostly focused on OECD countries, emerging economies like China – the focus of this paper – India or Brazil have been less studied. To the best of our knowledge, only Zhang and Wang (2017) have used individual data and Cheng et al. (2018) have used province data to study relationship between U-I interaction and research output in China. This paper aims to fill this gap by offering empirical evidence about Chinese university-industry interaction and university scientific productivity at organizational level.

Our empirical findings have confirmed the hypothesis that academic engagement and commercialization have different effect on scientific productivity: contract research commissioned by industry has an inverted U-shaped effect on university research whereas IP transfer has a negative effect on university scientific productivity. Furthermore, university internal R&D intensity weakens the effect of university-industry interaction on university scientific productivity. Finally, past university scientific production influences positively current academic engagement with industry (contract research) as well as academic commercialization (IP transfer).

This article is structured as follows. Section 2 develops the theoretical framework and sets the hypotheses. Section 3 describes the research context and methodology. The main results of the empirical analysis and its discussion are presented in section 4. Finally, the last section summarizes the main results and suggests policy implications.

2. Theoretical background

2.1 Effect of university-industry interactions on university scientific production

Recent studies have explored how industry involvement by academics affects their research productivity, measured as journal publication output. Some studies have shown that university–industry interactions have positive effects on researchers' productivity (Perkmann et al., 2013; Banal-Estanol et al., 2015; Muscio et al., 2017; Zhang and Wang, 2017; Chen et al., 2017; Tseng et al., 2018). For example, Owen-Smith (2003) argued that US universities have moved towards a "hybrid order" based on positive feedback effects between academic publishing and patenting. Gulbrandsen and Smeby (2005) established that Norwegian professors with higher levels of industry funding publish more than their colleagues. Azoulay et al. (2007) showed that academic patenting is generally preceded by high productivity in terms of journal publications. Carayol (2007), Breschi et al. (2008), Sengupta and Ray (2017) and Muscio et al. (2017) have shown similar results using European and American evidence.

However, there are also skeptical views suggesting that closer relationship with industry can generate time pressures and attention distractions, thereby reducing the ability to concentrate on university academically relevant outputs (Calderini et al., 2007; Breschi et al., 2008). Blumenthal et al. (1996) suggested that although life science faculty in receipt of industry funding publish more, their productivity decreases if this funding exceeds two-thirds of their total funding. Goldfarb (2008) established that faculty who maintain long-term relationships with "applied" sponsors publish less, suggesting that careers might be affected by the types of relationships academics maintain with their sponsors. Barbieri et al. (2018) also pointed out that creating a spin-off decreases the number of publications of researchers and has negative effect on research performance.

The ambiguous evidence emerging from these studies suggests that unexplored aspects might be at play. We argue that to determine whether U-I interactions will affect university scientific productivity depend on how U-I interactions influence the factors driving academic research.

As Stigler described in his 1982 Nobel lecture (Stigler, 1983): "*Any new idea - a new conceptualization of an existing problem, a new methodology, or the investigation of a new area-cannot be fully mastered, developed into the stage of a tentatively acceptable hypothesis, and possibly exposed to some empirical tests without a large expenditure of time, intelligence, and research resources*", access to knowledge, research resource and time are key factors that affect scientific production. In the meantime, Stephan (1996), Czarnitzki et al. (2014) and Banal-Estanol et al. (2015) also pointed out that the existence of constraints in the dissemination of research results might also affect university knowledge production. We argue that access to new knowledge, time constraint, research resource and disclosure constraint are the four main determinants that affect university scientific productivity:

1) **Knowledge**: acquiring new ideas is essential in scientific discovery. Greater knowledge base is not only useful to solve a problem but also to choose the problem and the sequence in which the problem is addressed. Interactions with industry offers another channel for researchers to gain new idea and expand their knowledge base rather than traditional academic research environment. The intellectual benefits from these interactions refer to the exchange of knowledge, ideas for new research, academic publications, scientific discoveries, new perspectives from which they can face problems, development of human resources, and the possibility of sharing the knowledge that is generated (Arza, 2010). Interactions with industry can expand academics' research agendas and improve the pool of research ideas (Rosenberg, 2010). Meanwhile, interactions help academics gain new insights for their own research and test the practical application of their theoretical ideas (Lee, 2000). The generation of ideas through puzzle-solving may in turn improve research outcomes and the resulting ideas can be transformed into academic papers (Aguiar-Diaz et al., 2015).

2) **Time:** although it is popular to characterize scientists as having instant insight, studies suggest that science takes time. Investigators often portray productive scientists and eminent scientists especially-as strongly motivated, with the "'stamina' or the capacity to work hard and persist in the pursuit of long-range goals" (Mary Frank Fox 1983, p. 287). Interactions with the industry can generate time pressures, thereby reducing the ability to concentrate on academically relevant outputs (McFadyen and Cannella, 2004; Calderini et al., 2007; Breschi et al., 2008; Banal-Estanol et al., 2015). U-I interactions may also come with "strings attached" in the form of academic consulting or commercial activities. The general duties of the academics, and research in particular, might be compromised by an increase in the time allocated to development, consulting or commercialization (Florida and Cohen, 1999), thus reducing scientific publication.

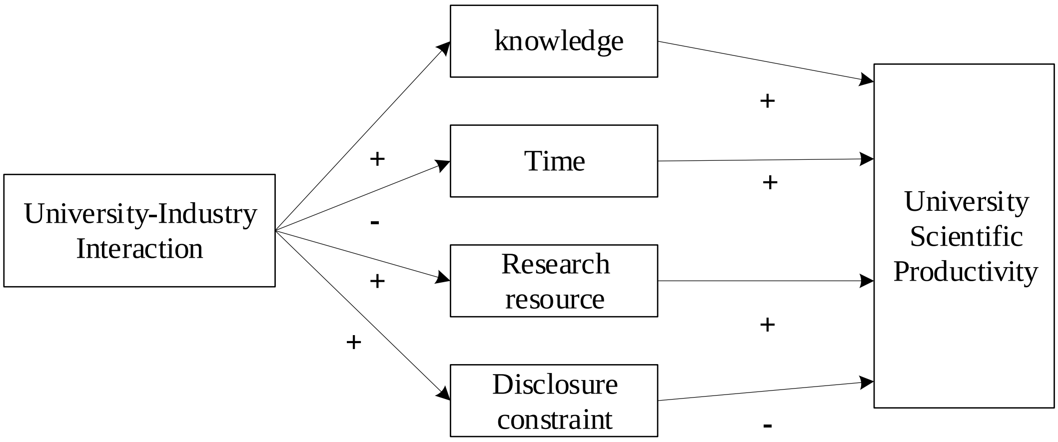
3) **Research resources:** scientific production also requires research resources. Funding becomes a necessary condition for doing research, at least research that is initiated and conceived of by the scientist. For example, in the social sciences this generally translates into a personal computer, access

to a database and one or two graduate research assistants. For physical scientists, the resource requirements are considerably more extensive, involving access to substantial equipment, and the assistance of numerous graduate students and postdocs. In the life sciences research also requires access to subjects (both of the human and nonhuman variety) as well as access to certain strains (Stephan, 1996). According to survey evidence in Lee (2000), two of the most important reasons for academics to collaborate with industry are to secure funds for graduate students and lab equipment, and to supplement funds for their academic research. As Muscio et al. (2017) pointed out, the positive effect of contract or joint research is based mainly on access to resources that complement research activities. Bercovitz and Feldman (2008) have pointed out that university faculty members would be more likely to get involved into academic commercialization because of financial incentives. Offering an alternative source of research funding for university rather than government is precisely the policies such as Bayh–Dole Act was proposed at the first place, which encouraging university technology transfer (Mowery et al., 2001).

4) **Disclosure constraints**: extant research suggests that the "secrecy problem" potentially exert a negative impact on university research productivity. Interacting with industry poses potential dilemmas rooted in the different institutional logics prevailing in academia and industry (Colyvas, 2007). To secure commercial appropriation of research results, academics might be required to delay or even forego publication (Geuna, 2001; Nelson, 2004). The "secrecy problem" (Florida and Cohen, 1999) leads to the tension between open science and proprietary knowledge, potentially restricting public dissemination of research results (Blumenthal et al., 1996; Nelson, 2004). Van Looy et al. (2004), Tartari and Breschi (2012) and Czarnitzki et al. (2015) argued that the confidentiality requirement would go against the academic norm of making available the new knowledge to the whole scientific community. In their study of US life science companies, Blumenthal et al. (1996) found evidence of both publication delay and secrecy (nondisclosure) restrictions on information resulting from academic research. For instance, 58% of the companies typically required researchers to keep information confidential for more than 6 months. Thursby and Thursby (2007) surveyed 112 firms engaged in university licensing and also find that 90 % of the university contracts include clauses on withholding of research results.

In a nutshell, U-I interactions may bring new ideas and research resources to university which have positive impacts on scientific productivity. However, U-I interactions will propose more time and disclosure constraint on university academics which negatively influencing scientific productivity.

Figure 1. Four determinants of university-industry interaction on university scientific productivity



As Figure 1 has shown, U-I interactions can have both positive and negative effects on the factors driving academic research. The relative magnitudes of these effects and their ultimate impact on scientific production change with the types of U-I interactions. For example, training for industry might raise additional income to academics but have little effect on the need to access industry skills and create new ideas (D'Este and Patel, 2007). Participation in consulting activities competes with the amount of time dedicated to research and that confidentiality issues may restrict the publication of the work. Research collaboration with industry will enable researchers to create new research ideas and access to more research facilities, but most companies typically required researchers to keep information confidential for certain period which delay publication (Czarnitzk et al., 2014; Gans and Murray, 2012).

Perkmann et al. (2013) have pointed out that academic engagement and academic commercialization are the two major types of U-I interactions. According to the survey data of physical and engineering academics in UK, D'Este and Perkmann (2011) finds that the academics who participate in academic engagement are more likely research-driven and commercialization plays no role in their engagement decision; academics involved in commercialization activities are more interested in deriving personal pay-offs and emphasizing utility-maximizing behavior which they do not appear to derive significant research-related benefits. In this study, we argue that academic engagement and commercialization activities have different impact on university scientific productivity due to the different motivations of the participates and characteristic of these two types of U-I interactions. Since U-I interactions can have both positive and negative effects on the factors driving academic research. We expect that the positive effects to be relatively more important and dominate in academic engagement activities, leading to overall positive impact on academic research; while the negative effects shall dominate in academic commercialization activities, leading the overall negative influence over academic research.

2.1.1 Academic engagement and university scientific productivity

Scholars have pointed out that academic engagement such as contract or sponsored research represents an important way in which academic knowledge is transferred into the industrial domain (Cohen et al., 2002). Universities' income from academic engagement is usually much higher than the income derived from intellectual property transfer (Perkmann et al., 2011). Academic engagement brings not only research resources but also allows academics access new learning opportunities, such as field-testing opportunities for their own research and obtaining new insights, which are positively related with university scientific productivity. For example, a study of German academic researchers in four disciplines suggests that acquiring additional research funds and learning from industry constitute the main motives for engaging with industry (Meyer-Krahmer and Schmoch 1998). Hottenrott and Lawson (2014) also show that research units that receive larger shares of funding originating from industry are also more likely to develop ideas stemming from private partners. Meanwhile, Lee (2000) found that science and engineering faculty at US research universities engagement with industry is looking for additional funds, equipment and support for students. In the same line, Manjarres-Henriquez et al. (2009), D'Este and Perkmann (2011) and Banal-Estanol et al. (2015) all pointed out that the positive effect between industry engagement and scientific production is based mainly on access to resources (cognitive, technical, and/or financial) that complement research activities.

In the meantime, despite the positive relationship between academic engagement and the two factors (knowledge and resource) driving academic research, people also express concerns that there is potential conflict between public- and private-oriented considerations in terms of diffusion of knowledge such as secrecy versus free dissemination (Florida and Cohen, 1999; Van Looy et al., 2005). However, since most academic engagement activities are research-driven, the academic researchers are more likely to negotiate with industry upfront to make sure their right to disclosure research results and ideas could be freely publicized (Glaser and Bero, 2005; D'Este and Perkmann, 2011).

Academic engagement brings new ideas to scholars, but the relative magnitudes of “knowledge” factor changes with the degree of academic engagement. The new ideas from industry may not be of the same quality at the beginning, which leads to smaller impact on research productivity at higher degree of engagements (Petruzzelli, 2011; Banal-Estanol et al., 2015; Muscio et al., 2017). As Laursen and Salter (2006) have pointed out, there are at least three reasons that too many ideas is not necessarily good for the innovation. First, the absorptive capacity problem limits the number of ideas for the university to manage and choose between. Second, many innovative ideas may come at the wrong time and in the wrong place to be fully exploited (‘the timing problem’). Third, since there are so many ideas, the attention allocation problem indicates that few of these ideas are taken seriously or given the required level of attention or effort to bring them into implementation.

Even though U-I interactions might bring new ideas to university research at beginning, there is a point at which engagement with industry becomes disadvantageous. From the discussion, we expect the positive ones (knowledge and resource) to be relatively more important and, thus, to dominate at the low degrees of academic engagements, while the negative effects (time and disclosure constraint) shall dominate at the high degrees of engagement activities. We hypothesize, that at the level of the university:

Hypothesis 1 (H1) *Academic engagement have an inverted U-shaped effect on university scientific productivity.*

2.1.2 Academic engagement and university internal R&D intensity

University internal R&D may also affect the efficiency of external collaboration such as university-industry engagement. This attention-based theory (Laursen and Salter, 2006) suggests that managerial attention is the most precious resource inside the organization. Since ideas are produced both internally and externally, the substitution effect between internal R&D and external collaboration indicates that greater attention to internal R&D will lower researchers’ attention for external sources. According to the attention allocation theory, decision-makers need to ‘concentrate their energy, effort and mindfulness on a limited number of issues’ in order to achieve sustained strategic performance (Ocasio, 1997).

We argue that the intensity of internal university R&D will also affect the efficiency of U-I interactions, since the managerial attention is limited and can only project to limited projects. For example, if there are already certain amount of research projects ongoing internally, external collaboration from industry will distract the ongoing research attention and rise attention allocation problem which leads to a weaker effect of academic engagement on university scientific productivity. we hypothesize:

Hypothesis 2 (H2) *University internal R&D intensity will weaken the effect of academic engagement on university scientific productivity.*

2.1.3 Academic commercialization and university scientific productivity

Over the last 30 years, academic and policy interest in the commercialization of new technologies from universities has increased considerably all over the world (Audretsch and Göktepe-Hultén, 2015). An important reason for this rise in university technology transfer was the passage of the Bayh–Dole Act of 1980 in United States, which decreased the uncertainty associated with the commercialization of federally funded research. This legislation encouraged universities to be more proactive in their efforts to commercialize scientific discoveries (Mowery et al., 2004) by transferring ownership from the government to universities and other contractors who could then license the intellectual property to firms. Although the effects of the Bayh-Dole Act on the increase of patenting are far from definite and conclusive, universities and other public research organizations are increasingly protecting their inventions—from genetic discoveries to software programs—with the expectation of generating additional funds for research as well as the formation of new ventures. Such reforms are actually not only confined to United States and European countries. For example, Japan has made legislative reforms to allow universities to protect and claim IP. China has amended Science and Technology Law of 1993 to the Bayh-Dole Act as of July 1, 2008 (Chen et al., 2016).

Unlike academic engagement, academic commercialization such as intellectual property transfer constitutes more degree of a transaction rather than interaction (Goel et al., 2017). Comparing with engagement, commercialization activity brings very little new research idea to university academics due to its transaction nature. For example, Thursby and Thursby (2002) pointed out that university licensing was largely due to universities' greater commercialization motivation rather than desires in new research ideas or new direction. Based on the study of UK physical sciences and engineering faculties, D'Este and Perkmann (2011) found that academic engagement such as contract research was driven by research considerations (i.e. learning and resource access), while commercialization activities such as spin-off company activity, consulting and patenting were mostly motivated by monetary incentives. Researchers who regard access to research funding as particularly important engage more frequently in academic engagement activities such as joint research and contract research, but shows no significant relationship with commercialization activities.

Furthermore, academic researchers who involved in commercialization activities practice higher degrees of secrecy than their non-commercializing colleagues (Campbell et al., 2002), and academic entrepreneurship may hamper the accumulation of knowledge in the public domain (Toole and Czarnitzki, 2010). Related research suggests that increased academic commercialization may slow the unencumbered diffusion of academic knowledge (Huang and Murray, 2009; Murray and Stern, 2007). Academic researchers with an interest in commercialization may employ greater levels of secrecy about their research results than their open science-oriented colleagues.

We expect the negative effects (time and disclosure constraint) shall dominate the positive ones (knowledge and resource) in academic commercialization, since commercialization brings little new ideas and the financial compensation is mostly for academic's monetary needs not research related issue. We hypothesize, that at the level of the university:

Hypothesis 3 (H3) *Academic commercialization has negative effect on university scientific productivity.*

2.2 Effect of university scientific productivity on university-industry interactions

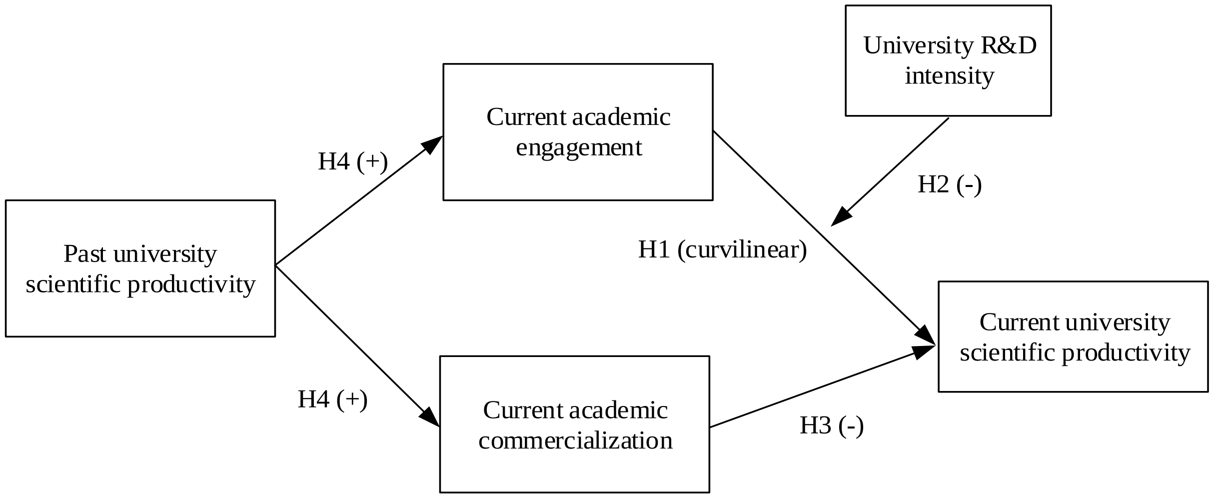
As scholars have pointed out, university scientific productivity may act as a signal to firms for identifying potential partner which leads to more U-I interactions activities, indicating the existence of reciprocal relationships between university scientific productivity and university–industry interactions. It is generally accepted that individual researchers and universities with higher quality research outputs are able to reap the rewards of recognition and reputation. At the organizational level, quality, the overall quantity, intensity and variety of research areas are also associated with overall reputational impact. For potential industry "buyers", the collaboration decision is often influenced by considerations of university reputation, and firms prefer to work with high-quality academic researchers (Cohen et al., 2002; Landry et al., 2007; Perkmann et al., 2008). For example, Abramo et al. (2011) and Banal-Estanol et al. (2015) have argued that researchers with a high scientific performance will attract more attention from industry. Cohen et al. (2002) find that the most important channels for universities to have an impact on industrial R&D are published papers. Landry et al. (2007) find that the number of papers was significantly and positively related to the technology transfer from universities to firms. Caldera and Debande (2010) analyze the determining factors of the transfer of technology at Spanish universities and find that the R&D contracts are determined by the number of publications.

Meanwhile, scholars have also claimed that the relationship between research output and U-I interactions needs to take the temporal dimension into consideration. Previous studies have shown that there is a significant lag between the point in time when a set of research results are finalized and that at which it is put into practice, given the complexities and delays involved in the "translation process" (Morris et al., 2011; Sengupta and Ray, 2017). For university, such delays may arise in the natural process of finding a "buyer" for the research or in the process of managing relationships and negotiations, even when a buyer has been found (Hughes and Kitson, 2012). For industry, the delays may increase because of searching process and carry out the technology validation process to make sure the university technology really matches the firm's needs (Landry et al., 2007; Cartalos et al., 2018). For all these reasons, examining the effect of scientific production on U-I interactions requires a dynamic approach rather than a static one. We hypothesize, that at the level of the university:

Hypothesis 4 (H4) *Higher university scientific production in the past will lead to higher degree of current academic engagement and academic commercialization.*

The hypotheses presented above attempt to capture the dynamic relationship that exists between U-I interactions (academic engagement and commercialization) and university scientific productivity, the analysis in this paper builds support for the conceptual model presented in Figure 2, indicating the connection between academic engagement and university scientific productivity (H1), the impact of university level characteristics such as internal R&D intensity on this connection (H2), the relationship between academic commercialization and university research (H3) and the inter-temporal relationship between past research production and current U-I interactions (H4).

Figure 2. Inter-Conceptual framework of university-industry interaction and university scientific productivity



3 Data and Methodology

3.1 Empirical context and data source

China's current higher education system was largely shaped by the history of the last 70 years since the founding of the People's Republic of China in 1949. The Soviet education model has played an important role in the formation of the current system (Hayhoe, 2004). Before the reform of higher education system in 1984, there was very little U-I interactions in China (Chen and Kenney, 2007). As part of the transition to market economy, the Chinese government implemented a series of policies aimed at encouraging research collaboration between university and industry and technology transfer. In 1999, the legal system was further changed by a set of regulations stipulating that universities could use a variety of strategies to either work with industry and commercialize high-technology achievements, including establishing their own firms. Researchers were permitted to take sabbaticals to establish new firms or assist in technology transfer (Chen at al., 2016). The academic engagement with industry and commercialization of academic research have been booming since the policy shift. For example, among total patents filed in China, the share from university went from 1.7% in 2002 to 7.4% in 2015; and astonishingly, for the invention patents, the university share has grown from 4.1% in 2002 to 15.3% in 2015. One of six invention patents filed in China is from university. The licensing in university is also experiencing dramatical growth. For example, the annually licensing revenue in Tsinghua University has increased from 254.67 million RMB in 2007 to 500.52 million RMB in 2015. The closer relationship between university and industry and the growth of university commercialization give us a great opportunity to investigate how university-industry interactions affect academic research.

As Perkmann et al. (2013) pointed out, the study of academic engagement faces several challenges, especially empirically. Academic commercialization leaves distinct traces. For example, academic entrepreneurship can be measured by number of university spin-offs. Information on patents is accessible via public patent database (Lissoni et al., 2008; Thursby et al., 2007). Even though more widely practiced, academic engagement is empirically more difficult to detect because it includes collaboration instances that may not be documented by generally accessible records. Researchers have approximated engagement via instances of co-authorship between university researchers and industry scientists (Liebeskind et al., 1996; Murray and Stern, 2007). This methodology is likely to underestimate collaborations that are more applied in nature and do not result in publications, such as contract research. Records held by universities on industry contracts would represent an ideal source of information but are not readily available because they are often considered commercially sensitive by university administrators. Moreover, they are difficult to standardize across large numbers of universities. Nevertheless, studies using record-based information for universities can offer powerful insights with a high level of granularity (Rawlings and McFarland, 2011).

Two major datasets are utilized to construct the dataset in our empirical analysis: 1) Higher Education Statistical Survey (HESS): the surveys conducted by Ministry of Education contains the R&D information about public universities in China; 2) Web of Science (WoS): WoS database to extract the information of university annually publication and citations. The higher education statistical survey (HESS) is conducted annually by Chinese Ministry of Education (MoE) which contains the organizational-level R&D information about universities in China since 1994. Since 2009, the survey started to cover detailed university level R&D information about universities which are directly affiliated to MoE. The information includes university publications, number of technology transfer contracts, funding resources, revenue from patent licensing, number of conferences the academics attended, number of ongoing research projects, etc.

Until 2015, there are 2560 Chinese higher education institution (HEI) offering bachelor degree program and 575 HEI in China have postgraduate programs. Among all the HEI in China, 72 universities are directly affiliated to the Ministry of Education (MoE) of China which are widely considered the most prestigious and research-intensive universities in China. For this study, I have constructed a balanced panel dataset containing university characteristics, publications, research funds, and IP transfer contracts for 59 universities[4] which are directly affiliated to MoE between 2010 and 2015. As indicated by Table 2, these 59 universities are the major players in academic engagement and commercialization in China. In 2015, the 59 universities in our sample have received 71.19% industry funding across China and 39.33 % of overall revenue from university IP transfer in China.

Table 1. major contributors of U-I interactions in China (59 universities in the sample, 2015)

	59 Universities	Overall in China	Share
Research Personnel (10000 persons)	9.60	83.88	11.44%
Research Funding (100 Million Yuan)	640.97	998.59	64.19%
Funding from Industry	214.65	301.50	71.19%
Funding from Government	408.52	637.26	64.11%
Publication	280,383	1,220,467	22.97%
IP Transfer Contract Revenue (100 Million Yuan)	21.25	54.03	39.33%

* Source: Chinese Higher Education Statistical Survey and Ministry of Education

3.2 Variables

To test the research hypotheses, this study relies on two dependent variables for scientific productivity: research quantity and research quality. Research quantity (*Publication*) is measured by the total number of publications by focal university in journals included in Thomson Reuters Institute for Scientific Information Web of Science (WoS) throughout the period 2010–2015; research quality (*Citation*) is measured as the sum of citations in next three year of the articles published by university in focal year. The explanatory variables investigating the research hypotheses refer to academic engagement and academic commercialization. *Contract research* is the proxy of academic engagement in this study (Gulbrandsen and Smeby, 2005; Aguiar-Diaz et al., 2015; Muscio et al., 2017), which is measured as ratio of industry funding over total research university funding in the given year. *IP transfer*

[4] 13 MoE universities are excluded from the sample which include 1 law school, 4 langrage universities, 3 art and music universities and 5 economic and finance schools.

is the proxy of academic commercialization (Van Looy et al., 2006; Perkmann et al., 2013) which is measured as IP transfer contracts revenue (including patent transfer contract, patent licensing contract and trade secrets contract) of the focal university in the given year.

Table 2. Data source and definitions

	Variable	Description	Source
University Scientific Production	Publication	Number of publications annually	WoS
	Citation	Number of citations in three years	WoS
Academic engagement	Contract research	Share of industry funding over total research university funding of the focal year	HESS
Academic commercialization	IP transfer	IP transfer contracts revenue (unit:1000RMB)	HESS
Control variables	Personnel	Number of research staff	HESS
	Funding	Total research funding (unit:1000RMB)	HESS
	Government funding	Research funding from Government (unit:1000RMB)	HESS
	Senior professor	Share of full professors	HESS
	Conference	Number of conferences the university academics have attended in the given year	HESS
	Keynote	Number of keynote speech that the university academics have been invited by conference in the given year	HESS
	Patent	Number of patent application	HESS
	Applied research	Share of applied research project out of total research projects	HESS
	R&D intensity	Number of university internal research projects	HESS
	Other funding	Research funding from other channels rather than government and industry (unit:1000RMB)	HESS

Furthermore, ten variables related to the university are considered: number of research staff (*Personnel*), total research funding (*Funding*), research funding from government (*Government funding*), share of full professors (*Senior professor*), number of conferences the university academics have attended (*Conference*), number of keynote speech that the university academics have been invited (*Keynote*) and number of patent application (*Patent*) and share of applied research project out of total research projects (*Applied research*), number of internal research projects (*R&D intensity*) and research funding from other channels (*Other funding*). The variables (*Personnel*, *Government funding*, *Senior professor, Conference and Keynote*) are expected to help increase the quantity and quality of scientific publications, while the others (*Patent*, *Other funding* and *Applied research*) are expected to facilitate the relationships between university and industry. Meanwhile, comprehensive universities, engineering-heavy universities, social science-heavy universities and universities with large medical schools have shown great difference in terms of U-I interactions. Two dummy variables are adopted the value 1 if the university belongs to a specific discipline: comprehensive and engineering. Table 3 provides a description of the variables and Table 4 reports the descriptive statistics.

Table 3. Descriptive statistics

VARIABLES	Obs.	Mean	Std. Dev	Min	Max
Publication	413	2,564	2,108	122	11,654
Citation	413	13,179	14,242	332	81,702
Contract research	413	0.343	0.200	0.0231	0.811
IP transfer	413	35,216	95,721	0	752,712
Personnel	413	1,533	818.7	124	5,932
Funding	413	912,117	774,655	14,260	5.078e+06
Government funding	413	554,614	542,670	12,268	3.301e+06
Senior professor	413	0.265	0.0654	0.124	0.472
Conference	413	1,157	1,325	18	8,157
Keynote	413	135.0	191.1	0	1,881
Patent	413	670.5	632.5	0	4,223
Applied research	413	0.433	0.180	0	0.932
R&D intensity	413	2,056	1,481	55	8,204
Other funding	413	29,141	40,839	0	323,941

3.3 Econometric model

As mentioned in the earlier section, the existence of reciprocal relationships between university scientific productivity and university–industry interactions introduce endogeneity issues in the econometric analysis. For this reason, a model of simultaneous system equations is considered. Two system equations are applied separately in our analysis: for research quantity system of equations, *Contract research* and *IP transfer* appear as the explanatory variable in the research quantity equation (Equation 1), whereas past university scientific production ($Publication_{t-1}$) is the explanatory variable in the contract research (Equation 2) and IP transfer equations (Equation 3); for research quality system of equations, *Contract research* and *IP transfer* appear as the explanatory variable in the research quality equation (Equation 4), whereas past university scientific production ($Publication_{t-1}$) is the explanatory variable in the contract research (Equation 2) and IP transfer equations (Equation 3).

Variables *Publication*, *Citation, Contract research* and *IP transfer* are considered as endogenous and are simultaneously determined. The remaining variables are exogenous. For each equations of system, three structural model equations have exclusion restrictions that allow the identification of structural parameters. Two dummy variables *Comprehensive* and *Engineering* are included in all equations where the focal university adopt the value 1 if it belongs to comprehensive or engineering university, respectively, and 0 if otherwise.

The explanatory exogenous variables present in one equation and absent in the other act as instruments in the estimation through three-stage least squares (3SLS). Specifically, in the research quantity and quality equations (Equation 1 and 4), two variables are included (*Conference* and *Keynote*) which are not considered as explanatory variables in the contract research equation (Equation 2) and IP transfer equation (Equation 3). *Conference* and *Keynote* present a high-correlation coefficient with *Publication* and *Citation* (Table 5), and the smaller correlation with the *Contract research* and *IP transfer*. Therefore, they affect both research quantity and quality equations but not to contract research and IP transfer.

In the contract research equation, the variable *Applied research* is included, which has been excluded from the both research quantity and quality equations and IP transfer equation. This variable is considered as instrument for contract research and have been selected considering the issues on the structural behavior of the scientific production, contract research and IP transfer, and the sample correlation with the endogenous variable *Contract research*. Given the fact that industry-funded research is more likely to be applied-orientated (Gulbrandsen and Smeby, 2005; Boardman and Corley, 2008). Table 5 also shows that the variable *Applied research* present a higher-correlation with the contract research than the university publication and citations.

Furthermore, in the IP transfer equation, the variable *Other funding* is included, which has been excluded from both research quantity, research quality equations and contract research equation. Additional research funding generated by university-run enterprise (Wang and Zhou, 2009) or other resource rather than government or industry indicates the commercialization ability of focal university. As Table 5 has shown, *Other funding* presents a high-correlation coefficient with *IP transfer*, and the smaller correlation with the *Publication* and *Contract research*. The following equations will be utilized in empirical investigation, where i = university and t = year:

Table 4. Correlation Matrix

	Publication	Citation	Contract research	IP transfer	Personnel	Funding	Government funding	Senior professor	Conference	Keynote	patent	Applied research	R&D intensity	Other funding
Publication	1													
Citation	0.955***	1												
Contract research	-0.0731	-0.195***	1											
IP transfer	0.425***	0.396***	0.00757	1										
Personnel	0.642***	0.530***	0.205***	0.232***	1									
Funding	0.868***	0.787***	0.103*	0.575***	0.621***	1								
Government funding	0.891***	0.856***	-0.190***	0.544***	0.551***	0.936***	1							
Senior professor	0.519***	0.563***	-0.366***	0.251***	0.109*	0.471***	0.566***	1						
Conference	0.557***	0.531***	0.0333	0.249***	0.355***	0.503***	0.473***	0.233***	1					
Keynote	0.443***	0.498***	-0.0658	0.133**	0.154**	0.310***	0.370***	0.239***	0.629***	1				
Patent	0.581***	0.503***	0.288***	0.391***	0.453***	0.648***	0.552***	0.178***	0.334***	0.224***	1			
Applied research	-0.0724	-0.0668	0.196***	0.115*	-0.139**	0.0289	-0.0241	0.0116	0.00558	-0.101*	0.0319	1		
R&D intensity	0.459***	0.422***	0.00957	0.0576	0.314***	0.374***	0.345***	0.176***	0.462***	0.377***	0.363***	-0.0981*	1	
Other funding	0.429***	0.376***	-0.0576	0.685***	0.267***	0.584***	0.554***	0.256***	0.239***	0.0341	0.346***	0.0688	0.0261	1

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Research quantity system of equations:

$$\begin{aligned}\text{Publication}_{i,t} =\ & \beta_1\text{Contract Research}_{i,t} + \beta_2\text{Contract Research}_{i,t}^{\;2} + \beta_3\text{IP Transfer}_{i,t} \\ & +\beta_4\text{R\&D intensity}_{i,t} + \beta_5\text{R\&D intensity}_{i,t} \times \text{Contract Research}_{i,t} \\ & +\beta_6\text{R\&D intensity}_{i,t} \times \text{Contract Research}_{i,t}^{\;2} + \beta_7\text{Personnels}_{i,t} \\ & +\beta_8\text{Funding}_{i,t} + \beta_9\text{Senior Professor}_{i,t} + \beta_{10}\text{Conference}_{i,t} \\ & +\beta_{11}\text{Keynote}_{i,t} + \beta_{12}\text{Comprehensive}_{i} + \beta_{13}\text{Engineering}_{i}\end{aligned} \qquad (1)$$

$$\begin{aligned}\text{Contract Research}_{i,t} =\ & \beta_1\text{Publication}_{i,t-1} + \beta_2\text{Patent}_{i,t-1} + \beta_3\text{Personnels}_{i,t} \\ & +\beta_4\text{Government Funding}_{i,t} + \beta_5\text{Applied research}_{i,t} \\ & +\beta_6\text{Senior Professor}_{i,t} + \beta_7\text{Comprehensive}_{i} \\ & +\beta_8\text{Engineering}_{i}\end{aligned} \qquad (2)$$

$$\begin{aligned}\text{IP transfer}_{i,t} =\ & \beta_1\text{Publication}_{i,t-1} + \beta_2\text{Patent}_{i,t-1} + \beta_3\text{Personnels}_{i,t} \\ & +\beta_4\text{Other Funding}_{i,t} + \beta_5\text{Senior Professor}_{i,t} \\ & +\beta_6\text{Comprehensive}_{i} + \beta_7\text{Engineering}_{i}\end{aligned} \qquad (3)$$

Research quality system of equations:

$$\begin{aligned}\text{Citation}_{i,t} =\ & \beta_1\text{Contract Research}_{i,t} + \beta_2\text{Contract Research}_{i,t}^{\;2} + \beta_3\text{IP Transfer}_{i,t} \\ & +\beta_4\text{R\&D intensity}_{i,t} + \beta_5\text{R\&D intensity}_{i,t} \times \text{Contract Research}_{i,t} \\ & +\beta_6\text{R\&D intensity}_{i,t} \times \text{Contract Research}_{i,t}^{\;2} + \beta_7\text{Personnels}_{i,t} \\ & +\beta_8\text{Funding}_{i,t} + \beta_9\text{Senior Professor}_{i,t} + \beta_{10}\text{Conference}_{i,t} \\ & +\beta_{11}\text{Keynote}_{i,t} + \beta_{12}\text{Comprehensive}_{i} + \beta_{13}\text{Engineering}_{i}\end{aligned} \qquad (4)$$

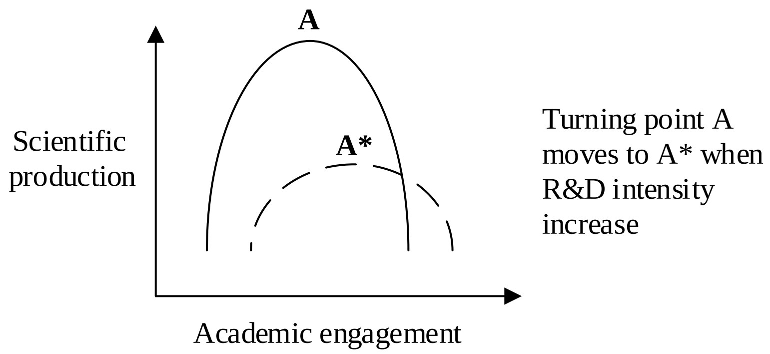
$$\begin{aligned}\text{Contract Research}_{i,t} =\ & \beta_1\text{Publication}_{i,t-1} + \beta_2\text{Patent}_{i,t-1} + \beta_3\text{Personnels}_{i,t} \\ & +\beta_4\text{Government Funding}_{i,t} + \beta_5\text{Applied research}_{i,t} \\ & +\beta_6\text{Senior Professor}_{i,t} + \beta_7\text{Comprehensive}_{i} \\ & +\beta_8\text{Engineering}_{i}\end{aligned} \qquad (2)$$

$$\begin{aligned}\text{IP transfer}_{i,t} =\ & \beta_1\text{Publication}_{i,t-1} + \beta_2\text{Patent}_{i,t-1} + \beta_3\text{Personnels}_{i,t} \\ & +\beta_4\text{Other Funding}_{i,t} + \beta_5\text{Senior Professor}_{i,t} \\ & +\beta_6\text{Comprehensive}_{i} + \beta_7\text{Engineering}_{i}\end{aligned} \qquad (3)$$

This study employs simultaneous equation models that are estimated using 3SLS, accounting for the possible interdependence between the dependent variables (Sakakibara, 2010; I. Breschi -Diaz et al., 2015). This method allows control for potential simultaneity equation bias (Heshmati and Kim, 2011). By estimating the model in this way, it avoids complications arising from the fact that U-I interactions may be endogenous to university scientific production (Jensen and Webster, 2009; Greene, 2012).

Furthermore, to test hypothesis 2, two interaction terms (*R&D intensity ×Contract research* and *R&D intensity ×Contract research*^{2}) have been introduced to the model. To determine the impact of R&D intensity on academic engagement's effect on scientific production. We have followed the methodology proposed by Haans et al. (2015). If the moderator (*R&D intensity* in our case) weakens the curvilinear mechanism, the turning point A (Figure 3) should move to the right and the inverted U-shape curve should become flattening when moderator increases. The direction of shift depends on the sign of the coefficients of four terms *Contract research, Contract research*^{2}*, R&D intensity ×Contract research* and *R&D intensity ×Contract research*^{2} (Haans et al., 2015; see Appendix 1; coefficients of these four terms are β_1, β_2, β_5 *and* β_6), if the coefficients of the four terms are statistically significant and $\beta_1\beta_6 - \beta_2\beta_5$ is positive, the turning point will move to the right as *R&D intensity* increases. Testing for flattening or steepening depends only on the sign of coefficient of *R&D intensity ×Contract research*^{2} (Haans et al., 2015; see Appendix 2) and a flattening occurs for inverted U-shaped relationships when coefficient is positive and significant.

Figure 3. Curvilinear mechanism between academic engagement and scientific production



4 Results

This section presents the estimates of the impact of academic engagement (contract research) and academic commercialization (IP transfe*r*) on university scientific production (Publication and Citations). The main results are introduced at first and then robustness checks are presented next. To test the hypotheses, a simultaneous equations model has been estimated by 3SLS across all models. Two dependent variables for scientific productivity – research quantity (*Publication*) and research quality (*Citation*) – have been included in the analysis and will be estimated separately.

For research quantity system of equations (includes Equation 1, 2 and 3), Model 1a and Model 2a consider *Publication* as the dependent variable and estimate the system equations with and without controlling the time fixed effect; Model 1b and Model 2b consider *Contract Research* as the dependent variable and estimate the equation 2 with time fixed effect and no time fixed effect; Model 1c and Model 2c consider *IP Transfer* as the dependent variable and estimate the equation 3 with time fixed effect and no time fixed effect. For research quality system of equations (includes Equation 4, 2 and 3), Model 3a and Model 4a consider *Citation* as the dependent variable and estimate the system equations with and without controlling the time fixed effect; Model 3b and Model 4b consider *Contract Research* as the dependent variable and estimate the equation 2 with time fixed effect and no time fixed effect; Model 3c and Model 4c consider *IP Transfer* as the dependent variable and estimate the equation 3 with time fixed effect and no time fixed effect.

Table 6 reports the estimates of the relationship between academic engagement and commercialization and university scientific productivity. Models 1a, 2a, 3a and 4a show the estimates of 3SLS models. In order to test the U-shaped relationship between contract research and scientific production, the quadratic term (*Contract research*^{2}) was included in the models. The coefficients of *Contract research* are positive and significant in all models indicating that it is positively related to both research quantity and quality. Meanwhile, the coefficients for its squared term are negative and significant in Model 1a – 4a, which indicates Hypothesis 1 is supported that contract research has an inverted U-shape relationship with the quantity and quality of university scientific research. Furthermore, the coefficients of *IP transfer* are negative and significant in all Models, indicating that it is negatively related to *Publication* and *Citation*, which indicates Hypothesis 3 is supported that IP transfer has negative effect on the quantity and quality of university scientific research at university level.

Table 5. The relationship between U-I interactions and scientific productivity

	Dependent Variable: Publication		Dependent Variable: Citation	
VARIABLES	Model 1a	Model 2a	Model 3a	Model 4a
Contract research	89,139***	76,018***	684,661***	521,962***
	(22,886)	(19,397)	(175,182)	(132,012)
Contract research^2	-112,188***	-95,778***	-869,332***	-666,143***
	(29,390)	(24,910)	(224,962)	(169,533)
IP transfer	-0.0154***	-0.0139***	-0.111***	-0.0925***
	(0.00482)	(0.00409)	(0.0368)	(0.0279)
Senior professor	6,913**	6,022**	63,379***	52,842***
	(3,000)	(2,603)	(22,950)	(17,727)
Conference	-0.213	-0.174	-2.161*	-1.621*
	(0.162)	(0.139)	(1.237)	(0.944)
Keynote	1.926**	1.712**	21.40***	18.51***
	(0.934)	(0.810)	(7.152)	(5.513)
Personnel	-0.451	-0.342	-4.490*	-3.082
	(0.343)	(0.291)	(2.624)	(1.984)
Funding	0.00361***	0.00341***	0.0246***	0.0220***
	(0.000676)	(0.000575)	(0.00517)	(0.00391)
R&D intensity × Contract research	-28.03***	-23.84***	-224.7***	-172.5***
	(7.990)	(6.755)	(61.16)	(45.98)
R&D intensity × Contract research^2	35.49***	30.04***	286.3***	218.3***
	(10.43)	(8.820)	(79.83)	(60.03)
R&D intensity	4.023***	3.434***	31.73***	24.40***
	(1.093)	(0.927)	(8.365)	(6.309)
Comprehensive	-538.9	-403.4	-4,276	-2,589
	(475.5)	(414.3)	(3,636)	(2,821)
Engineering	-1,917***	-1,643***	-14,278***	-10,866***
	(546.4)	(468.6)	(4,180)	(3,191)
Constant	-13,114***	-11,433***	-104,066***	-83,205***
	(3,110)	(2,616)	(23,808)	(17,801)
Observations	354	354	354	354
Chi-squared	235.30***	315.15***	171.15***	292.85***
Year FE	NO	YES	NO	YES

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

To test hypothesis 2, two interaction terms (*R&D intensity ×Contract research* and *R&D intensity ×Contract research*^{2}) have been introduced to the model. Following the methodology proposed by

Haans et al. (2015), as we discussed in the earlier section, if the moderator (*R&D intensity* in our case) weakens the curvilinear mechanism, the turning point A (Figure 3) should move to the right and the inverted U-shape curve should become flattening when moderator increases. Testing for flattening or steepening depends only on the sign of coefficient of *R&D intensity* × *Contract research*^{2} (Haans et al., 2015; see Appendix 2) and a flattening occurs for inverted U-shaped relationships when coefficient is positive and significant which has been shown in Model 1a-4a.The direction of shift depends on the sign of the coefficients of four terms *Contract research, Contract research*^{2} , *R&D intensity* × *Contract research* and *R&D intensity* × *Contract research*^{2}: first, the coefficients of these four terms are statistically significant; meanwhile, the product of coefficients of *Contract research* and *R&D intensity* × *Contract research*^{2} minus the product of coefficient of *Contract research*^{2} and *R&D intensity* × *Contract research* is positive in Model 1a-3a (equals 18913.47 in Model 1a, 233.2 in Model 1b and 679543.9 in Model 1c). According to these results, university internal *R&D intensity* weakens the curvilinear mechanism, the turning point A (Figure 3) should move to the right and the inverted U-shape curve should become flattening when *R&D intensity* increases. We claim that hypothesis 2 is supported that university internal R&D intensity will weaken the effect of academic engagement on university scientific productivity.

Table 7 reports the estimates of the relationship between past university scientific productivity and academic engagement. As the results have shown in Model 1b-4b, the coefficient of $Publication_{t-1}$ are both positive and significant, indicating past research output will signal the potential buyers and have positive impact to attract industry funding and increase the possibility of academic engagement. Meanwhile, the positive and significant coefficients of $Patent_{t-1}$ and *Applied research* suggest that the academics who have involved with entrepreneurial activities such as patenting or applied-oriented research will more likely collaborate with industry.

Table 6. The relationship between past university publication and academic engagement

	Research Quantity System		Research Quality System	
	Dependent variable: Contract research			
VARIABLES	Model 1b	Model 2b	Model 3b	Model 4b
Publication(t-1)	2.00e-05**	3.41e-05***	1.99e-05**	3.41e-05***
	(1.01e-05)	(1.06e-05)	(1.01e-05)	(1.06e-05)
Paten(t-1)	0.000131***	0.000142***	0.000131***	0.000142***
	(1.73e-05)	(1.74e-05)	(1.72e-05)	(1.74e-05)
Senior professor	-0.553***	-0.538***	-0.553***	-0.539***
	(0.160)	(0.157)	(0.160)	(0.157)
Personnel	7.38e-05***	7.04e-05***	7.39e-05***	7.04e-05***
	(1.33e-05)	(1.31e-05)	(1.33e-05)	(1.31e-05)
Government funding	-2.18e-07***	-2.60e-07***	-2.18e-07***	-2.60e-07***
	(3.22e-08)	(3.38e-08)	(3.22e-08)	(3.38e-08)
Applied research	0.179***	0.178***	0.181***	0.180***
	(0.0463)	(0.0457)	(0.0462)	(0.0457)
Comprehensive	0.0335	0.0228	0.0334	0.0227
	(0.0234)	(0.0232)	(0.0234)	(0.0232)
Engineering	0.108***	0.106***	0.107***	0.106***
	(0.0207)	(0.0204)	(0.0207)	(0.0204)
Constant	0.237***	0.261***	0.236***	0.260***
	(0.0493)	(0.0503)	(0.0493)	(0.0503)
Observations	354	354	354	354
Chi-squared	282.51***	305.24***	282.93***	305.52***
Year FE	NO	YES	NO	YES

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 8 reports the estimates of the relationship between past university scientific productivity and academic commercialization. As the results have shown in Model 1c-4c, the coefficient of $Publication_{t-1}$ are positive and but not significant. Academic research outputs usually take various forms – for instance journal articles, books, and patents, etc. Crespi et al. (2011) find that academic patenting and research are complements up to a certain level of patent output, after which they become substitutes. This substitution effect has usually been attributed to re-orientation of research agendas towards a more "applied" focus (Florida and Cohen, 1999) and to the tendency of enclosing research output within closed boundaries (Hane, 1999). As the public goods, the openness nature of academic publications will be less likely or more difficult to converse into commercial outputs for practitioners through knowledge transfer channels, comparing patents and any other intellectual property (Ambos et al., 2008; Sengupta and Ray, 2017). As Table 7 and 8 have shown, past patenting activities (*Patent*$_{t-1}$) have positive and significant impact on both current academic engagement and commercialization. In the nutshell, past publication record has positive impact on academic engagement but not necessarily on commercialization. Research outputs such as patent and other intellectual property such as copyrights will be more important to potential buyers in the case of academic commercialization.

Table 7. The relationship between past university publication and academic commercialization

	Research Quantity System		Research Quality System	
	Dependent variable: IP transfer			
VARIABLES	Model 1c	Model 2c	Model 3c	Model 4c
Publication(t-1)	3.370	3.745	3.525	3.617
	(3.471)	(3.537)	(3.473)	(3.536)
Patent(t-1)	24.29***	25.65***	23.89***	25.82***
	(7.974)	(8.062)	(7.986)	(8.054)
Senior professor	44,963	43,083	42,978	44,425
	(72,258)	(72,247)	(72,270)	(72,239)
Personnel	-6.616	-6.940	-6.761	-6.822
	(6.256)	(6.269)	(6.257)	(6.268)
Other funding	1.457***	1.446***	1.459***	1.447***
	(0.103)	(0.103)	(0.103)	(0.103)
Comprehensive	13,089	12,070	13,233	12,002
	(11,084)	(11,118)	(11,086)	(11,117)
Engineering	2,892	2,669	2,936	2,651
	(9,553)	(9,528)	(9,553)	(9,528)
Constant	-37,462*	-37,731*	-36,961*	-38,092*
	(21,167)	(22,583)	(21,170)	(22,581)
Observations	354	354	354	354
Chi-squared	361.87***	365.05***	362.49***	365.34***
Year FE	NO	YES	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For robustness checks, I used alterative measures of university contract research and IP transfer. Instead of using the ratio of industry funding out of total funding as the proxy of contract research, the volume of industry funding is applied in the robustness check. Meanwhile, instead of using the volume of IP transfer revenue, the number of IP transfer contracts is applied in the robustness check. As the

Appendix 3 has shown, the results do not differ from those obtained for previous models. Thus, contracts research has an inverted U-shape relationship with both the quantity and quality of university scientific research; IP transfer has negative impact on university scientific production; university R&D intensity will weaken the effect of academic engagement on university scientific productivity and past university scientific production will lead to more current academic commercialization (IP transfer) and academic engagement (contract research).

5 Conclusions and Policy Implications

Industry and other types of external interactions by university faculty has become a topic of intense interest by policy decision-makers and university managers. Government and universities themselves have made great efforts to increase academic engagement with industry and university knowledge commercialization over the last few decades for various reasons, ranging from the generation of societal legitimacy for publicly subsidized scientific research, the stimulation of economic activity, to raising revenue for universities (Perkmann et al., 2013). Despite the enthusiasm of "third mission" of fostering links with industry, however, there have been great concerns that a heavy involvement with firms or entrepreneurial activities will affect university scientific productivity. This study provides a couple of lessons with important policy implications on this issue.

First, academic engagement with industry (approximated by research contracting herein) and academic commercialization (approximated by intellectual property transfer) indeed present different mechanisms for academic research productivity. These two types of U-I interactions should be treated separately by researchers and policy decision-makers. Our study suggests that academic engagement has an inverted U-shape relationship with university scientific productivity (H1). H1 indicates that engagement spurs research performance and should be promoted if the desired policy outcome is to promote both quantity and quality of the university research. Meanwhile, the inverted U-shape relationship between academic engagement and research performance reveals that the incentives of university managers to focus on establishing a balance between the collaboration with firms. Over dependence or proximity with industry might distract university research agenda and bring attention allocation problem which leads to the decrease of scientific productivity. Turning to commercialization, our findings suggest that academic commercialization is negatively associated with organization-level research performance (H3), in contrast to its positive association with high individual as well as department-level research quality (Perkmann et al., 2013). This suggests that there is a large proportion of the IP income just being sourced from few "big winners" and universities might have accumulated a large volume of non-performing intellectual property assets, useful neither for commercialization nor for research. Our results indicate that university managers may need to reexamine their commercialization and entrepreneurial strategies in the future (Geuna and Nesta, 2006; Siegel and Wright, 2015; Sengupta and Ray, 2017).

Second, H4 confirmed that past research performance has a positive impact on both engagement and commercialization. Research performance drives engagement and interventions would need to promote research excellence leading to further engagement. This is especially relevant at the level of the organization, as an appropriate "ecosystem" of knowledge creation and academic engagement (Roux et al., 2006; Sengupta and Ray, 2017).

Finally, when it comes to a choice of channels U-I interactions, according to our findings, it is academic engagement such as contract research which are the main drivers of the virtuous cycle between research and knowledge transfer. However, H2 has shown that the effectiveness of academic engagement channel depends on not only the external factors but also university itself. The university internal R&D intensity will weaken the effect of academic engagement on university scientific productivity due to attention allocation problem. The dilemma here is that the university with higher internal R&D intensity will more likely attract potential collaborators from industry, but the marginal benefit of these involvements will lower at the high-ranking university than the low ranked university since R&D intensity will weaken the benefits through these engagements. The policy makers should promote academic engagement at the lower ranked universities which are lack of external knowledge and resources rather than high R&D intensity universities which already have overloaded attention and resources.

This paper offers a conceptual framework which helps us to understand how the university-industry interactions influence university scientific production. We believe the results have broader appeal than for a single type of university-industry interactions. Future studies should try to extent in other types of university-industry interactions such as academic consulting, industry sponsored conference, etc. Meanwhile, the impact of U-I interactions on educational outputs, such as time devoted to teaching, curriculum and courses development, and teaching quality need to be further explored.

Insights into this aspect of U-I interactions would be highly valuable in extending our knowledge of the benefits or costs of 'third stream' activities within the context of universities' other missions. Future research should also explore the relationship between academic engagement and commercialization. Our comparison suggests that both types of activities may be driven by different factors. On the one hand, there may be a temporal relationship between engagement and commercialization, in the sense that prior involvement in collaboration with industry may lead to commercial output later in time. On the other hand, researchers should investigate the possibility that some types of collaboration are complementary with commercialization outputs while others may be neutral or even compete with them. Knowing more about the relationship between academic engagement and commercialization would also benefit policy debates by clarifying whether the policies designed to stimulate entrepreneurship also stimulate academic engagement, or whether more focused approaches are needed.

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Appendix 1. Determining the direction of turning point shift as Z changes

Given the specification:

$$\mathrm{Y} = \beta_0 + \beta_1\mathrm{X} + \beta_2\mathrm{X}^2 + \beta_3\mathrm{XZ} + \beta_4\mathrm{XZ}^2 + \beta_5\mathrm{Z}$$

First order condition:

$$\frac{\delta\mathrm{Y}}{\delta\mathrm{X}} = \beta_1 + 2\beta_2\mathrm{X} + \beta_3\mathrm{Z} + 2\beta_4\mathrm{XZ} = 0$$

Solving for X yields the turning point,

$$\mathrm{X}^* = \frac{-\beta_1 - \beta_3\mathrm{Z}}{2\beta_2\mathrm{X} + 2\beta_4\mathrm{XZ}}$$

Taking the derivative of equation above with respect to Z determines how the turning point changes as Z changes:

$$\frac{\delta\mathrm{X}^*}{\delta\mathrm{Z}} = \frac{\beta_1\beta_4 - \beta_2\beta_3}{2(\beta_2 + \beta_4\mathrm{Z})^2}$$

As the denominator is strictly larger than zero, the direction of shift depends only on the sign of the numerator. If it is positive (negative), the turning point *X** will move to the right (left) as Z increases.

Appendix 2. Determining whether a flattening or steepening occurs

Given the specification (Equation A2.1):

$$\mathrm{Y} = \beta_0 + \beta_1\mathrm{X} + \beta_2\mathrm{X}^2 + \beta_3\mathrm{XZ} + \beta_4\mathrm{XZ}^2 + \beta_5\mathrm{Z}$$

When $Z=Z_1$, the turning point is at (Equation A2.2):

$$\mathrm{X_1}^* = \frac{-\beta_1 - \beta_3 Z_1}{2\beta_2 + 2\beta_4 Z_1}$$

When $Z=Z_2$, the turning point is at (Equation A2.3):

$$\mathrm{X_2}^* = \frac{-\beta_1 - \beta_3 Z_2}{2\beta_2 + 2\beta_4 Z_2}$$

where $Z_2 > Z_1$. Assume Equation A2.1 is an inverted U-shape and remains so within the relevant range of Z. Then going the same distance a ($a > 0$) to the left of both turning points, and designating S_1 the slope at $X_1^* - a$ and S_2 the slope at $X_2^* - a$:

$$S_1 = \beta_1 + 2\beta_2(\mathrm{X_1}^* - a) + \beta_3 Z_1 + 2\beta_4(\mathrm{X_1}^* - a)Z_1$$

$$S_2 = \beta_1 + 2\beta_2(\mathrm{X_2}^* - a) + \beta_3 Z_2 + 2\beta_4(\mathrm{X_2}^* - a)Z_2$$

If $S_2 > S_1$ the inverted U-shape is steepening, and if $S_2 < S_1$ the inverted U-shape is flattening. By symmetry, the same holds if we move a ($a > 0$) to the right of the turning points. Then (Equation A2.4):

$$S_2 - S_1 = 2\beta_2(\mathrm{X_2}^* - \mathrm{X_1}^*) + \beta_3(Z_2 - Z_1) + 2\beta_4[(\mathrm{X_2}^* - a)Z_2 - (\mathrm{X_1}^* - a)Z_1]$$

Substituting two equations A2.2 and A2.3 for X_1^* and X_2^*, respectively in Equation below, and collecting terms the following is obtained:

$$S_2 - S_1 = -2\beta_4(Z_2 - Z_1)a$$

Because $Z_2 > Z_1$ and $a > 0$, the inverted U-shape is steepening if $\beta_4 < 0$ and flattening if $\beta_4 > 0$.

Appendix 3 Robustness checks

For robustness checks, I used alterative measures of university contract research and IP transfer. Instead of using the ratio of industry funding out of total funding as the proxy of contract research as the proxy of contract research, the volume of industry funding as the proxy of contract research is utilized in the robustness check. Meanwhile, instead of using the volume of IP transfer revenue, the number of IP transfer contracts is applied in the robustness check. As the Appendix 3 has shown, the results do not differ from those obtained for previous models. Thus, contracts research has an inverted U-shape relationship with both the quantity and quality of university scientific research (Table 8); IP transfer has negative impact on university scientific production (Table 8); university R&D intensity will weaken the effect of academic engagement on university scientific productivity (Table 8) and past university scientific production will lead to more current academic engagement (contract research, Table 9) and academic commercialization (IP transfer, Table 10) .

Table 8. The relationship between U-I interactions and scientific productivity, robustness check, Part I

	Publication		Citation	
VARIABLES	Model 2	Model 5	Model 4	Model 6
Contract research (share)	101,038***		702,717***	
	(27,787)		(190,229)	
Contract research ^{2} (share)	-122,210***		-860,260***	
	(35,008)		(239,658)	
Contract research (volume)		0.0795***		0.535***
		(0.0170)		(0.115)
Contract research ^{2} (volume)		-6.12e-08***		-4.14e-07***
		(1.33e-08)		(8.99e-08)
IP transfer (revenue)	-0.0138***		-0.0953***	
	(0.00483)		(0.0331)	
IP transfer (number of contracts)		-35.49***		-243.2***
		(8.512)		(57.75)
Senior professor	6,648**	-7,944	56,397**	-40,697
	(3,298)	(6,114)	(22,590)	(41,511)
Conference	-0.0982	0.314*	-1.190	1.740
	(0.175)	(0.186)	(1.196)	(1.260)
Keynote	0.638	-1.669	11.47	-4.336
	(1.079)	(1.238)	(7.384)	(8.383)

Table 8. The relationship between U-I interactions and scientific productivity, robustness check, Part II

	Publication		Citation	
VARIABLES	Model 2	Model 5	Model 4	Model 6
Personnel	-0.658*	-3.655***	-5.444**	-25.34***
	(0.391)	(0.957)	(2.678)	(6.491)
Government funding	0.00540***	0.00764***	0.0358***	0.0520***
	(0.00102)	(0.00163)	(0.00696)	(0.0111)
R&D intensity	4.478***	3.024***	32.02***	21.02***
	(1.307)	(0.740)	(8.946)	(5.015)
R&D intensity × Contract research (share)	-31.49***		-228.4***	
	(9.509)		(65.09)	
R&D intensity × Contract research^2 (share)	40.71***		295.8***	
	(12.51)		(85.61)	
R&D intensity × Contract research (volume)		-2.09e-05***		-0.000146***
		(4.76e-06)		(3.22e-05)
R&D intensity × Contract research^2 (volume)		1.75e-11***		1.22e-10***
		(3.83e-12)		(2.60e-11)
Comprehensive	-901.4*	1,155	-5,888	8,032
	(528.7)	(745.9)	(3,622)	(5,063)
Engineering	-2,448***	-3,438***	-16,485***	-23,256***
	(669.3)	(941.3)	(4,584)	(6,384)
Constant	-14,998***	-3,907**	-108,532***	-32,886***
	(3,748)	(1,548)	(25,657)	(10,497)
Observations	354	354	354	354
Chi-squared	198.95***	57.16***	183.13***	58.02***
Year FE	YES	YES	YES	YES

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 9. The relationship between past university publication and academic engagement

	Contract research (share)	Contract research (volume)	Contract research (share)	Contract research (volume)
VARIABLES	Model 2	Model 5	Model 4	Model 6
Publication(t-1)	3.27e-05***	36.24**	3.27e-05***	36.13**
	(1.06e-05)	(16.83)	(1.06e-05)	(16.83)
Patent(t-1)	0.000142***	205.0***	0.000142***	204.9***
	(1.74e-05)	(27.48)	(1.74e-05)	(27.48)
Senior professor	-0.524***	-206,387	-0.524***	-206,457
	(0.157)	(248,659)	(0.157)	(248,660)
Personnel	7.18e-05***	120.0***	7.19e-05***	120.1***
	(1.31e-05)	(20.68)	(1.31e-05)	(20.68)
Government funding	-2.59e-07***	0.00433	-2.59e-07***	0.00461
	(3.38e-08)	(0.0535)	(3.38e-08)	(0.0535)
Applied research	0.178***	180,980**	0.179***	182,919**
	(0.0457)	(71,769)	(0.0457)	(71,798)
Comprehensive	0.0234	-46,230	0.0234	-46,220
	(0.0232)	(36,708)	(0.0232)	(36,708)
Engineering	0.107***	80,584**	0.106***	80,388**
	(0.0204)	(32,178)	(0.0204)	(32,179)
Constant	0.257***	-78,496	0.256***	-79,248
	(0.0503)	(79,257)	(0.0503)	(79,260)
Observations	354	354	354	354
Chi-squared	305.08***	351.64***	305.22***	351.71***
Year FE	YES	YES	YES	YES

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 10. The relationship between past university publication and academic commercialization

	IP transfer (revenue)	IP transfer (number of contracts)	IP transfer (revenue)	IP transfer (number of contracts)
VARIABLES	Model 2	Model 5	Model 4	Model 6
Publication(t-1)	5.296	0.0116**	5.250	0.0116**
	(3.561)	(0.00572)	(3.560)	(0.00572)
Patent(t-1)	23.97***	0.0739***	24.20***	0.0741***
	(8.191)	(0.0121)	(8.180)	(0.0121)
Senior professor	23,690	-98.03	24,094	-98.56
	(72,404)	(116.9)	(72,398)	(116.9)
Professor	-8.608	-0.0145	-8.588	-0.0145
	(6.281)	(0.0102)	(6.280)	(0.0102)
Other funding	1.447***	0.000816***	1.447***	0.000812***
	(0.103)	(0.000146)	(0.103)	(0.000145)
Comprehensive	12,437	23.30	12,321	23.20
	(11,141)	(18.06)	(11,139)	(18.06)
Engineering	2,753	12.38	2,717	12.35
	(9,530)	(15.53)	(9,530)	(15.52)
Constant	-32,741	25.10	-32,819	25.32
	(22,614)	(36.71)	(22,613)	(36.71)
Observations	354	354	354	354
Chi-squared	368.62***	162.98***	368.80***	163.06***
Year FE	YES	YES	YES	YES

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1