International and Intranational Technological Spillovers and Productivity Growth in China*

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Abstract
Technological spillovers from foreign direct investment (FDI) have been regarded as a major source of technical progress and productivity growth. This paper explores the role of international and intranational technological spillovers from FDI in technical change, efficiency improvement, and total factor productivity growth in Chinese manufacturing firms using a recent Chinese manufacturing firm-level panel data set over the 2001–05 period. International industry-specific research and development (R&D) stock is linked to the Chinese firm-level data, international R&D spillovers from FDI and intranational technological spillovers of R&D activities by foreign invested firms in China are examined as well. Policy implications are discussed.

1. Introduction

Three decades of the Chinese economy's fast economic growth has attracted substantial research interest. This impressive growth performance is not only due to factor accumulation, but to productivity growth as well. As the largest foreign direct investment (FDI) recipient in the developing world, how much has China benefited from the huge inflows of FDI? Technology transfer through FDI has been regarded as a major engine of technological upgrading in developing countries for a long period. What are the

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roles of international and intranational research and development (R&D) spillovers in the technical progress and productivity growth in China? Can developing countries rely on foreign technology to catch up with the industrialized countries?

Empirical evidence on the impact of FDI on the productivity growth of indigenous firms is mixed (Blomstrom and Kokko 1998; Aitken and Harrison 1999; Görg and Greenaway 2001; Javorcik 2004). It is found that intranational knowledge spillovers are a more important source of technological progress than the international spillovers for the United States and Japan (Branstetter 2001). In the context of China, Hu and Jefferson (2002) find significant productivity depression rather than positive spillover effects of FDI on domestic firms. Using cross-section data for 1995, Buckley, Clegg, and Wang (2002) find that non-Chinese multinational enterprises (MNEs) generate technological and international market access spillover benefits for Chinese firms, whereas overseas Chinese investors confer only market access benefits. Spatially, Chen, Li, and Shapiro (2008) find that in locations with a strong clustering of innovative foreign firms, local firms benefit from knowledge spillovers, but not in locations where foreign concentration is measured by employment or capital. These studies provide useful insights. However, foreign knowledge and the spillovers from FDI are often tested using an output/employment/asset share of foreign invested firms or productivity or R&D activities of foreign firms in the same industry or region. Although there are some studies that have tested the spillovers of international knowledge stock through international trade and FDI at the country and industry levels directly (e.g., Coe and Helpman 1995), no study at firm level has tested the international knowledge on spillovers directly.

This paper explores the role of inter- and intranational technological spillovers from FDI in technical change, efficiency improvement, and total factor productivity (TFP) growth in Chinese manufacturing firms using a recent Chinese manufacturing firm-level panel data set of 56,125 firms over the 2001–05 period. International industry-specific R&D stock is linked to the Chinese firm-level data by corresponding industry and adjusted by industry- and firm-level degrees of openness. Therefore, we employ two sources of R&D spillovers from FDI: R&D spillovers from innovation activities by foreign invested firms in the same industry and international R&D spillovers through FDI. We use the non-parametric frontier technique to decompose the TFP growth of firms into technical change and efficiency improvement. Unlike most of the existing studies that estimate TFP using a single unchanging production function across industries, this study allows for the differences in production technology across industries, and TFP is estimated for each industry separately.

This paper is organized as follows: Section 2 discusses the theoretical framework on international and intranational R&D spillovers. Section 3 discusses the data, model, and methodology. Section 4 presents empirical evidence. Section 5 provides conclusions.

2. Theoretical framework and innovation in China

The literature presents two alternative perspectives for the choice of technology development paths for developing countries. One perspective proposes that FDI technology transferred from developed countries has positive effects on developing countries (Eden, Lecitas, and Martinez 1997; Kokko, Tansini, and Zejan 1997), and therefore, the technology spillover effects of FDI may be more important than the effects of domestic investments (Borensztein, Gregorio, and Lee 1995). The degree of technology diffusion from FDI grows with the increase in technology distance between the hosts and the foreign countries (Findlay 1978). The greater the technology distance, the more difficult it becomes for developing countries to boost independent innovation.

Another outlook is that the introduction of FDI will make the competing domestic firms worse off (Aitken and Harrison 1999), and will reduce the R&D efforts of local firms (OECD 2002). Furthermore, the benefits of FDI technology spillovers are limited because most techniques transferred from foreign investment firms are usually mature techniques, not core techniques; and as the working conditions and rewards of overseas-funded firms are better than that of native firms, knowledge diffusion caused by turnover of native talented personnel is usually one-way from the native firms to overseas-funded firms. Moreover, technologies created in the industrialized countries are argued to be biased to the factor endowment of the country where the technology is developed, and therefore are capital and skilled-labor augmenting (Basu and Weil 1998; Acemoglu 2002). The advanced foreign technology, therefore, may not be appropriate for developing countries given their different factor, economic, and social conditions (Atkinson and Stiglitz 1969; Stewart 1983). Finally, considering that technology progress has the characteristic of path dependence, a country that is dependent on the technology spillover of FDI for a long period will later limit its independent innovation. Therefore, strengthening R&D and enhancing the independent creative abilities should be the main path for developing countries' technological advancement. Taking into account the pros and cons of the foreign and indigenous innovation, Lall (2003) argues that neither autonomous innovations nor FDI-reliant strategies can be used independently.

Theoretically, FDI contributes to technological upgrading in the host economy in several ways. First, advanced technology embedded in imported machinery and equipment can lift the level production technology of the host economy. Second, R&D and other forms of innovation generated by foreign firms and R&D labs of

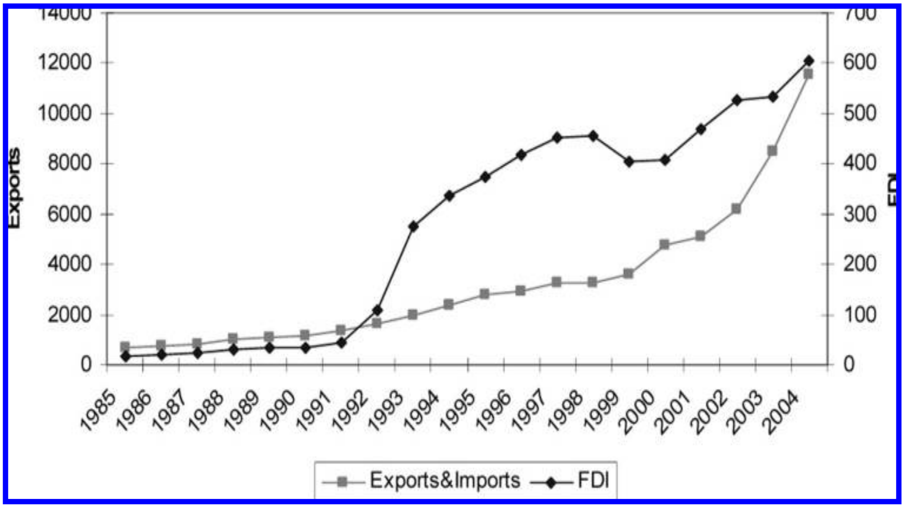
MNEs increase the innovation outputs in the country directly (Athreye and Cantwell 2007). Third, FDI may contribute to the local innovation system by bringing in advanced management practices and thus improving the innovation efficiency of the local innovation system (Fu 2008a). Finally, technological spillovers from foreign innovation activities may influence technical change and the catch-up of indigenous firms. Knowledge spillovers from foreign to local firms may take place through knowledge transfer within the supply chain, skilled labor turnovers, demonstration effects when local firms are learning by imitation, and competition effects when the competitive pressure caused by foreign presence forces the local firms to improve their production technology and management.

However, foreign R&D activities could also generate negative externalities to the domestic innovation activities. These negative effects could occur if foreign firms exploit their superior technology and marketing power to force local competitors to reduce their outputs or if they attract the most talented researchers and compete in the markets of innovation products that threaten local firms, or SMEs in particular (Aitken and Harrison 1999; Fu 2004, 2007; Aghion et al. 2005; UNCTAD 2005). Moreover, there are several reasons that local firms might not be able to enjoy the FDI spillover effects efficiently. First, knowledge transfer via supply chain requires effective linkages between foreign firms and local suppliers and customers (Balasubramanyam, Salisu, and Sapsford 1996; Fu 2004). Second, significant spillovers from FDI on local firms are also subject to sufficient absorptive capacity of the local firms and organizations (Cohen and Levinthal 1989; Girma 2005; Fu 2008a). Third, the appropriateness of the technology embedded in FDI affects the sign and significance of the productivity effects of FDI spillovers. Technologies created in industrialized countries are argued to be biased to the factor endowment of the country where the technology is developed (Basu and Weil 1998; Acemoglu 2002). Finally, different types of FDI have markedly different productivity spillover effects (Driffield and Love 2003).

Since it launched the economic reforms and invited foreign capital participation in its economy in 1979, China has received a large volume of international direct investment flows and stands as the second largest FDI recipient in the world. In 2004, FDI inflows into China reached a historical peak of US$ 60.63 billion (Figure 1). The sources of inward FDI in China have also evolved over time. While investment from overseas Chinese firms in Hong Kong, Macao, and Taiwan were the major sources of inward FDI in the 1980s, the 1990s saw increasing inward FDI from the major industrialized countries and other OECD countries.

Innovation efforts in China have grown rapidly during the past two decades. The total R&D expenditure in China has grown from 7.4 billion Yuan in 1987 to

Figure 1. Trade and FDI in China, 1985–2004



300.3 billion Yuan in 2006, with an average annual growth rate of 15 percent (Figure 2). Since the late 1990s, with the increasing globalization in innovation, R&D activities of foreign firms in China have been increasing, at a faster pace than that of the domestic firms. The average annual growth of R&D expenditure over the 1998–2004 period was 38 and 33 percent in foreign invested enterprises and Ethnic Chinese invested firms,[1] respectively. This is much higher than that of indigenous firms at 25 percent over the same time period.

Given the fact that foreign investors in China are mostly market- or resource- or cheap labor–seeking processing types, R&D spillovers from foreign invested firms are likely to be limited. Moreover, motivations, technology levels, endowments, and access to advanced technological and managerial knowledge all are different between foreign and ethnic investments. The productivity effects of foreign and ethnic investments are likely to be different.

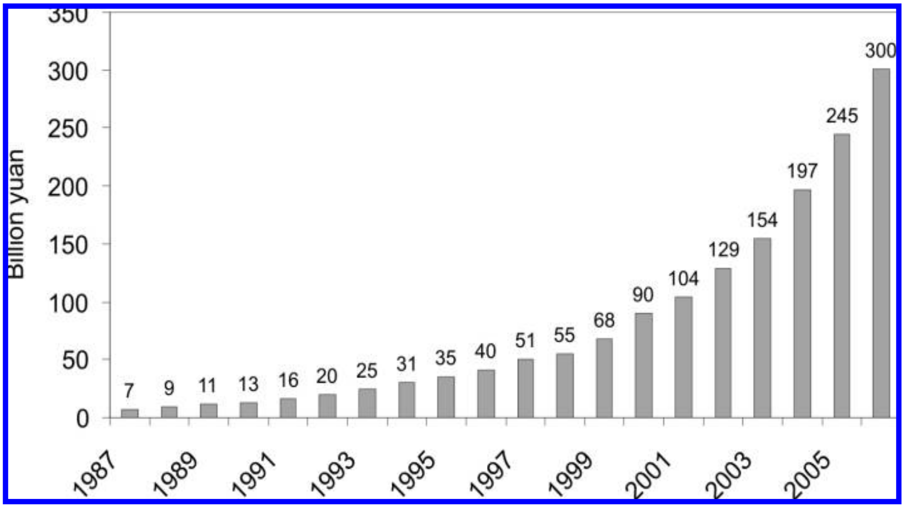
3. Data and methodology

3.1 Data

The empirical work is based on the Chinese manufacturing firm-level data set and the international industry-specific R&D stock data set. The Chinese firm-level data

1 Ethnic Chinese–invested firms refer to firms that have more than a 25-percent share of capital invested by Hong Kong, Macao, and Taiwan investors.

Figure 2. R&D expenditure, 1987–2006 (billion yuan)



set is from the Annual Report of Industrial Enterprise Statistics compiled by the State Statistical Bureau of China, covering all state-owned firms and other types of firms with an annual turnover of over 5 million Renminbi (about US$ 0.6 million). The data set includes all the variables we are interested in, such as firm ownership structure, industry affiliation, establishment year, employment, gross output, exports, R&D, and employee training expenditures.[2] The data cover the period 2001 to 2005. They are broadly classified under five ownership categories: (i) state-owned, (ii) collectively owned, (iii) privately owned, (iv) foreign-owned, and (v) others. Foreign-owned firms are further divided into firms with investments from Hong Kong, Taiwan, and Macao investors (so-called ethnic firms) and from other foreign sources (foreign invested enterprises; FIEs). "Other" firms are mainly shareholding enterprises.

As we are interested in the technology spillover effects from foreign firms on domestic firms, the econometric work is confined to domestic-owned enterprises. We, however, use the full sample to construct myriad variables of interest, such as the share of foreign firms in an industry-region or the Herfindahl index of market concentration. The final data set consists of 269,905 observations from 53,981 firms. We include only those firms with the full set of observations during the sample period

2 Nominal values are deflated using industry-specific ex-factory price indices obtained from the *China Statistical Yearbook 2006.*

as estimation of TFP growth and its components using DEA analysis, which requires balanced data sets. Table 1 reports the ownership structure of firms for each industry. Of the total 29 SIC two-digit manufacturing industries under study, 7 of them are dominated by FIEs that produce more than 50 percent of the total outputs. In cultural, educational and sports goods, electronic and telecommunications, and instruments and meters, foreign firms produce even 70 to 80 percent of the country's total output. This is phenomenal given the size of the Chinese industry. In these three categories and the apparel industries, more than 20 percent of the firms are invested through foreign capital mainly from OECD countries. Table 2 sees a steady modest growth in the portion of firms that invest in R&D across all industries over the sample period. The medical and pharmaceutical, tobacco, and electronic and telecommunications industries top the chart with 50, 45, and 33 percent innovative firms, respectively.

International industry-specific R&D stock is linked explicitly to the Chinese firm-level data. The estimates of international R&D capital stocks are based on R&D expenditure data from the OECD's *Main Science and Technology Indicators.* Real R&D expenditures are nominal expenditures deflated by an R&D price index (PR).[3] Following Coe and Helpman (1995), research and development capital stocks (S), which are defined here as beginning of period stocks, were calculated from R&D expenditure (R) based on the perpetual inventory model as

$$S_t = (1 - \delta)\, S_{t-1} + R_t\,.$$

Here δ is the depreciation or obsolescence rate, which was assumed to be 5, 10 and 15 percent, alternatively. The benchmark for S was calculated following the procedure suggested by Griliches (1979), as $S_0 = R_0/(g + \delta)$, where g is the average annual logarithmic growth of R&D expenditures over the period for which published R&D data were available, R_0 is the first year for which the data were available, and S_0 is the benchmark for the beginning of the year. The domestic R&D capital stocks were converted into euros at 2000 constant price. The R&D stocks of the 22 OECD countries are then summed to proxy the world R&D stock.

3.2 Methodology

For the empirical test, we first estimate TFP growth using the Malmquist index, and decompose it into technical progress and efficiency change. Secondly, we use econo-

3 PR is defined as PR = 0.5P + 0.5W, where P is the implicit deflator for business sector output and W is index of average business sector wages (the same source as for Y). This definition of PR implies that half of R&D expenditures are labor costs, which is broadly consistent with available data on the composition of R&D expenditures.

Table 1. Ownership structure in each industry group

SIC 2-digit industry	Indigenous firms		Foreign firms			
			% by number of firms			
	% by number of firms	% by turnover	all foreign firms	ethnic firms	non-ethnic foreign firms	% by turnover
13-Food processing	79	72	21	9	12	28
14-Food production	68	52	33	16	17	48
15-Beverage industry	78	60	22	10	13	40
16-Tobacco processing	97	100	3	3	0	0
17-Textile industry	74	74	26	17	9	26
18-Garments and other fiber products	48	48	52	30	21	52
19-Leather, furs, down, and related products	48	38	52	33	19	63
20-Timber processing	70	66	30	17	14	35
21-Furniture manufacturing	55	38	46	27	18	62
22-Papermaking and paper products	80	64	20	13	7	36
23-Printing and record medium reproduction	82	63	18	13	5	37
24-Cultural, educational and sports goods	42	30	58	39	20	70
25-Petroleum refining and coking	87	98	13	5	8	2
26-Raw chemical materials and chemical products	81	81	20	10	10	20
27-Medical and pharmaceutical products	80	73	21	10	11	27
28-Chemical fiber	73	72	27	16	10	28
29-Rubber products	74	58	27	16	11	42
30-Plastic products	61	52	39	27	13	48
31-Nonmetal mineral products	86	79	14	8	6	21
32-Smelting and pressing of ferrous metals	91	93	9	5	4	7
33-Smelting & pressing of nonferrous metals	87	87	13	7	6	13
34-Metal products	70	54	30	17	13	46
35-Ordinary machinery	84	72	16	6	10	28
36-Special purposes equipment	84	82	16	8	8	18
37-Transport equipment	81	75	19	9	10	25
39-Electric equipment and machinery	73	61	27	16	12	39
40-Electronic and telecommunications	40	22	60	32	28	79
41-Instruments and meters	58	23	42	22	20	77
42-Artifact and other manufacturing	55	46	46	30	15	54
Total	73	67	27	15	12	33
Total number of firms	39,639		14,342			

Note: *Industries dominated by foreign invested firms (FIEs) who produce more than 50% of the total outputs are highlighted by shading.*

Table 2. Proportion of firms investing in R&D

SIC 2-digit industry	2001	2002	2003	2004	2005
13-Food processing	0.1022	0.1080	0.1169	0.0786	0.0786
14-Food production	0.1711	0.1940	0.1743	0.1680	0.1680
15-Beverage industry	0.1692	0.1897	0.1888	0.1645	0.1645
16-Tobacco processing	0.4271	0.4583	0.5000	0.4479	0.4479
17-Textile industry	0.0857	0.0909	0.0962	0.0769	0.0769
18-Garments and other fiber products	0.0494	0.0589	0.0631	0.0536	0.0536
19-Leather, furs, down, and related products	0.1049	0.1258	0.1096	0.0841	0.0841
20-Timber processing	0.0756	0.0913	0.1041	0.0628	0.0628
21-Furniture manufacturing	0.0930	0.1027	0.0969	0.1008	0.1008
22-Papermaking and paper products	0.0748	0.0834	0.0753	0.0601	0.0601
23-Printing and record medium reproduction	0.0654	0.0592	0.0724	0.0675	0.0675
24-Cultural, educational and sports goods	0.1143	0.1212	0.1322	0.1006	0.1006
25-Petroleum refining and coking	0.1818	0.2102	0.2216	0.1875	0.1875
26-Raw chemical materials and chemical products	0.2126	0.2285	0.2294	0.1848	0.1848
27-Medical and pharmaceutical products	0.4451	0.4819	0.5092	0.5016	0.5016
28-Chemical fiber	0.2189	0.2090	0.2239	0.1791	0.1791
29-Rubber products	0.1921	0.1952	0.2127	0.1746	0.1746
30-Plastic products	0.0991	0.1071	0.1100	0.0832	0.0832
31-Nonmetal mineral products	0.1131	0.1304	0.1215	0.0822	0.0822
32-Smelting and pressing of ferrous metals	0.1388	0.1490	0.1521	0.0976	0.0976
33-Smelting and pressing of nonferrous metals	0.1683	0.1707	0.1851	0.1599	0.1599
34-Metal products	0.1092	0.1221	0.1178	0.0892	0.0892
35-Ordinary machinery	0.2168	0.2365	0.2514	0.1950	0.1950
36-Special purposes equipment	0.3237	0.3323	0.3253	0.2856	0.2856
37-Transport equipment	0.2738	0.2855	0.3035	0.2646	0.2646
39-Electric equipment and machinery	0.2476	0.2604	0.2671	0.2218	0.2218
40-Electronic and telecommunications	0.3114	0.3293	0.3332	0.3266	0.3266
41-Instruments and meters	0.3159	0.3368	0.3851	0.3133	0.3133
42-Artifact and other manufacturing	0.0926	0.1157	0.1278	0.0775	0.0775

metric techniques to estimate the impact of technological spillovers of FDI on TFP growth, technical change, and efficiency improvement. TFP is estimated for each industry separately, allowing for different technology and production functions.

Due to the limitations of the traditional parametric approach, this paper estimates TFP growth by using a non-parametric programming method developed by Fare et al. (1994). Following Fare et al.'s approach, a production frontier is constructed based on all the existing observations. The distance of each of the observations from the frontier is estimated by using non-parametric programming methods. Technical efficiency is defined as the distance of each observation relative to the frontier. TFP growth is defined as a geometric mean of two Malmquist productivity indexes, which is to be estimated as the ratios of distance functions of observations from the frontier. This approach has the advantage in that it allows for the decomposition of productivity growth into two mutually exclusive and exhaustive components: (1) efficiency change in movements toward (or away from) the frontier, which is a measurement of catching-up; and (2) technical change measured by shifts in technological frontier (Fare et al. 1994). This decomposition of TFP growth enables us to investigate the impact of foreign and indigenous innovation efforts on technical progress and technological catch-up.

Assuming a production technology that produces a vector of outputs, $y^t \in R_+^M$, by using a vector of inputs, $x^t \in R_+^N$, for each time period t = 1, . . . , T, the output-based Malmquist productivity change index is defined as the geometric mean of two Malmquist productivity indices as follows:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}\right)\left(\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}}. \quad (1)$$

A value greater than 1 indicates positive TFP growth in period t+1. When performance deteriorates over time, the Malmquist index will be less than 1. Rewriting equation (1), we have

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \times \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}}, \quad (2)$$

where

$$\text{efficiency change (EFFCH)} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}, \quad (3)$$

and

$$\text{technical change (TECHCH)} = \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}}. \quad (4)$$

TFP change is thus decomposed into two components: efficiency change and technical change. Efficiency change measures whether production is getting closer to or farther away from the frontier, reflecting the changes in x-efficiency. Technical change captures the shift in technology between the two periods. A value greater than one indicates catch-up with the frontier or technical progress. A value less than 1 indicates deterioration in performance. Scale efficiency is defined as the ratio of technical efficiency calculated under the assumption of constant returns to scale (CRS) to technical efficiency calculated under the assumption of variable returns to scale (VRS) (Fare et al. 1994). It measures how close a firm is to the most productive scale size. In this paper, output is measured by total output of firm, inputs are capital measured by net fixed assets, labor measured by number of employees, and intermediate inputs measured by variable costs. We use the output-oriented model under VRS for estimation.

Following the decomposition of productivity growth, the next step is to estimate the determinants of TFP growth, technical change, and efficiency improvement and to investigate the impact of indigenous innovation efforts and foreign R&D spillover effects on productivity growth and its components. R&D variables and FDI variables are two sets of variables that are of interest. In our specification, there are three types of innovation efforts: firm level, industry level, and international level. We construct the variables as follows: (1) at the firm level, R&D intensity is used as the direct effect of innovation on a firm's growth performance; (2) at the industry level, innovation effect in each of the 171 three-digit industries and 31 provinces are constructed as the proportion of R&D expenditure accounted for by different ownership types in the same industry and region; (3) the interaction terms of international industry specific R&D stock and FDI share at both the firm and industry level are adopted to measure the international innovation effect through FDI spillover effects. FDI is represented by two variables—the share of foreign and ethnic capital at the firm level. Therefore, the empirical analysis of the indigenous and foreign technology spillovers on the technology upgrading of indigenous firms are based on the model as follows,

$$\Delta p_{it} = \alpha + \varphi r_{it}^{f} + \chi r_{it}^{s} + \lambda_1 r_{it}^{w} * f_{it}^{s} + \lambda_2 r_{it}^{w} * f_{it}^{f} + \sigma X_{it} + \delta D_{it} + \varepsilon_{it} \qquad (5)$$

where the dependent variable p represents TFP growth, technical change, and efficiency improvement, respectively. r^f is firm R&D intensity, r^s is a vector of industry-level R&D spillovers variables measured by industry average R&D intensity by different ownership types, r^w is world R&D stock constructed from OECD STAN database as discussed earlier, and f^f and f^s are FDI intensity at the firm level and industry level, respectively. FDI intensity is further divided into foreign and ethnic capital intensity and enters the regression at the same time. X is a vector of control variables; D is the full set of time, sector, and year dummies, and ε is a random error term.

The choice of control variables is guided by the existing empirical literature on the determinants of TFP growth (e.g., Bernard and Jensen 1999; Aw, Chung, and Roberts 2000; Fu 2005, 2008b). It includes the initial level of technology efficiency, age, firm size, export, intangible assets, labor training, and market concentration that are hypothesized to affect the dependent variable. Smaller firms and firms with exports and more labor training are more likely to have faster TFP growth, technical change, as well as efficiency improvement. Firms standing at the frontier are less likely to grow as fast as other firms. There is no conclusive relationship between firm age, intangible assets,[4] and market concentration.

4 According to *Accounting System for Business Enterprises,* costs to develop intangible assets are regarded as R&D costs of self-created products that are registered for a legal right to the asset, such as a patent (Pacter and Yuen 2001).

Huang (2003) argues forcefully that a sizable portion of FDI (especially joint venture and acquisition FDI) in China has grown in response to the insolvency problems facing state-owned enterprises (SOEs). This suggests that industry-regional specific FDI might be endogenous in the sense that foreign-invested enterprises might be attracted to sectors or regions in which the performance of SOEs is weakest. The use of industry and region dummies in the regressions is designed to mitigate this potential endogeneity problem. However, in order to guard against further endogeneity problems unaccounted for by these (time-invariant) dummies, and to ensure the robustness of our results, we implement the FDI variables with their lagged values, the growth of total industry sales and changes in the output share of SOEs, and the proportion of loss-making SOEs, calculated at the industry and region[5] level.

There are good reasons to suspect that R&D, labor training, and foreign capital participation are potentially endogenous, even after controlling for fixed effects. For example, firms with relatively many R&D activities are more likely to have higher TFP growth and faster technical change than others. However, it is possible that firms with a higher growth rate will invest more in R&D activities to keep their technology advantages. Another example is the foreign share of a firm. Firms with a higher foreign share could have better access to foreign technology and therefore have higher growth rates. However, there also might be a "cherry-picking" effect (Huang 2003) where foreign firms choose the faster-growing firms to invest in. Similar arguments can also be made in the case of export and ethnic capital participation.

We employ the fixed effects generalized method of a moments regression technique (see, inter alia, Hansen 1982 and Arellano and Bond 1991) to deal with the endogeneity problem. Lagged values of the potentially endogenous variables are used as instruments. In addition, the shares of foreign and ethnic firms in the industry and region are used as extra instruments. We assume that a sector might be more efficient than others if there are more foreign firms or ethnic firms participating in it, given the low level of competition from state-owned firms. We formally test whether the assumption of endogeneity is borne out by the data at hand and whether our instruments are relevant in that they exhibit sufficiently strong correlation with the potential endogenous variables. We also carefully test for the appropriateness of the instrumental variable candidates using Hansen's J test for over identifying restrictions and the validity of the instruments with Sargan test. Reassuringly, we find that our instruments are appropriate on all counts.

5 These instruments, along with the FDI indices, are constructed for the 171 industries in each of the 31 provinces. Therefore, there is plenty of variability in them.

4. Results

Estimated TFP growth and its decomposed components for each industry are reported in Table 3. From all industries, the Chinese firms have experienced considerable TFP growth over the 2001–05 period at an average annual rate of 4.5 percent. The growth is mainly due to technical change at an average annual growth rate of 4.3 percent rather than efficiency change. The average annual growth rate of efficiency improvement was only 0.7 percent over the sample period, which suggests limited catch-up process of the followers to the innovation leaders in the Chinese manufacturing sector.

The growth is widely spread across different sectors. The industries in which foreign firms have obvious dominance include electronic and telecommunications, instruments and meters, culture, educational and sports goods, as well as the garment and leather products industries where ethnic firms have a clear lead. Indigenous firms have a dominant presence in the food-processing, beverage, tobacco, timber process, paper-making, printing, petrol refining, chemical fiber, smelting and processing of ferrous and nonferrous metals, metal products, and transport equipment industries, although the lead may be contributed to by different indigenous sectors in different industries.

Following Table 3, it is interesting to see that industries in which foreign firms produce more than 50 percent of the total outputs have a higher efficiency change rate but a lower technical change rate, as well as lower TFP growth rate than those industries dominated by indigenous firms. For example, among those industries dominated by FIE, the garment and other fiber products industry enjoy the highest efficiency rate (14.4 percent) and the lowest technical change rate (10 percent). It might suggest that foreign firms are more likely to keep their technical advantage in their home countries, and are more reluctant to improve their technical efficiency than their Chinese competitors are. Meanwhile, they focus on adapting their technology to the local technological frontier.

4.1 Determinants of productivity growth

Table 4 reports both the OLS and the General Method of Moments (GMM) estimates of effects of technological spillovers from foreign innovation efforts on the TFP of indigenous firms. Results from the Wu–Hausman specification test suggest significant endogeneity between R&D, exports, and FDI on one hand and the dependent variable on the other. The GMM estimation results is therefore preferred to the OLS estimates. For a robustness check, estimated results of the basic model and models with industrial and international R&D spillovers at three alternative depreciation rates

Table 3. Technical change, efficiency improvement, and productivity change, 2001–05

SIC 2-digit industry	Malmquist index (tfpch)	Technical change (techch)	Efficiency change (effch)	Scale change (sech)
13-Food processing	1.0542	0.9698	1.0879	1.0347
14-Food production	1.0321	0.9787	1.0604	1.0156
15-Beverage industry	1.0510	1.0828	0.9723	0.9864
16-Tobacco processing	1.0507	1.0432	1.0074	0.9963
17-Textile industry	1.0438	1.1728	0.8916	0.9476
18-Garments and other fiber products	1.0370	0.9074	1.1440	1.0040
19-Leather, furs, down, and related products	1.0379	1.1274	0.9273	0.9378
20-Timber processing	1.0427	1.0584	0.9885	0.9951
21-Furniture manufacturing	1.0275	0.9247	1.1135	1.0160
22-Papermaking and paper products	1.0535	1.0664	0.9899	0.9902
23-Printing and record medium reproduction	1.0213	1.0440	0.9793	0.9831
24-Cultural, educational and sports goods	1.0277	0.9890	1.0393	1.0206
25-Petroleum refining and coking	1.0461	1.1272	0.9302	0.9824
26-Raw chemical materials and chemical products	1.0486	1.1372	0.9272	0.9825
27-Medical and pharmaceutical products	1.0339	1.0634	0.9735	0.9871
28-Chemical fiber	1.0450	1.0510	0.9934	1.0011
29-Rubber products	1.0514	1.0094	1.0411	1.0773
30-Plastic products	1.0380	0.9891	1.0529	0.9848
31-Nonmetal mineral products	1.0698	1.0005	1.0693	1.0368
32-Smelting and pressing of ferrous metals	1.0566	1.0646	0.9992	1.0177
33-Smelting and pressing of nonferrous metals	1.0358	0.9690	1.0807	1.0838
34-Metal products	1.0420	0.9536	1.0958	1.0043
35-Ordinary machinery	1.0732	1.0207	1.0519	1.0189
36-Special purposes equipment	1.0555	1.1878	0.8895	0.9838
37-Transport equipment	1.0578	1.2346	0.8622	0.9215
39-Electric equipment and machinery	1.0541	1.0149	1.0438	1.0343
40-Electronic and telecommunications	1.0460	1.1088	0.9446	0.9737
41-Instruments and meters	1.0262	0.9497	1.0849	0.9947
42-Artifact and other manufacturing	1.0257	0.9667	1.0661	1.0374
Total	1.0450	1.0432	1.0074	0.9963

Note: *Industries dominated by foreign invested firms (FIEs) who produce more than 50% of the total outputs are highlighted by shading.*

were applied. The estimated coefficients from different model specifications are consistent suggesting the robustness of the estimated results. We have only reported the results with a 10 percent R&D depreciation rate due to space limitation.[6]

In terms of the coefficients of the control variables, we find that they all turn out as expected. Firms with better initial technical efficiency tend to grow more slowly. Smaller firms appear to be more productive. Firms with high export-intensity, high FDI-intensity, more training, and greater intangible assets have higher TFP growth than those who lack these characteristics. These estimated results are robust and statistically significant across industry sectors and different model specifications. Firm age does not appear to be a significant factor. Interestingly, industry concentration and low levels of competition seem to increase firm productivity although the estimated coefficient loses its statistical significance when international R&D spillovers are controlled.

6 Results of all the estimations are available from the authors.

The variables of most interest to us are, as we mentioned previously, the sets of R&D and FDI variables. Indigenous R&D efforts have a significant positive impact on firm-level TFP growth. The estimated coefficients bear the expected positive sign, and are statistically significant across different model specifications. R&D spillovers from domestic firms in the same industry exert a significant positive effect on the TFP growth of indigenous firms. However, it is interesting to see that innovation efforts from the FIEs in the same industry show a negative and significant impact on Chinese manufacturing firms, and there is no significant impact from ethnic firms at the same industry. This is likely because of either the competition effects of foreign R&D on the indigenous firms, or because the technologies developed by these sectors are not appropriate for the current technology frontier.

As we expected, both foreign and ethnic capital participations foster Chinese domestic firms' productivity growth. Foreign capital has a bigger influence on firm's growth than ethnic capital and both magnitudes of the coefficients have been doubted when international R&D spillover effects are controlled. For example, the estimate result based on the industrial level indicates that a 10 percent increase in the share of foreign capital leads to a 2.5 percentage point increase in the rate of productivity growth, whereas a 10 percent increase in the share of ethnic capital only leads to 1.7 percentage point growth. However, both growth rates increase to 5.6 and 4.9 percentage points, respectively at the specification with international R&D spillovers. It might suggest that domestic firms with foreign capitals have better channels to foreign advanced technical and management knowledge compared to their competitors with only ethnic capital participations.

The estimated coefficients on international R&D spillover variables are statistically negatively significant for firms with foreign and ethnic capitals at the firm level, but insignificant for firms with ethnic capitals at the industry level. It is likely to be explained by their inappropriate nature in the developing country context and the strong intellectual property rights protection in the high-technology industries. In addition, we should bear in mind that the international R&D spillover data are from the OECD countries, which might have a limited knowledge transfer through the ethnic channel.

4.2 Determinants of technical change and scale efficiency improvement

Table 5 reports the estimated result on the impact of indigenous innovation efforts and foreign R&D spillovers on technical change and efficiency improvements of the indigenous firms. We find no systematic relationship between the age of the firm and both technical change and efficiency improvement. Bigger firms appear to have experienced faster rates of technical change across all specifications. However, the

Table 4. Determinants of the TFP growth

	OLS			GMM		
Coefficient	**Firm level**	**Intranational spillovers**	**International spillovers**	**Firm level**	**Intranational spillovers**	**International spillovers**
Initial technical efficiency	−0.164***	−0.164***	−0.160***	−0.203***	−0.203***	−0.193***
	(0.00470	(0.0047)	(0.0047)	(0.0071)	(0.0071)	(0.0072)
Age	0.0013	0.0010	0.0012	0.0006	0.0004	0.0015
	(0.0011)	(0.0011)	(0.0011)	(0.0018)	(0.0018)	(0.0018)
Employment	−0.0179***	−0.0184***	−0.0190***	−0.0215***	−0.0220***	−0.0216***
	(0.0009)	(0.0009)	(0.0009)	(0.0013)	(0.0013)	(0.0013)
Market size	0.160***	0.148***	0.121***	0.187***	0.161***	0.135**
	(0.039)	(0.041)	(0.042)	(0.054)	(0.056)	(0.058)
Intangible asset	0.0043***	0.0043***	0.0043***	0.0047***	0.0047***	0.0051***
	(0.0007)	(0.0007)	(0.0007)	(0.0009)	(0.0009)	(0.0009)
Training expenditure	0.0682***	0.0677***	0.0682***	0.0731***	0.0727***	0.0726***
	(0.0067)	(0.0067)	(0.0069)	(0.0083)	(0.0083)	(0.0084)
Export intensity	0.0024***	0.0024***	0.0025***	0.0010***	0.0011***	0.0014***
	(0.0002)	(0.0002)	(0.0002)	(0.0004)	(0.0004)	(0.0004)
R&D intensity	−0.437***	−0.444***	−0.459***	0.936***	0.937***	0.943***
	(0.075)	(0.075)	(0.08)	(0.28)	(0.28)	(0.29)
Foreign share	0.0366*	0.0376*	0.0191	0.243***	0.246***	0.561***
	(0.022)	(0.022)	(0.035)	(0.073)	(0.073)	(0.2)
Ethnic share	0.0021	0.0028	0.0071	0.161**	0.171**	0.491**
	(0.016)	(0.016)	(0.023)	(0.075)	(0.075)	(0.22)
Domestic R&D share		0.0039***	0.0031***		0.0042***	0.0034***
		(0.0007)	(0.0008)		(0.001)	(0.0011)

Table 4. continued

	OLS			GMM		
Coefficient	**Firm level**	**Intranational spillovers**	**International spillovers**	**Firm level**	**Intranational spillovers**	**International spillovers**
Ethnic R&D share		−0.0008* (0.0004)	−0.0001 (0.0005)		−0.0007 (0.0005)	−0.0000 (0.0006)
Foreign R&D share		−0.0014** (0.0004)	−0.0009** (0.0005)		−0.0024*** (0.0007)	−0.0019*** (0.0007)
International R&D_foreign_firm			0.0008 (0.0011)			−0.0145** (0.0069)
International R&D_ethnic_firm			−0.0003 (0.001)			−0.0198** (0.0095)
International R&D_foreign_industry			−0.0053** (0.0013)			−0.0053*** (0.0018)
International R&D_ethnic_industry			−0.0005 (0.0013)			−0.0006 (0.0018)
Constant	0.153*** (0.0054)	0.134*** (0.0073)	0.189*** (0.014)	1.295*** (0.0088)	1.277*** (0.011)	1.325*** (0.022)
Observations	197,908	197,908	193,135	158,272	158,272	155,885
R^2	0.57	0.57	0.56	0.01	0.01	0.01
Exogenous test				0	0	0
Hansen J test				0.6792	0.5962	0.6451

Note: *Robust standard errors in parentheses. All specifications include the full set of time and two-digit industry dummies.*

**Statistically significant at the 10 percent level. **Statistically significant at the 5 percent level. ***Statistically significant at the 1 percent level.*

Table 5. Determinants of the technical change and efficiency improvement

	TECH		EFFCH	
Coefficient	**Intranational spillovers**	**International spillovers**	**Intranational spillovers**	**International spillovers**
Initial technical efficiency	−0.183*** (0.0076)	−0.189*** (0.0077)	−0.493*** (0.011)	−0.482*** (0.011)
Age	0.0029 (0.002)	0.0019 (0.002)	0.0029 (0.0027)	0.0048* (0.0027)
Employment	0.0161*** (0.0014)	0.0154*** (0.0015)	0.0009 (0.0019)	0.0020 (0.0019)
Market competition	−0.0951 (0.064)	−0.199*** (0.068)	0.0472 (0.094)	0.153 (0.097)
Intangible asset	−0.0039*** (0.001)	−0.0046*** (0.001)	−0.0007 (0.0013)	0.0002 (0.0014)
Training expenditure	−0.0414*** (0.008)	−0.0447*** (0.0081)	0.0532*** (0.012)	0.0559*** (0.012)
Export intensity	−0.0001 (0.0004)	−0.0001 (0.0004)	0.0011* (0.0006)	0.0009* (0.0006)
R&D intensity	−0.223 (0.17)	−0.239 (0.17)	1.395*** (0.33)	1.445*** (0.34)
Foreign share	−0.0957 (0.075)	−0.369* (0.2)	0.139 (0.11)	0.46 (0.29)
Ethnic share	−0.124* (0.071)	−0.2760 (0.2)	0.0086 (0.091)	0.0887 (0.26)
Domestic R&D share	0.0064*** (0.0013)	0.0029** (0.0014)	−0.00551** (0.0016)	−0.0017 (0.0018)
Ethnic R&D share	−0.0005 (0.0007)	0.0031*** (0.0008)	0.0000 (0.0009)	−0.0038*** (0.001)
Foreign R&D share	−0.0085*** (0.0008)	−0.0083*** (0.0009)	0.0031*** (0.0011)	0.0027** (0.0011)
International R&D_foreign_firm		0.0125* (0.007)		−0.016 (0.0098)
International R&D_ethnic_firm		0.0112 (0.0088)		−0.0051 (0.011)
International R&D_foreign_industry		0.0064*** (0.0022)		−0.0031 (0.003)
International R&D_ethnic_industry		−0.0193*** (0.0021)		0.0182*** (0.0027)
Constant	0.958*** (0.013)	1.096*** (0.025)	1.545*** (0.018)	1.375*** (0.035)
Observations	158,272	155,885	158,272	155,885
R^2	0.69	0.69	0.41	0.41
Exogenous test	0	0	0	0
Hansen J test	0.9587	0.3326	0.4248	0.4048

Note: *Robust standard errors in parentheses. All specifications include the full set of time and two-digit industry dummies. *Statistically significant at the 10 percent level. **Statistically significant at the 5 percent level. ***Statistically significant at the 1 percent level.*

effect of size is not statistically significant to efficiency improvement. Exports contribute to efficiency change and catch-up, but not the shift of the technology frontier. This result is consistent with the findings in Fu (2005), which uses Chinese industry-level panel data and suggests that the focus on low-cost competitiveness based on cheap unskilled labor and the dominance of process trading in the export structure provide no effective incentive for firms to innovate.

The estimated coefficients on the intangible assets variable are negative and statistically significant in the technical change equation. This is likely because intangible assets include, according to Chinese accounting practices, R&D investment in the development stage but not the research stage. For firms in technology-intensive industries, novel research activities may play a more important role in keeping them on the frontier and promoting TFP growth. The second reason may be that intangible assets are correlated with the fixed assets that we used for the TFP estimation. Therefore, technically, there is a negative association between TFP and intangible assets. Training exerts a significant positive impact on efficiency improvement as expected, but surprisingly bears a significant negative impact on technical change. This fact suggests that training is likely to occur for teaching new or advanced practices, but not for the creation of frontier technology. The estimated coefficients of market concentration are mostly insignificant.

The indigenous R&D of individual firms has no significant impact on technical change. However, it has contributed significantly to efficiency improvement, which reflects the catch-up process. This is not surprising given the fact revealed from the First National Economic Census in 2004 that about 95 percent of total business R&D expenditure was spent on development and only 5 percent was spent on basic scientific research. Interestingly, R&D activities in the domestic firms at the industry level have shown significant and robust positive spillovers on the technical progress of indigenous firms. This evidence suggests that it is collective indigenous R&D activities, namely, R&D at the industry level, which push up the technology frontier and drive the technology upgrading of indigenous firms. R&D activities of foreign invested firms at the industry level have shown a negative spillover effect on the technical change of indigenous firms but a positive spillover effect on technological catch-up. This may be explained by the competition effects from the foreign R&D activities and the findings of recent studies that the core technology development of MNEs still remain at the headquarters, while applied research and adaptation are the main tasks of its affiliates in foreign countries. Therefore, these R&D activities may not contribute to technical change but their impact on catching up is positive and statistically significant. The spillover effects of R&D investment in ethnic firms, however, only show significances when international R&D spillover effects are considered and have opposite signs from those of FIEs. It suggests that the R&D activities from ethnic firms at the industry level can help to foster technical upgrading, but not technological catch-up.

In terms of FDI spillover effects, there is no direct FDI impact on efficiency change, but a significant negative impact is detected on technical change. Again, this is likely for firms with foreign capital that might tend to keep their core technology research at their mother countries. Another explanation may be due to the small share of foreign capitals in the indigenous firms, which is no more than 25 percent. There is also no indirect FDI R&D spillover effect on efficiency change, but the impacts for indigenous firms with foreign capitals are positively significant at both the firm and industry level. This suggests the importance of intra-firm technology transfer of the frontier technology through FDI. Foreign investors may transfer the most advanced technology when they have more control of the firm.

5. Conclusions

This paper explores the role of inter- and intranational technological spillovers from FDI in technical change, efficiency improvement, and TFP growth in China. Over the 2001–05 period, our research finds that Chinese firms have experienced considerable TFP growth at an average annual rate of 4.8 percent. This growth spreads widely across the board, and is mainly due to technical change rather than efficiency improvement. Most of the FDI-dominated industries did not grow as fast as the other industries in terms of TFP growth and technical change. A considerable portion of rapid technical change took place in industries where the indigenous firms enjoyed a lead. All this suggests a turning point in China's post-reform era that indigenous industries started to take off in terms of technological progress and productivity growth, and reveals a period with TFP growth, which has been driven by technical change that benefited from internal and external technological spillovers.

Moreover, contrary to the normal expectations, R&D activities of foreign firms in China have exerted a significant productivity depression rather than positive spillover effects on indigenous firms. Collective indigenous R&D activities at the industry level are found to be the major driver of technology upgrading of indigenous firms that push up the technology frontier. However, firms with high FDI-intensity are likely to have high TFP growth, which reflects the benefits from FDI in non-technological aspects, such as managerial and marketing knowledge.

Finally, FDI, especially from non-ethnic Chinese investors, is proved to serve as an effective vehicle and facilitator of international transfer of technological knowledge. Interactions of international R&D stock and FDI openness at the firm level and industry level show a significant positive effect on the technical change of indigenous firms. However, the role of ethnic Chinese investment is rather controversial in this respect. Ethnic Chinese investors appear to confer only benefits in market access and managerial knowledge that mix the advantages of Western and Eastern management philosophies.

Findings from this research have important policy implications. Developing countries should not simply reply on FDI for indigenous technological upgrading. In the increasingly globalizing world when countries, regions, and firms are adopting more open innovation systems, they can use both internal and external knowledge sources for technology upgrading and productivity growth. The role of indigenous innovation, especially collective indigenous innovation efforts shall not be overlooked. Science and technology policies should be introduced to encourage innovation by indigenous firms so as to build up dynamic indigenous technological capabilities. On the other hand, FDI, especially from industrialized countries, should be encouraged as this type of investment does serve as an effective conduit of advanced foreign technological knowledge. This provides a role for trade and industry policies in developing countries to distinguish different sources of FDI and attract more FDI from industrialized countries.

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