



Productivity spillovers from R&D, exports and FDI in China's manufacturing sector

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Abstract

This paper assesses productivity spillovers from R&D, exports and the very presence of foreign direct investment (FDI) in China's manufacturing sector, based on a panel of more than 10,000 indigenous and foreign-invested firms for 1998–2001. There are positive inter-industry productivity spillovers from R&D and exports, and positive intra- and inter-industry productivity spillovers from foreign presence to indigenous Chinese firms within regions. OECD-invested firms seem to play a much greater role in inter-industry spillovers than overseas Chinese firms from Hong Kong, Macao and Taiwan within regions. The findings have important managerial and policy implications.

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Introduction

Recent endogenous growth theory suggests that technological knowledge has an important influence on a country's productivity, and is the main driving force of economic growth. Knowledge can be generated by an organisation's own research and development (R&D). Given its non-rivalrous nature, knowledge also spills via various channels, including R&D, international trade and foreign direct investment (FDI). There are respective strands of literature on knowledge spillovers from R&D, international trade and FDI, but few studies examine these channels within a single framework.

There are several studies on spillovers generated by FDI in China, including Li *et al.* (2001), Liu *et al.* (2001), Wei and Liu (2001), Buckley *et al.* (2002), Hu and Jefferson (2002), Liu (2002), and Huang (2004). There is only one study of domestic R&D spillovers, that is, Jefferson *et al.* (2006). No study, to our best knowledge, is on export spillovers.

As for productivity spillovers from FDI, various alternative measures of foreign presence have been applied in the literature, including capital, employment, R&D, exports, sales and output. However, there is no wide recognition that each of these indicators may capture a different aspect of spillover effects. This may partially explain why mixed results have been produced in the literature. (For surveys of the empirical literature, see Görg and Strobl (2001) and Görg and Greenaway (2004).)

The principal aim of this paper is to examine whether there are any spillovers from other firms' R&D and export activities and

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foreign presence in the manufacturing sector in China. There are three specific features in this study. First, the three main sources of technological knowledge spillovers are incorporated into a single framework. That is, productivity in indigenous Chinese firms is influenced by knowledge spillovers from the presence of foreign-invested firms and R&D and export activities in Chinese manufacturing. Second, various alternative measures of foreign presence identified in the literature are compared, and a robustness test is carried out to examine whether the productivity impacts of foreign presence depend on the way spillovers are proxied. Third, different from most of the existing studies for China, the current investigation uses a recent large firm-level data set and is the most comprehensive investigation for China.¹

The rest of the paper is organised in the following way. The next section reviews the literature. The subsequent two describe the methodology, data and variables. This is followed by a discussion of the empirical results. The final section summarises the findings and discusses managerial and policy implications.

Literature review

R&D and knowledge spillover

R&D has long been seen as an important source of knowledge generation and productivity improvement (Shell, 1966). Recently, endogenous growth theory has emphasised the importance of commercially oriented innovation efforts and R&D knowledge spillovers in explaining countries' productivity. R&D increases productivity by providing new products and processes or upgrading existing products and processes that enhance profits or reduce costs.

R&D not only directly affects the productivity of the firm that conducts R&D, but may also produce spillover effects that increase other firms' productivity. Given imperfect intellectual property rights and low marginal costs of reproducing results from R&D, technologies developed in one firm may spread to other firms through imitation, reverse engineering or recruitment of the investing firm's personnel (Braconier and Sjöholm, 1998).

R&D spillovers occur not only domestically but also internationally. In the latter case, multinational enterprises (MNEs) play an important role. MNEs from the developed world carry out much of the world's total R&D activities, and possess the bulk of the world's stock of advanced commercial technologies. Indeed, Mansfield and Romeo (1980)

find that technologies transferred from parent firms to their subsidiaries are of a later vintage than technologies sold to outsiders through licensing agreements. However, the technological knowledge transferred to the subsidiaries often leaks out to local firms. Thus R&D spillovers increase local firms' productivity.

As for empirical testing, there is an extensive literature on the effects of other firms' R&D on a given firm's productivity in a closed economy. Despite the differences in the data, methodologies and the measurement methods for R&D employed, the majority of the studies find the presence of R&D productivity spillovers, though their importance varies greatly across studies (Griliches, 1992). Research on international R&D spillovers is often carried out at the macro level.² Investigations at the firm level are relatively limited. One example is Bernstein (2000), who finds that a major component of total factor productivity growth in Canadian manufacturing over the period 1966–1991 was due to the spillover effects from the US. Another is Feinberg and Majumdar (2001), who show that significant R&D spillovers in the Indian pharmaceutical sector over the period 1980–1994 occurred only between MNEs as a group. Spillovers from MNEs to Indian firms did not take place at all. This mixed evidence suggests that the productivity effect of international R&D spillovers depends largely on the host-country policy environment (Feinberg and Majumdar, 2001) and the technological capabilities of local firms (Cantwell, 1993).

Exports and knowledge spillover

Exports raise productivity by giving rise to various benefits, such as more efficient use of resources, greater capacity utilisation and gains of scale effects associated with large international markets (Bhagwati, 1978; Krueger, 1978; Obstfeld and Rogoff, 1996). Endogenous growth theory (Rivera-Baits and Romer, 1991a, b; Coe and Helpman, 1995; Coe *et al.*, 1997) suggests that international trade is an important means of facilitating technology creation, transfer and diffusion. For instance, when local goods are exported, the foreign purchasing agents may suggest ways to improve the manufacturing process (Grossman and Helpman, 1991: 166). Buyers want low-cost, better-quality products from main suppliers. To obtain this, they transmit tacit and occasionally proprietary knowledge from their other, often OECD-economy based suppliers (World Bank, 1993: 320). Participating in export markets brings firms into contact with interna-

tional best practice and learning and productivity growth (World Bank, 1997). Exports may also raise productivity by spurring development of new technologies (Hejazi and Safarian, 1999).

Knowledge diffuses via export activities. Blomström and Kokko (1998) suggest that MNEs often have knowledge of, and experience in, international marketing, established international distribution networks and lobbying power in their home markets. This enables MNEs to possess strong competitive advantages in competing in the world market. According to Görg and Greenaway (2004), MNEs generally come already armed with international marketing knowledge and experience, and exploit them to export from the new host country. As a result of their export activities, MNEs may pave the way for indigenous firms in host countries to enter the same export markets, because they either create transport infrastructure or disseminate information about foreign markets that can be used by these indigenous firms. In terms of empirical evidence for knowledge spillovers from exports, there is a substantial literature on exported growth at the macro level, but there are few microeconomic studies, with one exception (to our best knowledge), that is, Clerides *et al.* (1998), which investigates large samples of firms in Mexico, Colombia and Morocco and finds some positive but weak regional externalities.

FDI presence and knowledge spillovers

The most important reason why countries try to attract FDI is perhaps the prospect of acquiring modern technology, interpreted broadly to include product, process, and distribution technology, as well as management and marketing skills (Blomström and Kokko, 1998). FDI is a package of capital, technology and managerial skills, and has been viewed as an important source of both direct capital inputs and technology and knowledge spillovers. Balasubramanyam *et al.* (1996) argue that developing countries can benefit significantly from FDI because it not only transfers production know-how and managerial skills but also produces externalities, or spillover effects.

Blomström and Kokko (1998) summarise the following means through which knowledge can spill over to indigenous firms in a host country. FDI contributes to efficiency by breaking supply bottlenecks, introduces new know-how by demonstrating new technologies and training workers who later take employment in local firms, breaks down monopolies and stimulates competition, transfers

technologies to local suppliers, and forces local firms to increase their managerial efforts. However, there can be negative externalities from FDI. As Aitken and Harrison (1999) note, the entry of local market-oriented foreign firms can draw demand from local firms, causing them to cut production. Thus the productivity of local firms would fall as they are forced back up their average cost curves. As a result, net local productivity can decline.

Some recent studies, such as Kokko *et al.* (1996) for the Uruguayan manufacturing sector, Liu *et al.* (2000) for UK manufacturing, and Li *et al.* (2001) and Wei and Liu (2001) for China, find positive spillover effects. Javorcik (2004) detects productivity spillovers taking place through backward linkages in Lithuania. Sinani and Meyer (2004) identify spillovers of considerable magnitude in Estonia, but these effects vary with the measure of foreign presence used and are influenced by the recipient firm's size, ownership structure and trade orientation. Ruane and Ugur (2005) find only weak evidence of spillovers in Ireland, and this evidence is also sensitive to the definition and measurement of foreign presence. Mixed results are also reported in Aitken and Harrison (1999) for Venezuelan industry and in Buckley *et al.* (2002), Hu and Jefferson (2002) and Huang (2004) for China. Different results may be due partially to the use of different measures of foreign presence.

Mixed results may also arise from different estimation methods applied. As indicated by Görg and Greenaway (2004), only 22 out of the 40 selected studies of horizontal productivity spillovers (up to the year of 2002) report unambiguously positive and statistically significant externalities. However, among these 22 studies, 16 use cross-sectional data and hence their results may be questionable, because panel data using firm-level information provide the most appropriate estimating framework (Görg and Strobl, 2001; Görg and Greenaway, 2004). Most very recent studies of productivity spillovers from FDI (e.g., Javorcik, 2004; Sinani and Meyer, 2004; Ruane and Ugur, 2005) do use a panel data approach at the firm or plant level, and the majority of them find some degree of positive externalities. This firm-level panel data approach is adopted in the current study.

Intra (inter)-region and intra (inter)-industry knowledge spillovers

Spillover effects could be received first by the neighbouring firms. The benefits may then gradually spread to other, more distant firms. If



the spillover effects are received by neighbouring firms only, spillovers are 'local' in scale. If spillover benefits are received by firms in other regions in the host country, then the spillovers are 'national' in scale. A study of geographical scale of productivity spillovers is particularly important when we measure the impact of FDI in all regions if the 'local' benefits are too small to offset the overall negative impact across all regions (Aitken and Harrison, 1999).

In addition to the difference between local and national spillovers in geographical scale, there is a difference between intra- and inter-industry productivity spillovers. If technological benefits are received by firms in the same industries, there are intra-industry or horizontal spillovers. However, if technological benefits are received by firms in other industries, there are inter-industry or vertical spillovers. Javorcik (2004) argues that firms have an incentive to prevent information leakage that would enhance the performance of their competitors, but no incentive to prevent technology diffusion to upstream sectors. Therefore, spillovers are more likely to be vertical than horizontal in nature. In our view, this argument may ignore the existence of other important ways in which productivity spillovers may arise. For instance, the theoretical literature identifies imitation, skill acquisition, competition and exports as the four main mechanisms through which spillovers may boost productivity (Görg and Greenaway, 2004). There is no doubt that intra-industry spillovers are taking place through all these mechanisms.

Firm ownership and knowledge spillovers

The effectiveness of knowledge or productivity spillovers depends largely on the technical capabilities of both foreign and local firms (Cantwell, 1993; Sinani and Meyer, 2004). In China, there are two main types of foreign investor: overseas Chinese investors from Hong Kong, Macao and Taiwan (HMT), and other investors, mainly from OECD countries. It is recognised that OECD firms are superior to HMT firms in product and innovation and in technological development (Yeung, 1997). The average labour productivity and the technical efficiency in OECD invested firms are higher than those in overseas Chinese invested firms in China (Huang, 2004). Therefore the magnitude of the effect of OECD firms on the productivity of indigenous Chinese firms should be greater than that of HMT firms (Buckley *et al.*, 2002).

In this literature review section, we have briefly discussed three sources of productivity spillovers: R&D, exports and FDI presence. Theoretically, all these sources of externalities contribute to the productivity improvement in a host country. However, the existing studies tend to focus on one of these sources only. In the present paper, first we try to capture productivity spillovers from all important sources of R&D, exports and foreign presence within a single framework, avoiding the possible situation where only one source is credited with knowledge spillovers that may be attributable to other sources. Second, given that different measure may capture different aspects of spillovers, we have compared the effects of several alternative measures of foreign presence. Third, the data set used in this study is the most recent and comprehensive for China. Like Aitken and Harrison (1999), we examine whether spillovers are regional or national in scale. Furthermore, we consider both inter- and intra-industry spillovers and compare the different roles of OECD and overseas Chinese invested firms in enhancing productivity in indigenous firms in Chinese manufacturing. Finally, we use a firm-level panel data approach, which is still rarely adopted for studying productivity spillovers in China. Given these features, the current study should make an important contribution to the empirical literature on productivity spillovers.

Methodology

In this paper, our estimations are confined to the impact of knowledge spillovers on the productivity of indigenous Chinese firms only. This is different from such studies as Aitken and Harrison (1999), where domestically and foreign-owned firms are pooled together. We argue that their model is restrictive because it imposes a condition of the same slope for domestically and foreign-owned firms. There are considerable differences between the two groups of firms in China. Based on our data set, foreign invested firms on average perform better than local firms according to various measures, including labour productivity (measured by the ratio of value added to employment), sales and profits.³ Statistics also reveal that foreign invested firms have higher capital intensity (measured by the ratio of fixed assets to employment), and are more R&D intensive (measured by intangible assets and sales revenues from new products) and export-oriented (measured by exports and the ratio of exports to sales revenues) than local firms. Therefore, slope coefficients should vary, and simple

inclusion of a dummy variable in the estimation is not sufficient.

The most common approach found in the empirical literature of knowledge spillovers is to estimate a Cobb–Douglas production function:

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta}e^{\varepsilon_{it}} \quad (1)$$

where Y , K and L denote output, physical capital and labour respectively; ε is an error term that reflects the effects of unknown factors, measurement errors and other disturbances; and subscripts i and t indicate the firm and time period under consideration. Usually, an assumption of constant returns to scale with respect to K and L is imposed ($\alpha + \beta = 1$). Here, instead, we let the estimation results indicate whether the assumption applies at the firm level. Nevertheless, the estimation results are little changed when the assumption is imposed. A is total factor productivity (TFP), which is a function of a firm's own R&D and export activities and is dependent upon other firms' R&D, exports and the presence of FDI. Hence, we can write the expression for A_{it} as follows:

$$A_{it} = f(\text{RD}_{it}, \text{EX}_{it}, \text{RDSP}_{it}, \text{EXSP}_{it}, \text{FDISP}_{it}) \quad (2)$$

where RD and EX are the firm's own R&D and export activities, respectively. Given that the focus of this paper is on knowledge spillovers from other firms, RD and EX are treated as the control variables in our model. These other firms are in firm i 's industry, firm i 's region or firm i 's industry in the region where firm i locates, depending on the question under investigation. RDSP represents knowledge spillovers due to other firms' R&D activities. EXSP represents knowledge spillovers due to other firms' export activities. FDISP is knowledge spillovers emanating from foreign-owned firms. The functional form for A_{it} is unknown, and we choose to use the following simple form:

$$\log(A_{it}) = \mu_1\text{RD}_{it} + \mu_2\text{EX}_{it} + \mu_3\text{RDSP}_{it} + \mu_4\text{EXSP}_{it} + \mu_5\text{FDISP}_{it} \quad (3)$$

where the coefficients μ capture the contributions of the R&D, export and FDI spillover variables to TFP.

One important econometric issue is the possibility of endogeneity. Investment in R&D, exports and the presence of FDI might well be influenced by productivity. For example, productivity may be higher among those firms undertaking R&D because they are better able to do so after they increase productivity. Similar to own R&D, own exporting may reflect either (1) learning from

exporting abroad or (2) that more efficient/productive firms export.⁴ Furthermore, foreign firms may be attracted to high-productivity sectors without generating spillovers. One common approach to deal with endogeneity is the use of instrumental variables. However, as is well known, it is very difficult to create an effective set of instruments. Among the list of candidates, few are likely to be truly exogenous. To keep the possible endogeneity problem to a minimum and take into account the lag between knowledge spillovers and productivity gains, we include R&D, exports and all spillovers variables with a lag of one year into the estimations.

The logarithmic transformation of Equation (1) after substituting for A_{it} from Equation (3) and taking into account the above argument gives us

$$\begin{aligned} \log(Y_{it}) = & \alpha \log(K_{it}) + \beta \log(L_{it}) + \mu_1\text{RD}_{it-1} \\ & + \mu_2\text{EX}_{it-1} + \mu_3\text{RDSP}_{it-1} + \mu_4\text{EXSP}_{it-1} \\ & + \mu_5\text{FDISP}_{it-1} + \varepsilon_{it} \end{aligned} \quad (4)$$

Equation (4) is estimated with correction for heteroskedasticity and autocorrelation.

Data and variables

The data used are mainly from the *Annual Report of Industrial Enterprise Statistics* compiled by the State Statistical Bureau of China (1999, 2000, 2001, 2002, 2003), covering firms in nine two-digit industries during the period 1998–2001. These industries are food processing, food manufacturing, beverage production, garments and other fibre products, medical and pharmaceutical products, ordinary machinery manufacturing, transport equipment manufacturing, electric machines and apparatuses, and electronic and telecommunications equipment. For each industry, the Bureau collects detailed data on each industrial firm in operation. The data include information on ownership classification, value added,⁵ output, capital stock, number of employees, costs of intermediate inputs, total sales, intangible assets, new product sales and exports. As for deflators, price indices for total manufacturing fixed assets and industrial output are obtained from the *China Statistical Yearbook 2002*. This data set has at least two advantages: it covers a very recent period, and it allows us to control for observable and unobservable firm-level characteristics in order to mitigate aggregation bias.

As a result of entry and exit and ownership restructuring, the number of firms in operation is changing over time. In this study, the same firms



have been identified, based on their identifiers, to produce a final balanced set of 15,761 firms for each year, of which 5861 are foreign-owned and 9900 are domestically owned. A firm has been defined to be domestically owned if its foreign equity participation, if any, is below 25%. In terms of employment, these firms altogether accounted for nearly 78% over the sample period.

The data are cleaned via extensive checks for nonsense observations, outliers, coding mistakes, and the like. In addition, only firms with at least 3 years of data for value added, output, capital stock, intangible assets, exports and total sales are kept. This finally leaves us with a panel of 7697 domestically owned firms. In this data set there are two types of foreign presence: overseas Chinese from Hong Kong, Macao and Taiwan (HMT), and other foreign investors mainly from OECD countries (OECD). Their different roles in productivity spillovers are examined in this study. Three sets of spillover variables are used in the paper. FDISP, RDSP and EXSP represent spillovers due to the presence of foreign-owned firms, R&D and exports, respectively.

Although several sources are identified, there is no consensus on the actual measurement of productivity spillovers from FDI because their nature is 'indirect'. Since Caves (1974) there have been numerous empirical studies, and various measures have been applied. Recent examples include the employment share of foreign-owned firms (Liu *et al.*, 2000; Buckley *et al.*, 2002), capital/investment share of foreign-owned enterprises (Liu *et al.*, 2001; Wei and Liu, 2001; Buckley *et al.*, 2002), output (or value added) share of foreign-owned firms (Kokko *et al.*, 1996; Konings, 2001), the share of sales of foreign-owned firms (Kathuria, 2002), the share of assets held by foreign firms (Haddad and Harrison, 1993), the share of R&D stock held by foreign firms (Feinberg and Majumdar, 2001), the share of foreign equity participation weighted by employment (Aitken and Harrison, 1999), and the share of foreign equity participation weighted by sales (Hu and Jefferson, 2002), depending on data availability. Görg and Strobl (2001) suggest that the choice of proxy variables for spillovers from FDI may be an important determinant of differences across studies, but they stop short of any further explanation.

We propose that different measures capture different channels or aspects of productivity spillovers from foreign presence. If a single proxy such as foreign capital or fixed assets is applied, then the positive spillover effect simply indicates that the

foreign presence produces a positive capital spillover effect. In this case, the positive externalities are closely related to the demonstration effect of the suitability of the project, or the superiority of machinery or equipment embodying updated technologies. Similarly, if employment in foreign firms is applied, then the spillover effect will be closely associated with employee turnover or contagion between employees in foreign and local firms. This can be referred to as employment spillovers. In the same manner, we can have sales, output, R&D and export spillovers from foreign presence. Sales spillovers are linked with knowledge diffusion of the superior product and marketing skills. Output spillovers are concerned with the demonstration effects of not only the superior product but also such characteristics of scale or scope economies. They may also be linked with knowledge acquisition via reverse engineering of the product. R&D spillovers are the leakage of R&D activities from foreign-invested firms to local firms. Finally, export spillovers are related with international marketing knowledge diffusion.

Some of the measures are expected to be correlated, but this needs to be empirically confirmed. In the existing literature, it is a general rule that only one measure is applied in a particular study, but the results are interpreted as the existence or absence of productivity spillovers from foreign presence as a whole. It can be the case that, when alternative measures are applied, different results will be obtained. It follows that when an individual measure (say, employment) is applied, then the research is actually examining one aspect of spillover effects rather than spillovers from foreign presence as a whole. The measures of foreign presence in the current study include capital, employment, sales, output, R&D and exports. Our rich data set allows us to examine various channels and aspects of productivity spillovers from foreign presence in Chinese manufacturing.

In terms of measuring R&D, some studies use input indicators of technology such as R&D expenditures and patents, whereas others use output indicators such as intangible assets. One disadvantage of input indicators is that they cannot measure the 'efficiency' of knowledge development. In this paper, we shall use an output indicator: intangible assets. R&D expenditure is only available for year 2001, and therefore is not used. The variable of R&D spillovers is measured as the unweighted sum of the R&D stocks of all other firms. In the literature of R&D spillovers, weights

are used to take into account the different ability of firms to internalise other firms' knowledge (Kaiser, 2002). The weights are often assumed to be proportional to the similarity between two firms' 'technological space', which is determined by a vector containing the number of patents or the share of scientists per technology field or geographical distance. However, we have no data for patents and the number of scientists at the firm level. In addition, it is unclear to what extent those weighting schemes are appropriate for capturing knowledge spillovers. Therefore, we choose to use unweighted measures. The definitions and measures of variables are provided in the Appendix. The summary statistics of the variables including their means, standard deviations and Spearman's correlation coefficient matrix are provided in Table 1.

Empirical results

Table 2 presents the main empirical results. In all estimations, year dummies are included to capture the unobserved, year-specific effects. To allow for

industry-specific effects, we include not only industry dummies at the two-digit level, but also the interaction terms between the industry dummies and LK (log of K), LL (log of L) and RD.⁶

A 'region' in China is normally defined as a province such as Zhejiang, an autonomous region such as Inner Mongolia, or a municipality directly under the central government such as Beijing. Our data set covers all the provincial-level regions in mainland China (see Figure 1). As a result of high correlations between the individual regional dummy variables and the regional spillover variables, we use the so-called 'area' dummy variables instead. As shown in Figure 1, China can broadly be divided into three macro areas: the coastal area (Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi and Hainan); the central area (Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan); and the western area (Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang). These area dum-

Table 1 Descriptive statistics

	Mean	Standard deviation	Spearman's rank correlation coefficient matrix							
			LK	LL	RD	EX	RDSP	EXSP	FDISP_HMT	
LK	8.86	1.92								
LL	5.27	1.43	0.82							
RD	0.10	0.87	0.26	0.25						
EX	0.06	0.19	0.33	0.37	0.18					
<i>Industry</i>										
RDSP	0.08	0.04	0.07	0.08	0.12	0.00				
EXSP	0.17	0.22	0.04	0.13	0.04	0.32	0.04			
FDISP	0.35	0.22	0.11	-0.13	0.00	0.07	-0.02	0.44		
FDISP_HMT	0.12	0.11	-0.16	-0.21	-0.04	0.02	-0.11	0.22		
FDISP_OECD	0.24	0.17	-0.05	-0.05	0.02	0.08	0.05	0.44	0.28	
<i>Region</i>										
RDSP	0.08	0.03	0.04	0.04	0.11	0.12				
EXSP	0.16	0.15	0.01	-0.01	0.06	0.20	0.44			
FDISP	0.30	0.19	0.02	0.01	0.06	0.20	0.37	0.82		
FDISP_HMT	0.08	0.08	0.03	0.01	0.04	0.18	0.24	0.71		
FDISP_OECD	0.21	0.13	0.02	0.02	0.07	0.19	0.38	0.77	0.67	
<i>Industry within region</i>										
RDSP	0.07	0.14	-0.02	-0.01	0.10	0.04				
EXSP	0.11	0.21	0.04	0.09	0.07	0.32	0.39			
FDISP	0.21	0.26	-0.05	-0.06	0.05	0.14	0.50	0.54		
FDISP_HMT	0.06	0.13	-0.03	-0.06	0.04	0.12	0.36	0.38		
FDISP_OECD	0.14	0.22	-0.02	-0.01	0.07	0.15	0.47	0.53	0.39	

Notes: Variable definitions are provided in the Appendix. LK=log(K). LL=log(L). FDISP_HMT and FDISP_OECD represent FDI spillovers from HMT and OECD firms, respectively.

Table 2 Production function estimates, all firms

	2(1)	2(2) Industry	2(3) Region	2(4) Region	2(5) Industry within region	2(6) Industry	2(7) Region	2(8) Region	2(9) Industry within region
EX	0.264*** (0.053)	0.317*** (0.054)	0.240*** (0.053)	0.238*** (0.053)	0.269*** (0.054)	0.317*** (0.054)	0.247*** (0.053)	0.253*** (0.053)	0.268*** (0.054)
RDSP		0.444** (0.218)	0.998*** (0.284)	0.986*** (0.284)	0.036 (0.059)	0.425** (0.218)	0.951*** (0.284)	0.950*** (0.284)	0.038 (0.059)
EXSP		-0.368*** (0.079)	0.159 (0.160)	0.753*** (0.116)	-0.131** (0.067)	-0.381*** (0.079)	0.479*** (0.176)		-0.131** (0.067)
FDISP		-0.012 (0.072)	0.784*** (0.148)		0.262*** (0.054)				
FDISP_HMT						0.123 (0.116)	0.033 (0.227)	0.481*** (0.156)	0.300*** (0.082)
FDISP_OECD						-0.061 (0.079)	1.059*** (0.161)	1.244*** (0.146)	0.247*** (0.060)
Industry-specific capital effects	Included***	Included***	Included***	Included***	Included***	Included***	Included***	Included***	Included***
Industry-specific labour effects	Included***	Included***	Included***	Included***	Included***	Included***	Included***	Included***	Included***
Industry-specific R&D effects	Included	Included	Included	Included	Included	Included	Included	Included	Included
Industry effects	Included***	Included***	Included***	Included***	Included***	Included***	Included***	Included***	Included***
Geographic area effects	Included***	Included***	Included***	Included***	Included***	Included***	Included***	Included***	Included***
R ²	0.622	0.623	0.626	0.625	0.624	0.624	0.627	0.626	0.624
F test	881.951***	885.712***	897.116***	893.295***	889.493***	869.240***	880.444***	876.689***	869.240***
Wald test 1	43.084***	42.311***	42.918***	41.443***	42.259***	41.937***	44.115***	44.790***	41.921***
Wald test 2	32.300***	33.086***	32.594***	32.233	31.601***	33.251***	32.070***	32.320***	31.751***
Wald test 3	2.960	2.902	3.210	3.096	2.963	2.854	3.164	3.152	2.983
Wald test 4		29.143***	80.682***	52.806***	24.290***	31.429***	99.921***	92.881***	24.700***
Wald test 5						2.255	19.012***	12.653***	0.371

Notes:

Variable definitions are provided in the Appendix. $LK = \log(K)$. $LL = \log(L)$. *FDISP_HMT* and *FDISP_OECD* represent FDI spillovers from HMT and OECD firms respectively.

The total number of observations is 23,091 for all specifications.

Dummy variables to capture industry effects and geographic area effects and interaction terms between industry dummies and LK , LL and RD are included, but their corresponding coefficients are not reported here.

Standard errors are in parentheses.

***, ** and * indicate that the coefficient is significantly different from zero at the 1%, 5% and 10% levels, respectively.

F-test tests the model's goodness of fit.

Wald test 1 tests that LK has the same coefficients across industries.

Wald test 2 tests that LL has the same coefficients across industries.

Wald test 3 tests that RD has the same coefficients across industries.

Wald test 4 tests that the coefficients on spillover variables are jointly zero.

Wald test 5 tests that the coefficients on *FDISP_HMT* and *FDISP_OECD* are not statistically different.



Figure 1 Map of China Source: Zheng *et al.* (2004)

mies are introduced to control for area-specific effects (e.g., infrastructure).

The interaction terms of LK and LL with each of the industrial dummies are highly significant and highly stable across specifications.⁷ The statistics of Wald test 1 and Wald test 2 suggest that the coefficients on LK and LL vary across industries for all specifications. The assumption of constant returns to scale with respect to capital and labour is tested. In all specifications, it is rejected. The interaction terms of R&D with the industrial dummies are statistically insignificant. The Wald test 3 statistics suggest that the coefficients on R&D do not vary across industries for all specifications. Finally, EX as a control variable is highly significant and highly stable across specifications. This indicates a close relationship between the firm's own export activities and productivity.

Given the main purpose of the study, we are particularly interested in the behaviour of knowledge spillover variables RDSP, EXSP and FDISP. In Table 2, regression 2(1) gives the estimation results without these spillover variables for comparison. Regression 2(2) investigates industrial spillovers, regressions 2(3) and 2(4) examine regional spillovers, and, finally, regression 2(5) assesses industrial spillovers within specific regions respectively. The difference between regressions 2(3) and 2(4) is that FDISP is dropped in the latter, owing to the multicollinearity problem as reflected by the high correlation coefficient between FDISP and EXSP at the regional level in Table 1. The Wald test 4 statistics suggest that spillover variables are jointly significant in explaining a firm's productivity.

As shown in Table 2, the significant coefficient on RDSP in the 'industry' regression 2(2) indicates that there is evidence of intra-industry spillovers. The significant RDSP in the 'region' regressions 2(3) and 2(4) suggests the possibility of the existence of inter- and/or intra-industry spillovers within regions. However, the same variable is no longer statistically significant in the 'industry within region' regression 2(5), although it retains the positive sign. Putting together the regressions 2(2)–2(5), the results confirm that there are cross-region intra-industry R&D spillovers and very strong within-region inter-industry R&D spillovers. The coexistence of some positive R&D spillovers and insignificant effects of R&D on the firm's own productivity are consistent with those of Raut (1995), who investigates the impact of R&D on productivity for private manufacturing firms in India. One possible explanation is that intangible assets as a proxy can capture only part of productivity-enhancing R&D activities. Another tentative explanation is that an individual Chinese firm's R&D may not be significant enough to enhance its own productivity. Technological knowledge from its R&D activity spills over to create public domain knowledge. Then the industry- or region-wide knowledge contributes to private productivity gains.

Also from Table 2, EXSP is negative and highly significant in the 'industry' regression 2(2), and the 'industry-within-region' regression 2(5), but positive and highly significant in the 'region' regression 2(4) after FDISP is dropped from the estimation (to avoid the multicollinearity problem). The results indicate coexistence of negative intra-industry export spillovers within as well as across regions and positive inter-industry spillovers within regions. These results are very interesting, as they may be closely associated with some specific features of China as a transitional economy. Export activities are highly encouraged by the Chinese government. For example, one of the governmental incentives for this is the refund of value added tax for exported products. Partly because of this policy, both indigenous and foreign-invested firms compete for exports of products in the same industries, often at reduced prices. Exports thus generate negative intra-industry competition effects, which tends to lower productivities of indigenous Chinese firms.

On the other hand, the positive inter-industry spillover effects by export activities may be generated by industrial linkages. Industrial linkages nearly always entail an exchange of information, technical knowledge and skills. Strong linkages

can promote production efficiency, productivity growth, technological and managerial capabilities and market diversification in supplier firms (UNCTAD, 2001). Through these linkages with exporting firms, indigenous Chinese firms' productivities are significantly improved. Furthermore, the fact that positive export spillovers via industrial linkages are local in scale may be caused partly by local protectionism in China. It is well documented that there are still barriers to the movement of factors of production and output across regions in China. These include constraints on local enterprises for the sales of products across regions (Cai *et al.*, 2002; Yang, 2002). Put another way, there is regional protectionism as free flow of goods and services across regions may not hold in China (Batisse and Poncet, 2004). The barriers to flow of goods and services reduce industrial linkages, and hence block knowledge spillovers from export activities across regions.

Turning to spillover effects from FDI, the coefficient on FDISP is negative but statistically insignificant in the 'industry' regression 2(2), and positive and highly significant in the 'region' regressions 2(3) and the 'industry-within-region' regression 2(5) in Table 2. This suggests that there is no significant evidence of intra-industry productivity spillovers from FDI across regions, but there are strong inter- and intra-industry positive spillovers within regions. Put another way, like R&D and exports, positive productivity spillovers from FDI are fundamentally local rather than national. Like R&D and export spillovers, we believe that the barriers to free flow of goods and services contribute significantly to the existence of positive FDI spillovers on a local rather than a national scale. The spillover effects from FDI may be stronger without these barriers.

Table 2 also reports the estimation results when foreign-invested firms are grouped into Hong Kong, Macao and Taiwanese (HMT) firms and OECD firms. The coefficients on RDSP and EXSP in regressions 2(6)–2(9) are qualitatively very similar to those in regressions 2(2)–2(5), confirming the existence of intra-industry R&D spillovers across regions, strong inter-industry R&D spillovers within regions, strong negative intra-industry export spillovers within and across regions, and positive inter-industry export spillovers within regions.

Focusing on a comparison of knowledge spillovers from different sources of foreign-invested firms, both the FDISP_HMT and the FDISP_OECD variables are statistically insignificant in the 'industry' regression 2(6). When EXSP is excluded from

the model to avoid the multicollinearity problem, both FDISP_HMT and FDISP_OECD are highly significant in the 'region' regression 2(8), and the 'industry-within-region' regression in 2(9). These results first confirm that there are strong intra- and inter-industry productivity spillovers from both overseas Chinese and OECD invested firms, but they are clearly at the local rather than the national level. The Wald test 5 statistics show that there is a significant difference in the magnitude of the coefficient for FDISP_HMT and for FDISP_OECD in the 'region' regressions 2(7) and 2(8), but there is no significant difference in the 'industry-within-region' regression 2(9). Put another way, comparing the coefficient magnitudes for FDISP_HMT and FDISP_OECD in 2(8), FDI from OECD countries has played a much greater positive role in inter-industry productivity spillovers to indigenous Chinese firms than FDI from Hong Kong, Macao and Taiwan. From the 'industry-within-region' regression 2(9), FDI from these two different sources has played a similar role in terms of magnitude in intra-industry productivity spillovers within regions.

Although foreign-invested firms from HMT and OECD generate positive intra-industry productivity spillovers to indigenous Chinese firms with a similar magnitude within regions, their contributions may be of a different nature. The industrial projects launched by HMT firms, which are mainly labour intensive, may be more compatible with mainland China's current resource endowments. The technologies, managerial and marketing know-how transferred or diffused by HMT firms are crucial for the development of indigenous Chinese firms. On the other hand, foreign-invested firms from OECD countries have higher technological capabilities, and their productivity spillovers may concentrate on the enhancement of technological knowledge and competence in indigenous Chinese firms, and this is very important for China's move to a higher development stage.

Turning to regression 2(8), the magnitude of the coefficient on FDISP_OECD is three times as high as that on FDI_HMT. This, along with regression 2(9), suggests that FDI from OECD countries has exerted much greater positive inter-industry productivity spillovers to indigenous Chinese firms than FDI from HMT. Our tentative explanation is that the FDI projects launched by OECD-invested firms may be more technologically sophisticated and involved in more inter-industry linkages and hence generate more positive inter-industry externalities than those projects launched by HMT-invested firms.

Put together, even though the bulk of inward FDI in China is from HMT,⁸ our results indicate that the overall positive spillover impact of FDI from OECD is greater than that from HMT, though their spillover effects are both confined within regions.

As argued earlier, different measures of FDI may capture different aspects of productivity spillovers. In this study, we have compared the results for spillovers from the following seven measures of FDI at the intra-industry level within regions:

- (1) the shares of foreign capital in total capital;
- (2) the share of foreign-owned firms' employment in total employment;
- (3) the share of sales accounted for by foreign firms in total sales;
- (4) the share of output accounted for by foreign firms in total output;
- (5) the share of foreign-owned firms' R&D in total R&D;
- (6) foreign equity participation weighted by employment; and
- (7) foreign equity participation weighted by sales.

Using unweighted measures with capital, employment, and R&D and weighted measure with sales, FDI is found to generate regional productivity spillovers. Using unweighted measures with sales and output and weighted measure with employment, there are no intra-industry regional productivity spillovers from FDI.⁹

These findings have confirmed our earlier argument that different measures of foreign presence can produce different results. Therefore, our results cast doubt on previous studies based on only one measure of spillovers from foreign presence. In this study, the pairwise Spearman's rank correlation coefficients range from 0.999 to 0.512. This implies that these seven indicators should be introduced in separate regressions to avoid multicollinearity problems. However, by so doing, much important information may be lost. To gain efficiency, we adopt a principal components approach by combining some of the indicators into a 'grand' composite index. The first principal component has been identified, which explains more than 66% of the variance of these seven indicators. It shows that, with other things being given, indigenous Chinese firms benefit from FDI spillovers.

Conclusions

This paper has assessed the productivity spillover effects from R&D, exports and the presence of FDI

in Chinese manufacturing. Our general findings are as follows.

- (1) Indigenous Chinese firms seem to benefit significantly from R&D spillovers. Therefore the level of technological opportunities and the size of the knowledge pool matter.
- (2) There coexist negative intra-industry export spillovers within and across regions and positive inter-industry export spillovers within regions. The incentives provided by the Chinese government may accelerate the competition for exports between foreign-invested and indigenous Chinese firms in the same industries, leading to the negative intra-industry spillovers.
- (3) There is strong evidence of intra- and inter-industry productivity spillovers from foreign presence to indigenous Chinese firms, but these positive spillovers are confined within regions.
- (4) In terms of magnitude, OECD-invested firms play a much greater role in inter-industry spillovers than, but a similar role in intra-industry spillovers to, overseas Chinese firms from Hong Kong, Macao and Taiwan within regions.
- (5) The fact that positive spillover effects are confined mainly within regions may be due to regional protectionism in China.
- (6) Different measures of foreign presence may capture different aspects of spillovers, and hence could lead to different results. However, our principal components approach has confirmed positive regional FDI spillover effects on the productivity of indigenous Chinese firms.

Differently from the existing literature, this paper combines the three major channels of productivity spillovers into a single framework, compares the seven alternative measures foreign presence, and provides a principal component that explains more than 66% of the variance of these seven indicators to confirm the positive spillover effects. All this should significantly enhance our understanding of productivity spillovers.

Our findings have important implications both for managers and for policymakers. For Chinese managers it is important to learn from the export and R&D experience in other firms, and especially to learn from foreign-invested firms in order to enhance productivity and competitiveness. For Chinese policymakers it may be important to promote free flow of goods and services and coordinate regional development strategies in order to maximise (minimise) positive (negative) aspects of productivity spillovers from R&D, exports and

FDI. In addition, given that OECD firms generate much stronger positive spillover effects, more FDI should be attracted from OECD countries.

There are several limitations to this study, including: the possible bias in measuring value added due to the incentives offered by the Chinese government for exporting firms; the relatively short time period for the data set; and the unavailability of detailed information on the country of origin of non-overseas Chinese investors. The use of a data set with a longer time period and a comparison of the spillover effects from North American, European, Japanese and overseas Chinese investors (rather than just between overseas and non-overseas Chinese investors) would reveal even more insightful results.

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Notes

¹Large-sample firm-level studies for China are very rare, and Hu and Jefferson (2002) is an exception, where firm-level data in the electronic and textile sectors for 1995–1999 are used.

²International R&D spillovers across groups of countries are detected by such studies as Coe *et al.* (1997), Engelbrecht (1997), Lichtenberg and van Pottelsberghe de la Potterie (1998), Coe and Hoffmaister (1999), and van Pottelsberghe de la Potterie and Lichtenberg, (2001). However, other

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macro-level studies such as Kao *et al.* (1999) do not find evidence of international R&D spillovers. More recently, Luintel and Khan (2004) argue that many previous panel data studies do not allow for the possible heterogeneity of knowledge diffusion across countries. Based on the belief that countries differ in their stage of development, openness and stock and intensity of R&D, Luintel and Khan (2004) have carried out a country-level study and found a diversity of spillover parameters across a group of 10 countries.

³Information is available upon request.

⁴We thank one referee for suggesting this.

⁵The measure of value added for exporting firms may suffer from some bias in China. Since 1994 China has revised its VAT refund policies for exports from time to time, in terms both of methodologies and of refund rates. In addition, not all products are entitled to receive a full VAT refund for exports (see, e.g., Guo, 2003). Given these practices, our measure of value added is unable to precisely reflect these refunds. Therefore caution must be exercised when the results are interpreted.

⁶We are grateful for this suggestion by one referee.

⁷The coefficients on the interaction terms of R&D, LL and LK with industrial dummies are not reported because of space limitation, but are available upon request.

⁸Up to 1998, FDI from Hong Kong alone accounted for about 44% of total inward FDI stock in China (Wei and Liu, 2001: 23).

⁹A detailed table for these estimated results is not provided because of space limitations, but is available upon request.

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Appendix: Measurement of variables

Y	Value-added
K	Physical assets
L	The number of employees
RD	The ratio of a firm's intangible assets to its fixed assets
EX	The ratio of a firm's exports to its sales
RDSP	The ratio of intangible assets held by all other firms (the firm's own intangible assets are excluded) to fixed assets in an industry, in a region, or in an industry within a region.



EXSP The ratio of exports by all other firms (the firm's own exports are excluded) to sales in an industry, in a region, or in an industry within a region.

FDISP The share of foreign-owned firms' capital in total capital in an industry, in a region, or in an industry within a region.

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