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The effect of institutional proximity in non-local university–industry collaborations: An analysis based on Chinese patent data

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ABSTRACT

Based on Chinese patent data from 1985 to 2004, this study aims to provide a comprehensive analysis of formal university–industry collaborations in China, with a specific focus on the compound effect of geographic distance and other predictors. The results show that geographic distance is indeed an obstructive factor in achieving university–industry collaborations, as many previous studies have shown. However, proximities in other dimensions could intervene to attenuate that negative effect. The most salient finding is that central Ministries and local governments are two sources of institutional force that could impose or encourage university–industry collaborations without considering the geographic distance between them. The vertical and horizontal institutional proximities engendered by subordination to the same administrative unit significantly enhance the probability of collaboration, and those effects are more significant when the distance increases. Social proximity and university prestige, as verified by previous studies, could also help bring non-local academic and industrial partners together. However, when confronting with institutional interference that is of overarching importance in the Chinese context, these effects could decrease.

1. Introduction

Knowledge produced by the public sector has been traditionally viewed as a public good contributing to economic growth (Arrow, 1962; Nelson, 1959). A large number of studies have verified the effect of academic research on industry innovation. (Adams, 1990; Mansfield, 1991; Rosenberg and Nelson, 1994). As a major source of new knowledge, research universities play a key role in promoting technological innovation. In the past 30 years, governments of many Western countries adopted an innovation-oriented science policy, with an emphasis on promoting university–industry linkages (e.g., Ballesteros and Rico, 2001; Beesley, 2003; Liu and White, 2001). Though not opening her doors until the late 1970s, the Chinese government has been advocating an application- oriented science policy since the 1950s, encouraging universities to engage in down-stream work to improve industrial capabilities. With the beginning of economic reforms and its WTO ascension in 2001, China has been increasingly involved in international competition. In the eyes of the state, universities and research institutes are thus expected to conduct cutting-edge research and effectively transfer knowledge to Chinese industry in order to enhance its competitiveness.

Nonetheless, various studies (e.g., Hicks et al., 2001; Jaffe, 1989; Jaffe et al., 1993; Zucker et al., 1998a) conducted in the US have found that knowledge transfers from universities to industry are to a large extent confined to the local area, suggesting that broadening the impact of university research on industry may require special measures. A large body of literature ensued to study whether geographic distance is a detrimental factor in university–industry collaborations and whether other factors might be complementary to geographic proximity (e.g. Adams, 2005; Broström, 2010; D'Este and Iammarino, 2010; Laursen et al., 2011). Specifically, the French School of Proximity Dynamics introduces multiple dimensions of proximity and argues that these proximities are no less important than geographic proximity in promoting interactive learning and innovation (e.g. Kirat and Lung, 1999; Torre and Gilly, 2000). Boschma (2005) further elaborates this work by discussing the proper level of various proximities and whether cognitive, social, organisational, and institutional proximities can be complementary to geographic proximity. While these discussions on proximities shed new light on our understanding of collective learning, most of the claims have not been verified by empirical study. Moreover, the interaction effect between institutional and geographic proximities has not been clearly specified. That is probably because institutional proximity has been treated as a vague and abstract term functioning at the macro level. It is therefore

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difficult to either find a measuring variable for it or analyse how it interacts with geographic distance.

Based on interviews conducted with Chinese academics and technology transfer officials in the summer of 2004, the contribution of Chinese publications and conferences to industry innovativeness is trivial. University–industry collaborations, encouraged by the government since the 1950s, and pursued by more and more companies due to China's economic reform, is one of the key mechanisms for transferring knowledge from university to industry. Using patent co-applications by universities and firms as an indicator for university–industry collaboration, this study empirically examines the effect of organisational, institutional, and social proximities on university–industry collaborations in China from 1985 to 2004 and specifically tests the interaction effects between these proximities and geographic distance.

The most salient finding from this study is that the vertical and horizontal institutional proximities engendered by subordination to the same administrative unit significantly enhance the probability of collaboration, and these effects are more significant when the distance increases. Stories from interviewees further suggest that other major predictors (i.e. prior collaboration experience and university prestige) might lose their effects when confronting with institutional interference that is of overarching importance in the Chinese context. The results not only show a key mechanism connecting universities and industry in China, but also empirically test propositions long held in this field. The unique Chinese context in which many universities and firms are administered by various units constitutes the bases of our research. It enables the specific expression of institutional proximity as a socialist legacy, as well as facilitates comparative investigations in other institutional settings.

The paper is organised into five sections. The following section reviews the literature from multiple disciplines and proposes five hypotheses. The third section introduces the data and methods used. The fourth section presents the results and specifically shows the interaction effects between organisational, institutional and social proximities and geographic distance. The fifth section offers conclusions based on our analysis.

2. Theoretical background

The literature on inter-organisational relationships has found the importance of geographic proximity in building inter-organisational ties (Green, 1983; Harrison, 1994; Kono et al., 1998; Molotch, 1976; Perrucci and Pilisuk, 1970; Scott, 1988). Green (1983) has shown that distance reduces the level of interlocking between firms in different North American cities. Allen found that local interlocking was more likely to happen because of the operational difficulty involved in long-distance interlocking (1974) or firms' dependence on local resources (1978). Kono et al. (1998) further argued that geographic distance was an important intervening variable in predicting interlocking ties between corporations, which had been neglected in many previous studies.

Given the importance of university knowledge to industry innovativeness, social scientists and policy makers have been concerned that whether the channels connecting universities and industry are confined to the local area. Various studies have shown that university research enhances local industry innovativeness at the state level (Audrestch and Feldman, 1996; Branstetter, 2000; Jaffe, 1989) and the sub-state level (Anselin et al., 1997), suggesting that knowledge externalities are geographically constrained. Treating patent citations as paths of knowledge flow, Jaffe and his colleagues (Henderson et al., 1998; Jaffe and Trajtenberg, 1996, 1999; Jaffe et al., 1993) have revealed that knowledge spillovers are localised, especially in early years when the knowledge was created. Based on the same methodology, Hicks et al. (2001) found that corporate patents cited more locally produced academic papers, indicating that publication, as a channel transferring knowledge from academia to industry, is subject to geographic constraints. Zucker, Darby and their colleagues (Zucker and Darby, 1996; Zucker et al., 1998a,b) also emphasised that localised ties with star scientists were important for firm performance. Some firms even purposely located themselves near star scientists.

One major reason why geographic proximity is important is that much knowledge used in actual production is tacit, requiring face to face interaction to transfer (Polanyi, 1967). Various studies have shown that distance impedes the flow of knowledge and technology (Acs et al., 1994; Polanyi, 1967; Scott, 1988; Tyre and Von Hippel, 1997) and reduces communication efficiency even within the same organisation (Hough, 1972; Tomlin, 1981). Feldman and Lichtenberg (1997) observed geographically concentrated organisations when knowledge transferred among them was tacit. Audretsch and Stephan (1996) also found that the costs of transferring tacit knowledge increased with distance. Economic geographers have been arguing that tacit knowledge accumulated through close interactions within specialised industrial clusters is a key component in constructing learning regions and that the difficulty in transferring this form of tacit knowledge constitutes the competitive advantage of these successful regions (Cooke and Morgan, 1998; Morgan, 1997; Storper, 1997).

However, some other studies conducted in the U.S., Japan, and Europe have found that geographic proximity does not necessarily facilitate university–industry interactions (Beise and Stahl, 1999; Bercovitz and Feldman, 2011; Schartinger et al., 2002; Zucker and Darby, 2001). The French School of Proximity Dynamics also claims that geographic proximity is just one dimension of multiple forms of proximities to consider in collective learning (Kirat and Lung, 1999; Torre and Gilly, 2000). Boschma (2005) further theorises five types of proximity and proposes that they can be complementary assets to geographic proximity. His theoretical discussion raises questions of the relationship between institutional and geographic proximity which can be clarified through empirical study.

Having seen these unexplored aspects of previous studies, and corresponding to the call for systematic studies of the contingent effect of geographic distance (Broström, 2010), this paper is intended to offer a comprehensive analysis by empirically testing the interaction effect between geographic distance and organisational proximity, institutional proximity, social proximity and university prestige.

2.1. Organisational proximity

Boschma (2005) has drawn extensively on transaction cost theory to develop the concept of organisational proximity. Williamson (1975, 1985) outlines two ideal types of organizing – the market and hierarchy – representing buying a product from the market and producing it within an organisation, respectively. The decision to buy or to make is determined by the specificity of the product and in turn determined by the transaction cost involved (Williamson, 1981). According to Boschma (2005), therefore, organisational proximity is a continuous variable measuring to what extent two organisations share the same organisational regulation, with the low extreme representing arm-length market relationships in a market and the high extreme being hierarchical control within an organisation. While admitting the importance of geographic proximity in knowledge transfers, Boschma (2005) has argued that organisational proximity can to some extent substitute geographic proximity.

Learning from Soviet Union, the Chinese government developed a highly centralised governmental structure. Below the State Planning Commission (SPC) that has ultimate control over economic

plans and resource allocation, there are a range of central Ministries that oversee different activities. Often times, a Ministry in charge of an important industry also oversees one or more universities and research institutes specializing in that industry. If we view the central Ministries as huge organisations, universities and firms subordinated to the same Ministry are predicted to have high organisational proximity. In the planned economy, firms were often assigned an academic partner belonging to the same Ministry, regardless of the geographic distance between them. A 1994 education reform urged decentralisation in the supervision of universities in order to increase efficiency (Hayhoe and Zha, 2004; Yang, 2000). As a result, only 35 of the 358 national universities were still solely overseen by a central Ministry, the Ministry of Education. Supervision of the other 323 universities was distributed among 62 central Ministries as well as their local governments (Qian and Verhoeven, 2004). This reform to some extent reduced organisational proximity between universities and firms belonging to the same Ministry, but we expect that firms still prefer to seek academic advices from within-Ministry research institutions due to organisational inertia (Hannan and Freeman, 1977).

In addition, Ministries prefer to spend their industry R&D funding on their own research institutes and universities.[1] For example, the first author interviewed a firm that had maintained a collaborative relationship with a prestigious university, such that it listed the school as a collaborator in its application for an R&D grant from its supervising Ministry. In response, the Ministry expressed dissatisfaction: "We have so many universities specializing in this field. Why did you choose that university?" The Ministry then recommended collaboration with a college belonging to the Ministry, despite the fact that the research calibre of the recommended college was lower than the prestigious university. The Ministry even provided relevant materials to the college to help it win the following competition. In the end, the firm still chose the prestigious university, suggesting Ministry power is attenuated by university quality and prior collaboration experience. Nonetheless, this case shows the strong effect of organisational proximity.

H1. When we control for organisational proximity by examining a firm and a university subordinate to the same Ministry, the effect of purely geographic proximity will decrease.

However, Ministries are very different from common organisations due to their size and institutional functions. As we argue below, being subordinate to the same central Ministry engenders not only organisational proximity, but also vertical institutional proximity.

2.2. Institutional proximity

While organisational proximity coordinates inter-organisational relationships at the micro-level, institutional proximity helps bring organisations together through sharing similar values and norms at the macro-level (Boschma, 2005; North, 1990). The institution-level values and norms could be informal cultures and habits that foster trust and facilitate interactions (e.g., a common language), or formal laws and rules (e.g., a legal system that effectively secure intellectual property rights) that reduce uncertainty and risks (Edquist and Johnson, 1997; Maskell and Malmberg, 1999; Zukin and DiMaggio, 1990). Torre and Gilly (2000) have argued that institutional and organisational proximity both conform to a similar logic, except that the former functions at a higher level. In that sense, institutional proximity is intricately intertwined with organisational proximity. The central Ministry in China discussed above, which offers both an organisational hierarchy at the micro level and institutional norms and rules at the macro level, is such an exemplar. On the one hand, institutional proximity provides predictable and reliable conditions under which knowledge transfer can effectively take place. The central Ministry thus expected within-Ministry collaborations to happen. On the other hand, too much institutional proximity might cause institutional inertia and obstruct innovation (Boschma, 2005; Herrigel, 1993). We have seen that the relatively prestigious university was rejected at the outset because it was not affiliated with the central Ministry. Therefore, when a firm and a university are subordinate to the same Ministry, their organisational and institutional proximities can compensate for the negative effect of geographic distance, as hypothesised by H1.

While the use of Ministry affiliation as a measure of institutional proximity is innovative, most previous studies see institutional proximity as a vague feeling of intimacy at the regional level. For example, Amin and Thrift (1994) use "institutional thickness" to describe the atmosphere of successful learning regions. Some firms and universities are directly overseen by their local governments in China, this percentage has increased after the decentralizing reform. This enables us to construct another measure of institutional proximity, the affiliation with the local governments. Some local governments do not want their local firms to provide research funding to a non-local university. A professor in Hubei province offered a story:

An automobile factory in Hunan province once tried to collaborate with us to develop a hybrid electric vehicle. We almost signed our contract. You know what? The Science and Technology Office in Hunan province did not approve it. It said, "We have Hunan University.[2] It's in the same city with you. Why don't you collaborate with it?" We finally lost the contract.

The local government prefers to match firms with local universities because the officers are more likely to get promotions if significant innovations are made due to their efforts. Another concern is that the local government wants to keep its money within its territory. Firms and universities, if institutionally proximate, are supposed to be aware of these expectations. Therefore, businesses and educational institutions under the administration of the same local government are more likely to collaborate.

H2. When we control for institutional proximity by examining a firm and a university subordinate to the same local government, the effect of purely geographic proximity will decrease.

In China, power over a range of matters has been distributed vertically and horizontally for a long time. This so-called "fragmented authoritarianism" (Lieberthal, 1995) indicates the potential conflict between central Ministries and local governments. In that sense, institutional proximity tested by H1 and H2 could be named as vertical and horizontal institutional proximity respectively. Liu and White (2001) have criticised that decision-making in China's national innovation system is highly multi-centric. This has prevented primary actors from adopting innovations and initiating collaborative linkages. Therefore, China's universities and firms might be burdened by too much institutional proximity (Boschma, 2005), as well as conflicting institutional proximity.

2.3. Social proximity

Opportunism is a major source of uncertainty in university–industry collaborations, as well as in other inter-organisational relationships. My interviews with Chinese academics and technology transfer officials suggest it is quite

[1] While universities have mandates of both education and research, research institutes only carry out research activities.

[2] In this case, Hunan University is also less prestigious than the university in Hubei.

common that a firm will not pay the full amount of money listed on its development contract with universities. This type of unethical behaviour is mostly attributed to small private firms. A Chinese technology transfer officer stated their strategies for dealing with this kind of opportunism:

It has been a big problem. Now we require that firms to pay 40–50% of the contract money at the beginning. We will ask professors if that amount of money is OK with them, because they would better not be expecting the remaining money. We would not help them sue those firms. Lawsuits are too time-consuming. That's why we emphasise the first payment. At least we do not lose too much if cheating occurred.

However, there is also some evidence of opportunism on the part of professors as well, typically taking the form of over-promising in order to get up-front research funds from firms.

From an economist's perspective, people always try to take advantage of others through opportunism because of their self-interest seeking nature. Granovetter (1985) criticised this undersocialised approach and argued that social networks may restrain such opportunistic behaviour. In a study on apparel firms in New York City, Uzzi (1997) claimed that many economic transactions were based on social networks rather than considerations of economic efficiency. People embedded in the social structure do not make their business decisions only based on their self-interest. Therefore, in university–industry collaborations, social networks are expected to play an important role, both in reducing opportunistic behaviour and in the embeddedness effect. These socially embedded relations between organisations, or their "social proximity" (Boschma, 2005; Lundvall, 1993), will reduce uncertainty, promote effective learning in addition to open communication (Lundvall, 1993) and facilitate the transfer of tacit knowledge (Maskell and Malmberg, 1999).

Since interpersonal data are not available for joint patent applications that take place at the organisational level, we measure social proximity based on prior collaborations. We expect social proximity to increase concurrently with increases in collaborative experiences (which build inter-organisational trust through mutual adjustment). It has been verified by many previous studies (Bercovitz and Feldman, 2011; Doz, 1996; Gulati, 1995) that prior collaborations significantly increase the likelihood of future collaborations. Bruneel et al. (2010) have specifically argued that university–industry collaborations are obstructed by two types of barriers for firms, one coming from different values and norms between the two sectors, the other one stemming from transaction costs involved in negotiating legal issues with university administrators. Prior experience working with universities would help firms establish certain routines to adjust with different norms and possible conflicts. Ideally, the two parties will converge in norms and protocols overtime. In that sense, prior collaborations breed not only social proximity, but also organisational and institutional proximity. Under this circumstance, geographic proximity becomes even less important.

H3. When we control for social proximity by examining a firm and a university with prior collaborations, the effect of purely geographic proximity will decrease.

2.4. Prestige

Meyer and Rowan (1977) suggested that firms ceremonially adopted institutional elements from the environment to enhance their legitimacy. For example, by allying with famous companies, small firms gain considerable recognition, reputation, and legitimacy (Barringer and Harrison, 2000; Wiewel and Hunter, 1985). Crawford and Gram (1978) and Schermerborn and Shirland (1981) showed that firms participated in inter-organisational relationships to enhance their reputation and public images. Through a study of the California Wine industry, Benjamin and Podolny (1999) also found that affiliation with high-status partners had a positive impact on the outcome of wine producers, especially for those firms with high status already. Firms sometimes engage in alliances largely for mimetic reasons (Barringer and Harrison, 2000).

Firms might also ally with universities for legitimacy. Those firms contributing to basic research can gain respect from both the industrial and academic sectors (Hirano and Nishigata, 1990). This prestige enhances firm legitimacy (Barringer and Harrison, 2000). In addition, by creating relationships with prestigious universities, firms gain more credibility for the quality of their products. Under these considerations, firms would choose to collaborate with those universities that could provide the firm with improved reputation and legitimacy.

Thus, in theory firms considering their reputation and legitimacy would prefer to collaborate with more prestigious universities. Mansfield and Lee (1996) found that distance reduced a university's probability of being funded by industry, but this effect was mediated by university prestige. While second-tier universities were particularly vulnerable to the effect of distance, top-tier universities were still able to attract remote industrial supporters. Similarly, Adams (2005) argued that firms interested in funding cutting-edge research would collaborate with top-tier universities regardless of distance between them. Laursen et al. (2011) also found that firms prefer to collaborate with top-tier universities rather than second-tier universities nearby. D'Este and Iammarino (2010), different from previous studies, have found a curvilinear relationship between research quality and geographic distance, suggesting that when research quality reach a certain threshold, the effect of geographic proximity becomes salient again. In China, we assume the situation is consistent with the majority of the literature.

H4. When a university has high prestige, the effect of geographic proximity will decrease.

3. Data and methods

Multiple data sources are used in this study. First, Chinese patent data are used to identify ties between universities and industry. The Chinese Intellectual Property Press provides a dataset with complete patent information since 1985. The Chinese patent law was enacted in 1984. The database includes the names of the inventions; the dates of application, publication, and grant; the names and addresses of inventors and assignees; and industry categories. By examining the assignee information, we identify university–firm joint applications for patents as a mark of successful collaboration.

Patents are not the only output from university–industry collaborations, of course. The ideal proxy should be university–industry contracts archived in Chinese universities. Considering the difficulty in collecting such documents from various universities and the possibility of missed historical data, patent data is the most reliable source that allows us to analyse university–industry collaborations over a 20-year period (1985–2004) in all regions of China. Co-authorship is a potential rival measure, suggesting collaborations at the basic science level. However, according to my interviews, firms typically collaborate with universities at the downstream level, and are not as interested in publication with the exception of university start-ups. Many research personnel working in university start-ups are still affiliated with the university; they are doing both academic research and industrial R&D to meet the evaluation criteria of both sectors. Therefore, university–industry ties identified by co-authorship might give a highly biased sample, concentrating on university start-ups and

Table 1
Patents jointly applied for by higher education institutions and industrial entities from 1/1/1985 to 7/10/2005 (search made in September 2005).

	University	College	School
Company	4265	1288	81
Factory	411	261	32
Group	504	100	4
Enterprise	36	22	2

a few large firms (probably international firms) conducting basic research.

One possible problem with using patents as an indicator of innovation in the Chinese context is that sometimes a university does not show up as a co-applicant even though its employees are among the inventors. This omission can result in biased data. To address this concern, we selected an engineering department at Tsinghua University to see whether the patents listed by professors, especially university–industry co-applications, use Tsinghua University as one of the applicants. Among the 52 professors listed, 35 have personal webpages and 18 provide their patent application records. The total number of patents is 105, and only three (which are not university–industry co-patents) were granted to the individual inventors rather than to Tsinghua University. In addition, the four patents with firms are all in our sample. Therefore, our data includes the majority of university–industry collaborations.[3]

Another concern is that the issuing of the "Chinese Bayh-Dole Act" (Hong, 2008) and the following WTO ascension have induced a huge increase in university patent applications since 1999. Therefore, the number of university–industry collaborations captured by joint patents is expected to be higher in the later period than in the earlier period. This possible bias of the data urges a cross-time examination of the results.

Individual Chinese patent records are available for search on the website http://www.patent.com.cn/. By appropriately setting search conditions, we can access patents assigned to both the industrial and academic sectors. For the industry sector, assignee names could be a company (*Gongsi*), a factory (*Chang*), a group (*Jituan*), an enterprise (*Qiye*), or a combination of several of them (e.g., *Qiye Jituan Gongsi)*; for the academic sector, the assignee names could be a university (*Daxue*), a college (*xueyuan*), or a school (*xuexiao*). Thus we have twelve searching combinations and get 7006 university–industry collaboration cases in total, as shown in Table 1.

Second, information on Chinese companies, including the basic characteristics of firms (e.g., size, the date of establishment, ownership, and address), was obtained from their registration record and double checked on their websites. Third, rankings of Chinese universities have been provided by various sources since the 1990s, with more recent ratings often including "prestige scores". Since prestige scores of universities are relatively stable over years, it is safe to impute the prestige scores in early years with the latest available scores. Fourth, detailed information on Chinese universities is available from their websites, from which we can learn whether a university is under the supervision of a Ministry or the local government and how that jurisdiction changes over time. Fifth, the geographic information (e.g. latitude, altitude) of cities can be obtained from the internet sources.

Conventionally, we can use logistic regression to estimate the effects of geographic distance and other covariates on the likelihood of formation of university–industry linkages. However, according to the Chinese patent database, 521,152 patent applications were submitted by firms and 41,642 by universities in the 20-year period. Thus, there are 21,701,811,584 (521,152 × 41,642) potential ties between firms and universities, but only 4861 (0.0000224%) of them were realised. If we run logistic regression with all of the potential ties, firms and universities will enter the analysis repeatedly, thereby violating the independence assumption and generating a biased estimation. Additionally, it would be difficult to compile, manage, and analyse such a huge dataset (King and Zeng, 2001; Sorenson and Stuart, 2001). One way to solve this problem is to reduce the full dataset to the realised collaborations and a control group of unrealised collaborations, with each potential (but unrealised) dyad composed of a firm from a realised tie and a university from another realised tie for a given quarter year (e.g., see Sorenson and Stuart, 2001). However, logit estimates using this dataset will be biased because of the change in the probability of forming a tie. Moreover, to ensure computation stability and to deal with the potential problem of perfect separation, we utilised Bayesian version of logistic regression (Gelman, 2008) to estimate the following models. After obtaining the estimates from the logistic regression in R (R Development Core Team, 2012), we corrected the aforementioned biases using the method proposed by King and Zeng (2001) and Tomz et al. (2003).

In addition to the quantitative analysis we performed, the first author also conducted 40 semi-structured interviews with university scientists and technology transfer officers in China in the summer of 2004 (Hong, 2006). Based on the factors of overall research intensity and economic development, Beijing and Wuhan were chosen as the cities to study. Beijing, one of the most developed cities in China, is home to the best universities and high-tech companies. It also accounts for nearly one fifth of national R&D expenditures (The Chinese Statistics Bureau, 2001). Technology transfer activities in Beijing should be the most active in China. Wuhan is the capital city of Hubei Province. Since a market-oriented economy was first initiated in the southern and eastern coastal regions, the farther a city is from the coastal area, the less developed its economy. Wuhan, a city located in central China, should be representative of big cities developing at a moderate level. Also, R&D expenditures in Hubei province in 2000 were 3.48 billion RMB,[4] which is very close to the average level of 2.89 billion RMB (Chinese Education Ministry, 2001). By choosing one outstanding city and one representative city, we anticipate we will obtain a broad picture of typical forms of university–industry collaboration in China. More importantly, we expect to observe more Ministry influence in Beijing and more local government influence in Wuhan.

Among the 40 semi-structured interviews conducted, 30 were with academic scientists from 4 universities, and 10 were with technology transfer officers from 5 universities. These interviews provide an understanding of how university–industry collaborations are achieved, problems encountered in those collaborations, and the degree of influence of the central and local government.

3.1. Dependent variable

The dependent variable is the presence or absence of a tie between university and industry as measured by the co-application of a patent.

3.2. Independent variables

Geographic distance: The spherical distance between a firm and a university can be calculated by: $d_{uf} = 6371 \{\arccos[\sin(lat_u)\sin(lat_f) + \cos(lat_u)\cos(lat_f)\cos(|long_u - long_f|)]\}$,

[3] Though it would be more convincing if we could sample another less prestigious university, since most Chinese universities only provide brief biographies of professors, their patent applications cannot be reliably identified.

[4] RMB is the Chinese currency. One RMB is approximately equal to US$0.13 in 2001.

where u indexes the university's city, and f indexes the firm's city; *lat* (latitude) and *long* (longitude) are respectively calculated from the mean of the above and below latitude and the mean of the left and right longitude, which are available from a city's website; and 6371 (km) is the mean radius of the Earth. However, the distance variable we obtain is negatively skewed with a long tail and a spike on 0, showing that there are many firms that are adjacent to a university and a small number of firms are quite further away from a university. We coarsen the distance variable into 5 subclasses by the optimum quantile probability (0%, 11%, 35%, 65%, 89%, 100%) suggested by Cochran (1968), and treat the new distance variable as a continuous predictor where 1 means the firm is very close to a university and 5 means it is very far away.

Obviously, the geographic distance alone is not sufficient to account for travel-time between Chinese cities. Travelling between two distant cities by airplane may take less time than travelling between two adjacent cities by bus. Sorenson and Stuart (2001) have argued that the use of log distance can deal with the non-linearity between a distance and the time and money necessary to travel that distance in the U.S. In China, this non-linearity is further complicated by the well-known regional inequality in economic development. Will people from remote regions spend more time than people from developed regions to travel the same distance? Are there any sites or regions inaccessible by modern transportation? We assume the log transformation works in China as well for the following reasons (1) because the train system in China is very well developed and widely used, regional disparity in transportation is relatively low. (2) Most of Chinese universities, as well as their industrial partners are located in big cities or at the very least more developed regions to and from which transportation is relatively convenient. (3) According to the interviewees, travel is convenient for them. We do not use log transformation here because the distance variable contains 0. Since the distribution of the coarsened distance is similar to that of log transformation, it still resolves the non-linearity problem.

University prestige: there are two online sources that provide data on universities' prestige scores. One is http://www.netbig.com/, the other is http://www.cuaa.net/. The former provides prestige scores since 1999, while the latter only provides scores from 2004 to 2006. After calculating the correlation coefficients of the two sets of prestige scores from 2004 to 2006, it was found that the two measurements were highly consistent. Given that the Netbig provides more data, it was chosen as the data source and a correlation matrix of the prestige scores in different years was calculated. It was found that as expected the scores were stable over years. Therefore, for the years when the data are available, the data are used in the analysis; for the years when the data are not available, the prestige scores are imputed from the latest available scores.

Ministry origin: For each dyad, a dichotomous variable was coded, with "1" meaning the two are within the same Ministry" and "0″ as not in the same Ministry. For some cases, a university was administered by a Ministry but was later transferred to another Ministry or local government, but the firm involved belonged to the former Ministry. I would assume that the collaboration was still facilitated by their old ties due to the same Ministry origin and therefore code the variable as "1".

Local administrative effect: There are 30 provinces of various sizes in China, below provinces are cities and then counties. Local administrative effects could come from provinces, cities, and counties. In this paper, whether the university and the firm are administered by the same provincial government is coded as a dichotomous variable to measure the administrative effect from the local government.

Table 2
Variables and descriptive statistics (for those realised university–firm collaborations).

Variable	Obs.	Mean	S.D.	Min.	Max.
Firm size	3771	2.98	1.18	1	5
Firm age	3859	2.93	1.23	1	5
SOE	3942	0.55	0.50	0	1
Private firm	3942	0.38	0.49	0	1
Foreign firm	3942	0.07	0.25	0	1
Start up	4145	0.18	0.39	0	1
Distance	4145	2.17	1.29	1	5
University prestige	4145	70.52	21.07	32	100
Ministry	4145	0.10	0.30	0	1
Local	4145	0.05	0.22	0	1
Prior tie	4145	0.36	0.48	0	1

Prior tie: A time-varying dichotomous variable, measured for each pair for each year t by the existence of a tie between the pair before year t, calculated using MATLAB.

3.3. Control variables

Firm size: Large firms are less likely to be confined by geographic distance when searching for academic partners (Wen, 2001). Thus firm size (number of employees) is controlled here. Similar to the distance variable, the firm size variable is coarsened into 5 subclasses. We treat the new firm size variable as a continuous predictor where 1 means a small sized firm and 5 means a large one.

Firm age: A firm's age can be calculated based on the firm's founding year and the year in which the patent application was submitted. Similar to the distance variable, the firm age variable is coarsened into 5 subclasses. We treat the new firm age variable as a continuous predictor where 1 means a young firm and 5 means an old one.

Firm type: state own enterprises, private firms and foreign firms or joint ventures are three categories of firm type here. In the post-reform China, they are expected to operate and perform differently.

University start-up: If a firm originated from a university, they have a higher probability to collaborate with each other. A dummy variable indicating whether the firm in a potential tie is a spin-off of the university should be created to control this situation. Since being attached to a university is a good advertisement for a firm, university start-ups usually announce their university origin in their web pages.

To facilitate comparison and interpretation, we rescale all the continuous variables by subtracting their means and divided by 2 standard deviations; and all the binary variables are centred at 0. Henceforth, the coefficients in the models are comparable between variables and the interpretations of coefficients of continuous variables and binary variables are roughly on the same scale (Gelman, 2008).

4. Results

Table 2 shows the variables and their descriptive statistics. Correlations between variables are displayed in Table 3. Except for the pair of the SOE and the private firm, correlations between other variables are quite low.

Table 4 shows the rare events logistic regression models with the geographical distance between universities and firms as the central concern. All coefficients are statistically significant ($p < 0.01$). The statistics of the variance inflation factor (VIF) are all below 5, indicating that the problem of multi-colinearity is less of an issue here.

Model 1 reports the baseline estimates of the probability of university–industry collaborations using all the control variables

Table 3
Correlations of independent variables.

Variable	1	2	3	4	5	6	7	8	9
1. Distance	1.00								
2. Firm size	0.12	1.00							
3. Firm age	0.12	0.33	1.00						
4. SOE	0.08	0.59	0.38	1.00					
5. Private firm	−0.10	−0.55	−0.34	−0.87	1.00				
6. Ministry origin	−0.04	0.30	0.07	0.22	−0.19	1.00			
7. University prestige	−0.06	−0.03	−0.08	−0.09	0.08	−0.09	1.00		
8. Local admission	−0.14	0.02	0.11	0.10	−0.08	−0.04	−0.04	1.00	
9. Prior collaboration	−0.23	0.27	−0.04	0.14	−0.11	0.24	0.11	−0.04	1.00

Numbers displayed are all the pairwise correlation coefficients between the variables. All correlations, except the pair of firm size and local admission, are significant at 99% level.

without any interaction term with geographical distance. Since we have standardised all the predictors, the coefficients are comparable here. Among all the predictors, being a start-up of a university has the largest predictive power in the university–industry collaboration. Because start-ups usually keep close interaction with their founding research groups, when technical difficulties arise, firms will tend to approach their parent universities first.

As verified by many previous studies, geographic distance has a significant and negative effect on university–industry collaborations. Thus at the mean values of all other variables, a unit increase in distance (2 standard deviations increase) corresponds to an approximate 41% negative difference in probability of university–industry collaborations. As for the firm type, since our baseline type is the foreign companies or joint venture firms, the coefficients of the State Own Enterprises (SOE) and the private firms show that these two firm types are less probable (approximately 12% less) to have a university–industry collaboration compared to the foreign companies. Moreover, if a firm and a university are subordinated to the same Ministry or the same local government, the probability of collaboration increases approximately 25% and 64%, respectively. Likewise, if a university and a firm have prior collaboration, this also enhances the probability of collaboration by

Table 4
Rare events logistic regression models.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	−14.87*	−14.81*	−14.84*	−14.87*	−14.15*	−14.07*
	(0.08)	(0.08)	(0.09)	(0.10)	(0.17)	(0.29)
Firm size	−0.51*	−0.53*	−0.57*	−0.63*	−0.06	0.58
	(0.08)	(0.08)	(0.09)	(0.10)	(0.16)	(0.36)
Firm age	0.61*	0.62*	0.66*	0.47*	0.52*	−0.19
	(0.07)	(0.07)	(0.07)	(0.08)	(0.14)	(0.31)
Firm type (SOE)	−0.53*	−0.52*	−0.65*			
	(0.12)	(0.12)	(0.13)			
Firm type (private)	−0.46*	−0.43*	−0.42*			
	(0.12)	(0.12)	(0.13)			
University start-up	5.39*	5.60*	5.59*	5.36*	4.65*	2.69
	(0.86)	(0.86)	(0.86)	(0.99)	(0.73)	(1.28)
Distance	−1.63*	−1.56*	−1.60*	−1.29*	−2.55*	−1.86*
	(0.08)	(0.08)	(0.09)	(0.09)	(0.27)	(0.39)
Ministry origin	1.59*	1.60*	1.86*	1.68*	3.39*	2.47
	(0.14)	(0.14)	(0.18)	(0.14)	(1.29)	(1.53)
Ministry origin × distance		1.44*	1.68*	0.79*	1.21	1.08
		(0.29)	(0.37)	(0.29)	(2.11)	(2.28)
Local admin.	2.56*	3.62*	4.48*	2.68*	3.99*	−0.03
	(0.31)	(0.68)	(0.92)	(0.55)	(1.15)	(2.43)
Local admin. × distance		3.07*	4.33*	1.49	−0.40	−0.59
		(1.20)	(1.55)	(0.97)	(2.30)	(2.43)
Prior collaboration	2.07*	2.05*	2.36*	1.58*	4.79*	4.73*
	(0.09)	(0.09)	(0.10)	(0.11)	(0.58)	(1.02)
Prior collaboration × distance		1.76*	1.86*	1.97*	−0.50	1.19
		(0.16)	(0.18)	(0.19)	(0.97)	(1.32)
University prestige	−0.26*	−0.26*	−0.28*	−0.21*	−0.39*	−0.28*
	(0.06)	(0.06)	(0.07)	(0.08)	(0.10)	(0.23)
University prestige × distance		0.99*	1.09*	1.06*	0.89*	1.45
		(0.14)	(0.16)	(0.19)	(0.25)	(0.48)
N	7302	7302	6212	4034	2802	466
Subset			Year > 1995	SOE	Private	Foreign

Numbers in parentheses are robust standard errors.
* Significant at 1% level.

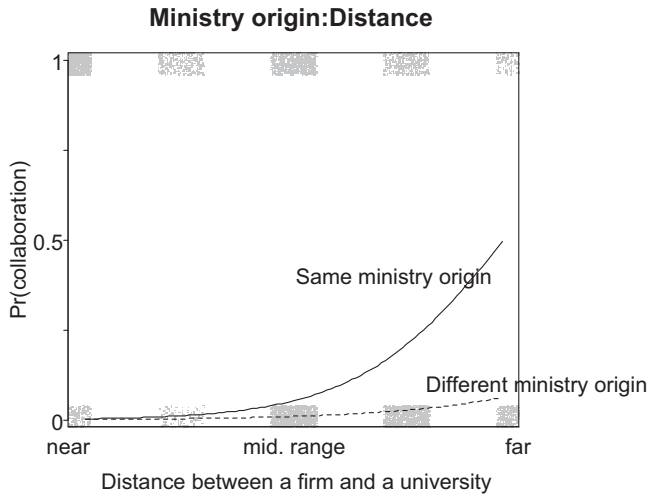

Fig. 1. The interaction effects of distance and Ministry origin on probability of collaboration.

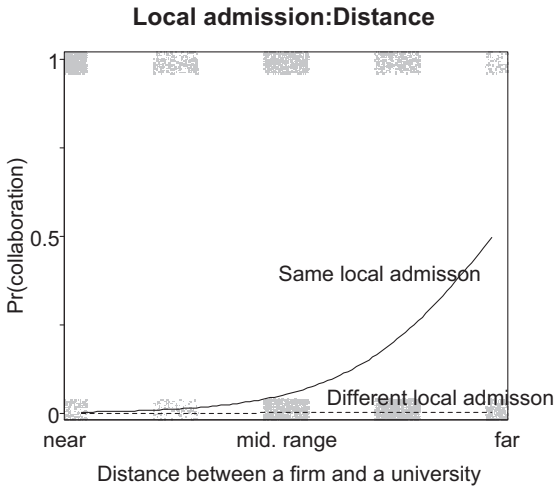

Fig. 2. The interaction effects of distance and local administration on probability of collaboration.

54%. Finally, prestigious universities are less likely to attract industrial partners. A unit increase in university prestige is associated with 7% decreases in probability of collaborations. In earlier stories, both a central Ministry and a local government tried to impose within-institution collaborations regardless of prior collaborations and university prestige. These findings to some extent explain why the former failed and the latter succeeded.

Model 2 demonstrates the full model with interaction terms of major predictors and geographical distance. The main effects without interactions are similar to those of model 1. Namely, firms and universities that either belong to the same central Ministry or are subordinate to the same local government, are more likely to collaborate. In addition, prior collaborations are more likely to assure further collaboration, though prestigious universities are less likely to attract industrial partners. According to Ai and Norton (2003), for logistic regression models, we cannot interpret the interaction effects by simply reading the interaction coefficients because the interaction effects vary across different values of the independent variables. We therefore use figures to show the changing effects.

Fig. 1 shows the interaction effects of distance and Ministry origin on probability of collaboration (H1) under the hypothetical setting that a mid-sized, mid-aged firm belonging to a university start up and a university with an average prestige score, are both subordinate to the same local government and have prior collaborations. Fig. 1 demonstrates that when a firm and a university are administered by the same Ministry, they are more likely to collaborate than without the same Ministry origin. The effect is more significant when the distance between such a dyad increases; but is less significant when the distance is minimal. This finding is consistent with H1 and proves that organisational and institutional proximities stemming from subordination to the same Ministry significantly attenuate the negative effect of geographic distance.

Fig. 2 shows the interaction effects of distance and local administrative effect on probability of collaboration (H2) under the hypothetical setting that a mid-sized, mid-aged firm belonging to a university start up and a university with an average prestige score share the same Ministry origin and have prior collaborations. Fig. 2 demonstrates that when a firm and a university are subordinate to the same local government, they are more likely to collaborate than the scenario when a university and a firm are not subordinate to the same local government. Similar to Fig. 1, this effect of institutional proximity is more significant when the distance between such a dyad increases; but is less significant when the distance is minimal.

As predicted, the vertical and horizontal institutional proximities can compensate for the negative effect of geographic distance. Nonetheless, the previous two stories show that when institutional forces intervened, the industrial party were always push to collaborate with a less favoured partner. Institutional proximity not only mediates the effect of geographic proximity, but also dominates over all other forms of proximity.

This government interference is usually ineffective in promoting innovation. One professor mentioned that the government once assigned an electric vehicle project to an automobile company, but that company was interested in hybrid electric vehicles rather than in purely electric vehicles. That company subcontracted the project to a university and then concentrated on the project they were really interested in. That professor said:

If a company has a genuine interest in a project, it will invest a lot of money and energy. Another automobile company that is interested in developing an electric vehicle bought a battery factory simply for that purpose. Companies are committed to their own projects, rather than projects allotted by the government.

Fig. 3 shows the interaction effects of distance and prior collaborations on probability of collaboration (H3) under the hypothetical setting that a mid-sized, mid-aged firm belonging to a university start up and a university with an average prestige score share the

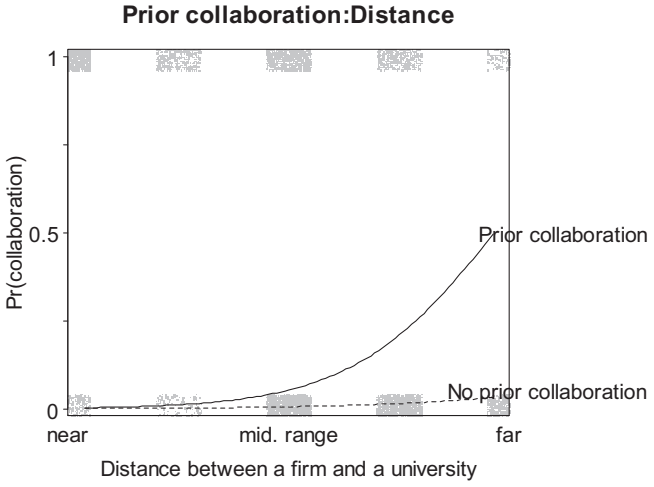

Fig. 3. The interaction effects of distance and prior collaboration on probability of collaboration.

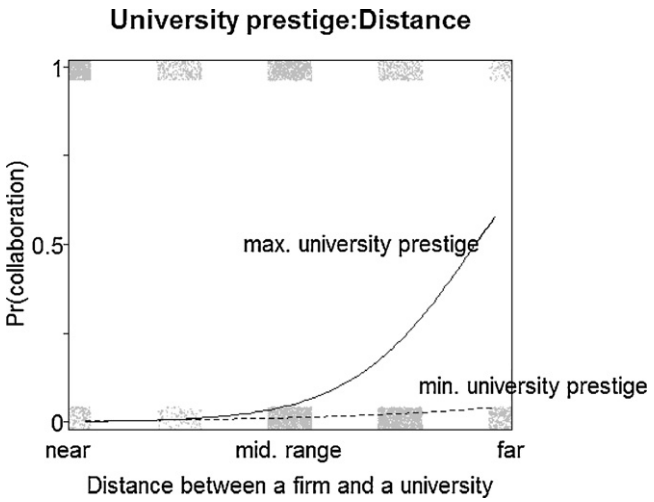

Fig. 4. The interaction effects of distance and university prestige on probability of collaboration.

same Ministry origin, and are subordinate to the same local government. Fig. 3 demonstrates that a dyad with prior collaborations is more likely to work together again than those without prior collaborations. The effect of social proximity is more significant when the distance between such a dyad increases; but is less significant when the distance is minimal. Given that strong ties are deemed particularly important in the Chinese society (Bian, 1997), this finding is unsurprising and consistent with previous studies.

Fig. 4 shows the interaction effects of university prestige and distance on the probability of collaboration (H4) under the hypothetical setting that a mid-sized, mid-aged firm belonging to a university start up and a university share the same Ministry origin, are subordinate to the same local government, and have prior collaborations. Hence, Fig. 4 compares two dyads, with one university having the highest prestige score and the other one having the lowest. It is clear that when a university is more prestigious, the distance between the two parties is less important. Nonetheless, such an interaction effect is more significant when the distance between such a dyad increases; but is less significant when the distance is minimal. Therefore, although the main effect shows that prestigious universities are less likely to attract industrial partners, they are more likely to attract non-local industrial partners, which is consistent with H4. Because firms in China are usually not involved in cutting-edge research and a local second-tier university can probably solve their problems, firms might not consider a university's prestige when they want a solution for their specific problems. Under these circumstances, non-elite universities have a higher chance of being selected by firms as collaborating partners. But when the firms cannot find a local university to solve their problems and have to assume extra costs to seek a non-local partner, they prefer to work with prestigious universities.

A earlier study used logit p^* models to analyse the same dataset (Hong, 2010). It was found that university–industry collaborations in the early reforming years were predominated by interactions between Beijing and other provinces, many of which were not in the same administrative region with Beijing. We thus assume that spatial autocorrelation is not a problem in the model estimates, at least for the period from 1984 to 1995. Model 3 examines whether or not the estimates are robust in time by dropping observations from 1984 to 1995. Overall, the result is almost identical to Model 2, showing that the estimates are also robust in time.[5] This further assures us that spatial autocorrelation is less of a concern here. Models 4–6 test the hypotheses with three subsets of the data: SOEs, private firms, and foreign firms. We can see that most of the results remain valid for SOEs, but not for foreign firms. The most interesting finding is that the interaction effect between Ministry origin and distance is only significant for SOEs, suggesting that the institutional proximity effect is most salient for the firms institutionally embedded in the system. Also, the negative effect of firm size from Model 2 suggests that big firms are less likely to collaborate with universities, which is contradictory to our intuitions. Models 4–6 show that this is because many big firms are at the same time SOE—huge SOEs are usually sluggish in reforming and are less proactive in the realm of innovation. The size effect is not significant for private and foreign firms. Although Models 4–6 are not exactly the same model as Model 2, these comparisons remind us that the findings from this study are best suited for SOEs.

[5] For over-time patterns of university–industry collaborations, interested readers can refer to (Hong, 2008) for vivid pictures.

5. Conclusions

This paper shows how geographic distance between universities and industry affects the likelihood of their collaborations, and how organisational, institutional, social proximities and university prestige mediate that effect. The results corroborate previous studies, demonstrating that geographic distance is indeed an obstructive factor in achieving university–industry collaborations.

However, as predicted, multiple forms of proximity could intervene to attenuate that effect. First, the central Ministries and the local governments are two sources of institutional force that could impose or encourage university–industry collaborations without considering the geographic distance between them. Universities and firms subordinate to the same administrative unit thus have organisational/institutional proximities that enhance their collaboration probability. Second, prior collaborations, as have been shown in many prior studies, are a strong predictor of future collaborations. The trust built in prior collaborations engenders social proximity that is strong enough to cancel out the negative effect caused by long distance. Finally, although those universities with high prestige are not of particular interest to industry, they do seem to be attractive when firms need to pay extra costs due to long distance between universities and firms.

China, now making the transition from a planned economy to a market economy, has an institutional context and level of economic development very different from the Western countries where most previous studies are conducted. With the unique Chinese patent data, this study deviates from previous studies in that (1) it finds that institutional proximity is not just one of several dimensions of proximity, but an overarching factor in connecting universities and firms in China. (2) It introduces the notions of vertical and horizontal institutional proximities based on the multicentric nature of decision making process in China. (3) It empirically examines the interaction effect between geographic proximity and other dimensions of proximity in a systematic way and has shown how the interaction effects change across distance.

This study warns us that too much institutional proximity, though help bring university and industry together, could lead to unfavourable collaborations and ultimately do harm to innovation enterprises. The institutional proximity measured by relationships to central Ministries and local governments are particularly useful for SOEs in the Chinese context, but we expect that China is not the only setting to detect such effects. The results will shed new light on the geographic dimension of university–industry relationships and illuminate a feasible direction to further study on proximities in a range of institutional settings.

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