Scientometrics (2015) 103:725–749
DOI 10.1007/s11192-015-1552-3

Collaboration strategies and effects on university research: evidence from Chinese universities

Yuandi Wang · Die Hu · Weiping Li · Yiwei Li · Qiang Li

Received: 26 October 2014 / Published online: 22 March 2015

Abstract Previous studies have provided inconsistent evidence pertaining to the relationship between university–industry collaboration and university performance. This study's objective is to go beyond traditional viewpoints, which mostly confine university–industry collaboration within a separate channel, to build the relationship between university–industry collaboration overall channel characteristics and university research performance. In doing so, we define two collaboration strategies, collaboration breadth, which is the scope of different channels, and collaboration depth, which is the extent that universities deepen into different channels. Based on a comprehensive panel dataset of Chinese universities in mainland China in 2009–2013, we find that collaboration breadth and collaboration depth have a linear and curvilinear effect on academic research performance, respectively. Moreover, the interaction of collaboration breadth and depth shows a negative impact on academic research performance.

Keywords University–industry collaborations · Collaboration breadth · Collaboration depth · Academic research

Introduction

Governments, both advanced and emerging, have put great emphasis on building university–industry linkages. Recently, in addition to teaching and research, and often on the initiative of policy-makers, many universities have taken action to develop a 'third mission' by fostering links with knowledge users and enabling technology transfer (Cohen et al. 2002; D'Este and Patel 2007; Etzkowitz and Leydesdorff 2000; Liu and White 2001; Perkmann et al. 2013; Wang et al. 2013a, b). Historically, providing research results to the market has not been a primary concern for universities. However, since the late 1970s a

Y. Wang · D. Hu · W. Li · Y. Li (✉) · Q. Li
Sichuan University, Chengdu, Sichuan, China
e-mail: workshopscu@126.com

third university mission has rapidly emerged, that of transferring knowledge to the private sector; this is in addition to the traditional teaching and scientific research missions (Malik 2013; Maruyama 1988; Mowery and Ziedonis 2002; Rosenberg and Nelson 1994). The growing involvement of universities in technology transfer and industrial innovations has garnered increased concern among academics and policy-makers (Balázs et al. 1995; Cohen et al. 1998; Giuliani and Arza 2009; Motohashi 2005; Sa and Litwin 2011; Siegel et al. 2007; Villasana 2011). One key issue of concern is whether close university–industry links could facilitate or impair university scientific research capabilities, which have been seen as an important driver of a county's long-term economic growth and global competitiveness (Bozeman 2000; Dutrénit and Arza 2010; Link et al. 2007; Perkmann et al. 2013; Rosenberg and Nelson 1994). Until recently, most empirical studies on this topic, however, have taken a separate approach or independent view (limited to one or very few channels) to examine how a specific type of university–industry linkage influences university research performance and have produced inconsistent findings. While some studies have found positive effects (Bozeman 2000; Geuna and Muscio 2009; Gulbrandsen and Smeby 2005), others have shown that university–industry linkages have no effect or even have a negative effect (Blumenthal et al.; Gulbrandsen and Smeby 2005; Rosenberg and Nelson 1994).

To reconcile the mixed findings, scholars have recently argued that there are a wide variety of channels through which knowledge and technology are simultaneously being transferred between universities and industry (Arza and Vazquez 2010; Bekkers and Bodas Freitas 2008; D'Este and Patel 2007; Eun et al. 2006; Perkmann et al. 2013). A one-to-one relationship between university and industry does not appear to exist. Thus, one type of university–industry linkage is not expected to correspond to university research performance that may be derived from many types of linkages. Bekkers and Bodas Freitas (2008), for example, distinguish 23 distinct transfer channels between industry and university, ranging from recruitment of university graduates to personnel exchanges, joint research, contracted research, patents and licensing, joint research, consulting, licensing, spin-offs, publications, meetings and conferences. Furthermore, they find that universities engage more frequently in channels, such as consultancy and contracted research, joint research, or training, compared to traditional patenting or spin-out activities. Link et al. (2007) categorize university–industry collaboration channels as formal and informal and investigate the propensity of academics to engage in informal university technology transfer. Perkmann et al. (2013) distinguishes university–industry linkages into engagement and commercialization channels, and examines the antecedents and consequences of these two general channels in a comparative view based on a systemic literature review. Finally, they also call for research on differentiating the different effects of engagement and commercialization channels on universities' distinct outputs.

Thus, it is crucial for university–industry collaboration research to shift from the separate channel toward a channel portfolio view, simultaneously investigating more channels. We believe this is noteworthy because, as previous studies state, in reality, a university always adopts a variety of channels to link it to the private sector. Thus, to reconcile the inconsistent findings related to the relationship between the university–industry link and university research performance, there is a need for more detailed analyses based on a portfolio perspective. Although prior studies have noted a variety of channels used by universities to establish links with industry, there is no systemic empirical evidence related to the relationship between a university's diverse collaboration channels and relevant research performance.

In this paper, our objective is to analyze how the variety of university–industry collaboration channels influences university research performance in terms of scientific paper outputs and patent applications. More precisely, we attempt to explain the variance in university research performance as a result of channel breadth (defined as number of different university–industry linkages) and channel depth (defined as the degree of interaction within each of these collaboration channels). In addition, we will examine how channel breadth and depth exert different effects on university scientific and technological outputs. To achieve this objective, this paper will use a combined dataset from Chinese authorities with detailed information regarding the Chinese all '211 project', which is university collaboration practices with industry in 2008–2012. In this manner, we attempt to improve our understanding of the relationship between university–industry collaboration and university research performance in a novel way.

This paper is structured as follows. In 'Literature review and hypothesis', we first review the literature on the relationship between university–industry collaboration and its effect on the university, and the recent literature on the portfolio view of university knowledge transfer channels. Next, we develop our hypotheses. 'Methodology' introduces the data and methodology used in this study. 'Results' presents our empirical results. 'Conclusion and discussion' concludes this paper, and discusses the findings, and ultimately provides implications for both universities and policy-makers.

Literature review and hypothesis

In this section, we review the literature that has explored the university–industry interaction and its implications for university research performance and university–industry interaction channels. Based on this background knowledge, we propose concepts of university–industry collaboration channel breadth and depth and further predict their effect on university research.

The relationship review of university–industry collaboration and university research

As scientific knowledge becomes increasingly important for innovation and new business development, universities have played an enhanced role in today's economic growth around the globe (Balázs and Plonski 1994; Etzkowitz and Klofsten 2005; Leydesdorff and Meyer 2003; Mansfield et al. 1982). Traditionally, teaching and research have been the universities' main mission. Since the 1980s, this has gradually changed with the emergence of new disciplines such as biotechnology, increased globalization, and reduced basic funding. Today, most universities and policy-makers in both advanced and emerging countries have acknowledged that universities have been endowed with a third mission, to actively serve industry with scientific knowledge and advanced technology (Chataway and Hewitt 1999; Etzkowitz and Klofsten 2005; Liang et al. 2012; Rasmussen et al. 2006; Sutz 2000; Wang et al. 2013a, b; Williams 2011).

However, on the one side are those who have argued that universities can and should play a larger and more direct role in assisting industry (Bhattacharya and Arora 2007; Etzkowitz et al. 2004; Mansfield 1995). On the other side, many academics, policy-makers, and some practice players are worried and state that this increasing involvement may be a threat to the integrity of academic research by corrupting academic research and teaching, thus diverting attention away from basic research towards short-term applied research (Agrawal 2001; Baldini 2006). Thus, a key issue highlighted by scholars is to explore the relationship between university–industry collaboration and university research performance.[1]

In general, in the extant literature, there are two distinct views, optimistic versus pessimistic, on the implications of increased university–industry interactions. From the optimistic view, universities' intensified involvement in industry is complementary to universities' traditional missions of teaching and research because of the advantage that universities can obtain, such as access to additional sources of funding, new ideas, unpublished data, and instruments (Meyer-Krahmer and Schmoch 1998; Van Looy et al.). Moreover, close links between academia and industry can imply increased flexibility and autonomy for academics. Universities thereby can strengthen their traditional norms and their research and teaching activities (Benner and Sandström 2000). Scholars in this area thus have the belief that university collaborative activities with industry and scientific performance in academia can be reconciled (Van Looy et al. 2004).

Evidence available to support this optimistic view is very clear. Some important findings are introduced here. Based on a survey of more than 1200 biotechnology research faculty at 40 U.S. Universities, (Blumenthal et al. 1997) find that faculty with industrial support publish at higher rates, have more patents and are more active in professional activities than those who do not have such support. A similar study was conducted in Norway by Gulbrandsen and Smeby (2005). They collect data through questionnaires from 1697 professors at universities, accounting for 60 % of all professors in Norway. Their study indicates that professors with industry funding report higher publishing levels and higher levels of entrepreneurial output. However, interestingly, they did not find either a positive or negative relationship between academic publishing and entrepreneurial outputs, such as commercial products, patents, spin-off companies and consulting contracts. When the scenario shifts to Belgium, Van Looy et al. (2004) focus on one famous Belgian university, the Catholic University of Leuven, to investigate whether faculty who have industry linkages (e.g., collaboration contracts) publish more or less and whether they have different publishing profiles (basic or applied). Their study shows that university collaborative activities with industry are compatible with scientific outputs, and higher collaborative activities are positively associated with higher publication rates. In addition, Zucker et al. (1998) also find that academic entrepreneurial activities and outward technology transfer can be harmonious with a high level of scientific output. In the work of Agrawal and Henderson (2002), the authors state scientists with higher patent rates could be followed by higher citation impact for their journal publications.

In contrast, the pessimistic view notes a substitution effect between involvement in commercialization activities and academic output, which assumes that university collaborative activities can occur at the expense of academic fundamental research, and scientific productivity (Behrens and Gray 2001; Godin and Gingras 2000; Slaughter and Leslie 1997). There are two main theories to support this pessimistic argument, namely, the 'secrecy' theory and the 'skewing' theory (Florida and Cohen 1999). Traditionally, a university is considered an independent institution that allows academics to freely contribute to research on an endless frontier in a purely curiosity-driven system. With the

[1] There are inconsistent terms used to capture interactions between university and industry, such as collaboration, relation, relationship, knowledge/technology transfer, university engagement and university commercialization, university–industry links, science-technology interface, and others. There might be various reasons for their interpretations of a university–industry link, and, consequently, different terms are used. In this study, we will not differentiate between these different terms because channels under our examination include different aspects of university–industry collaboration, which is difficult to combine into one single term.

intensification of collaboration with industry, there has been an increase in restrictions or delays in the publication of their findings from industrial works, which is referred to as ‘secrecy’ theory. In the era of highly collaborative relationships between universities and industry, firms often ask universities to maintain the confidentiality of results, which may reduce the incentive to publish and runs counter to the academic norm of open dissemination of scientific knowledge (Blumenthal et al. 1996; Florida and Cohen 1999). Another theory to support the pessimistic view is related to the ‘skewing’ problem, stating that the academic research agenda has been shifted from basic research to more applied research (Florida and Cohen 1999). Under this theory, it is believed that increased industrial activities will force universities to take on ever more applied and commercial work, which unavoidably leads them to neglect their responsibilities for long-term knowledge development (Geuna and Nesta 2003; Johnson 2001).

Empirical work provides mixed results pertaining to the ‘secrecy’ and ‘skewing’ theories. For instance, Blumenthal et al. (1996) investigate life science and companies in the U.S., and find evidence for the fact that delaying publications and restricting information sharing widely exist. Brooks and Randazzese (1999) find evidence that there is an association between greater faculty involvement in industry and increased levels of applied research. However, Hicks and Hamilton (1999) compare university–industry coauthored papers to single university papers and find that the number of university–industry coauthored papers increased significantly more than those of single university papers, and the former received more citations as well. Thus, this finding did not support the ‘skewing’ theory.

In short, until recently, the extant literature does not appear to have had sound evidence to support the positive or negative relationship between university–industry interactions and scientific productivity. Even in some studies, some scholars argue that universities perform a dual role in their interactions with firms: they substitute for and complement the research and development done by the firms themselves (e.g. Rapini et al. 2009). Nevertheless, one clear drawback of current studies is the use of one or a limited number of specific collaboration channels (e.g., consulting (Perkmann and Walsh 2008), University-run enterprises (Eun et al. 2006), industrial funding (Gulbrandsen and Smeby 2005), coauthoring papers (Liang et al. 2012), patenting and licensing (Motohashi and Yun 2007; Mowery et al. 2001; Wang et al. 2013a, b)within the overall spectrum of university–industry interactions. In fact, as certain researchers (D’Este and Patel 2007; Florida and Cohen 1999) state, knowledge or technology transfers from university to industry can occur through a variety of channels, such as consulting, joint-research, contracted research, spin-offs, conferences and meetings. Each channel has its own advantages and disadvantages for academic research. When universities seek to use a wide range of channels, their joint effects on university scientific outputs may be complex because some channels may strengthen scientific productivity, while others may weaken it. A university’s scientific productivity is thus a result of combinatory channels. Resorting to the use of various channels may be a promising way to reconcile the inconsistent empirical evidence. In the next sub-section, a review of university–industry interaction channels is presented.

Review of university–industry interaction channel

A university–industry interaction channel is defined as the mechanism or the pathway through which knowledge/technology is transferred between universities and industry. This knowledge transfer includes the majority of knowledge transferred from universities to industry; in addition, in some cases, it also includes knowledge transferred to universities, e.g., for joint research. Until recently, channels under consideration in prior studies include subsets of publications, patents, research contracts, research joint ventures, university spin-offs, consulting, licensing, formal and informal meetings, and personal mobility. These categories are the most mentioned in the literature, but they are no longer the sole channels. For instance, in Bekkers and Bodas Freitas (2008) work, the channels have been divided into 23 distinct categories. These 23 distinct types include the most popular, as listed above, such as patents, licensing, in addition to new ones, such as financing of PhD projects, students working as trainees, participation in workshops, and university graduates as employees. However, it is noteworthy that rather than listing specific channels, some scholars use more general categorizations, such as formal versus informal channels and market-based and nonmarket-based channels. For example, Link et al. (2007)categorize licensing agreements, research joint ventures, and university-based startups as formal university technology transfer channels, while they put commercial technology transfer, joint publications and industrial consulting into an informal channel portfolio. In Mowery and Ziedonis's work (2001), the authors see positive knowledge externalities from university research (i.e., knowledge spillovers) as a nonmarket-based transfer channel, but they see channels such as licensing and various types of employment relationships between academic scientists and firms as a market-based channel.

In accordance with a university technology transfer channel, the existing studies have explored different aspects of university technology channels, which thus strengthens our understanding pertaining to university technology transfer mechanisms. A thorough literature review indicates that the burgeoning literature on university technology transfer channels is generally divided into several primary streams, the antecedents, relative importance, and conditions for specific channels chosen by recipients.

The first stream of literature that focuses on antecedents of a university technology channel has been the focus of scholars for a long time. These studies have examined the determinants of technology transfer from various perspectives, including faculty involvement, institutions, and university characteristics (Audretsch and Link 2012; Harmon et al. 1997; Lee 1996; Malik 2013; Teixeira and Mota 2012; Zhou 2012). In a recent study, González-Pernía et al. (2013) investigate the determinants of university technology transfer in terms of licensing and spin-off firm creation through a multi-level perspective (Fontana et al. 2006; Jeong et al. 2011; Schrader 1991). They found that technology transfer offices with more experienced, expertly staffed teams and universities with clearly established rules for generating academic startups and with higher patenting numbers are more likely to obtain better licensing and spin-off firm outcomes. Moreover, they found that the regional context concerning a university's location also appears to matter for explaining the variation in academic spin-off and licensing records across universities. In contrast to the investigation of antecedents on formal channels, there have emerged other studies that focus on informal channels. For instance, Link et al. (2007) explore the determinants of three types of informal technology transfer, and find that male, tenured and research-grant active faculty members are more likely to engage in all three forms of informal technology transfer. Unfortunately, to date, there is no consistency regarding which determinants and to what extent they can be used to explain the variation among the different channels that universities have used. It is noted that studies from developing countries mostly explain the growth university–industry links through institutional changes, government and social capital (Balázs et al. 1995; Bhattacharya and Arora 2007; Datta and Saad 2008; Li 2009; Motohashi and Yun 2007; Rapini et al. 2009; Williams 2011). For instance, Chataway and Hewitt (1999) conduct a comparative study of institutional change and efforts with aim at creating networks and linkages in the science and technology systems of Poland and Tanzania at a time of market-led economic reform.

Because there are a variety of university technology transfer channels, scholars in the second stream intend to investigate the relative importance of different channels. Typical work by Cohen and colleagues (Cohen et al. 2002) believes that publications and reports, public conferences, meetings, informal information exchange, and consulting are the key channels through which university technology are channeled to industry. While, Narin et al. (1997) and Meyer-Krahmer et al. (1998) consider patents and formal collaboration as the most important channels. Similarly, Agrawal and Henderson (2002) compare patents with papers and explore the relative importance of a set of other transfer channels. Arza and Vazquez (2010) illustrate that there are various channels for the exchange of knowledge between public research organisations (e.g. universities) and industry, and discuss the relative effectiveness of different channels in Argentina. They find that the service channel is effective for driving the benefits for researchers, the traditional channel does so for firms. And, however, they also find that only the bi-directional channel ensures long-term benefits simultaneously for both actors. Moreover, Arza and colleagues (Arza and Vazquez 2010) conduct a similar study based on four countries, Argentina, Brazil, Costa Rica and Mexico, and find almost similar results.In addition, in the Chinese context, a country that lags behind in terms of R&D investment and in the capacity of harvesting returns from innovation-driven economic activities, Liu (2005) and Wang et al. (2013a, b) state the importance of market-based technology transfer channels, such as licensing and contract research. Therefore, most scholars believe that different channels have different roles in university technology transfer, and one or more channels are more important than other(s) (Colyvas et al. 2002; Shane 2002). However, this insight was essentially renewed recently. Research by Bekkers and Bodas Freitas (2008) illustrates that, indeed, there is no real perceived relative importance among different university technology transfer channels. That is, in the universities they investigated, all equally used a variety of transfer channels, with no favored channels (such as traditionally emphasized patents, licensing, and contract research). Thus, this line of inquiry provides compelling evidence related to the importance of a specific university technology transfer channel. This may lead to a third stream of investigation that aims to provide a better condition for a specific channel rather than comparing the relative importance of channels.

In the third research stream, many publications are on the technology receipt side to examine preferable conditions, most at the industry, discipline and firm levels, for specific university technology transfer channels, and to provide many findings. At the industry level, prior studies show that industries strong in R&D tend to pursue collaborative research, whereas service and industry lean towards personal mobility and training (Schartinger et al. 2001). For instance, according to Cohen et al.'s (2002) survey, it is found that industries, such as drugs, glass, steel, TV/radio, and aerospace, intend to moderately use the channel of collaborative research. However, in industries such as biotechnological and pharmaceutical industries, which are much more dependent on academic knowledge and basic research, publications become an important channel. In addition, Balconi and Laboranti (2006) find that electrical and electronic industries are prone to use the mobility of university students. In parallel, some research focuses on the scientific disciplines. Based on a survey of Austrian universities on the use of nine types of technology transfer in 49 different economic sectors, Schartinger et al. (2001) find that chemistry, biotechnology, engineering and information technology are intensively using research cooperation and personnel mobility. Moreover, Zucker et al. (1998) find that university spin-off with the well-known joint research between top professors and the firms are widely used in biotechnology academic breakthrough discoveries. In chemistry, the provision of skilled students and informal contacts play a crucial role in transferring university technology to industry (Meyer-Krahmer and Schmoch 1998). Eventually, with regard to firm level, firms with strong absorptive capacity and larger size with higher financial and skill resources tend to make use of collaborative research with universities, while others intend to use technology licensing and an influx of university personnel to transfer university technology (Bekkers and Bodas Freitas 2008; Cohen and Levinthal 1990; Wang et al. 2013a, b).

In summary, these prior studies have analyzed the antecedents, the relative importance of different channels, and the preferable conditions for specific channels. All their findings have strengthened our understanding of university technology transfer channels. However, in recognition of the fact that there are various channels available for universities to bring innovative ideas and inventions to marketplace, missing evidence of what the relationship is between channels and university performance remains. In addition, evidence is missing regarding how a university manages its channel portfolio to achieve a reciprocal cycle between its collaboration with industry and academic research performance. In the next sub-section, we will discuss two properties, channel breadth and channel depth; we will also predict their relationship to university research performance.

Collaboration breadth and depth and their effects on university research

The above-mentioned literature review reveals that various channels have been used simultaneously by universities to build university–industry interactions, and these channels often operate together in synergistic ways. In this regard, it may be a mistake to alter the system in separate ways, for instance, by establishing the relationship between one channel and scientific outputs. In other words, this also points to a promising departure to reconcile previous studies that find ambiguous and inconsistent evidence pertaining to the effect of collaboration on academic research by taking various channels in an integrated view. Motivated by this observation, this article attempts to define two collaboration strategies, collaboration breadth and collaboration depth, to characterize a university's various channels. The former refers to the number of channels that a university uses to establish links with industry. The latter is defined as the extent to which universities draw deeply from the different collaboration channels.

Collaboration breadth and effect on academic output

Previous studies indicate that channels through which knowledge and technology are being transferred between universities and industry are chosen by universities contingent on various factors, such as the disciplinary origin, the characteristics of the underlying knowledge, the characteristics of researchers involved in producing and using this knowledge, and the environment in which knowledge is produced and used (Bekkers and Bodas Freitas 2008). However, from a university perspective, the different channels are chosen primarily based on a comparison of benefits and costs and the short- and long-term strategies (Landry and Amara 1998). Universities must invest in each link to industry and seek promising channels coinciding with their objective, development stage, and university characteristics (Lv 2014). For instance, since the late 1970s, most universities have established their technology transfer offices and built other important infrastructures, including science parks, incubators, and research centers, and generally collaborated with governments and other entities (Agrawal and Henderson 2002; Mowery et al. 2001). These structural changes and infrastructure investments have led to intensified university–industry interactions; this also provides several benefits to academic research, such as fostering the emergence of new ideas, accessing new data and research materials, and securing funds for basic research (Bray and Lee 2000; Breschi and Catalini 2010; Link et al. 2007; Perkmann and Walsh 2009).

However, there are good reasons to believe that benefits from university–industry collaboration for academic research are not increasing accordingly. First, with the enlarging breadth of collaboration channels, university administrators must invest more money to coordinate different reward and incentive systems derived from different channels, which, in turn, reduces additional investments in research work and thus may assert a negative effect on university academic research. Second, transaction costs are usually an unavoidable result of enlarging collaboration channel breadth (Landry and Amara 1998). Lee and colleague (Lee and Bozeman 2005) argue that collaborating with industry is a time- and energy-consuming process because a university must remain in touch with various partners, cultivating different channels, engaging in various social ingratiation, and waiting for partners to comment, respond, and do their part of the research, even in the best collaborative relationships. They highlight that there are no ideal collaborations. Thus, we predict that with the rise of collaboration channels, these factors confronting collaborations may provide high transaction costs for universities, and further decrease universities' scientific productivity because of the demands they impose on the limited time and resources of researchers.

H1: Collaboration breadth is curvilinearly (taking an inverted U-shape) related to the academic research performance.

Collaboration depth and its effect on academic output

An increase in collaboration depth can positively influence academic research through several effects. First, using the same collaboration channel repeatedly accumulates universities' management experience in a collaboration relationship. For any collaboration type, universities must invest to build the relationship, cultivating it properly, and create trust among the university and industry partners. In this way, universities are able to accumulate experience in managing particular channels and thus provide more resources and funds back to university research work, with the potential to improve academic research. Second, repeated usage of a given array of collaboration channels can lead to significantly deeper understanding of those channels, and relevant partners, and boost universities' ability to reduce collaboration uncertainty, risk, and costs and, furthermore, to improve their collaboration performance and thereby benefit universities' academic work.

However, excessive collaboration depth may also lead to negative consequences. First, universities may lose many opportunities due to path-dependent effects or rigidity. For example, traditionally, universities have widely used licensing as their main channel to collaborate with and make money from industry. For instance, according to Bray and Lee's work (2000), the average annual income from the spin-offs is more than 10 times that from traditional licenses. If a university cannot shift from its previous popular channel, i.e., licensing, towards a new channel, such as spin-offs, it may lose much money; this money can be used to support its academic research. Second, with excessive collaboration depth, universities may be subject to diminishing returns to adopting the same channels. It appears that improvement by concentrating on the same channel is possible only until the intrinsic performance limit of that channel is encountered. When the limits of the potential benefits are reached, benefits from the subsequent close collaboration in a pertinent channel will increase at a declining rate. Thus, at some point, for universities that seek to further benefit from this channel, it becomes expensive and difficult and may lead to the costs of depth ultimately exceeding its benefits. Thus, benefits from collaboration for academic research will unavoidably decrease. Combining them, we predict,

H2: Collaboration depth is curvilinearly (taking an inverted U-shape) related to the academic research performance.

Combinatory effect on academic outputs of collaboration breadth and depth

Hypothesis 1 and hypothesis 2 are developed based on the distinct characteristics of collaboration strategies, the breadth and the depth. Here, we predict that these two strategies are mutually detrimental and have interactive effects. The mechanism underlying this hypothesis can be discussed in two ways. First, a detrimental effect of breadth and depth is likely to happen when combining various channels with unfamiliar channels. Previous studies indicate that different channels have their own natures and imply different management issues for universities (Perkmann and Walsh 2008). University administrators deepen these channels when they seek to extend the scope of their channels at the same time. In this situation, a university may be confronted by the difficulty of managing new channels and by the difficulty of deeply understanding them. Thus, a balance should be addressed by universities between collaboration breadth and collaboration depth instead of widening and deepening their channel portfolio at the same time. Thus, we predict that the combination has a negative effect on academic research because involved researchers have a negative expectation for their industrial activities; therefore, they will be unavoidably disturbed by unfamiliar collaboration channels that need more time and energy to manage. This is therefore harmful for their research work and performance. Second, it is unlikely for universities to obtain an alignment effect between a flexible channel portfolio and university science bases. Some studies argue that one type of relationship between an academic knowledge base and industrial demand is not existent (Cohen et al. 2002; Schartinger et al. 2001). Some academic fields are relevant to a large number of industrial sectors of activity and need different university–industry collaboration channels, while others are of high relevance to a very limited number of industrial activities and may need other types of channels. Universities seeking to adjust their channels frequently among different channels and demonstrating their flexibility in channel management may ignore costs and risks at the same time. When this occurs, it is unlikely they will address this situation through aligning a channel portfolio with a knowledge base and ultimately provide benefits for academic research. Instead, confusion becomes constant for universities and researchers and negatively affects academic research.

H3: The interaction of collaboration breadth and depth is negatively related to the academic research performance.

Methodology

A brief description of research setting: China national innovation system

This study sets China as the research context due to its rapid growth in university–industry interactions in its innovation system (Lundvall et al. 2006; Motohashi and Yun 2007).

China has adopted the Soviet model of innovation system before it reform in the 1980s. For the Soviet model, science and technology activities were completely separated at public research institutes, including universities, and production at state-owned firms (Xue 1997). In the 1980s, in accordance with its economic shift from a centrally planned system to a market-based economy, the reform of China's innovation system is enacted to introduce the proper incentive systems for both science, technology and business sectors for innovations. Universities, research institutes, and firms were given greater autonomy in developing new product, technology, and interactions among these partners have been proliferated (Motohashi and Yun 2007). According to China authorities, the China GERD [gross domestic expenditure on research and development (R&D) of gross domestic production (GDP)] in 1991 is 0.73, while it has doubled in 2006 (1.42). In 2012 this percent has raised to 1.98, more than what in European Union (1.94), an overall view is illustrated in Fig. 1. The R&D investment structures during the period of 1995-2012 is shown in Fig. 2. Currently, 70 % R&D investment in China in business sectors. The values that universities selling to business sectors maintain stable growing since 2006. In 2012, it surges to 3.75 billion (RMB) (Fig. 3).

Data and sample

The research sample is drawn from Chinese universities. Some considerations motivated our choice of Chinese universities as the setting of the study. First, current studies available to us are predominately based on universities in western countries, such as the U.S. and western Europe (Perkmann et al. 2013). Thus, using China and its universities as our research setting may address this imbalance and elucidate emerging countries. Second, from the availability of data, the uniqueness of the dataset in this study could benefit our investigation of university–industry collaborations. To our best knowledge, most existing publications are based on survey data through university administrators or firm managers. Thus, these studies are unavoidably subject to statistical bias of cross-sectional data, such as the endogeneity problem, and unobserved heterogeneity bias. Fortunately, in the present study, the main data source is based on historical statistical data, which records universities' collaborative activities with industry in detail longitudinally. Thus, a panel dataset is likely obtained, and this, in turn, could provide more sound evidence compared to that

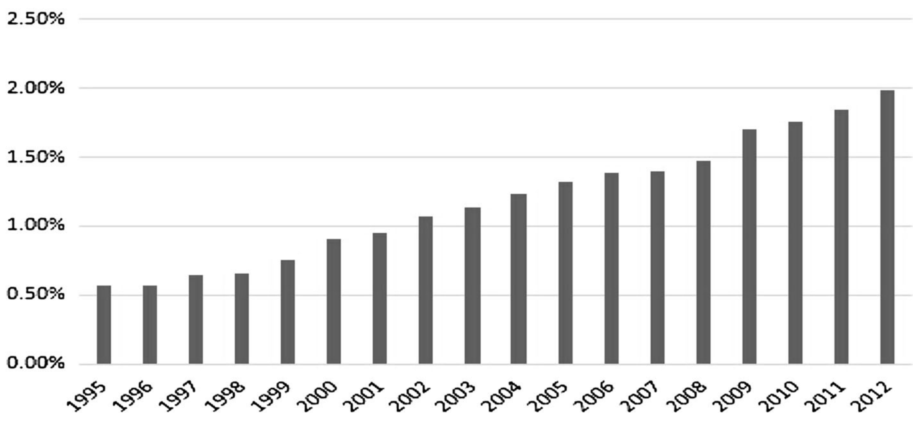

Fig. 1 China's gross domestic expenditure on R&D (GERD) as a percentage of GDP (1995–2012)

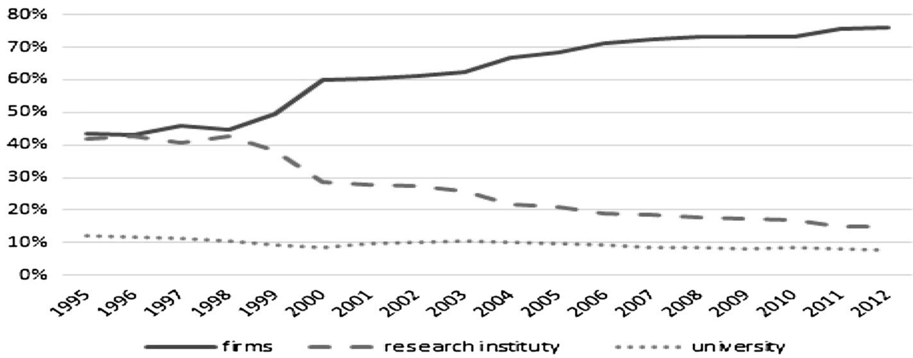

Fig. 2 China's investment structure changes of research and development among research institutes, universities, and firms (1995–2012)

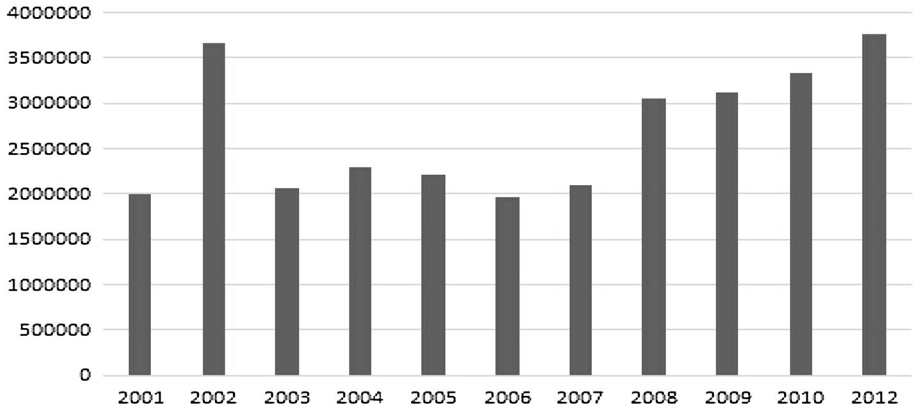

Fig. 3 Values of technology selling from universities to business sectors (unit: 1000 RMB) (2001–2012)

from survey data. In China's official annual report, *Chinese University Science and Technology (S&T) Development Annual Report (Gaodeng Xuexiao Keji Tongji Ziliao Huibian)*, important information regarding all Chinese universities, such as, university staff, number of students, and research inputs and outputs, is collected. More importantly, this annual report focuses great and detailed attention on universities that are directly supervised by the China Ministry of Education. Through these statistics, we are able to obtain information in terms of university–industry collaborations, for instance, patent applications, technology trade, and income through industry service. Because this information is not found for other universities before 2009, we therefore use this group of universities as our sample. In total, there are 61 universities during the period of 2009–2013.

To have more channels that universities use to interact with industry but that are not available in *Chinese University Science and Technology (S&T) Development Annual Report*, we combine two other datasets with *Chinese University Science and Technology (S&T) Development Annual Report*, China licensing dataset and China patent dataset. The

China licensing dataset has been widely used in recent years in the literature (Li-Ying et al. 2014; Wang and Li-Ying 2014; Wang et al. 2013a, b). This dataset contains all patent licensing activities in China. Thus, through this dataset, we are able to identify all licensing activities between Chinese universities and industry. Previous studies (Motohashi and Yun 2007; Wang and Zhou 2013) have largely used a co-patent to measure collaborative research; we thus resort to China patent datasets to help identify this variable. Thus far, the China patent dataset has published all patents filed in China's patent system since 1985.

In sum, this study combines a unique and unexplored dataset with two other important datasets to provide more information regarding the Chinese universities' collaboration channels through which knowledge was transferred between universities and industry. Due to the availability of the dataset, we focus on all Chinese universities that are directly supervised by the China Ministry of Education between 2009 and 2013. In total, there are 244 observations (due to a 1 year lag for operationalizing controls; the time frame in this study is 4 years) and a balanced panel dataset.

Concerning university–industry channels, this study considers seven distinct channels, the maximum number based on our combined dataset. These channels are also chosen in accordance with prior studies. A short description is present in Table 1. All definitions are based on the observation year.

To verify that our seven channels are carefully chosen to reflect different aspects of university–industry collaborations and to reduce their overlap, we summarize their basic descriptive statistics and correlations in Table 2. Through Table 2, it is found that the correlations are moderately lower with certain exceptions, such as the one between patent licensing and patent applications (0.609). Thus, we believe these different collaboration channels can be significantly used to mirror a university's channel portfolio. Next, the dependent variable, independent variables, and control variables are defined.

Table 1 Definitions of different university–industry collaboration channels

Channel No.	Name	Description	References
1	Patent application	Number of patent applications by a focal university	Breschi and Catalini (2010), Van Looy et al. (2006)
2	Patent sale	Money obtained through selling a university's patents to industry	Gluck et al. (1987), Thursby and Thursby (2002)
3	Licensing	Number of patents that a university licensed out to industry	Bray and Lee (2000), Bulut and Moschini (2009)' Wang et al. (2013a, b)
4	Technical service	Income from technical service for industry	Perkmann et al. (2013), Sutz (2000)
5	Collaborative research	Number of co-patents between a university and it industry partners	Motohashi and Yun (2007), Wang and Zhou (2013)
6	Technology transfer contract	Number of contracts between a university and its industry partners	Etzkowitz (1998), Hemmert et al. (2014)
7	Scientist mobility	Number of staff holding positions in a university sending to industry	Bekkers and Bodas Freitas (2008), Lv (2014)

Table 2 Statistics of collaboration channels and correlations among them

Variable	Mean	S.D.	Min	Max	1	2	3	4	5	6
1. Patent application	490.3	549.2	1	4223	1					
2. Patent sale	12.71	20.26	0	130	0.583	1				
3. Licensing	14.80	20.12	0	139	0.609	0.583	1			
4. Technical service	213.8	304.0	0	1667	0.411	0.308	0.273	1		
5. Collaborative research	479.7	661.3	0	4530	0.277	0.276	0.0651	0.152	1	
6. Thchnology transfer contract	63.82	136.6	0	1030	0.441	0.510	0.255	0.229	0.324	1
7. Scientist mobility	22.29	43.65	0	389	0.371	0.405	0.190	0.207	0.269	0.357

Variable operationalization

The dependent variable, *academic research performance*, is defined as a university's number of published papers in the observation year, according to previous studies (Geuna and Nesta 2006; Lee and Bozeman 2005; Van Looy et al. 2006).

Two independent variables, *collaboration breadth* and *collaboration depth*, are operationalized as follows. As we discussed before, *collaboration breadth* means the scope of a university's collaboration channels through which the university interacts with industry. In accordance with D'Este and Patel's (2007) work, we define this variable by examining the number of distinct channels of collaboration in which the university has engaged. If a university's report has no interaction with industry in any of the seven categories listed in Table 1, then the dependent variable takes the value 0; if a university reports an interaction in just one type of channel, the value is 1; if a university is involved in two types of channels, the value is 2. Thus, collaboration breadth reaches a maximum value of 7 if universities collaborate in all seven different channels. Again, similar to D'Este and Patel's (2007) work, *collaboration depth* is operationalized as the number of distinct channels of collaboration in which a university has engaged more frequently than the average (relative to our overall sample of universities). This variable ranges between 0 (if collaboration is below average in each of the seven categories) and 7 (if collaboration is above average in each of the seven categories).

According to extant literature, a series of control variables are included in the analyses. First, a university's reputation is controlled by using the reputation score (in logarithm form) under a comprehensive assessment of an online resource (http://www.cuaa.net/). Second, a dummy variable is generated to control for whether the universities are '985 Project' universities. The '985 Project' universities are part of a constructive project for funding world-class universities in the 21st century; this project is conducted by the Chinese government and was initiated in 1998 (www.Chinaeducenter.com). Currently, nearly 40 universities belong to this group. For this group, universities have more resources than other universities under the same supervisor of the China Ministry of Education. Third, human investment (in logarithm form) is controlled by using full time research and development staff in universities. This higher value indicates a higher propensity to industrial collaborations. Fourth, a dummy variable is created to control for whether a university has technology transfer office (TTO). If yes, then the value is 1; otherwise, the value is 0. Fifth, university research capability is controlled by examining the number of projects (in logarithm form) at the national level, such as projects from National Science Founding. Sixth, a university's professional type is controlled for. Chinese universities have been categorized into different types, such as a national research university, regional university, industrial research university, professional and regional research university, and professional university. Five dummies are created, and the regional university is omitted as the reference group. Seventh, university location is controlled using three dummies, East China, Middle China, and West China.[2] Eighth, due to the rapid transition of Chinese society and the economy, there may be time effects on academic research. To control for such time effects, we employ year dummies (2009–2013). Year 2012 is omitted as the reference category. Finally, all control variables (excluding location, university type, and year dummies) are lagged for 1 year for a potential coincidence problem, and some heterogeneity problems are accounted for.

Analysis method

Because the dependent variable of this research, i.e., the number of published papers, included quantities of papers, a panel Negative Binominal regression is used (Katila 2002). A Poisson specification ensures that this is the most common model to handle count variables. However, in reality, with this model, it is difficult to satisfy the assumption of the equal mean and variance. For instance, in our study, the mean is 1.24 times its variance. Thus, scholars often resort to using an extended Poisson model, the Negative Binominal, which is set to control for the bias due to an unequal mean and variance (Greene 2003).

To control for university heterogeneity, we utilize the generalized estimation equations (GEE) regression method. This method accounts for autocorrelation due to repeated yearly measurement of the same university by estimating the correlation structure of the error terms (Liang and Zeger 1986). When using the GEE method, in accordance with prior studies (Hilbe 2011), an 'exchangeable' matrix structure is chosen. In addition, to account for any over-dispersion in the data, it reports all results with robust, or empirical, standard errors.

Results

Table 3 presents the descriptive statistics and correlations. As the descriptive statistics on the control variables indicate, the universities in the sample differ largely in reputation, research capability, and human investment. Additionally, half of the universities have technology transfer offices. Approximately 59 % of universities belong to the '985 Project' category. The low correlation (0.429) between collaboration breadth and depth is also noteworthy; it suggests that these two variables represent two distinct dimensions of a university collaboration channel portfolio, meaning universities use different collaboration strategies to establish relations with industry. The correlation matrix shows that the collinearity among the main variables is low. Furthermore, a variance inflation factor (vif) test indicates that the highest vif is 4.33, which is lower than the critical threshold value of 10 (Chatterjee and Price 1991).

[2] East China includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; Middle China includes Anhui, Hubei, Hunan, Shanxi, Jilin and Heilongjiang; and West China includes Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu and Guangxi.

Table 3 Descriptive statistics and correlations

Variable	Mean	S.D.	Min	Max	1	2	3	4	5	6	7
1. Published papers	3713	2994	38	16,023	1						
2. University reputation	31.18	17.74	1.27	100	0.402	1					
3. Research capability	35.15	48.74	0	269	0.554	0.54	1				
4. Human investment	852.5	742.7	14	5101	0.532	0.518	0.545	1			
5. TTO	0.508	0.501	0	1	0.258	0.124	0.177	0.102	1		
6. 985 project	0.59	0.493	0	1	0.335	0.571	0.361	0.475	0.007	1	
7. Breadth	6.216	1.152	2	7	0.278	0.0549	0.282	0.339	0.0311	0.221	1
8. Depth	2.433	1.988	0	7	0.504	0.343	0.474	0.474	0.35	0.397	0.429

University type and year dummies are excluded

Table 4 reports the results of the GEE negative binominal regression analysis. Model 1 in Table 4 acts as the baseline model including only all control variables, university reputation, university research capability, human investment, TTO, '985 Project', and other dummies. In models 2–3, we introduce collaboration breadth and its squared terms into the analysis. Similarly, in models 4–5, we introduce collaboration depth into the regression. The last column reports the effect of interaction of collaboration breadth and collaboration depth. Before we enter the interaction term, we first standardize and then form the interaction.

Hypothesis 1 predicts that collaboration breadth will have a curvilinear relationship with academic research performance. In Model 3 in Table 4, the coefficient for collaboration breadth is positive and significant, but the squared term fails to provide a good fit in Model 3. This indicates that Hypothesis 1 is not supported; however, it suggests a positive, linear effect of collaboration breadth on university academic research. We discuss the possible explanations for the linear effect of collaboration breadth in the conclusion and discussion section. Hypothesis 2 proposes a curvilinear relationship between collaboration depth and academic research performance. In Model 5 in Table 4, the coefficient for collaboration depth is positive, and that for the squared term of collaboration depth is negative and significant, supporting Hypothesis 2 and indicating that a curvilinear relationship exists. Hypothesis 3 predicts that collaboration breadth and collaboration depth leverage each other, yielding a combined negative effect on academic research performance. The estimated negative interaction between collaboration breadth and collaboration depth in Model 6 in Table 4 offers support for this hypothesis. We plot the interaction effect in Fig. 4.

Regarding the control variables, it is found that university reputation and human investment have a consistent positive effect on academic research performance, as predicted. However, TTO and research capability have inconsistent effects on academic research performance. University location appears to not matter for university academic research. TTO has been widely recognized as an important structural change at a university to foster technology transfer, and it explains much of the university–industry collaboration performance in Western countries; however, it has an inconsistent effect on academic performance. Our finding is in accordance with this study. It is surprising that research

Table 4 Results of regression analysis

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	7.923***	7.607***	7.589***	7.728***	7.773***	7.724***
	(0.196)	(0.245)	(0.287)	(0.198)	(0.197)	(0.280)
University reputation	0.191***	0.201***	0.201***	0.176***	0.164***	0.182***
	(0.0488)	(0.0472)	(0.0467)	(0.0448)	(0.0454)	(0.0437)
Research capability	0.0461	0.0399	0.0399	0.0480*	0.0513*	0.0395
	(0.0286)	(0.0297)	(0.0299)	(0.0286)	(0.0272)	(0.0273)
TTO	0.123*	0.137*	0.137*	0.0988	0.101	0.104
	(0.0715)	(0.0704)	(0.0705)	(0.0696)	(0.0681)	(0.0706)
Human investment	0.224***	0.233***	0.233***	0.238***	0.231***	0.232***
	(0.0769)	(0.0755)	(0.0768)	(0.0693)	(0.0678)	(0.0677)
985 project	0.166	0.151	0.152	0.136	0.127	0.120
	(0.171)	(0.165)	(0.165)	(0.164)	(0.163)	(0.157)
Middle China	0.0160	0.0183	0.0173	−0.00505	0.0269	0.0114
	(0.150)	(0.147)	(0.146)	(0.135)	(0.137)	(0.134)
West China	0.296	0.316	0.315	0.295	0.336	0.322
	(0.241)	(0.236)	(0.236)	(0.236)	(0.234)	(0.228)
Breadth		0.0464***	0.0486*			−0.000651
		(0.0178)	(0.0285)			(0.0303)
Breadth squared			0.00283			
			(0.0144)			
Depth				0.0692***	0.0771***	0.0780***
				(0.0185)	(0.0206)	(0.0198)
Depth squared					−0.0458**	
					(0.0215)	
Breadth × Depth						−0.0597*
						(0.0338)

Table 4 continued

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Observations	244	244	244	244	244	244
Deviance	38.11	35.83	35.92	31.11	31.90	30.10
df_m	14	15	16	15	16	17

Dummies for university types and years were included but are not shown, Standard errors in parentheses, Two-tailed tests for variables

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

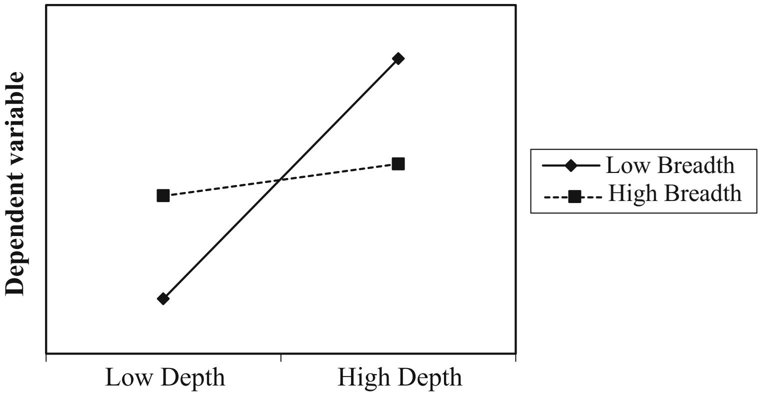

Fig. 4 The interaction effect of breadth with depth

capability (measured as number of national projects) shows an inconsistent effect on academic research performance. This may be explained by the huge waste of research inputs in a Chinese university; many universities have applied many projects but have lower performance.

Additionally, we conduct a robustness check when we split our dependent variable, i.e., the number of published papers, into individual Chinese journal articles and international journal articles, and patent applications. These additional analyses provide consistent results. Moreover, we conduct analyses without lagging controls. Thus, we have full observations from 2009 to 2013. However, we still found large differences pertaining to our key independent variables. These additional analyses are available upon request from the authors.

Conclusion and discussion

In the past few decades, it has been observed that increasingly more universities, in both advanced and emerging countries, have become increasingly involved in industrial innovation and development, the so-called third mission. There also emerged beliefs that industrial involvement coincides with university academic research, while empirical work has failed to provide grounded evidence to support this hypothesis. Some pioneering scholars have sought to reconcile this inconsistency by acknowledging the variety of channels through which knowledge is transferred from universities to industry because in existing studies, scholars essentially limited their focal channels to one or two, not capturing the complete picture of university–industry collaborations. Thus, it is necessary to investigate the combinatory effects of various channels that are together responsible for the overall academic performance; in addition, it is difficult to separate each channel's independent contribution. However, this new insight lacks empirical evidence.

In this study, we therefore are motivated to investigate the relationship between university collaboration channels and academic research performance through a fresh and overall view of various channels. Specifically, we defined two key variables to characterize a university's overall collaboration channels, the collaboration breadth, and collaboration depth. Subsequently, the study was executed in an integrated manner rather than with a specific channel(s), as was commonly used in prior studies.

Using unique archival sources in Chinese universities, we empirically examined the relationships between collaboration breadth, collaboration depth and academic research performance by using a panel dataset of 61 universities that were directly supervised by the China Ministry of Education during the period of 2009–2013. Empirical results suggest that a university's collaboration breadth has a positive effect on its academic research performance, while collaboration depth shows a curvilinear effect on academic research performance. The interaction of collaboration breadth and collaboration depth exerts a negative effect on academic research performance.

Our study adds to the literature in several ways. Prior work on university–industry collaboration has frequently focused on specific collaboration channels and explored their impact on academic research. A key contribution of this study is the idea that instead of focusing on specific channels, we need also focus on the overall characteristics of a channel portfolio. Different dimensions (e.g., breadth and depth in our study) have different effects on academic research. We argue that universities can differentiate their university–industry collaborations as to the scope of their channels in addition to the extent to which they deepen each channel. Thus, we extend the current research on university–industry collaboration channels from a separate and independent view to a portfolio view to capture a complete picture of various channels. Relatedly, we draw attention to the fact that adopting and cultivating a specific channel is important; however, more importantly, managing various channels simultaneously becomes vital.

Next, our study extends our understanding of the recent argument of the multifaceted nature of university–industry relationships in a structural view. Traditionally, university–industry relationships have referred to patenting, licensing activities, and spin-offs. Recently, attention has shifted to forms of interaction that involve direct collaboration between university and industry (Cohen et al. 2002; Perkmann and Walsh 2008). Thus, scholars have increasingly realized the multifaceted nature of university–industry relationships. Particularly, in 2013, Perkmann et al. (2013) advance this discussion substantially by distinguishing two distinct categories of university–industry relationships, defined as university engagement and university commercialization. They suggest that academic engagement is distinct from commercialization in that it is thoroughly associated with traditional academic research activities and pursued by academics to access resources supporting their research agendas, such as collaborative research, contract research and consulting and informal channels. However, this line of discussion focused solely on the nature of collaboration forms and ignored the structural aspect. Our study therefore emphasizes the different structural characteristics (e.g., breadth and depth in the present study) within a university's collaboration channel portfolio.

This study also expands the work on university–industry collaboration to a new realm, emerging countries. Prior work has highlighted the important role of universities in advanced countries owing to their role in fostering new knowledge generation and diffusion. Relatedly, extent literature has focused great attention on understanding the nature of university–industry relationships and their implications for both industry and universities. As a result, we know little regarding the university–industry relationship in emerging countries. Our research setting based on Chinese universities could thus readdress this imbalance and provide new insights for this line of study. For instance, we did not find a positive relationship between academic research investments and academic outputs, as evidenced in western countries.

The unexpected result of this research, i.e., the linear effect of collaboration breadth on academic research performance instead of the expected curvilinear effect, deserves more attention. A possible explanation is that in the empirical sample of this research, few companies have 'over-collaborated' along this dimension. Thus far, there is no answer for how many channels are available for universities to use. To our best knowledge, the maximum number is 23 in the work by Bekkers and Bodas Freitas (2008). In our study, limited to the available data, we included seven channels in our analysis. Thus, compared to 23, our analysis only represents a small portion of channels. Consequently, instead of a nonlinear relationship, only the linear, increasing portion of the curve was detected.

Our study also offers useful implications for university administrators, particularly those in charge of university–industry collaboration issues such as TTO officers. We suggest that attention should be focused on the overall characteristics of their channels. First, simply extending their channel scope or deepening into a number of channels may not improve their academic research performance through university–industry collaborations. Traditional channels are familiar to universities, but they are not always beneficial for academic research. Seeking new channels and gaining incremental familiarity with them becomes increasingly imperative. Our results suggest that universities must improve their academic research in one way, either to extend the channel scope or to deepen into particular channels.

Despite these contributions to the literature, we should acknowledge that there are research limitations, which also compose future avenues of research. First, although we benefit from a unique dataset, the sample size remains small. Future study may reexamine our results, use other similar datasets or wait until we can have more sample universities in later years, particularly, appropriately assigned coauthored papers into relevant institutions. Second, because many university–industry collaboration channels are informal and difficult to observe, a combined dataset with an archival resource with questionnaire-based survey data may identify more channels and reexamine our results in future study. Third, in this study, we propose two collaboration strategies, namely breadth and depth. Indeed, these concepts also might be interpreted into diversity/complexity, and intensity which can be related to some theories such as network, transaction cost and resource-based view of firm. Future study thus is suggested to take a broad view of collaboration strategies to fully understand a university's collaboration strategies. Finally, we must acknowledge that this study investigated academic research performance in a quantitative manner; future studies may investigate in a qualitative manner, for instance using a number of papers published in science citation-indexed journals. Again, because industry-collaboration has a wide impact not only on academic research but also on teaching activities, future research should push this research forward to examine how a university's different collaboration strategies influence its teaching quality.

References

Agrawal, A. K. (2001). University-to-industry knowledge transfer: Literature review and unanswered questions. *International Journal of Management Reviews, 3*(4), 285–302.

Agrawal, A., & Henderson, R. (2002). Putting patents in context: Exploring knowledge transfer from MIT. *Management Science, 48*(1), 44–60.

Arza, V., & Vazquez, C. (2010). Interactions between public research organisations and industry in Argentina. *Science and Public Policy, 37*(7), 499–511.

Audretsch, D. B., & Link, A. N. (2012). Entrepreneurship and innovation: Public policy frameworks. *The Journal of Technology Transfer, 37*(1), 1–17.

Balázs, K., Faulkner, W., & Schimank, U. (1995). Transformation of the research systems of post-communist Central and Eastern Europe: An introduction. *Social Studies of Science, 25*(4), 613–632.

Balázs, K., & Plonski, G. A. (1994). Academic-industry relations in middle-income countries: East Europe and Ibero-America. *Science and Public Policy, 21*(2), 109–116.

Balconi, M., & Laboranti, A. (2006). University–industry interactions in applied research: The case of microelectronics. *Research Policy, 35*(10), 1616–1630.

Baldini, N. (2006). University patenting and licensing activity: A review of the literature. *Research Evaluation, 15*(3), 197–207.

Behrens, T. R., & Gray, D. O. (2001). Unintended consequences of cooperative research: Impact of industry sponsorship on climate for academic freedom and other graduate student outcome. *Research Policy, 30*(2), 179–199.

Bekkers, R., & Bodas Freitas, I. M. (2008). Analysing knowledge transfer channels between universities and industry: To what degree do sectors also matter? *Research Policy, 37*(10), 1837–1853.

Benner, M., & Sandström, U. (2000). Institutionalizing the triple helix: Research funding and norms in the academic system. *Research Policy, 29*(2), 291–301.

Bhattacharya, S., & Arora, P. (2007). Industrial linkages in Indian universities: What they reveal and what they imply? *Scientometrics, 70*(2), 277–300.

Blumenthal, D., Campbell, E. G., Causino, N., & Louis, K. S. (1996). Participation of life-science faculty in research relationships with industry. *New England Journal of Medicine, 335*(23), 1734–1739.

Blumenthal, D., Causino, N., & Campbell, E. G. (1997). Academic-industry research relationships in genetics: A field apart. *Nature Genetics, 16*, 104–108.

Bozeman, B. (2000). Technology transfer and public policy: A review of research and theory. *Research Policy, 29*(4–5), 627–655.

Bray, M. J., & Lee, J. N. (2000). University revenues from technology transfer: Licensing fees vs. equity positions. *Journal of Business Venturing, 15*(5–6), 385–392.

Breschi, S., & Catalini, C. (2010). Tracing the links between science and technology: An exploratory analysis of scientists' and inventors' networks. *Research Policy, 39*(1), 14–26.

Brooks, H., & Randazzese, L. (1999). University–industry relations: The next four years and beyon. In L. M. Branscomb & J. Keller (Eds.), *From investing in innovation: Creating and innovation policy that works* (pp. 361–399). Combridge: MIT Press.

Bulut, H., & Moschini, G. (2009). US universities' net returns from patenting and licensing: A quantile regression analysis. *Economics of Innovation and New Technology, 18*(2), 123–137.

Chataway, J., & Hewitt, T. (1999). Managing institutional change in the science and technology systems of Eastern Europe and East Africa. *Development in Practice, 9*(1–2), 88–102.

Chatterjee, S., & Price, B. (1991). *Regression analysis by example*. New York: Wiley.

Cohen, W. M., Florida, R., Randazzese, L., & Walsh, J. (1998). Industry and the academy: Uneasy partners in the cause of technological advance. In R. Noll (Ed.), *Challenges to research universities*. Washington, DC: Brookings Institution Press.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly, 35*, 128–152.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and impacts: The influence of public research on industrial R&D. *Management Science, 48*(1), 1–23.

Colyvas, J., Crow, M., Gelijns, A., Richard, R. M., Nelson, R. R., Rosenberg, N., & Sampa, B. N. (2002). How do university inventions get into practice? *Management Science, 48*(1), 61–72.

D'Este, P., & Patel, P. (2007). University–industry linkages in the UK: What are the factors underlying the variety of interactions with industry? *Research Policy, 36*(9), 1295–1313.

Datta, S., & Saad, M. (2008). Social capital and university–industry–government networks in offshore outsourcing—the case of India. *Technology Analysis and Strategic Management, 20*(6), 741–754.

Dutrénit, G., & Arza, V. (2010). Channels and benefits of interactions between public research organisations and industry: Comparing four Latin American countries. *Science and Public Policy, 37*(7), 541–553.

Etzkowitz, H. (1998). The norms of entrepreneurial science: Cognitive effects of the new university–industry linkages. *Research Policy, 27*(8), 823–833.

Etzkowitz, H., de Carvalho Mello, J. M., & Jose, M. (2004). The rise of a triple helix culture: Innovation in Brazilian economic and social development. *International Journal of Technology Management & Sustainable Development, 2*(3), 159–173.

Etzkowitz, H., & Klofsten, M. (2005). The innovating region: Toward a of knowledge-based regional development. *R&D Management, 35*(3), 243–255.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From national systems and "Mode 2" to a triple helix of university–industry–government relations. *Research Policy, 29*(2), 109–123.

Eun, J.-H., Lee, K., & Wu, G. (2006). Explaining the "University-run enterprises" in China: A theoretical framework for university–industry relationship in developing countries and its application to China. *Research Policy, 35*(9), 1329–1346.

Florida, R., & Cohen, W. M. (1999). Engine or infrastructure? The university role in economic development. In L. M. Branscomb, F. Kodama, & R. Florida (Eds.), *From industrializing knowledge. University–industry linkages in Japan and the United States* (pp. 589–610). Cambridge MA/london: MIT Press.

Fontana, R., Geuna, A., & Matt, M. (2006). Factors affecting university–industry R&D projects: The importance of searching, screening and signalling. *Research Policy, 35*(2), 309–323.

Geuna, A., & Muscio, A. (2009). The governance of university knowledge transfer: A critical review of the literature. *Minerva, 47*(1), 93–114.

Geuna, A., & Nesta, L. (2003). *University patenting and its effects on academic research*. No. 99. SPRU-Science and Technology Policy Research, University of Sussex.

Geuna, A., & Nesta, L. J. J. (2006). University patenting and its effects on academic research: The emerging European evidence. *Research Policy, 35*(6), 790–807.

Giuliani, E., & Arza, V. (2009). What drives the formation of 'valuable' university–industry linkages? Insights from the wine industry. *Research Policy, 38*(6), 906–921.

Gluck, M. E., Blumenthal, D., & Stoto, M. A. (1987). University–industry relationships in the life sciences: Implications for students and post-doctoral fellows. *Research Policy, 16*(6), 327–336.

Godin, B., & Gingras, Y. (2000). Impact of collaborative research on academic science. *Science and Public Policy, 27*(1), 65–73.

González-Pernía, J. L., Kuechle, G., & Peña-Legazkue, I. (2013). An assessment of the determinants of university technology transfer. *Economic Development Quarterly, 27*(1), 6–17.

Greene, W. (2003). *Econometric analysis* (5th ed.). Upper Saddle River: Pretice-Hall.

Gulbrandsen, M., & Smeby, J.-C. (2005). Industry funding and university professors' research performance. *Research Policy, 34*(6), 932–950.

Harmon, B., Ardishvili, A., Cardozo, R., Elder, T., Leuthold, J., Parshall, J., et al. (1997). Mapping the university technology transfer process. *Journal of Business Venturing, 12*(6), 423–434.

Hemmert, M., Bstieler, L., & Okamuro, H. (2014). Bridging the cultural divide: Trust formation in university–industry research collaborations in the US, Japan, and South Korea. *Technovation, 34*(10), 605–616.

Hicks, D., & Hamilton, K. S. (1999). Does university–industry collaboration adversely affect university research? *Issues in Science and Technology, Summer, 99*(16), 74–75.

Hilbe, J. M. (2011). *Negative binomial regression* (2nd ed.). Combridge: Cambridge University Press.

Jeong, S., Choi, J. Y., & Kim, J. (2011). The determinants of research collaboration modes: Exploring the effects of research and researcher characteristics on co-authorship. *Scientometrics, 89*(3), 967–983.

Johnson, A. (2001). 'Functions in innovation system approaches,' In Editor (ed.)^(eds.), From *Book Functions in innovation system approaches*, City, at.

Katila, R. (2002). New product search over time: Past ideas in their prime? *Academy of Management Journal, 45*(5), 995–1010.

Landry, R., & Amara, N. (1998). The impact of transaction costs on the institutional structuration of collaborative academic research. *Research Policy, 27*(9), 901–913.

Lee, Y. S. (1996). 'Technology transfer' and the research university: A search for the boundaries of university–industry collaboration. *Research Policy, 25*(6), 843–863.

Lee, S., & Bozeman, B. (2005). The impact of research collaboration on scientific productivity. *Social Studies of Science, 35*(5), 673–702.

Leydesdorff, L., & Meyer, M. (2003). The triple helix of university–industry-government relations. *Scientometrics, 58*(2), 191–203.

Li, X. (2009). China's regional innovation capacity in transition: An empirical approach. *Research Policy, 38*(2), 338–357.

Liang, L., Chen, L., Wu, Y., & Yuan, J. (2012). The role of Chinese universities in enterprise–university research collaboration. *Scientometrics, 90*(1), 253–269.

Liang, K.-Y., & Zeger, S. L. (1986). Longitudinal data analysis using generalized linear models. *Biometrika, 73*(1), 13–22.

Link, A. N., Siegel, D. S., & Bozeman, B. (2007). An empirical analysis of the propensity of academics to engage in informal university technology transfer. *Industrial and Corporate Change, 16*(4), 641–655.

Liu, X. (2005). 'China's development model: An alternative strategy for technological catch-up,' in Editor (ed.)^(eds.), From *book China's development model: An alternative strategy for technological catch-up*, City, at.

Liu, X., & White, S. (2001). Comparing innovation systems: A framework and application to China's transitional context. *Research Policy, 30*(7), 1091–1114.

Li-Ying, J., Wang, Y., & Salomo, S. (2014). An inquiry on dimensions of external technology search and their influence on technological innovations: Evidence from Chinese firms. *R&D Management, 44*(1), 53–74.

Lundvall, B.-Å., Intarakumnerd, P., & Vang-Lauridsen, J. (2006). *Asia's innovation systems in transition* Cheltenham, UK; Northampton, MA: E. Elgar, at http://www.loc.gov/catdir/toc/ecip062/2005031680.html.

Lv, P. (2014). How does openness affect innovation? Evidence from national key laboratories in China. *Science and Public Policy, 41*, 180–193.

Malik, T. H. (2013). National institutional differences and cross-border university–industry knowledge transfer. *Research Policy, 42*(3), 776–787.

Mansfield, E. (1995). Academic research underlying industrial innovations: Sources, characteristics, and financing. *The Review of Economics and Statistics, 77*(1), 55–65.

Mansfield, E., Romeo, A., Schwartz, M., Teece, D., Wagner, S., & Brach, P. (1982). *Technology transfer, productivity, and economic policy*. New York: Norton.

Maruyama, M. (1988). Technology policy and economic performance: Lessons from Japan : Christopher Freeman 155 pages, ? 0.00 (London, Frances Pinter, 1987). *Futures, 20*(2), 210–213.

Meyer-Krahmer, F., & Schmoch, U. (1998). Science-based technologies: University–industry interactions in four fields. *Research Policy, 27*(8), 835–851.

Motohashi, K. (2005). University–industry collaborations in Japan: The role of new technology-based firms in transforming the national innovation system. *Research Policy, 34*(5), 583–594.

Motohashi, K., & Yun, X. (2007). China's innovation system reform and growing industry and science linkages. *Research Policy, 36*(8), 1251–1260.

Mowery, D. C., Nelson, R. R., Sampat, B. N., & Ziedonis, A. A. (2001). The growth of patenting and licensing by U.S. universities: An assessment of the effects of the Bayh–Dole act of 1980. *Research Policy, 30*(1), 99–119.

Mowery, D. C., & Ziedonis, A. A. (2001). The geographic reach of market and non-market channels of technology transfer: Comparing citations and licenses of university patents. In C. John (Ed.), *From globalization and the location of firms*. Northampton, MA: Edward Elgar Publishing Limited.

Mowery, D. C., & Ziedonis, A. A. (2002). Academic patent quality and quantity before and after the Bayh–Dole act in the United States. *Research Policy, 31*(3), 399.

Narin, F., Hamilton, K. S., & Olivastro, D. (1997). The increasing linkage between U.S. technology and public science. *Research Policy, 26*(3), 317–330.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., et al. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations. *Research Policy, 42*(2), 423–442.

Perkmann, M., & Walsh, K. (2008). Engaging the scholar: Three types of academic consulting and their impact on universities and industry. *Research Policy, 37*(10), 1884–1891.

Perkmann, M., & Walsh, K. (2009). The two faces of collaboration: Impacts of university–industry relations on public research. *Industrial and Corporate Change*.

Rapini, M. S., e Albuquerque, E. D. M., Chave, C. V., Silva, L. A., de Souza, S. G. A., Righi, H. M., & da Cruz, W. M. S. (2009). University–industry interactions in an immature system of innovation: Evidence from Minas Gerais, Brazil. *Science and Public Policy, 36*(5), 373–386.

Rasmussen, E., Moen, Ø., & Gulbrandsen, M. (2006). Initiatives to promote commercialization of university knowledge. *Technovation, 26*(4), 518–533.

Rosenberg, N., & Nelson, R. R. (1994). American universities and technical advance in industry. *Research Policy, 23*(3), 323–348.

Sa, C. M., & Litwin, J. (2011). University–industry research collaborations in Canada: The role of federal policy instruments. *Science and Public Policy, 38*(6), 425–435.

Schartinger, D., Schibany, A., & Gassler, H. (2001). Interactive relations between universities and firms: Empirical evidence for Austria. *The Journal of Technology Transfer, 26*(3), 255–268.

Schrader, S. (1991). Informal technology transfer between firms: Cooperation through information trading. *Research Policy, 20*(2), 153–170.

Shane, S. (2002). Selling university technology: Patterns from MIT. *Management Science, 48*(1), 122–137.

Siegel, D. S., Veugelers, R., & Wright, M. (2007). Technology transfer offices and commercialization of university intellectual property: Performance and policy implications. *Oxford Review of Economic Policy, 23*(4), 640–660.

Slaughter, S., & Leslie, L. L. (1997). *Academic capitalism: Politics policies and the entrepreneurial university*. Baltimore, MD: Johns Hopkins University Press.

Sutz, J. (2000). The university–industry–government relations in Latin America. *Research Policy, 29*(2), 279–290.

Teixeira, A. C., & Mota, L. (2012). A bibliometric portrait of the evolution, scientific roots and influence of the literature on university–industry links. *Scientometrics, 93*(3), 719–743.

Thursby, J. G., & Thursby, M. C. (2002). Who is selling the ivory tower? Sources of growth in university licensing. *Management Science, 48*(1), 90–104.

Van Looy, B., Callaert, J., & Debackere, K. (2006). Publication and patent behavior of academic researchers: Conflicting, reinforcing or merely co-existing? *Research Policy, 35*(4), 596–608.

Van Looy, B., Ranga, M., Callaert, J., Debackere, K., & Zimmermann, E. (2004). Combining entrepreneurial and scientific performance in academia: Towards a compounded and reciprocal Matthew-effect? *Research Policy, 33*(3), 425–441.

Villasana, M. (2011). Fostering university–industry interactions under a triple helix model: The case of Nuevo Leon, Mexico. *Science and Public Policy, 38*(1), 43–53.

Wang, Y., Huang, J., Chen, Y., Pan, X., & Chen, J. (2013a). Have Chinese universities embraced their third mission? New insight from a business perspective. *Scientometrics, 97*(2), 207–222.

Wang, Y., & Li-Ying, J. (2014). When does inward technology licensing facilitate firms' NPD performance? A contingency perspective. *Technovation, 34*(1), 44–53.

Wang, Y., Pan, X., Chen, Y., & Gu, X. (2013b). Do references in transferred patent documents signal learning opportunities for the receiving firms? *Scientometrics, 95*(2), 731–752.

Wang, Y., & Zhou, Z. (2013). The dual role of local sites in assisting firms with developing technological capabilities: Evidence from China. *International Business Review, 22*(1), 63–76.

Williams, D. (2011). Russia's innovation system: Reflection on the past, present and future. *International Journal of Transitions and Innovation Systems, 1*(4), 394–412.

Xue, L. (1997). A historical perspective of China's innovation system reform: A case study. *Journal of Engineering and Technology Management, 14*(1), 67–81.

Zhou, W. (2012). Determinants and effects of research partnerships in China's emerging market. *Contemporary Economic Policy, 30*(1), 129–147.

Zucker, L. G., Darby, M. R., & Armstrong, J. (1998). Geographically localized knowledge: Spillovers or markets? *Economic Inquiry, 36*, 65–86.