Can locally-recruited R&D personnel significantly contribute to innovation in multinational subsidiaries in an emerging economy?

Xiaoying Li[a], Jue Wang[b], Xiaming Liu[b,c*]

[a]Brunel Business School, Brunel University, Uxbridge, UB8 3PH

[b]School of International Business, Southwestern University of Finance and Economics, Chengdu, China, 611130

[c] School of Business, Economics and Informatics, Birkbeck College, University of London, London, WC1E 7HX, UK

Abstract

This paper assesses the role of locally-recruited R&D personnel relative to their expatriate counterparts as regards innovation in multinational subsidiariesin an emerging economy. Two hypotheses are developed based on a network approach to multinational enterprises in an emerging economy setting, and tested on a sample of 317 multinational subsidiaries in China. Our results indicate that locally-recruited R&D personnel have played a limited role in innovation within multinational subsidiaries. While making a marginally significant contribution to R&D output due to their direct supply of technological knowledge, locally-recruited R&D personnel are unable to translate subsidiary R&D expenditure into successful patent applications probably because of their lack of technology management skills. In comparison, R&D expatriates significantly contribute to multinational subsidiary R&R output in both dimensions.

Key words: local R&D personnel; R&D expatriates; multinational subsidiary; innovation; China.

1. Introduction

Innovation is a key source of competitive advantage and successful business performance in contemporary economies. The R&D and innovation network of a multinational enterprise (MNE) is distributed globally (Bartlett & Ghoshal, 1998; Hedlund, 1994), and its subsidiaries can play an important role in the MNE's innovative activities and the overall enhancement of competitiveness (Rugman & Verbeke, 2001). Therefore, the development and diffusion of innovation are key strategic challenges for MNEs in the globalised business environment (Gupta & Govindarajan 1991; Schuler, Dowling & De Cieri, 1993; Taylor, Beechler & Napier 1996; Gammelgaard, Holm & Pedersen 2004; Collings, Scullion & Dowling, 2009). Given this recognition, there have recently been several studies on knowledge diffusion and MNE subsidiary innovation. In particular, Frost (2001), Almeida & Phene (2004) and Phene & Almeida (2008) examine how subsidiaries use both externally and internally available knowledge sources, measured by patent citations, to generate innovation. In another study, Kotabe, Dunlap-Hinkler, Parente & Mishra (2007) investigate the relationship between international knowledge flows and innovative performance.

In the strategic international human resource management (SIHRM) literature, HRM practices are believed to facilitate the development of competencies that are firm specific and generate organisational knowledge and hence contribute to sustained competitive advantage (Lado & Wilson, 1994; Simonin & Özsomer, 2009). In this literature, global R&D staffing is believed to play an important role in innovation and organisational learning. Schuler, Dowling & De Cieri, (1993), Gong (2003) and Collings, Scullion & Dowling (2009) suggest that an appropriate mix of parent country nationals, host country nationals and third country nationals can have a significant impact on an MNE's ability to achieve learning, innovation and corporate integration. However, little empirical research has been conducted on the roles of different sources of R&D staff in subsidiary innovation.

Moreover, the existing literature tends to focus on MNE subsidiary innovation in developed countries, and few studies have been carried out in an emerging economy setting. In recent years, some emerging economies such as India and China have made tremendous and largely successful efforts in building a large pool of R&D personnel (OECD 2007, p. 23). This has enabled MNEs to tap into local expertise via their global R&D networks. On the other hand, compared to developed economies, technological resources in a typical emerging economy are relatively weak (Wooldridge, 2007; Dietz, Orr & Xing, 2008; Tarique & Schuler, 2010). Can locally-recruited R&D personnel significantly contribute to multinational subsidiary innovation? An understanding of the role of locally-recruited R&D staff relative to their expatriate counterparts in multinational subsidiary innovation in an emerging economy is important not only for the competitiveness of these subsidiaries and their corporations as a whole, but also for local technological capability development.

The current paper assesses the role of host country (i.e. locally-recruited) R&D personnel relative to their expatriate counterparts in multinational subsidiary innovation in an emerging economy. Specifically, we focus on R&D activities which can be measured in terms of R&D input and output. R&D input is R&D expenditure, and R&D output is patent counts and citations (Pandit, Wasley & Zach, 2011). Using these definitions, this paper develops two hypotheses based on a network approach to multinational enterprises in an emerging economy setting and tests them on a panel data set from 317 multinational subsidiaries in China over the period 1999-2005. We find that locally-recruited R&D personnel have made a positive impact (although only marginally significant) on multinational subsidiary R&D output (patent counts) by directly contributing their knowledge and skills. However, unlike their expatriate counterparts who play an important role in internal network building, tacit knowledge diffusion (Cantwell & Santangelo, 1999) and leadership provision in an emerging economy, locally-recruited R&D personnel are unable to transform subsidiary R&D input (R&D expenditure) into R&D output (patent counts) due to their lack of technology management skills.

The study contributes to the existing literature by differentiating the role of direct technological knowledge to R&D output from that of R&D management, and comparing these roles played by locally-recruited R&D personnel with their expatriate counterparts in multinational subsidiaries in an emerging economy setting. In the next section, we develop hypotheses based on network theory. Section 3 explains the data and methodology used. Section 4 reports the results. Finally section 5 provides discussion and conclusions.

2. Theory and Hypothesis Development

Following a network approach to multinational enterprises, an MNE is a differentiated network of internationally dispersed units which are simultaneously embedded in two business contexts: the internal MNE and the external (host country) environment (Ghoshal & Bartlett, 1988). In this network, a multinational subsidiary can have access to knowledge from both the rest of the MNE and its host country business environment. The merging of knowledge from different sources can be an essential driver of firm innovation (Galunic & Rodan, 1998), and the recombination of existing knowledge from different sources to facilitate technological or managerial innovation is one of the fundamental functions of an MNE (Kogut & Zander, 1992; Cantwell & Janne, 1999; Cantwell & Pocatello, 2000). Direct knowledge flow through patent citation internally and externally is an essential knowledge source for innovation in MNE subsidiaries (Frost, 2001; Almeida & Phene, 2004; Phene & Almeida, 2008). Internal and external R&D personnel linkage is another important aspect of the internationally integrated R&D network. One difficulty associated with knowledge diffusion is the tacit nature of technology (Kogut & Zander, 1993; Zander & Kogut, 1995; Choi & Lee, 1997; Simonin, 2004; Criscuolo & Narula, 2007). Therefore, R&D personnel linkage is more important than patent citation in this sense.

For a multinational subsidiary located in a developed country, both internal and external linkages are important sources of advanced knowledge. In the MNE R&D network, different nationalities of employees have access to different knowledge bases (Collings, Scullion & Dowling, 2009). Specifically, R&D expatriates from parent firms are seen as key in transferring knowledge from the home country to subsidiaries, although such expatriation is costly and sometimes unsuccessful (Downes & Thomas, 2000), and a subsidiary can improve its technological and managerial capabilities by learning from the home country and parent firm (Inkpen & Beamish 1997). On the other hand, locally-recruited R&D personnel in a multinational subsidiary possess or have access to local advanced knowledge via their linkages with local firms in their host countries. Both R&D expatriates and locally-recruited R&D personnel play important roles in internal and external technological knowledge diffusion, integration and creation, and hence innovation.

When located in an emerging economy, a multinational subsidiary operates below the international technological frontier (Jindra, Giroud & Scott-Kennel, 2009). As a result, it would tend to rely more on internal knowledge diffusion and integration in order to enhance their innovative capabilities, and therefore R&D expatriation is expected to play a relatively more important role in subsidiary innovation in an emerging economy than a developed economy. On the other hand, locally-recruited R&D personnel in a subsidiary in an emerging economy are relatively technologically weaker than those in a subsidiary in a developed economy. However, they possess or have relatively easy access to indigenous technology and local knowledge via their links with local firms, and may also be able to make an important contribution to subsidiary R&D and innovation.

The importance of R&D expatriation in subsidiary innovation is well recognised. However, the role of locally-recruited R&D personnel in multinational subsidiary innovation is less well researched. In the following subsections, we develop our key novel argument that locally-recruited R&D personnel in an emerging economy such as China can significantly contribute to multinational subsidiary R&D output, although their positive contribution is not as great as that of R&D expatriates.

2.1. Locally-recruited R&D personnel and multinational subsidiary innovation

R&D personnel linkage is one important aspect of an internationally integrated R&D network. MNEs following global strategies need to manage and co-ordinate competences (Lado & Wilson, 1994; Beret, Mendez, Paraponaris, & Richez-Battesti, 2003). This involves the deployment of competences where they are required, the identification and development of expertise on a global basis and the global dissemination of local knowledge and innovation (Roberts, Kossek & Ozeki, 1998). Criscuolo, Narula & Verspagen (2005) and Cantwell & Santangelo (2006) suggest that an organization needs to rely on not just its own resources but complementary resources associated with the relevant local innovation system for the exploitation and enhancement of its technological competences. The expansion of R&D and innovative activities is motivated by a firm's needs to acquire new knowledge and capabilities, and to gain access to unique human resources (Cantwell, 1995; Dunning & Wymbs, 1999;

Florida, 1997; Howells, 1990; Lam, 2003). Since the mid-1980s, a large number of MNEs have no longer confined themselves to simply transferring parent company technologies to their overseas subsidiaries, but have been developing major innovations for the global market by leveraging the unique knowledge resources of some host country environments. Internationally integrated networks of technological development not only promote internal knowledge diffusion and creation, they also enable MNEs to tap into specialized local expertise (Chen, 2007) to enhance their innovative capabilities.

Recent international management literature calls for research on contributions by host country nationals (HCNs) in the success of the foreign operations of MNCs (Toh & DeNisi, 2003, 2005; Vance & Paik, 2005; Tarique, Schuler & Gong, 2006). Vance, Vaiman & Anderson (2009) discuss the HCN liaison role (cultural interpreter, communication facilitator, information resource broker, talent developer, and change partner) in local knowledge management, and argue that the host country workforce is "a critical source of local knowledge and information" (p. 650). Gong (2003) focuses on R&D and suggests that the participation of local scientists and engineers in subsidiary R&D activities contributes to a more heterogeneous staffing composition, facilitating access to and recognition of diverse sources of innovation and organisational learning. Lewin, Massini & Peeters (2009) suggest that offshoring innovation activities can increase the pool of resources (talent) available to a firm, and alleviate some constraints that potentially impede the achievement of the firm's growth objectives.

While emerging economies as a whole typically face technological resource scarcity, some of them are rapidly catching up. UNCTAD (2005) observes that some emerging economies already realize the importance of science and technology for their economic growth, and have recently invested heavily in developing their technological capabilities. For example, China, India and the Russian Federation together accounted for almost a third of all tertiary technical students in the world in 2000-2001, and they can directly contribute their technological knowledge and skills to multinational subsidiary innovation. Therefore, these emerging economies have become new attractive locations for global R&D activities because of the growing availability of scientific and engineering skills and manpower at competitive costs, the ongoing globalization of manufacturing processes, and substantial and fast-growing markets (UNCTAD, 2005). Multinational subsidiaries can benefit from indigenous technologies and local knowledge possessed by local firms in an emerging economy like China (Wei, Liu & Wang, 2008). Some recent studies also regard the availability of skilled labour and talented engineers and scientists as one important reason for foreign R&D investment in emerging economies (Chen, 2007; Sun & Wen, 2007). Competing in the emerging global market for knowledge workers creates new sources of talent, and has already become a strategic priority for many firms, especially those high-tech ones.

All the above helps explain why some emerging economies with talent pools are now emerging as nodes in the R&D networks of MNEs (UNCTAD, 2005). They offer new geographic knowledge clusters (diverse labour pools and specific expertise) that MNEs can tap via their international networks in order to globalise their activities (Lewin, Massini & Peeter, 2009). The current literature tends to suggest that locally-recruited R&D personnel in an emerging economy can make a direct contribution to R&D and innovation of MNEs. Therefore, our first hypothesis is as follows.

H1: Locally-recruited R&D personnel in an emerging economy like China can have a positive impact on multinational subsidiary R&D output due to their direct contribution of technological knowledge.

2.2. R&D personnel, input and output in a multinational subsidiary in an emerging economy

In line with the network approach to multinational subsidiary innovation in an emerging economy setting, we now assess another possible role of locally-recruited or expatriate R&D personnel: turning subsidiary R&D input (R&D expenditure) into R&D output (patent counts). Although R&D staff can directly contribute their technological knowledge, whether they can help translate subsidiary R&D investment into innovation output is another issue. This is related more to R&D leadership or management than technological knowledge.

As indicated earlier, the R&D literature suggests that firm-level R&D expenditure is the measure of R&D input (effort), and patent counts (quantity) and citations (quality) are the measures of R&D output (Sougiannis, 2011). While many studies find a positive relationship between R&D effort and output, (e.g., Bound, Cummins, Griliches, Hall, & Jaffe, 1984;

Griliches, 1980), decreasing returns to R&D expenditures may occur (Graves and Langowitz, 1993). Furthermore, although it is widely agreed that technological innovation is the most powerful source of competitive advantage, the value created by skyrocketing R&D expenditures is sometimes seriously challenged (Mank and Nystrom, 2001). Technology-based firms often struggle for the effectiveness and efficiency of their R&D functions (Lin & Chen, 2005).

The above literature also shows that corporate strategy to develop and exploit a firm's technological resources has a profound impact on its long-term performance (Sadowski and Roth, 1999). In addition, a firm designing research projects using more recent information is more productive in R&D, and a firm that has strong absorptive capability with respect to the scientific advance would enjoy first mover advantage in R&D competition (Nagaoka, 2007). As can be seen in the following discussion, R&D expatriates can play an important role in the implementation of corporate technology strategy in multinational subsidiaries, the diffusion of technological information and the building of absorptive capability in multinational subsidiaries. Specifically, R&D expatriates can help improve the effectiveness and efficiency of subsidiary R&D activities via their role in internal network building, tacit knowledge diffusion and leadership provision within the MNE's international R&D network.

As argued by Birkinshaw & Hood (2001), it is essential for would-be innovators to have access to professional and informal networks if innovation is to be facilitated in an MNE. The building of an international network is an important way to achieve this purpose. When talented employees are deployed on short-term overseas assignments, they can provide useful resources for current projects in the short-run, and increase the number and variety of professional networks from which the next ideas are likely to emerge in the long run. Downes & Thomas (2000) also argue that expatriation can facilitate the communication process between the parent firm and its subsidiaries and across subsidiaries, and help in establishing country linkages. International communication enables employees to use the knowledge that resides in the firm to its fullest potential (Pfeffer, 1998) and is likely to contribute to employees' motivation for knowledge transfer (Minbaeva, Pedersen, Bjorkman, Fey & Park, 2003). This is conducive for subsidiary innovation. As a result, R&D personnel deployed by the parent firm on overseas assignments help promote professional and informal networks and facilitate technological knowledge flows and hence innovation in subsidiaries.

R&D expatriates from the parent firm enhance tacit knowledge diffusion in the MNE network. One important transfer mechanism for knowledge, skills, and competencies of the parent firm is expatriates (Downes & Thomas 2000; Bonache & Brewster, 2001; Subramaniam & Venkatraman, 2001; Minbaeva, Pedersen, Bjorkman, Fey & Park, 2003; Widmier, Brouthers & Beamish, 2008). Actually, the most important reason for expatriation is knowledge transfer (Harzing, 2001a; Hocking, Brown & Harzing, 2004) into different units of MNEs. It is often argued that the tacit nature of technology makes its diffusion difficult (Kogut & Zander, 1993; Zander & Kogut, 1995; Choi & Lee, 1997; Simonin, 2004; Criscuolo & Narula, 2007). This is partly because tacit knowledge cannot be codified and transmitted in a formal, systematic language or representation (Kogut & Zander, 1993; Choi & Lee, 1997; Simonin, 2004). The tacit nature of technology implies that knowledge diffusion across disciplines and units is more efficiently internalised if there is close physical proximity between the units, or between the individual researchers (Criscuolo & Narula, 2007). The development of information and communication technologies (ICTs) in the past decades has facilitated the management and coordination of global research networks, but geographical distance remains a barrier to (especially tacit) knowledge diffusion (Howells 1990). International project teams and temporary assignments of R&D personnel to other R&D units create a common understanding and help to identify 'who knows what' in other R&D units (Frost & Zhou 2005). Noorderhaven & Harzing (2009) suggest that social interaction between managers from different units of an MNE is an important factor stimulating intra-MNE knowledge-sharing. R&D expatriation can lead to face-to-face social interactions which are very conducive to the transfer of tacit, non-codified knowledge. In this way, tacit knowledge can be effectively diffused, and the existing R&D resources can be effectively used to promote innovation in different multinational subsidiaries of an MNE.

R&D expatriates from the parent firm may also play a leadership role in innovation in subsidiaries of an MNE network. Widmier, Brouthers & Beamish (2008) argue that, as a worldwide resource, expatriates can be easily reassigned to where their expertise is needed. Elenkov & Manev (2009) note that MNEs often appoint expatriates at higher ranks within local subsidiaries as they are expected to play a critical role in the diffusion of managerial and technological expertise and control over subsidiaries which are spread across the globe (Harzing, 2001b; Minbaeva & Michailova, 2004). This enables subsidiaries to better implement corporate technology strategies. Due to this important role, effective leadership from R&D expatriates can have a positive impact on innovation in subsidiaries of an MNE network. For example, expatriate managers can stimulate their subordinates' learning, provide autonomy to act, facilitate creativity, and offer positive feedback and encouragement (Elenkov & Manev, 2009). Expatriate managers can also help create a work environment that can unleash creativity by setting up personal example of support for innovation (Amabile, Schatzel, Moneta & Kramer, 2004).

A firm's own R&D is widely regarded as an important source of its absorptive capability. A firm with a high level of absorptive capacity is likely to harness new knowledge from various sources to help its innovation (Cohen & Levinthal, 1990). Although MNEs from the developed world are increasingly attracted to and are exploring new science and engineering clusters in emerging economics, these MNEs still remain at the forefront of innovation activities at least for the foreseeable future (Hirshfeld & Schmid, 2005). In an emerging economy, MNEs may not be under pressure to conduct substantial R&D activities and develop their technological capabilities to compete with local firms. Instead, they may tend to rely on internal knowledge diffusion within the MNE network. Hence internal technology transfer from the parent becomes particularly important for successful operations in an emerging economy (Jindra, Giroud & Scott-Kennel, 2009). R&D investment in a subsidiary based in an emerging economy may focus on adapting technologies internally from the MNE to the local market. This is consistent with the observation of UNCTAD (2005, pp. 127-128) that most of the R&D carried out by MNEs in developing countries has traditionally been of an adaptive nature, although recently more sophisticated activities are also expanding. In other words, these subsidiaries mainly play the role of knowledge exploitation in developing or emerging economies.

Given their positive role in internal network building, tacit knowledge diffusion and leadership provision, expatriates from the parent firm can positively encourage a multinational subsidiary based in an emerging economy to conduct its R&D activities and enhance its technological capabilities not only for internal technology exploitation but also technology creation. Makela & Brewster (2009) suggest that cross-border and expatriate/repatriate interaction contexts are associated with more interpersonal trust and shared cognitive ground than all other contexts. In these contexts, the expatriates are in a good position to assess the innovation potential of the subsidiary, recommend a greater role that the subsidiary can play in the corporate R&D plan, and help integrate the subsidiary into the MNE's global innovation network. Making subsidiary R&D part of the MNE's global R&D effort is an important technology management strategy given the weak intellectual property protection in an emerging economy. When expatriates are involved in subsidiary R&D efforts in this way, a subsidiary's own R&D input may better lead to R&D output. In short, the cross-border and expatriate/repatriate interaction contexts promote better internal knowledge transfer and integration, and can have a positive impact on innovation and new product development (Makela & Brewster, 2009).

On the other hand, while locally-recruited R&D personnel are talented and can directly contribute their scientific, engineering and local knowledge and experience towards subsidiary innovation (Gong, 2003; UNCTAD 2005; Vance, Vaiman & Anderson, 2009), they may find it difficult to play such a coordinating and leadership role in the MNE R&D network. In other words, it may not be easy for locally-recruited R&D personnel to turn subsidiary R&D input into R&D output. Firstly, there is a general shortage of managerial skills for science and technology development in an emerging economy like China (OECD 2007, p. 27) and locally-recruited R&D personnel still need to develop such skills. Secondly, locally-recruited R&D staff may have limited knowledge of and influence in the MNE's global R&D network. Although locally-recruited R&D personnel can act as cultural interpreter, communication facilitator, information resource broker, talent developer, and change partner in local knowledge management (Vance, Vaiman & Anderson, 2009), R&D expatriates from parent firms are in a better position than locally-recruited R&D personnel to translate subsidiary R&D investment into R&D output.

H2: Unlike their expatriate counterparts, locally-recruited R&D staff may be unable to translate subsidiary R&D expenditure to R&D output in multinational subsidiaries in an emerging economy.

From our discussion, it is clear that H1 and H2 focus on different dimensions of subsidiary R&D activities. Specifically, H1 emphasises the direct contribution of technological knowledge. Talented engineers are locally available in an emerging economy like China. When recruited by a multinational subsidiary, they join the R&D team and directly contribute their technological knowledge towards successful patent applications. On the other hand, H2 focuses on the role in converting a subsidiary's R&D input (investment) into R&D output. This role involves guidance, leadership and management. An R&D staff member can directly contribute his/her technological knowledge towards successful patent applications, but may or may not be able to play a significant role in the process of turning R&D input to R&D output at the same time. So H1 and H2 can co-exist.

3. Methodology

3.1 Data

The data for testing the two hypotheses were obtained from a survey questionnaire conducted in 2006. Given the nature of this research, our questionnaire contained both factual and subjective questions. The former included general and financial statistics, such as the number of employees and their composition, value added, sales, profits, exports, fixed assets, R&D expenditure and successful patent applications. The latter included the assessment of the degree of a subsidiary's internal and external linkages and autonomy. To prepare a realistic but representative sample, we decided to focus on three cities in China: Chongqing, Nanjing and Beijing, which are representative of western, eastern and northern cities respectively.[1] Given that all firms must register with, and provide their annual financial reports to the Department of Enterprise Management (DEM) of the local Bureau of Industrial and Commercial Administration (BICA), our sample frame was the list of multinational subsidiaries in these cities from which 1,223 subsidiaries were randomly drawn using the systematic sampling method discussed in Ghauri & Gronhaug (2005, pp. 149-150).[2] This sampling method enabled the subsidiaries in the sample to be spread evenly over the ordered population, and could increase precision.

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[1] Due to resource constraints, only limited locations could be chosen. In fact, these three locations may represent different levels of development in China. Beijing is the capital and one of the commercial centres of China. Nanjing is the highly developed industrial and commercial region in eastern China, while Chongqing is the commercial and transportation centre of western China.

[2] In Beijing for example, there were 10527 multinational subsidiaries in 2005. Beijing Bureau of Industrial and Commercial Administration allowed us to contact up to 5% of the subsidiaries. As a result, the total number of

We followed the procedures for a survey suggested by De Vaus (2002) to construct and administer our questionnaire. In carrying out a pilot study, we conducted interviews of 18 multinational subsidiaries in the three cities during May and June 2006 to test and modify our questionnaire. The postal survey was conducted under the auspices of the DEM of BICA in Chongqing, Nanjing and Beijing respectively during June and July 2006. In the cover letter the DEM explained that the purpose of the survey was to find out more about multinational subsidiaries' business operations in order to better serve foreign subsidiaries. The questionnaire was addressed to the managing director or general manager. The DEMs enclosed a prepaid self-addressed envelope and promised that the information obtained would be treated extremely confidentially. Telephone calls were made before and after the survey for the purpose of inviting people to participate in the survey on a voluntary basis and checking the reliability of returned questionnaires.

Article 3 of the *Statistics Law of the People's Republic of China* (adopted in 1983 and revised in 1996) requires that any organization under statistical investigation shall "provide truthful statistical data. They may not make false entries or conceal statistical data, and they may not refuse to submit statistical reports or report statistical data belatedly". The basic information about the multinational subsidiaries provided by the DEM made possible our selection of a random sample of multinational subsidiaries as mentioned earlier and our test for non-response bias. In addition, the pilot study and telephone calls after the survey allowed us to double-check the subjective information obtained from the postal survey.

We received 369 completed questionnaires from multinational subsidiaries.[3] We examined the possibility of non-response error by comparing the characteristics of the respondents with those of the original sample. There were no statistically significant differences between the responding and non-responding firms for foreign share (t=-1.23, p>0.10), age of the firm (t =0.63, p>0.10), firm size (t =0.79, p >0.10), or firm performance measured by return on assets (ROA) (t =1.16, p>0.10).

subsidiaries was divided by the sample size (n = 529), and the sample was chosen by taking every 19th subject, following a random choice of firm No.3 as the starting point.

[3] Following the initial distribution of 1,233 questionnaires and some follow-up letters and telephone calls, 493 foreign invested firms responded among which 369 firms had at least 50% foreign ownership. Following Jarillo and Martinez (1990), we define these 369 firms as multinational subsidiaries.

Furthermore, 52 firms were excluded due to insufficient information provided in the response.[4] We finally obtained a sample of 317 subsidiaries (i.e. the usable response rate = 26%) including firms in knowledge-intensive sectors such as automobile, airplane and computer industries and labour-intensive sectors such as food, beverage, garment and shoe making. We adopted a retrospective approach by asking the sampled firms to provide data for the period 1999-2005, leading to a panel data set which "gives more informative data, more variability, less collinearity among variables, more degree of freedom and more efficiency" (Baltagi, 1995). We cleaned the data by excluding observations with illogical data and we also excluded observations with too many missing values. In total, we have an unbalanced panel data of 1629 observations covering 317 firms for seven years.

3.2. Measures and Model

Our aim is to assess how locally-recruited R&D staff affect multinational subsidiary R&D output relative to their expatriate counterparts. Consistent with Frost (2001), Almeida & Phene (2004) and Phene & Almeida (2008), we focus on technical knowledge patents and use the number of successful patent applications as our dependent variable. Data on patent number was collected from the questionnaire survey. Some existing studies discuss the determinants of a broad definition of knowledge creation including marketing, sales, general management, and services as well as technical knowledge (Andersson, Björkman& Forsgren, 2005), competence development (Andersson, Forsgren, & Holm, 2002) or competence-creating status (Cantwell & Mudambi, 2005). Although a broad definition of knowledge creation or competence development may capture managerial as well as technological aspects of knowledge, patents tend to be an objective measure of technological knowledge creation. In addition, the use of patents as a measure of technological knowledge helps reduce the possible common movement bias when a survey data set is used for estimation.

[4] We excluded firms that had been in full operation for less than two years. Eventually, all firms in our sample were in full operation for at least two years, and from the returned questionnaires all of these firms seemed to have the functions we have asked about.

There are potential problems with the use of patents as a measure of R&D output. Firstly, patents are only a partial measure of technological knowledge as they do not always include tacit knowledge such as organisation routines (Almeida & Phene, 2004). Nevertheless, as Mowery, Oxley & Silverman (1996) argue, codified knowledge represented by patents is closely linked with, and complementary to, tacit knowledge. As a result, a high number of patents may imply a high level of tacit technological knowledge. Secondly, since our sample covers multinational subsidiaries from a wide range of industries (see Table 1), there are some differences in industry innovation level as measured by patents (Pavitt, 1988). To deal with this potential problem, we introduced industry dummies to control for this industrial influence. Thirdly, similar to the case of Almeida & Phene (2004)[5], our sample mean of the count dependent variable is only 0.62 (see Table 2), indicating that many multinational subsidiaries produce no patents. As discussed below, a proper method to deal with excessive zero is the zero-inflated negative binomial (ZINB) model. In this study, we use this method. For these reasons, we use a subsidiary's number of successful patent applications to measure R&D output in this paper.

We measure the variable of local R&D staff as the ratio of the R&D personnel recruited from local Chinese firms from 1999 (new R&D staff from the sample starting year) to the total R&D personnel in a subsidiary (base year = 1998), and R&D expatriates as the ratio of R&D expatriates from the parent firm from 1999 (new R&D expatriates from the sample starting year) to the total R&D personnel in a subsidiary (See Table 2). In this sense, we actually assess the impact of an incremental increase in R&D staff on subsidiary R&D output. We also include the interaction terms between R&D personnel and R&D intensity (defined below) to see how they jointly affect subsidiary R&D output. This variable is used to test hypothesis 2, and is one of the key variables of the study.

Past studies indicate that many other factors also affect knowledge diffusion and innovation. In addition to the most commonly used variables such as R&D intensity and technology capability, these factors include country of origin (Frenz, Girardone & Ietto-Gillies, 2005), firm size (Harris & Trainor, 1995), location (Kleinknecht & Poot, 1992; Love & Roper, 2001; Roper, 2001), age and age squared (to represent the non-linear component) of the firm (Smith, Broberg & Overgaard, 2002) ownership type (Harris & Trainor, 1995), firm-specific

[5] In their study, the sample mean is 0.7.

effects (Liu, Wei & Wang, 2009) and R&D autonomy (Taggart, 1998). To control for these effects, we include the following variables in the analysis: firm age, age squared, wholly-foreign-owned subsidiary (WFOE), R&D autonomy, home country, host city/region, year and firm dummies.

R&D intensity is measured as the ratio of R&D expenditure to total sales, and technology capability as the ratio of R&D personnel to total employees. Subsidiary age is measured as the number of years the subsidiary has operated in China. Subsidiary size is measured as the logarithm of the total number of employees in the subsidiary. The value of the WFOE is 1 when a subsidiary is wholly foreign owned, and 0 if it is a Chinese-foreign joint venture. The measure of R&D autonomy is adopted from Taggart (1998) and Taggart & Hood (1999). Using a five-point interval scale ranging from 'strongly disagree' to 'strongly agree', the respondent was asked to answer the question "were subsidiary R&D decisions made (1) by the parent without consulting the subsidiary? (2) by the parent after consulting the subsidiary? (3) by the subsidiary after consulting the parent? (4) by the subsidiary without consulting the parent? (See Table 2).

Insert Table 1 and 2 about here

The most often used methods to estimate count data such as the number of patents are Poisson and Negative Binomial (NB) models. In this study, we use zero-inflated negative binomial (ZINB) models to test the hypotheses. Two features of the data make this model preferable. Firstly, as shown in Table 2, variance of the patent numbers is much larger than the mean. The large variance in patent numbers makes an NB model preferable to a Poisson model. This is because the Poisson regression is very restrictive and in fact assumes homogeneity. Secondly, the excessive zeros of the dependent variable make a ZINB preferable to a NB model. Although having zero patents is a frequent occurrence, it may be the case that the patents have not yet been observed, or it may also be the case that certain firms do not conduct R&D or apply for patents. This leads to excessive zeros in the patent number, that is, the number of zeros may be inflated. Introduced by Lambert (1992), the ZINB model has the property of correcting for excessive zeros. As shown in our results in Table 4, the Vuong statistic (Vuong, 1989) for ZINB models shows large positive values, suggesting that the ZINB model is favoured over the standard NB model in our study.[6]

The ZINB regression generates two separate models to distinguish the two possible processes that arrive at zero outcomes and then combines them. Let *N* be the number of patents a firm produces, then the ZINB regression takes the following form:

Regime 1:

$$E(N) = \exp(\beta_0 + \beta_1 \cdot P_1 + \beta_2 \cdot P_2 + \mathrm{B} \cdot \Lambda)$$

Regime 2:

$$E(N) = 0, \text{ Prob(Regime 1)} = \exp(\gamma_0 + \gamma_1 N)(1 + \exp(\gamma_0 + \gamma_1 N))$$

Where *N* is the number of patents, P_1 and P_2 are local R&D staff and R&D expatriates respectively, and Λ is a vector of control variables including firm fixed effect, year dummies, home country dummies, host city dummies and other control variables. We include a set of inflated variables, which we believe will influence the number of patents a subsidiary produces, including the number of existing patents, and the numbers of patents transferred from local firms and within the MNE.

4. Empirical Results

As can be seen from Table 3, the correlation coefficients of the variables are generally very low, indicating no problem of collinearity. Another significant issue is the possible two way relationship between subsidiary R&D output and R&D expatriates. It is possible that more expatriates lead to more subsidiary R&D output, but it may also be true that a more innovative

[6] Vuong tests were originally developed by Vuong (1989) to test non-nested models. Statistically they are likelihood-ratio based tests using the Kullback-Leibler information criterion (see Greene (1994) for more detail). Greene (1994) adapts one of these tests to the cases of model selection between zero-inflated Poisson and Poisson and between zero-inflated negative binomial and negative binomial models. This paper uses the Vuong test adapted by Greene (1994) to test for model selection. As described in Long (1997), large positive values of this statistic favour the zero-inflated model and large negative values favour the non zero-inflated version. Values close to zero in absolute value favour neither model.

subsidiary needs and attracts more R&D expatriates from the headquarter. To address the possible endogeneity problem, we use the Durbin-Wu-Hausman (DWH) augmented regression test to check endogeneity. We use the variables: autonomy in R&D decision, technology capability, WFOE dummy and R&D intensity as instrumental variables for the DWH test as they are likely to influence R&D expatriates but are not directly correlated with the unobserved factors in the equation of patent number and the result suggests that the variable of R&D expatriates is not endogenous. The result of the Sargan test confirms that the instruments are valid and there is no over-identification problem. We then carry on conducting ZINB analysis.

The ZINB regression results are presented in Table 4. Column or equation (1) is our baseline model, providing the influences of all control variables on subsidiary R&D output. As can be seen, most control variables are statistically significant, indicating an an appropriate choice of relevant variables from the existing literature.

Insert Table 3 and 4 about here

In equation (2), we add R&D personnel as the key explanatory variables to test H1. The coefficient on locally-recruited R&D personnel is positive and significant at the 10% level. This lends some support to H1 which suggests that R&D personnel from local firms in an emerging economy environment like China can have a significantly positive impact on subsidiary R&D output.

To test H2, we first add the interaction term of R&D intensity with R&D expatriates from the parent firm in equation (3), i.e. to see whether R&D expatriates influence the effectiveness of a subsidiary's own R&D expenditure. From Table 4, the interaction term of R&D intensity and R&D expatriates from the parent firm is significant at the 5% level, indicating that R&D expatriates and subsidiary R&D expenditure are complementary with each other to promote subsidiary R&D output.

One noticeable result from equation (3) is that, while insignificant in equations (1) and (2), the coefficient on subsidiary R&D intensity becomes significant at the 10% level. In other words, after the introduction of the interaction between subsidiary R&D intensity and R&D expatriates from parent firms, R&D intensity has a significant impact on multinational subsidiary R&D output.

To further test H2, we replace the interaction of R&D intensity and R&D expatriates from the parent firm with that of R&D intensity and locally-recruited R&D personnel in column (4). It is clear that this interaction term is statistically insignificant. In our analysis, the R&D intensity variable is given. When it is interacted with R&D expatriates, the interaction term is statistically significant. When it is interacted with locally-recruited R&D personnel, the interaction term is statistically insignificant. This clearly shows that R&D expatriates have played a statistically significant role in translating subsidiary R&D intensity to R&D output while locally-recruited R&D personnel have not. Therefore, H2 is supported by the data.

To ensure greater confidence in the findings that we observed in our empirical tests, we conducted additional analyses as robustness check. Firstly, we ran regressions using three randomly selected subsamples (90%, 80% and 70% respectively) of the total observations, and found that our results were consistent with those found with the full sample. Secondly, we ran regressions on the sample of firms located in Chongqing only and obtained qualitatively the same results. Thirdly, we used total assets as an alternative measure of firm size and re-ran the regressions and obtained results which are consistent with those reported in Table 4.

5. Discussion and Conclusions

H1 is marginally supported in equations (2), (3) and (4). This confirms that locally-recruited R&D personnel can significantly (although marginally) contribute to R&D output in multinational subsidiaries. China relied heavily on technology imported from abroad, but since the end of the last decade China has made significant progress towards developing its innovative capabilities (OECD 2007, p. 9) and China already has a “vast pool of talent” (UNCTAD, 2005, p. 166). Although its general scientific and technological level is still below those in developed economies, talented R&D personnel can make some positive contributions to subsidiary R&D output. This finding also explains why multinational enterprises would like to expand their R&D activities in China, as observed by a number of studies including UNCTAD (2005).

One possible explanation of the insignificant impact of a subsidiary's R&D intensity on its R&D output from equations (1) and (2) is that since there is no pressure for multinational subsidiaries in an emerging economy to conduct innovation to compete with local firms, not enough is spent on subsidiary R&D, and the efficiency of R&D spending at the subsidiary level is low. A more plausible reason for the insignificant impact of R&D intensity on subsidiary R&D output may be associated with the adaptive nature of most R&D in an emerging economy like China. With MNEs increasing their production in China, some adaptive R&D follows. However, R&D is widely seen to be the least "fragmentable" of economic activities, and requires skill and knowledge support, and dense knowledge exchange (much of it tacit) between the producers and users (UNCTAD, 2005, p. XXIV). R&D intensity, measured by R&D expenditure/total sales, is a good indicator of subsidiary R&D resources, but may not be able to capture the support from the parent and knowledge exchange between the parent and its subsidiaries. Only when both subsidiary R&D resources and knowledge support and leadership from the parent are in place, can a subsidiary succeed in R&D output. The fact that the coefficient on R&D intensity becomes significant and positive in equations (3) and (4) lends some support to this explanation.

The above explanation is further confirmed by the findings from the test of H2. The empirical support to H2 indicates that R&D expatriates and subsidiary R&D intensity are complementary to each other, and that a subsidiary's own R&D intensity needs to interact with R&D expatriates from parent firms in order for it to play a significant role in subsidiary R&D output. Given the possible lack of motivation, commitment and efficiency, multinational subsidiaries in China need knowledge diffusion, leadership, guidance and support from R&D expatriates from parent firms in order for them to succeed in R&D output.

The fact that the interaction term of R&D expatriates with subsidiary R&D intensity is statistically significant while the interaction term of locally-recruited R&D staff with subsidiary R&D intensity is not tends to suggest that locally-recruited R&D personnel lack innovation leadership and managerial skills. Although there has been rapid growth of human resources for science and technology, and although China already has a vast pool of talent, *China's R*&D capability is below OECD countries (Watkins-Mathys & Foster, 2006), and the efficiency of locally-recruited R&D personnel is still relatively low compared to advanced economies (OECD, 2007, pp. 28-29). Furthermore, there are significant disparities among Chinese provinces in terms of R&D intensity and innovation performance, and top performers such as Beijing and Shanghai far surpass the others (OECD, 2007, p. 26; Chen, 2007; Sun & Wen, 2007). There is also a shortage of innovation managers in many areas (OECD 2007, p. 29). As a result, multinational subsidiaries in China still need knowledge transfer and integration, leadership and guidance from their parent firms in order for them to conduct successful innovation.

In summary, in line with the network theory of foreign direct investment in an emerging economy setting, we have assessed the impact of locally-recruited R&D personnel relative to their R&D expatriate counterparts on multinational subsidiary R&D output based on a sample of 317 multinational subsidiaries in China. While there are several studies explaining subsidiary innovative activities in terms of their internal and external technology sourcing, few discuss this issue for an emerging economy setting. Furthermore, little research can be found on comparative roles of different sources of R&D staff in subsidiary R&D output. Methodologically, we have applied the zero-inflated negative binomial method to improve the estimation efficiency over the widely used standard negative binomial method. Our main results indicate that R&D expatriates significantly promote subsidiary R&D output, while locally-recruited R&D personnel play a limited positive role. A subsidiary's own R&D intensity needs to interact with R&D expatriates in order for it to play a significant role in subsidiary R&D output.

The findings from this study seem to be different from those in developed economies which have high levels of technological capability. The findings from this study may be generalised to some other emerging economies with a similar level of development. Multinational subsidiaries in an emerging economy operate below the international technological frontier. Therefore, multinational subsidiaries may have to rely much more on internal knowledge diffusion and integration in order to create new knowledge. In this process, R&D expatriates play a significant role in internal network building, tacit knowledge diffusion, and leadership provision. On the other hand, while China has made significant progress toward the development of technological capabilities, it is not always easy for multinational subsidiaries to use its networks to source suitable locally-recruited R&D personnel as there is still a lack of specialised human resources for science and technology and of innovation management skills in China.

There are several managerial and policy implications of this study. Firstly, in an emerging economy with limited local technological capabilities, subsidiary managers need to actively seek knowledge resources from their parent firms in order to carry out effective innovative activities. Multinational enterprises also need to realize that external knowledge sources from an emerging economy may not be as strong as from a developed economy, and hence more knowledge diffusion and leadership need to be provided in order for their subsidiaries to effectively innovate. R&D expatriation is an important means for knowledge diffusion, R&D network integration and subsidiary innovation promotion. The Chinese government needs to provide more support to science and technology education, public research and on-the-job training across regions and commercial industries, and improve other institutional factors such as intellectual property protection to make more regions in China become attractive to international R&D. By so doing, there can be a dynamic co-development of local institutions and international R&D in all regions and commercial industries to promote overall R&D capability and economic development in China.

There are several limitations of this study. One is the measure of R&D output. While patents are an objective measure of technological knowledge, it has its limitations as discussed in Section 3.2. The number of patents may not reflect the significance of the R&D output, and simply using industry dummies may not be able to sufficiently address this issue.[7] Another problem is that the patents may have been granted by different patent offices, and hence it is very difficult to compare them as they may have gone through different screening procedures.[8] Alternative measures such as competence development (Andersson, Forsgren, & Holm, 2002) and competence-creating status (Cantwell & Mudambi, 2005) can be used in future research in an emerging economy. Secondly, the use of 1998 as the base year is somewhat arbitrary. Multinational subsidiaries entered China in different years, some of which may have already had well-established R&D teams in 1998, while others may have not. As a result, there may be lower incremental increase of R&D expatriation and locally-recruited R&D staff in the former than in the latter. This may affect R&D staff measurement. Thirdly, we hypothesise that R&D expatriates will have a positive impact on multinational subsidiary R&D output in an emerging economy due to their roles in internal network building, tacit knowledge diffusion and leadership

[7] We thank one anonymous referee for this point.
[8] We thank one anonymous referee for this input.

provision, but we have tested this hypothesis by assessing the aggregate association between R&D expatriates and subsidiary R&D output. It would be more interesting to test these three mechanisms independently. Fourthly, while our sample is representative in terms of the level of regional development, it is not in terms of the geographical distribution of FDI in China. It would be ideal if multinational subsidiaries from Guangdong and Zhejiang had been included. Fifthly, we asked the sampled firms to provide data for the past 7 years. Although all key variables used in this study were factual, the person who completed the questionnaire for the firm had to check all the information in the firm's records in these years. This was not a small commitment, and not all the information provided could be double checked. Sixthly, although the DWH test has been conducted to test for endogeneity, the choice of the instrumental variables is not ideal as it is hard to find real exogenous instruments in addition to data limitations. Finally, China has been experiencing rapid progress towards the building up of a stock of high-quality human resources for science and technology development and management. If we conduct a similar study today, we may be able to see a greater role played by locally-recruited R&D personnel in multinational subsidiary R&D output in China. This is consistent with the argument that patterns of man-made comparative advantage change over time (Blinder, 2006; Doh, Bunyaratavej & Hahn, 2009). Therefore, the finding of this study regarding the role that locally-recruited R&D staff can play in multinational subsidiary R&D output may need to be interpreted with caution.

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Table 1: Industry distribution of the firms in the sample (n=317)

Industry	Number of firms	Percentage (%)
Transport equipment	91	28.71
Pharmaceutical	26	8.20
General and special machinery	33	10.41
Metal products	42	13.25
Chemical products	19	5.99
Telecommunication, computing, and other electronic equipment	29	9.14
Electrical equipment	27	8.52
Food , beverage and agricultural products	11	3.47
Textile and leather products	7	2.21
Non-metallic mineral products	14	4.42
Rubber and plastic products	6	1.89
Others	19	5.99

Table 2: Description of the variables (n=317)

Variable	Mean	Std.	Measurement
Patent	0.62	1.58	The number of successful patent applications
Firm age	5.82	3.47	Log of the age of a firm
Firm size	5.27	1.33	Log of the total employee of a firm
R&D personnel	0.16	0.15	R&D personnel / total employee
R&D intensity	0.10	0.19	R&D expenditure / total sales
Local R&D personnel	0.05	0.16	R&D personnel from local Chinese firms / total R&D personnel
R&D expatriates	0.10	0.17	R&D expatriates from parent firms / total R&D personnel
Exporting-oriented dummy	0.33	0.47	1 if share of export in total sales is larger than 50%, 0 otherwise
Autonomy	2.2	0.68	Subjective measure of autonomy in R&D decision from 1 to 5 with increasing autonomy
WFOE dummy	0.46	0.49	1 for wholly foreign owned firms, 0 otherwise

Table 3: Correlation of the variables (n=317)

Variable	1	2	3	4	5	6	7	8	9	10
Patent	1.00									
Age	-0.05	1.00								
Size	0.35	0.16	1.00							
R&D capacity	0.04	-0.09	-0.38	1.00						
WFOE	0.04	-0.18	-0.13	0.06	1.00					
Exporting-oriented	0.08	0.05	0.02	-0.18	0.13	1.00				
Autonomy	0.20	-0.15	0.13	0.05	0.04	0.08	1.00			
R&D intensity	0.05	-0.17	-0.22	0.44	0.00	-0.10	0.06	1.00		
R&D expatriates	-0.01	0.04	0.03	0.10	0.00	-0.02	-0.20	0.00	1.00	
Local R&D personnel	0.00	-0.03	-0.03	-0.07	0.06	0.03	-0.05	0.03	-0.19	1.00

Table 4: Innovation in subsidiaries, zero-inflated negative binomial regression (n=317)

	Equation 1	**Equation 2**	**Equation 3**	**Equation 4**
Age	-0.4012*	-0.466**	-0.484**	-0.488**
	(0.198)	(0.203)	(0.202)	(0.202)
Age square	0.073	0.075	0.081	0.082
	(0.071)	(0.073)	(0.073)	(0.073)
Size	1.369***	0.868***	0.744**	0.703**
	(0.213)	(0.286)	(0.292)	(0.297)
Technology capability	1.201***	0.722*	0.365	0.305
	(0.398)	(0.420)	(0.447)	(0.454)
WFOE dummy	0.024	0.107	0.108	0.103
	(0.108)	(0.111)	(0.111)	(0.111)
Export-oriented dummy	0.127	0.060	0.044	0.043
	(0.112)	(0.103)	(0.103)	(0.103)
Autonomy	0.186**	0.167**	0.182**	0.177**
	(0.079)	(0.083)	(0.084)	(0.084)
R&D intensity		-0.082	0.694*	0.695*
		(0.132)	(0.373)	(0.374)
R&D expatriates		0.008***	0.012***	0.011***
		(0.002)	(0.002)	(0.002)
Locally-recruited R&D personnel		0.011*	0.011*	0.012*
		(0.006)	(0.006)	(0.006)
R&D intensity* R&D expatriates			0.620**	
			(0.286)	
R&D intensity* locally-recruited R&D personnel				0.281
				(0.398)
Home country dummies	Yes	Yes	Yes	Yes
Host city dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Firm dummies	Yes	Yes	Yes	Yes
Inflate				
Patents from the MNE	0.036	0.034	0.036	0.036
	(0.035)	(0.040)	(0.040)	(0.039)
Patents from local companies	1.101**	1.108**	1.175**	1.164**
	(0.432)	(0.479)	(0.488)	(0.483)
Existing patents in the subsidiary	-0.255	-0.251	-0.256	-0.266
	(5.306)	(5.213)	(6.427)	(10.674)
Vuong test	16.31	16.94	16.96	16.87
Number of observations	1280	1272	1224	1216

Notes: 1. *** p<0.01, ** p<0.05, * p<0.1.

2. Numbers in the parentheses are robust standard errors.