Technology Spillovers through Foreign Direct Investment

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1 Introduction

The two important questions concerning technology diffusion in a developing country are (1)What is the quantitative importance of technology spillovers to the economic growth of a laggard country (a developing country)? and (2) What can a recipient of the technology do to maximize such spillovers?

This paper attempts to answer these questions when foreign direct investment (FDI) is the carrier of an advanced technology. Using survey data on 468 manufacturing firms in China between 1990 and 1992, I study the importance of technology spillovers and of a firm's effort to build up skills to account for a firm's productivity growth.

This is an empirical test of the investment equation proposed by Parente and Prescott (JPE, 194): A firm increases its productivity (total factor productivity) via two main channels. Either it can benefit from technology spillovers from the existing foreign knowledge ("catch-up"), or it can make the investment in worker skills necessary to adopt a new technology (training).

The contribution of this paper is twofold. First, there are few studies in the literature of economic growth that empirically investigate the role of FDI as a channel of technology spillovers.[1] This is due to a paucity of suitable data, particularly in developing countries. The data set used for this study is based on a firm-level survey conducted in eight cities in China between 1990 and 1992. This unique data set allows me to examine in detail local firms' behavior in response to rapid inflows of foreign capital. Also, the recent Chinese experience is of special interest in studying the effect of FDI on growth, since China's "open-door" policies are often thought of as one of the main causes for its rapid economic growth in recent years.

Second, this is one of the first attempts to decompose spillovers from FDI into four components: the demonstration-imitation effect, the competition effect, the foreign linkage effect, and the training effect[2]. By separating the training effect from the others, I will be able to highlight the importance of building up the absorption capacity for technology spillovers to materialize.

[1]Coe, Helpman, and Hoffmaister (1994) and Borensztein, De Gregorio, and Jong-Wha Lee (1995) examine the relation between FDI and economic growth. Trade is also a channel of international technology spillovers (Grossman and Helpman, 1991: Keller, 1995: Ben-David and Loewy, 1995).

[2]See Section 2.1. for the definitions.

The main findings of this study are (1)The catch-up effect (spillovers) and the firm's own worker training are both important sources of productivity growth; (2)Local Chinese firms are more likely to train skilled workers than their foreign counterparts are. This has accelerated the extent of technology spillovers from foreign to local firms; (3) Foreign joint ventures are not statistically significant in explaining the growth rate of TFP between 1990 and 1992; (4) Foreign-owned firms in China are unlikely to invest in the education of local workers. On the contrary, they tend to maintain product quality by importing intermediate goods from their home countries and by transferring managers from their headquarters.

This paper is organized as follows. In the next section, I will discuss the evidence of spillovers in the existing literature which will provide a necessary background for my analysis. In section 3, the various channels through which technology spills over from foreign to local firms are discussed. Drawing upon Parente and Prescott (1994), I then present empirical models in which a firm can increase its productivity either by way of spillovers from the leading firms or from its own effort to build up skills (worker training). In section 4, the data and summary statistics are described and regression results are examined in section 5. Finally, section 6 contains a summary of my findings.

2 Framework

2.1 Identifying technology spillovers via FDI

There are four channels through which FDI can possibly affect the productivity of local firms. First, the demonstration effect, or contagion-imitation effect (Kokko, 1990), arises from differences in the levels of technology between foreign and local firms. Foreign firms with more advanced technologies enter a local market and introduce newer technologies to the industry. Through direct contact with foreign affiliates, local firms can watch and imitate the way foreigners operate and can therefore become more productive. This may also occur through a labor turnover from foreign to local firms. The early theoretical literature on technology transfer via FDI focuses mostly on this type of externality (Findlay,1978: Koizumi and Kopecky, 1977: Das, 1987). This type of spillover is exogenous to both the MNC and the host country since the initial differences in "what is known" determine the degree of spillovers (Jovanovic and Rob, 1988).

Second, the competition effect may occur as follows: the entry of foreign firms leads to more intense competition in the local industry and local firms are forced to be more efficient in using existing technologies and resources. Local firms may also have to introduce new technologies by themselves in order to maintain market shares. Increased competition may be able to eliminate monopolistic profits and enhance the welfare of a host country. As Aitken and Harrison (1992) and Kokko (1992) point out, however, there is also a possibility that the competition effect is harmful to a host economy when local firms are not efficient enough to compete with foreign entrants. In this case, local firms may be wiped out of the market and monopoly rents will simply be transferred from a domestic monopolist to a foreign monopolist. This type of spillover generally occurs on an intra-industry scope.

Third, spillovers through backward and forward linkages may arise when foreign affiliates materialize transactions with local suppliers and customers. When the cost of communication and transportation is high, then the MNCs often choose to purchase intermediate goods from local producers. Foreign firms may provide technical assistance and training to local suppliers, or may assist them in purchasing raw materials so as to maintain the quality of intermediate goods. Even in the absence of such direct involvement, local suppliers are forced to meet demand for higher quality and on-time delivery and to innovate more. This is the "backward linkages" effect. Backward linkage is encouraged in the presence of "local content requirements"[3]. In many industries in developing countries, as technical complexity increases, domestic producers may seek to purchase intermediaries from foreign suppliers (forward linkages) whose goods are superior to those obtained from local suppliers. Note that the competition effect is on an intra-industry scope while the backward-forward linkages effect represents inter-industry spillovers. Lall (1978) uses the ratio of local to total purchases as a proxy for backward linkages. This study uses the latter measure of linkage effects due to the constraints of data.[4]

[3] "Local content requirements" means that foreign firms have to purchase a certain percentage of intermediate inputs in a host country instead of importing from suppliers from the home country.

[4] There are a few theoretical works on linkage effects via FDI. Recently, Rodriguez-Clare (1996) formalizes the concept of backward linkage effects by introducing linkage coefficients that are the ratio of employment generated in upstream industries to the labor

Finally, the costly effort to train local workers leads to productivity improvements. This is referred to as the "training effect." On-the-job training may be provided by foreign joint venture partners, foreign buyers or suppliers. Often local firms train their own workers to increase product quality in order to cope with foreign entrants with a competitive edge. The arrival of new technology alone may not create productivity growth in a host country unless the labor force builds up the corresponding skills[5]. Training which involves the accumulation of these skills is considered as an invaluable investment. Since the skill is specific to the technology, it incurs an adoption cost, that is, the cost of training. Empirical evidence seems to support the importance of the accumulation of skills as an engine of growth. In the case of the recent NICs (Newly Industrialized Countries), Dahlman et al. (1987) find that the probability of a successful technological transfer is increased if the labor force begins to study, train and practice well in advance of the inception of the new project.

The mechanism through which technology is transferred from foreign to local firms is very complex in reality. Although four types of spillovers are discussed separately, some effects cannot be distinguished from one another. For example, the training effect may take place due to an increase in competition (the competition effect) or due to pressure from foreign buyers (the backward linkage). They may be by way of imitating a new technology demonstrated by foreign firms (the demonstration effect). As I will discuss later, this allows me to measure only the composite spillover effects rather than separate channels in some cases.

2.2 Catch-up and training effects on TFP growth

In this subsection, I will present an empirical model in order to examine the effects of technology spillovers and an investment in skills (training of skilled workers) on the productivity of local firms when FDI is present. For

hired directly by the firm.

[5]The distinction between technology and human capital is discussed in Jovanovic(1997): "Technologies are laws of physics that are relevant to a particular way of producing something. These laws are described in blueprints. A blueprint, however, is an incomplete description of what it is useful to know about the technology at hand..... This incompleteness creates a role for training and learning by doing as ways of building up the specific human capital...."

this purpose, I will refer to the investment equation proposed by Parente and Prescott (1994). Productivity growth of a firm in their model can be explained by the firm's investment, positive externalities from stock of the world knowledge (the catch-up effect), and the barriers to technology adoption.[6] In addition to the training effect in Parente and Prescott, other channels such as the foreign linkages effect and the demonstration effect are also examined as potential sources of productivity growth.

Parente and Prescott (1994) propose a theory of economic development in order to explain the existing income disparity as well as "development miracles" in Japan and East Asian countries. The focus of their model is technology adoption and the barriers to such adoption. In their model, a firm's investment decision to advance its technology level depends on two factors: the level of general and scientific knowledge in the world and the size of barriers to adoption in the firm's country. If the existing level of world technology is greater relative to a firm's country, then a firm can benefit from the existing technologies. An interpretation of their model is that a firm can either depend on the high level of technology in the rest of the world to diffuse advanced technology or it can make an investment in R&D in order to advance its technology level. The former term can be referred to as the "catch-up" effect of developing countries, or the advantage of a laggard country in the process of economic development.[7]

Parente and Prescott base their argument on the size of adoption barriers across countries that is consistent with the disparity in per capita income. For this study, I use data on manufacturing firms in selected cities in China. Even if there are any barriers to adoption, regulatory and legal constraints are expected to be much smaller across firms in the same country than across countries.[8]

The investment equation [9] in Parente and Prescott (1994) is transformed

[6] Note that the degree of the spillover effect here is related to the speed of convergence in Baumol (1986) and Barro and Sala-i-Martin (1991, 1995).

[7] See Benhabib and Rustichini (1990).

[8] The inland dummy is included in the regressions to control for such regulatory differences but it is only significant in TFP level specification.

[9] The equation (3) in Parente and Prescott (1994) is as follows:

$X_{A_t} = \pi \int_{A_t}^{A_{t+1}} (\frac{S}{W_t})^{\alpha} dS$ where X_{A_t} is an investment that a firm has to make to advance technology level from A_t to A_{t+1}, π is the parameter that indexes the size of barriers to if we assume that the time interval between A_t and A_{t+1} is sufficiently small. Furthermore, when I evaluate $\frac{A}{W_t}$ at A_t, I get the expression for $\dot{A}$ of the i th firm in the k th industry in terms of two types of spillovers:

$$\dot{A}_t^i = \mu(\frac{{A_t}^i}{{W_t}^k})^\theta {X_{At}}^i \tag{1}$$

where:

$$\begin{aligned} \dot{A}_t^i &= \text{TFP growth of the } i \text{ th firm} \\ {W_t}^k &= \text{best practice firm's level of TFP in the } k \text{ th industry} \\ {X_{At}}^i &= \text{own investment of the } i \text{ th firm} \\ \mu &= \text{an inverse of the adoption barrier parameter } (\pi) \\ & \quad \text{in Parente and Prescott(1994)} \end{aligned}$$

In this model, TFP growth is affected by three things: one is the adoption barrier parameter. As mentioned before, it is assumed that all sample firms have the same size of adoption barriers since they are located in cities where the same "open-door" policy is implemented.

The other is a spillover term that is defined here as the ratio of a firm's TFP level to the highest TFP level in the industry. This variable, $\frac{A_{it}}{W_t^{k_i}}$ is the relative position of the i th firm to the best practice firm within the industry. If the i th firm is less productive than the best practice firm initially, then it may benefit from positive externalities from more productive firms. Finally, ${X_{At}}^i$ is the training variable that represents a firm's costly efforts to accumulate knowledge.

The problem of implementing the above equation empirically is that training (X_{At}) is a 0-1 variable. Whenever a firm does not provide training in the above specification, TFP growth will be 0 and it will wipe out any potential catch-up effect. In Parente and Prescott's original model, this feature is incorporated in order to assure that a firm cannot benefit from being behind unless it makes an investment. Self-training is a necessary condition for advancing technology. In this study, however, this assumption is relaxed. In other words, there might also be cases in which firms can advance their technology solely through the catch-up effect in the absence of their own investment.

technology adoption in the firm's country, and W_t is the stock of knowledge in the world.

I assume that an investment is a function of a binary training variable in a particular form:

$$X_{At} = e^{\eta T_i} \tag{2}$$

where T_i is the incidence of training, which equals 1 if a firm trained skilled workers before 1992 and 0 otherwise. Also transforming the dependent variable in 1, we get:

$$e^{\frac{\dot{A}_{it}}{A_{it}}} = \mu(\frac{A_{it}}{W_t^k})^{\theta} e^{\eta T_i} \tag{3}$$

3 is a base model. Next I add various foreign variables to the base model to identify through which channels foreign investments affect a firm's TFP growth. Furthermore, I take industry differences into account as well as a firm's attributes (e.g. age). That is to say, μ becomes a function of additional variables[10] (i subscript is dropped):

$$\mu = \pi^{-1} = \exp(\beta_0 + \beta_1 \text{FORGN} + \beta_2 \text{LINK} + \beta_3 \text{For\_ind} + \zeta) \tag{4}$$

where:

$$\begin{aligned} \text{FORGN} &= \text{foreign joint venture (binary)} \\ \text{LINK} &= \text{foreign forward-backward linkages (binary)} \\ \text{For\_ind} &= \text{foreign presence in the industry} \\ \zeta &= \text{firm-specific fixed effect (e.g. age)} \end{aligned}$$

Industry dummies have a high correlation with foreign presence in the industry since "foreign presence" is measured as the employment share of foreign firms to total employment in the industry.[11] Thus, industry dummies are dropped when foreign presence in the industry is included and vice versa. Notice that μ is no longer a simple parameter for adoption barriers. It contains various variables that may facilitate an adoption of new technology.

Taking logs of both sides of 3 embedded with 2 and 4, the equation that I estimate becomes:

$$\frac{\dot{A}_{it}}{A_{it}} = \beta_0 + \theta \ln \frac{A_{it}}{W_t^k} + \eta T_i + \beta_1 FORGN + \beta_2 LINK + \beta_3 For\_ind_k + \zeta_i + \varepsilon_{it} \tag{5}$$

[10] Note that μ is no longer an adoption barrier parameter.

[11] Foreign presence in the industry takes seven distinctive values for all firms.

where $\frac{\dot{A}_{it}}{A_{it}}$ is $\ln \frac{A_t}{A_{t-1}}$ in a discrete time. The data in 1990 and 1992 on capital, unskilled and skilled labor is used to obtain TFP growth. First, I estimate the Cobb-Douglas production function for each year and test if the estimates are the same for both years. A Chow test did not reject the null hypothesis that the coefficients are the same for both years. A time trend is also rejected in the test and excluded from the regression. Residuals plus the intercept are defined as TFP levels[12]. Each firm now has A_{90} and A_{92}. Second, I compute the log of TFP level in each year and construct $\ln \frac{A_t}{A_{t-1}}$, which is the average growth rate between 1990 and 1992.

The estimate of θ reflects the magnitude of a "spillover" effect from a leading firm to the rest of the firms within the industry. This is a more direct measure of the demonstration effect than the variable of foreign presence within the industry. If there are indeed spillovers or the catch-up effect, then θ is expected to be a negative and significant coefficient. Benhabib and Spiegel (1994) use the inverse of $\frac{A_{it}}{W_t^k}$, $\frac{H_t \max}{H_{it}}$ in place of A_{it}, H_{it} that has a similar implication in a cross-country context. For a comparison with the results of convergence literature, however, I keep the form $\frac{A_{it}}{W_t^k}$.

Parente and Prescott (1994) suggest that besides the adoption barriers a firm has to make an investment in human capital in order to benefit from the catch–up or spillover effect. Thus, $\frac{A_{it}}{W_t^k}$ and T_i are expected to work as complements to TFP growth. Although it is impossible to test their claim (e.g. if $\frac{A_{it}}{W_t^k}$ Granger-causes T_i) in the data, a close look at the relative importance of the catch-up and training effects in TFP growth regressions will suggest the determinants of TFP growth as well as a pattern of technology spillovers in China. These are of interest to policy makers in developing countries who ponder the wisdom of inducing growth via "open-door" policies to foreign investment.

3 Data

The data used in this analysis is based on a special survey conducted by the World Bank in 1992 in eight cities in China.[13] Six of these cities are located

[12]Note that TFP levels could be either positive or negative.

[13]As a part of economic reforms that started at the end of the 1970s, China adopted "open-door" policies to foreign investment in the coastal provinces, which led to a rash of

in coastal provinces that were chosen as "Special Economic Zones" while the other two are inland cities that receive relatively less foreign investment due to fewer incentives. The survey questionnaire was distributed to 468 firms in November 1992. All firms returned the questionnaire with some missing information. The response rate is, therefore, 100%. There is a great presence of foreign-owned firms in the sample since most of the sample firms are located in "Special Economic Zones". In terms of the main product produced, it varies from food to machinery (in 2-digit industry classification).

The questionnaire was designed to assess factors that explain rapid growth in the coastal provinces. Specifically, the purpose of this survey was to study a firm's effort to imitate or innovate in response to changing competitive conditions by investing in human capital (training). It was also designed to examine the relative importance of different sources of foreign knowledge. Finally, the benefits received through these different sources are central issues in the survey. The questionnaires were distributed to 60 firms[14] randomly chosen in each region. In the original data, there are 468 firms in total. Most of the questions relate to the firms' activities in the "past year" (1991) or in the "current year" (1992). For instance, a firm is asked if it trained skilled workers in the "past year" or not. It is not known when a firm started worker training. The foreign joint venture variable is measured only in 1992. The year when the foreign joint venture was initiated is not reported.[15] However, in the short run (two years), the ownership is assumed to be unchanged.[16]

The original data contains detailed classification of ownership. According to the percentage of ownership shares, the firms are divided into four types: state-owned, collectively-owned, privately-owned, and foreign firms. For this analysis, the first three groups are redefined as domestic or non-FDI firms and the last group as foreign or FDI firms.[17] Sample firms are classified into seven industry groups according to ISIC (International Standard Industry Codes): food, textile, wood & pulp, chemical, non-metallic minerals, machinery, and

investors and to phenomenal economic growth.

The eight cities in which the survey was conducted are Chengdu(CD), Chongquing(CQ), Dongguan(D), Fuzhou(F), Guangshou(G), Quanzhou(Q), Shenzhen(S), and Xiamen(X).

[14]Chengdu and Chonquing have only 55 and 53 sample firms, respectively.

[15]Nor is the amount of expenditure on training reported.

[16]See Appendix 2 for definitions of the variables.

[17]If more than 10% of shares are owned by foreigners, then the firm is defined as foreign-owned. The remaining firms are defined as domestic.

Table 1: Sectoral shares of foreign stock

	Foreign share	**Number of obs.**
food	0.30	27
textile	0.60	40
wood	0.24	17
chemical	0.23	44
non-metallic	0.13	15
machinery	0.26	122
others	0.50	62
all industries	0.34	327

other manufacturing.

3.1 Relative performance of foreign firms

Table 1 shows sectoral shares of foreign firms and the number of valid observations by industry. Sectoral shares show the percentage of foreign firms to total firms in the industry. In this sample, 34% of all firms are foreign firms. A foreign presence is most prominent in textile, other manufacturing and food[18]. These are labor-intensive industries in which China has a comparative advantage. Multinational firms seem to choose the area in which a host country is efficient.

Table 2 summarizes the key variables[19] as a measure of relative performance of foreign firms by each industry group. Each entry indicates the ratio of mean of foreign to that of local firms. If it is greater than one, then foreign firms on average exceed domestic ones in a certain variable.[20] If the number is less than one (and positive), then the mean of domestic firms is greater than that of foreign.

[18]Other manufacturing industries are mainly sports and athletic wares such as sneakers.

[19]Summary statistics and correlation matrix are shown in Appendix 3 and 4, respectively. See Appendix 2 for definitions of the variables.

[20]The negative values in a table arise because the mean of either group (foreign or domestic) is negative. In the column of TFP in table 2, negative entries in all industries but machinery occur because the mean of domestic firms is negative.

The reason why a host country's economy can benefit from FDI is that foreign firms are initially assumed to be more productive than local firms. In the last column, the level of TFP in 1992 is greater than 1 in all industries but in "other" industry, which means foreign firms typically exhibit much higher TFP than domestic ones. In textile, non-metallic, and machinery industries, average TFP levels of domestic firms are negative. This causes the ratios of the two to be negative. Labor productivity measures also show the same tendency at the TFP level. In the second from the last column, average labor productivity of foreign firms is higher than domestic firms in all industries but "other" industries. These observations suggest the superiority of foreign-owned firms in terms of the productivity level.

In the last row of column I, capital intensity for foreign firms is three times as high as for domestic firms. The average size of foreign firms measured as total sales, on the other hand, is smaller in most industries except in food and textile. In column II, the firms that have foreign joint ventures tend to be smaller in size. As the economic reforms progressed in China, there has been a significant increase in the number of non state-owned enterprises such as Township-Village Enterprises (TVEs). As opposed to large state-owned firms, these new entrants are smaller in size. This suggests that foreign joint ventures take place more in the non state-owned firms than in the state-owned firms. In column III, export-propensity shows a mixed picture. Although overall foreign firms are more export-oriented in the last row, there are some industries that are less so: food, wood, and chemical. Smaller firms tend to export less in general and as in the case for wood and chemical. The age or the establishment year of foreign firms column shows that foreign firms are newer than domestic firms. Training is less for foreign firms, which may seem surprising at first glance since efficient foreign enterprises are expected to make more R& D efforts to train their workers. However, FDI often leads to imports of skilled workers. Less training, or even no training by foreign firms in the wood industry is plausible in this respect. Finally, "linkages" (foreign backward-forward linkages) are higher for foreign firms in all industries, particularly in the food and wood industries. Thus, foreign firms are likely to buy intermediate goods from suppliers in their host countries.

In summary, foreign firms are relatively more productive than domestic counterparts. The reason for this is that they import highly trained skilled workers from home rather than train local workers. They are also likely

Table 2: Relative performance of foreign to local firms

	K/L	SIZE	EXP	AGE	TRN	LINK	Y/L	TFP
food	6.38	1.72	0.46	1.29	0.47	4.00	5.81	5.39
textile	1.38	1.99	1.54	1.30	0.69	1.70	1.72	-3.25
wood	1.67	0.87	0.63	1.33	0	6.00	1.66	9.42
chemical	1.61	0.36	0.93	1.24	0.48	1.39	1.24	2.75
non-metallic	4.65	0.86	2.83	1.15	0.75	3.85	4.49	-20.33
machinery	4.89	0.64	2.58	1.23	0.56	2.88	3.53	-2.57
others	1.65	0.29	2.06	1.25	0.51	2.29	0.77	0.27
all industries	3.07	0.64	2.41	1.25	0.49	2.65	2.40	-5.50

Notes:

(1) A number in each cell is calculated as $\frac{\text{average of foreign firms}}{\text{average of domestic firms}}$.

to have foreign suppliers and buyers in order to reap spillover externalities. Overall, foreign firms are more export oriented.

4 Estimation Results

4.1 Catch-up effect and investment in skills

Table 3 reports the results of OLS regressions on the catch-up and training effects. The dependent variable is $\ln \frac{A_{92}}{A_{90}}$. [21] This analysis is consistent with the Parente-Prescott investment equation in the setting of manufacturing firms in China between 1990 and 1992.

Column I is a base regression of the catch-up and training effects. The coefficient of the catch-up term, θ is -.346 and is significant at a 1% level. This means that the rate of productivity growth of a firm increases by an annual average of 34.6% since its productivity level was behind the leading firm in the previous period. This figure may, however, reflect not only the

[21] $\frac{\dot{A}_t}{A_t} = \frac{d \ln A_t}{dt} \cong \frac{\triangle \ln A_t}{\triangle t}$ in a discrete time. Furthermore, $\frac{\triangle \ln A_t}{\triangle t} = \frac{\ln A_{t+1} - \ln A_t}{1} = \ln(\frac{A_{t+1}}{A_t})$.

catch-up effect but also other effects such as industry-specific demand shocks. When a particular industry experiences a positive shock during this period, the catch-up effect may be overestimated. For example, when an entire industry is growing, the speed of "catch-up" by an individual firm in that industry is also increasing. To correct for such an industry-specific shock, industry growth rate between 1990 and 1992 is added to the base regression. However, this is statistically insignificant, thus leaving the coefficients of both "catch-up" and training unchanged. The result is not reported in Table 3.[22]

Training, η is also significant at the 10% level. It is less important than the catch-up effect. Firms that provide skilled workers with training exhibit higher rates of productivity growth: 4.8% faster than firms without training. The result in column I shows that the Parente-Prescott investment equation holds true for the manufacturing firms in China with the catch-up effect greater than that of the firm's investment in skills or worker training.

An addition of industry dummies[23](column II) does not improve the adjusted $R^2$and the F-test cannot reject the null hypothesis that industry differences do not account for TFP growth. Inclusion of industry dummies exaggerates the effect of catch-up slightly and lessens that of training. Nevertheless, both coefficients are robust.

The other dimensions of the data are attributes of regions or specific firms. To control for region attributes, one can add region dummies. Another variable that can be used is the "inland" dummy. Chengdu and Chongquing are located inland where the policy environments for foreign investments are much more conservative than in the "Special economic zone" in the southern coastal cities. There is a greater presence of state-owned firms in these two cities than in the other six cities on the coast. They are also less open to foreign capital. The inland dummy takes into account not only geographical distance from the port but also more conservative policies towards foreign

[22]Industry growth rates during 1990-1992 are computed from a series of industry gross output in constant prices in the UNIDO industrial statistics: food 35%, textile 34.5%, wood & papers 34.9%, chemical 44%, non-metallic minerals 59.7%, basic metal & fabricated metal 66.8%, and others 53.4%.

The coefficient of industry growth rate is -.147 and is rejected at the10% level in the t-test.

[23]Six industries are jointly tested in the F-test. The "other manufacturing" dummy is dropped as a base.

Table 3: Catch-up and training effects

	I	II	III	IV
θ (catch-up)	-.346***	-.351***	-.362***	-.368***
	(.062)	(.064)	(.062)	(.063)
η (training)	.048*	.047*	.063**	.063**
	(.026)	(.026)	(.026)	(.027)
ζ (age)	—	—	.001**	.002**
			(.0008)	(.0008)
industry dummies	no	yes	no	yes
adjusted R^2	.1032	.1028	.1190	.1229

Notes:

(1) Dependent variable = TFP growth between 1990 and 1992.
Number of observations used = 256.

(2) Intercept is included in regressions but is not reported here.

(3) Parentheses are standard errors. ***,**, and *indicate 1%, 5% and 10% significance levels, respectively.

capital. However, neither region dummies nor the inland dummy improve the fit and therefore the results are not reported here.

There are several variables to account for firm-attributes: age, export-propensity and skill level.[24] Each of these three variables is tested in the regression and "age" is the only one that is statistically significant. Column IV shows the results after including "age" which is defined as the year of establishment. The positive and significant coefficient of "age" shows that younger firms exhibit a higher productivity growth. Note that foreign joint ventures in China began recently after the revision of a joint venture law in 1979 as well as after the establishment of Special Economic Zones on the southern coast in 1980. In other words, the result implies that the newer firms grow faster and are likely to be foreign owned.

Introduction of the firm attribute "age" in column IV strengthens the result both in the size of the coefficients and the size of the statistical significance of the catch-up and training effects. This suggests that the error term in the base model is negatively correlated with these two variables. Firms that are far behind the leader or those who trained workers are less likely to record a higher rate of productivity growth.

Overall, the catch-up and training effects remain robust throughout regressions. Industry and region differences do not change the base result. A firm-attribute such as "age" shifts both coefficients slightly upward. But the relative importance of the catch-up and training effects remains the same. Thus, the results are consistent with the investment equation by Parente and Prescott.

Note that the coefficient of the catch-up effect ranges from -.345 to -.362. These figures are much higher than what the previous studies found as the rate of convergence for regional and cross-country set-ups[25]. For example, Barro and Sala-i-Martin (1991) use the data on U.S. states over more than a decade and find that the annual rate of convergence among states is roughly around 2%. On the other hand, our regression results suggest that the annual rate of intra-industry convergence among firms in China is 34% which is 17 times as high as that in Barro and Sala-i-Martin. There are several reasons why this is so.

First, a comparison may be difficult to make between the two results

[24] See Appendix 2 for definitions of the variables.

[25] θ is a reciprocal of the rate of β-convergence.

since the previous studies refer to convergence at the more aggregate level (state or country) than at the firm level. It is natural to expect that the more disaggregated the unit of convergence, the faster is the rate of the convergence: "catch-up" across firms in the 2-digit ISIC industry classification is faster than that across states. Second, China underwent a phenomenal economic growth during the period. Growth in industrial output was 14.7% on average between 1990 and 1992 (Wang, 1994). Furthermore, the cities in which the firms are located for the current survey are the powerhouses of fast-growing China. If the whole industry is growing so fast, the rate of convergence among firms in the industry is also expected to be faster.

On the other hand, a convergence of 34% may be overstated even if we take into account the unique Chinese experience. In reviewing the book by Baumol, Blackman, and Wolff (1989), Friedman (1992) points out that there is a possibility that the strong tendency for convergence they find may be due to a "regression fallacy." The authors of the book plot annual growth rates of countries between 1950 and 1979 against GDP per work-hour in the initial year (1950). Since the annual growth rates are regressed toward the mean, there will be a downward bias in the coefficient. If they plot the growth rate on the terminal year instead of the initial year, the negative correlation disappears. Citing the review by Hotelling (1933), Friedman concludes that the real test of a tendency to convergence should be plots of a coefficient of variation against time (e.g. σ-convergence) and that the results from Baumol et al.(1989) do pass the test. The problem of implementing the test in the current data set is, however, that there are only two data points available (e.g. 1990 and 1992), too few to carry out such a test.

Other reasons for a negative correlation between the growth rate and a catch-up term are (i) measurement error in the variables and (ii) other effects that may be contained in the catch-up term. (i) is discussed further in appendix 4. (ii) suggests that the catch-up term may capture more than a mere "catch-up". One of the candidates for such other effects is industry-specific shocks. If a particular industry is growing faster than other industries, the catch-up term may contain such a positive shock. However, controlling for such an industry-specific shock does not change the base result: we see this in column III, table 3. In any event, we need to read the coefficient of the catch-up term cautiously since it is likely to be downward biased.

Training is significant and positively related to TFP growth. Previous studies on the effect of training on a firm's productivity level/growth include

Bartel (1991) and Aw and Tan (1994). Their results show that training has a positive impact on productivity. Bartel uses labor productivity as a dependent variable in a time series while Aw and Tan use total factor productivity in a cross-section. Thus, a direct comparison of the coefficient is not possible here. What is common in their results and mine is that the coefficient of training is significantly positive.

4.2 Do foreign investments explain TFP growth?

In the previous section, we found that the catch-up and training effects are both important sources of firms' TFP growth as the model predicts. In this section, we want to determine whether "foreignness" of a firm (e.g. foreign joint ventures, foreign linkages, foreign presence in the industry) plays any role in raising a firm's productivity growth. As discussed in section 2, if foreign technologies spill over to domestic counterparts via various avenues, then we would observe an increase in productivity for those domestic firms which have foreign joint venture partners, foreign suppliers or buyers, or a great foreign presence in the industry.

Table 4 reports the results from the base model plus foreign variables for all firms. Foreign joint venture, foreign stock in the industry, and foreign stock in the region are the variables that are often discussed in the previous literature while foreign linkages and training are new additions to it. Foreign joint venture reflects the direct benefit of having a foreign joint venture partner. Foreign stock in the industry and that in the region are the conventional ways to capture the indirect effect of FDI. Many authors term these as "spillovers" from FDI by having foreign presence in the industry or region.

Each one of the variables represents a different channel through which FDI benefits the firms. There is some overlapping of areas: the foreign joint venture variable represents the demonstration effect that takes place internally in a firm. Foreign linkages is the backward-forward linkages effect via transactions with foreign suppliers and buyers. Foreign stock in the industry or in the region is the competition and demonstration effect. This indicates the competition effect because the presence of foreign and more productive firms within the same industry or city in which a firm is located necessarily increases the degree of competition. It is also the demonstration effect because the more foreign firms there are in the same industry or city, the higher the likelihood of advanced technologies being transmitted to local firms. The training effect is included as "training" even though we cannot distinguish the firm's own training from training provided by foreign joint venture partners or foreign buyers.

Column I is the base model plus all foreign variables. The four foreign variables are found to be statistically insignificant. Foreign joint venture and linkages are positively related to TFP growth. In particular, the coefficient of foreign joint venture is .039 which means that firms with foreign joint venture partners have a 3.9% higher growth rate of TFP. However, this is statistically insignificant. Both coefficients of foreign stocks in the industry and region are negative and insignificant. The result suggests that there is no evidence for the hypothesis that foreign investment helps increase the productivity growth of local firms via foreign joint ventures, foreign linkages, and the mere presence of foreign firms in the industry.

The limited impact of foreign investment is also found in Haddad and Harrison (1993) and Aitken and Harrison (1994). Haddad and Harrison (1993) find a result very similar to mine in explaining TFP growth of Moroccan manufacturing firms between 1985 and 1989. They define "DFI(firm)" as a share of a firm's assets which are foreign owned. This is a continuous version of our foreign joint venture variable. "DFI(sector)" is defined as a share of FDI in each three-digit sector which represents foreign presence within the industry. Regressing output growth of the firm on these two variables plus growth of capital and labor inputs, they find both coefficients are statistically insignificant and even negative in most cases. In the subsequent study, Aitken and Harrison (1994) examine the impact of foreign investment in annual census data on Venezuelan manufacturing firms between 1979 and 1989. Their main finding is that foreign equity participation increases both level and growth rate of productivity of an individual firm while the coefficients of sectoral and regional FDI are negative and statistically significant.

Column II is the same as column I except for "foreign stock in the region". The distribution of FDI among eight cities in the sample is very similar except for the two inland cities, Chengdu and Chongquing. In the previous subsection, we found that regional differences represented as region dummies and an inland dummy are statistically insignificant. Dropping "foreign stock in the region," the coefficients of independent variables remain almost unchanged.

Firm-attribute (age) is added in column III. This is statistically significant. Notice that moving from column II to III, there are reductions in sizes of the coefficients in all foreign variables and the catch-up effect and there is an increase in training. In particular, "foreign joint venture" lessens from

Table 4: With foreign variables

	I	II	III	IV
θ (catch-up)	-.372***	-.372***	-.368***	-.382***
	(.056)	(.066)	(.065)	(.066)
η (training)	.056**	.056**	.064**	.063**
	(.027)	(.026)	(.027)	(.027)
ζ (age)	—	—	.002*	.001*
			(.0009)	(.0009)
β_1 (foreign joint venture)	.039	.039	.007	.013
	(.032)	(.032)	(.036)	(.036)
β_2 (foreign linkages)	0.10	.010	.007	.015
	(0.29)	(.029)	(.029)	(.029)
β_3 (foreign stock	-.014	-.014	-.012	-.348**
in the industry)	(.126)	(.126)	(.126)	(.168)
foreign stock	-.003	—	—	—
in the region	(.093)			
industry dummies	no	no	no	yes
adjusted R^2	.0971	.1007	.1092	.1177

Notes:

(1) Dependent variable = TFP growth between 1990 and 1992. Number of observations used = 256.

(2) Intercept is included in regressions but is not reported here.

(3) Parentheses are standard errors. ***,**, and *indicate 1%, 5% and 10% significance levels, respectively.

.039 to .007 with no statistical significance. This suggests that the error term in column III is positively correlated with foreign variables and "catch-up" and is negatively correlated with training.[26] This remains the same after adding industry dummies in column IV with the exception of foreign stock in the industry.

Foreign stock in the industry becomes greater in size and statistical significance. The sign remains negative. Five industry dummies are included instead of six dummies. Because of the way the variable of foreign stock in the industry is constructed, [27] there would be a perfect correlation among both 6 industry dummies and foreign stock in the industry if they are all in the regression. Therefore, food industry and other industries dummies are dropped as bases in column IV. Overall, Table 4 supports no evidence of technology spillovers from foreign investment in terms of productivity improvements. If there are any spillovers at all, they would be through the training effect.

To make the analysis comparable with the previous studies, I divide sample firms by foreign ownership (Table 5). The indirect effects of technology spillovers on local firms are more easily interpreted if we look at the catch-up effect on domestic firms, or "firms without FDI". Firms without FDI are state-owned, collectively-owned and include very few private firms while firms with FDI are foreign-owned firms. In column I, the size of the coefficient in "catch-up" is very similar to that for all firms in Tables 1 and 2 whereas that of training is greater. As for foreign firms, the catch-up effect also exists but to a lesser degree.

The difference between domestic and foreign firms becomes sharper once we include industry dummies (column III and IV). Foreign linkages seem to be effective in increasing productivity growth only when a firm has foreign participation. Foreign presence in the industry remains insignificant. In order to increase productivity growth, domestic firms make investments in human capital in the form of training whereas foreign firms rely mostly on imports of intermediate goods. This observation suggests that foreign firms are not actively engaged in training local workers. What is significant is that they transfer management capital from their home country.

[26] See also correlation matrix of key variables in Appendix 4.

[27] Foreign stock in the industry is computed for each of the seven industries as foreign employment share to total employment in the industry.

The reason why the catch-up effect is smaller in foreign firms may also be that foreign firms are more efficient to start with and there may not be as much room for spillovers to take place as in the case of domestic firms. In any case, columns I and III in Table 5 strengthen the observation from table 4 that training is the key source of productivity improvements for local Chinese firms.

In Table 6, samples are divided in terms of whether a firm has any foreign linkages or not. "Firms without LINK" are those who have no transaction with foreign suppliers or buyers. Foreign linkages are one measure of a firm's "openness" to foreign sources. There are small differences between "firms without LINK" and "firms with LINK" in the first two rows (column I and II). The difference arises in "foreign joint venture". The existence of "foreign joint venture" is effective in raising TFP growth if firms have foreign suppliers or buyers. The coefficient of 'foreign joint venture' is .073 with a 10% level of statistical significance. Furthermore, the training effect is greater for firms with foreign linkages. But this reverses once we include industry dummies. So does the catch-up effect (column III and IV). Only the significance of the training effect remains robust.

One of the few studies that examine the effect of foreign linkages on a firm's productivity is done by Aw and Batra (1994). They analyze the case of Taiwanese firms and examine the relation between foreign linkages and firms' efficiency. Foreign linkages in their study allow firms to have direct access to foreign technologies. They include those with FDI, purchases of foreign licenses or exports. Their conclusion is that firms that engage in positive investments in R&D and training tend to have higher technical efficiency and that the effect of the investments is independent of foreign linkages. The result obtained in my study contrasts with Aw and Batra's in the latter point: Firm efficiency measured as productivity growth is dependent on both training and linkages. Conditional on the existence of foreign linkages, training contributes to TFP growth (columns II and IV). In the theoretical literature, Lucas (1993) points out that trade or 'openness' of a country increases the mix of goods it produces and helps a country grow faster through learning from more advanced countries. "Openness" is also a necessary condition for a country to move up the "quality-ladder" as is demonstrated in Grossman and Helpman's (1991) model. Openness in their context also means direct access to the technology frontier. At the country level, openness is international trade while, at the firm level, it is trading with foreign sources, otherwise defined as "foreign linkages" in my study.

In this subsection, we find that the effect of foreign investment on the productivity growth of Chinese firms is rather limited. Regressions for all firms (Table 4) show that no foreign variables carry statistical significance to explain growth. "Catch-up" and training are the two most important sources for growth. There is evidence in Table 5 that local Chinese firms did

Table 5: Firms with and without foreign joint venture

	I	II	III	IV
	FDI=0	FDI=1	FDI=0	FDI=1
θ (catch-up)	-.382***	-.332***	-.409***	−.323***
	(.078)	(.124)	(.081)	(.121)
η (training)	.072**	.057*	.077**	.030
	(.033)	(.046)	(.033)	(.045)
ζ (age)	.001	.001	.001	.0003
	(.001)	(.004)	(.001)	(.004)
β_2 (foreign linkages)	-.021	.077	-.022	.087*
	(.036)	(.033)	(.037)	(.048)
β_3 (foreign stock	-.002	.022	-1.217	-7.108***
in the industry)	(.189)	(.160)	(2.12)	(2.83)
industry dummies	no	no	yes	yes
n	182	74	182	74
adjusted R^2	.1171	.0717	.1153	.1615

Notes:

(1) Dependent variable = TFP growth between 1990 and 1992.
Number of observations used = 256.

(2) Intercept is included in regressions but is not reported here.

(3) Parentheses are standard errors. ***,**, and *indicate 1%, 5% and 10% significance levels, respectively.

(4) FDI=0 and FDI=1 stand for domestic and foreign firms, respectively.

make investments in worker skills which proved to be a substitute for having foreign joint ventures. As the technology frontier advanced due to inflows of foreign knowledge, domestic firms might have been forced to learn more. And they indeed reacted accordingly. We also find that foreign joint ventures and foreign linkages are complements in increasing a firm's productivity.

4.3 Sample selection bias

One reason why foreign variables are insignificant in the growth regressions may be related to an incidental selection of sample firms. Initially, there are 468 firms in the sample. When I compute TFP levels for each firm in two years, the number of observations is 591. Some firms failed to report observations in two consecutive years so the number of observations in the growth regressions drops to 256. The growth rate is calculated from productivity levels for two years, 1990 and 1992. Moving from "level" to "growth rate," 21.7 % of the observations drop out of the sample. This occurs typically because some firms did not record the level of productivity for both years. For example, a firm that was established in 1991 did not have a productivity level in 1990. Thus, this relatively new firm is excluded from the sample. If this is indeed the case, then we may have a sample selection bias such that a firm's certain characteristic for "entry" in and after 1990 is a selection mechanism at work. Or, there could be another type of self-selection of the samples. In the existence of such a sample selection, then the resulting OLS estimates would be biased even asymptotically since the expected value of the error term is no longer zero.

To see whether there is a sample selection bias in our sample, I first divide the samples into two groups: "non-missing" (firms that have no missing growth rate of productivity) and "missing" (firms that have missing growth rate), and then examine the characteristics of the firms in both groups. This indicates that the average year of establishment ("age") for "missing" firms is 1982 which is ten years earlier than that for "non-missing" firms. However, only 15.3% of drop-outs were established in and after 1990. The entry selection that we suspect, if there is any, concerns only a part of the missing firms. The rest of the firms failed to report their output levels for other reasons. As for the ownership structure, the missing firms are more likely to have foreign joint ventures and are less likely to be state-owned than the non-missing firms. Recalling that 'age' of the firm is positively correlated with

Table 6: Firms with and without foreign linkages

	I LINK=0	II LINK=1	III LINK=0	IV LINK=1
θ (catch-up)	-.373***	-.363***	-.383***	–.401***
	(.091)	(.087)	(.093)	(.094)
η (training)	.063	.069*	.070*	.065*
	(.041)	(.032)	(.042)	(.034)
ζ (age)	.002	.0006	.002*	.0003
	(.001)	(.001)	(.001)	(.001)
β_1 (foreign joint venture)	-.058	.073*	-.054	.086**
	(.060)	(.041)	(.060)	(.043)
β_3 (foreign stock	-.001	.005	-4.010	-1.570
in the industry)	(.238)	(.119)	(2.461)	(2.534)
industry dummies	no	no	yes	yes
n	153	103	153	103
adjusted R^2	.0924	.1644	.0982	.1392

Notes:
(1) Dependent variable = TFP growth between 1990 and 1992.
Number of observations used = 256.
(2) Intercept is included in regressions but is not reported here.
(3) Parentheses are standard errors. ***,**, and *indicate 1%, 5% and 10% significance levels, respectively.
(4) LINK=0 and LINK=1 stand for firms without and with foreign linkages, respectively.

foreign ownership, this is simply a restatement of a previous observation: the missing firms are younger, the new firms are likely to be foreign-owned, thus it is more likely that the missing firms are foreign-owned.

A comparison between the "missing" and "non-missing" firms shows that the pattern of potential selection bias is related to "age" of the firm and foreign ownership. One way of correcting this is to include "age" and foreign ownership in the OLS regression of TFP growth. If these are the only causes of sample selection, then the OLS estimates will no longer be biased. Another way is to perform a Tobit analysis [28] to see if the censored regression yields significantly different estimates from the OLS. However, there is not enough quantitative information to define the selection mechanism in the current data set.

In sum, there is no serious selection problem associated with the pattern of missing values. Even if there is any, the inclusion of "age" and foreign ownership should correct for it.

5 Conclusion

Using firm-level data, I examined both the empirical importance of the catch-up effect and of a firm's investments in skills (training) in explaining productivity improvements for 468 manufacturing firms located in eight cities in China between 1990 and 1992. Past studies often use the effect of foreign presence on the productivity level or growth as a proxy for indirect

[28] We estimate: $y = \beta' x + \varepsilon$. where y is the rate of TFP growth and x is the vector of the catch-up effect and training variables. Suppose there is a selection mechanism in which y is observed if $z = 0$ and y is not observed if $z = 1$ where $z = 0$ if $z^* \succ 0$ and $z = 1$ if $z^* \leq 0$. z is a indicator function and z^* is a latent variable, e.g. gain from reporting TFP level in both years. $z^* = \gamma' w + u$ and ε and u are bivariate normal with $(0, 0, \sigma_e, \sigma_u, \rho)$.

The moment of a truncated distribution is :

$E(y \mid x,\, z^* \succ 0)$

$= \beta' x + E(\varepsilon \mid z^* \succ 0)$

$= \beta' x + E(\varepsilon \mid u \succ -\gamma' w)$

$= \beta' x + \rho \sigma_e \sigma_u \frac{\phi(\frac{-\gamma' w}{\sigma_u})}{1-\Phi(\frac{-\gamma' w}{\sigma_u})}$

$= \beta' x + \rho \sigma_e \lambda$ if we normalize $\sigma_u = 1$ and $\lambda = \frac{\phi(\gamma' w)}{\Phi(\gamma' w)}$.

$\beta' s$ will be biased because of the covariance between ε and u. The direction of the bias depends on the sign of ρ. Due to a lack of appropriate w's, this is not implemented here. See Chapter 22 in Greene(1990) for more exposition.

spillover effects. In the current study, I am able to distinguish various types of spillovers by introducing new variables such as training and foreign linkages.

The results show that both "catch-up" and training were important sources of productivity growth for manufacturing firms in China between 1990 and 1992. This is consistent with the Parente and Prescott investment equation. All foreign variables in the base model for all firms fail to bear statistical significance. Once we condition them on foreign ownership, however, we see the importance of some foreign variables. Both the catch-up and training effects are more important for domestically-owned firms than for foreign firms which rely on the import of intermediate goods. In particular, there is evidence that local Chinese firms trained workers more often than did their foreign counterparts. This might have facilitated the process of intra-industry spillovers from foreign investments. The foreign stock in the industry variable that is traditionally used to measure spillovers from FDI is found unimportant after taking into account the more detailed measures of spillovers. Also, the presence of foreign ownership ("foreign joint venture") proved to be insignificant in the TFP growth regressions.

In this study, I find that the catch-up effect is indeed important for productivity growth of local firms. What is more important, however, is the firm's costly effort to build a skill base for greater absorptive capacity which is proxied here as the incidence of training. Chinese local firms have survived increased competition due to the entry of more advanced foreign firms and have accomplished rapid growth because of this.[29]

For policymakers, these findings suggest that opening up to foreign investments is not sufficient for a country to benefit from foreign technology spillovers. In order to maximize the incidence of spillovers from foreign direct investment, the continuing effort to create corresponding skills is indispensable for a host country's economy.

[29]Wang and Mody(1994) find that China's existing human capital and infrastructure have contributed to rapid economic growth since the 1980s.

Appendix 1. Description of the data

The data in this study is based on the firm-level survey data collected by the World Bank in 1992. The questionnaire was distributed to 468 manufacturing firms. Sixty firms are located in each of six southern coastal cities: Dongguan, Fuzhou, Guanshou, Quanzhou, Shenzhen, and Xiamen. One hundred and eight firms are located in two inland cities: Chengdu and Chongquing. [30]

The data covers the information on capital investment, number of production employees by type, the value of total production (at current and constant prices), and cost of materials (at current price). These figures are reported for 1980 and every other year from 1984 through 1992. However, there are many missing values before 1990. In order to perform an econometric analysis, I used the information between 1990 and 1992.

The dependent variable in the production function is value-added calculated as the value of total output minus the cost of intermediate inputs at the current price, which deflated by the annual GDP deflator.

The capital series are constructed by the perpetual inventory method. We are given with $\{I_{80}, I_{84}, I_{86}, I_{88}, I_{90}, I_{92}\}$. First, investments are deflated by the annual GDP deflator. Second, the investment series in missing intervals is calculated by averaging. For example, the investment in 1982, I_{82} is computed by $(\frac{I_{80}+I_{84}}{2}) * \frac{1}{.7867}$ where .7867 is a GDP deflator in 1982. For each year, we have an investment figure after filling in the intervals. Suppose that the value of investment in the base year (e.g. 1980) is approximately the same as the value of capital stock in the same base year. That is, $K_{80} \simeq I_{80}$ where the subscript denotes the year. The capital stock in 1981 is computed by $K_{81} = I_{81} + K_{80}(1-\delta)$ where δ is a depreciation rate which is set to 0.10. Finally, we have the complete capital series $\{K_{80}, K_{81}, \ldots K_{92}\}$. [31]

Labor inputs are measured as the numbers of workers. They are of two types: the unskilled workers measured as the number of production workers and the skilled workers as the number of total workers minus the number

[30] Out of 108 firms, 55 firms are located in Chengdu and 53 firms are located in Chongquing.

[31] In the original survey, firms report $\tilde{K}_{92}$, value of fixed capital stock in 1992. When I construct the series backwards from $\tilde{K}_{92}$, $K_{90}(=\frac{K_{92}-I_{92}}{1-\delta})$ often becomes negative since $K_{92} \prec I_{92}$. Discarding $\tilde{K}_{92}$ in the original data, I set the capital stock in the first observed year as $K_0 \simeq I_0$ and construct the series forward.

of production workers. Skilled workers include technicians, engineers, plant supervisors, and others.

The foreign variables which include foreign joint venture, foreign linkages, foreign stocks and training are available only in 1992. Foreign joint venture and foreign linkages are constructed from answers to the following questions: "Do you currently have foreign joint venture partners (foreign buyers or suppliers) ? " The training variable answers the question: " In the past year, did your enterprise send any of your plant supervisors and technicians/engineers to formal training? " Thus, foreign joint venture, linkages, and training are all binary (=1 if yes, =0 if no). Foreign stocks in the industry takes seven values since they are computed for each 2-digit industry group. Foreign stocks in the region consists of eight values for each city in which a firm is located.[32]

In computing the level of total factor productivity (TFP) of the firm, the number of observations used is 591. As we proceed to compute the growth rate of TFP, the number of usable observations goes down to 256. This is because we need to observe TFP levels in two consecutive periods (e.g. 1990 and 1992) for the same firm.

[32] See Apendix 2 for definitions of the variables.

Appendix 2. Definitions of the variables

variables	definitions
AGE	the year in which a firm is established.
catch-up	the catch-up effect in j th industry $=\frac{A_j^i}{W_j}$ where W_j=TFP. level of the best practice firm in j th industry.
EXP	export propensity computed as value of exports to total sales.
FORGN	FORGN=1 if a firm has any foreign joint venture partner, = 0 otherwise.
FOR_ind	foreign stock in the industry computed as the foreign share of employment in the industry.
FOR_reg	foreign stock in the region computed as the foreign share of employment in the city.
industry dummies	food, textile, wood, chemical, non-metallic, machinery, and others ("others" is used as a base).
inland	inland=1 if it is located in Chengdu and Chongquing, =0 otherwise.
K/L	capital-labor ratio.
LINK	LINK=1 if a firm has either foreign suppliers or buyers, =0 otherwise.
SIZE	total sales in RMB.
TFP	total factor productivity. $=\ln Y - \alpha_k \ln K - \alpha_{l1} \ln L1 - \alpha_{l2} \ln L2$.
TRN	TRN=1 if a firm trained skilled workers in the previous year, =0 otherwise.
Y/L	labor productivity = $\frac{\text{value-added}}{\text{\# of total workers}}$.

Appendix 3. Summary Statistics

	n	**mean**	**std. dev.**
A	365	0.067	1.18
Age	449	76.15	14.51
TRN	450	0.36	0.48
FORGN	450	0.32	0.46
LINK	450	0.43	0.49
For_ind	450	0.11	0.11
For_reg	450	0.18	0.15
Y/L	385	23717	72612
K/L	450	18506	36433
Size	450	649	1648
Exp/sales	406	0.30	0.40

Appendix 4. Correlation matrix of key variables

	A	age	TRN	FORGN	LINK	For_ind	FOR_reg
A	1.00						
age	0.10*	1.00					
TRN	0.12*	−0.28**	1.00				
FORGN	0.15**	0.50**	−0.19**	1.00			
LINK	0.10*	0.28**	−0.06	0.42**	1.00		
For_ind	0.03	0.12**	−0.13**	0.20**	0.23**	1.00	
For_reg	−0.05	0.30**	−0.16**	0.17**	0.19**	0.19**	1.00

Appendix 5. Measurement error in the catch-up term

Suppose the true relationship is described as follows: (e.g. $Y_t = \ln A_t$)

$\triangle Y_t = Y_{t+1} - Y_t = \lambda Y_t$

However, what we can observe is:

$\tilde{Y}_t = Y_t + \varepsilon_t \Rightarrow \triangle \tilde{Y}_t = \triangle Y_t + \triangle \varepsilon_t$

Actually, we run the regression expressed as follows:

$\tilde{Y}_{t+1} - \tilde{Y}_t = \theta \tilde{Y}_t$

$\Rightarrow cov(\triangle \tilde{Y}_t, \tilde{Y}_t) = cov(\triangle Y_t + \triangle \varepsilon_t, Y_t + \varepsilon_t) = cov(\triangle Y_t, Y_t) + cov(\triangle \varepsilon_t, \varepsilon_t) = \lambda - \sigma_\varepsilon^2$

while the actual covariance is:

$cov(\triangle Y_t, Y_t) = \lambda$.

Therefore, θ will be biased downward from the true λ by $-\sigma_\varepsilon^2$.

Appendix 6. Is foreign ownership endogenous?

Suppose that a ith firm's production function is as follows:

$\tilde{Y}_{it} = A_i + \alpha_k \tilde{K}_{it} + \alpha_l \tilde{L}_{it} + \alpha_h \tilde{L}_{2it} + \eta_i + e_{it}$

where $\tilde{Y}_{it}, \tilde{K}_{it}, \tilde{L}_{it}, \tilde{L}_{2it}$mean logarithmic expressions. η_i is an unobserved characteristic of a firm. If we estimate from cross-sectional data, then estimates will be biased because of η_i. In order to eliminate this, difference between t and t-1:

$\tilde{Y}_{it} - \tilde{Y}_{it-1} = \hat{\alpha}_k(\tilde{K}_{it} - \tilde{K}_{it-1}) + \hat{\alpha}_l(\tilde{L}_{it} - \tilde{L}_{it-1}) + \hat{\alpha}_h(\tilde{L}_{2it} - \tilde{L}_{2it-1}) + (e_{it} - e_{it-1})$

The estimates $\hat{\alpha}_k, \hat{\alpha}_l, \hat{\alpha}_h$ are consistent since an error term is no longer correlated with independent variables. Thus, we calculate residuals of 1992 from consistent estimators:

$\tilde{Y}_{it} - \hat{\alpha}_k \tilde{K}_{it} - \hat{\alpha}_l \tilde{L}_{it} - \hat{\alpha}_h \tilde{L}_{2it} = A_i + \eta_i = TFP_t$

where $t = 1992$.

Finally, we check the covariance of FORGN (foreign joint venture) and TFP_t to see if they are correlated. As mentioned in Section 4, they are not correlated. Thus, FORGN will be unbiased in OLS.

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