

Foreign direct investment and technology spillovers: Theory and evidence

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Abstract

Within the endogenous growth framework, we offer an explanation on how foreign direct investment (FDI) generates externalities in the form of technology transfer. We distinguish between the level and rate effects of spillovers on the productivity of domestic firms. A new insight gained from the theory is that the level and rate effects of spillovers can go in opposite directions. The negative level effect underscores the fact that technology transfer is a costly process—scarce resources must be devoted to learning. The positive rate effect indicates that technology spillovers enhance domestic firms' future productive capacity. Using a large panel of Chinese manufacturing firms, we find suggestive evidence that an increase in FDI at the four-digit industry level lowers the short-term productivity level but raises the long-term rate of productivity growth of domestic firms in the same industry. We also find that spillovers through backward and forward linkages between industries at the two-digit level have similar effects on the productivity of domestic firms, and backward linkages seem to be statistically the most important channel through which spillovers occur. © 2006 Elsevier B.V. All rights reserved.

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1. Introduction

Attracting foreign direct investment (FDI) has become an essential part of development strategies among less developed countries (LDCs). Many offer special incentives to foreign investors, such as tax holidays, tariff reductions or exemptions, and subsidies for infrastructure.¹

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¹ In China, for example, foreign-invested firms are exempt from paying income tax for 2 years from the first profit-making year and are allowed a 50% tax reduction thereafter for 3 years. For an overview of FDI in China, see Liu (2002).

To a large extent, such policies have indeed been instrumental in accelerating FDI flows into LDCs. According to the latest World Bank report,² the net FDI flows into low-income countries were more than tripled between 1990 and 2001, increasing from about \$2.6 billion in 1990 to \$9 billion in 2001. Middle-income countries also experienced an increase in the net FDI inflows from about \$21 billion to \$162 billion over the same period. China stands out among middle- and low-income countries with a net FDI inflow of about \$44 billion in 2001, which is more than 12 times of the 1990's \$3.5 billion. Although FDI is widely believed to be beneficial to its recipient countries from financing a savings gap or balance of payments deficit to increasing exports and earning foreign currency, to increasing employment,³ preferential policies toward FDI rest, in large part, on the assumption that FDI generates externalities in the form of technology transfer, including advanced technology, management methods, new products and new processes.

There are arguments in favor of FDI as a conduit for technology transfer. Domestic firms can learn from foreign-invested firms by observation or by establishing business relations with the latter or through labor turnover as domestic employees move from foreign to domestic firms. In an influential study, Findly (1978) suggests that the capital in foreign-invested firms play the role of a generalized promoter of technology improvement—the more chances do domestic firms have to observe the advanced technology used by foreign-invested firms, the faster does domestic technology level grow. Wang (1990) extends Findly's model by establishing a link between FDI and the growth of domestic human capital. In his model, an increase in FDI induces more investments in human capital, which enhances the catch-up potential of the recipient country. Fosfuri et al. (2002) and Glass and Saggi (2002a) present models of technology spillovers through labor turnover. Walz (1997) suggests that the presence of foreign-invested firms in LDCs brings about knowledge spillovers to the domestic R&D sector and hence contributes to economic growth. Glass and Saggi (1998) maintain that product imitation by local firms in an LDC is possible only when a foreign-invested firm produces the product within the country. Glass and Saggi (2002b) further argue that the presence of FDI benefits domestic firms by lowering the cost of imitation.

The empirical evidence on whether FDI facilitates technology spillovers is ambiguous. Caves (1974) finds positive and significant spillovers in the Australian manufacturing sector. Rhee and Belot (1989) claim that the entry of foreign firms is largely responsible for the creation and subsequent growth of domestically owned textile firms in Mauritius and Bangladesh. However, Germidis (1977) examines a sample of 65 multinational subsidiaries in 12 developing countries and finds almost no evidence of technology transfer from foreign to local firms. Haddad and Harrison (1993) find negative spillovers associated with FDI in Morocco. In a study of Venezuelan firms, Aitken and Harrison (1999) find that FDI affects adversely the productivity of domestic firms. To explain their results, they put forward a “market-stealing” hypothesis arguing that, while FDI may promote technology transfer, foreign-invested firms gain market shares at the expense of domestic firms and force the latter to produce smaller outputs at higher average costs. As a result, the overall benefit of FDI is small. Using a panel of manufacturing industries from China, Liu (2002) shows that FDI has large and significant impacts on the productivity of manufacturing industries in the domestic

² World Bank, *World Development Indicators*, 2003, Washington, DC: World Bank (2003).

³ In a survey article, de Mello (1997) claims that efficiency spillovers from foreign to domestic firms determine ultimately the impact of FDI on output growth in the recipient country. Some have questioned whether the benefits of FDI exceed its costs to the host country by pointing out potential detrimental effects of FDI, such as increasing the host country's technology dependence on foreign sources and therefore retarding innovations by domestic firms, destroying domestic firms through an intense competition and lending greater market powers to foreign firms, introducing inappropriate products, technology, and consumption patterns (see, e.g., Nafziger, 1990).

sector. Javorcik (2004) reports evidence for positive productivity spillovers from foreign firms to their local suppliers in upstream sectors in Lithuania.

In this paper, we investigate whether the presence of FDI affects the productivity level as well as the rate of productivity growth of domestic firms. The distinction between the short-term level effect and long-term rate effect of FDI on the productivity of domestic firms is important. If resources must be expended in order to learn from foreign-invested firms, it is possible that the spillovers have a negative effect on the productivity of domestic firms in the short run yet a positive effect on the productivity of domestic firms in the long run, because such learning helps enhance the firm's future productive capacity. The latter depends crucially on whether technology spillovers affect the rate of productivity growth of domestic firms. We offer one possible explanation for this scenario in the context of a model of endogenous growth at the firm level, in which firm-specific capital is the engine of firm-specific productivity growth. The accumulation of such capital requires the investment by managers of the firm in terms of time and effort. Since such investment activity, although enhances the firm's future productive capacity, diverts managerial time and effort away from current production of outputs, it affects adversely the short-term productivity level of the firm.

The basic idea is not entirely new. The firm-specific capital is analogous to human capital in endogenous growth models, such as those presented in Lucas (1988) and Romer (1990), and is in spirit similar to the organization capital stressed in Prescott and Visscher (1980). The model analyzed in this paper extends the endogenous growth model developed in Ehrlich et al. (1994) by incorporating externalities into the production of firm-specific capital. Specifically, the public knowledge on technology, management methods as well as new products and processes associated with FDI serves as an input in the production of firm-specific capital, augmenting the productivity of all other factors. An increase in the stock of public knowledge leads the firm to change the optimal allocation of managerial time between current production of outputs and accumulation of firm-specific capital in favor of the latter which in turn reduces the firm's short-term productivity level but raises its long-term rate of productivity growth. The model has the feature that technology transfer (even in the form of spillovers) does not take place automatically and is a costly learning process.⁴

In the empirical analysis, we estimate models that are appropriate for testing the implication of our theory and yet flexible enough to accommodate other considerations. We also distinguish between intraindustry and interindustry spillovers. Our empirical results based on a large panel of Chinese manufacturing firms are by and large consistent with the predictions of our theoretical model. First, FDI facilitates technology transfers to domestic firms through spillovers. Second and more importantly, such spillovers lower the short-term productivity level, but raise the long-term rate of productivity growth of domestic firms. Third, taken together the level and rate effects of spillovers, the overall external benefits associated with FDI in terms of productivity gains accruing to domestic firms are positive and substantial. Fourth, while there is suggestive evidence for intraindustry or horizontal spillovers, backward linkages seem to be statistically the most important channel through which technology spills over from foreign to domestic firms.

The rest of the paper is organized as follows. Section 2 presents a model of firm-specific productivity growth that incorporates the external effects of FDI. The theoretical analysis provides a basis for the empirical model to be discussed in Section 3. Section 4 contains a description of the data and key variables used in the empirical estimations. The results are presented in Section 5. Section 6 concludes.

⁴ Eeckhout and Jovanovic (2002) propose a theory of knowledge spillovers with costly copying process. In their model, firms must incur costs of collecting information about existing technologies and checking patent status once a suitable technology is identified.

2. The model

We assume that foreign investors bring superior technology, managerial know-how, and other non-tangible productive assets to LDCs in general and to local partners in particular, in case that foreign investment takes the form of equity joint venture. We also assume that productivity growth is firm specific and endogenous to the firm. The engine of growth is firm-specific organization capital,⁵ which augments the productivity of all inputs. The accumulation of the firm-specific capital competes with the production of physical outputs for non-reproducible managerial time.

Assuming that the technology is separable between value-added and intermediate goods and technical change is value-added augmenting, we specify the firm's production function as:

$$Q_t = A_t B_t L_t^\alpha K_t^\beta [H_t M_t]^\gamma, \quad (1)$$

where A_t represents exogenous, common technical factors, B_t is the productivity parameter relating to the superior technology brought to a joint venture by the foreign partner, L_t and K_t are labor and capital inputs, H_t is the stock of firm-specific capital, M_t is the fraction of managerial time (normalized to be one) devoted to directing current production, and subscript t denotes time. To focus on the determinants of firm-specific productivity growth, A_t is treated as a constant or assumed to grow at the constant rate. Since B_t depends on the direct contribution of the foreign partner to the productivity of the firm, it is assumed to be greater for foreign-invested firms than for domestic firms.

The production of firm-specific capital requires the inputs of managerial time ($1 - M_t$) and knowledge from two sources. The first, internal to the firm, is the current stock of firm-specific capital (H_t). The second source of knowledge is situated in the public domain and its value to the firm depends on the firm's ability to convert the knowledge from the public pool into firm-specific capital. To focus on the impacts of spillovers emanating from FDI, we assume that foreign-invested firms are one of the external sources of knowledge. In other words, the technical and managerial know-how associated with foreign-invested firms are at least in part public information, which is used by other firms as an unpaid input factor in the production of firm-specific capital as represented by the following function:

$$\dot{H} = rH_t[1 - M_t]^\delta G_t^\varphi, \quad (2)$$

where r is an efficiency parameter of the production, $0 < \delta \leq 1$ indicates whether managerial inputs are subject to diminishing returns, G denotes public information on technology and management methods associated with foreign-invested firms,⁶ and $\varphi \geq 0$ represents the intensity of spillovers. If there are no spillovers, however, φ takes the value of zero.

The firm chooses the amount of managerial time to devote to directing current production, M^* (hence $1 - M^*$ to accumulating firm-specific capital), the amounts of labor and capital to hire, so

⁵ See Prescott and Visscher (1980) for a discussion on organization capital. In Bahk and Gort (1993), firm-specific learning-by-doing, as a productivity-enhancing factor, is decomposed into three components: organization learning, capital learning, and manual task learning. They assume that organization capital is the product of organization learning.

⁶ G can be considered as an index of technology gap between domestic and foreign invested firms: $G=1$ for the firm with the most advanced technology and $G>1$ for all others, especially domestic firms. Also, for a domestic firm, G can come from foreign firms operating in the same industry or in a downstream or upstream industry. It is not necessary for us to distinguish between intraindustry and interindustry spillovers because theoretically the predicted effects of spillovers are independent of the channels through which spillovers occur. However, this distinction becomes important empirically. We allow spillovers to occur through multiple channels in our empirical estimations. Also, if no effort is required for learning, spillovers can be viewed as an exogenous technological change that benefits all firms. The term A in Eq. (1) captures spillovers of this type.

that the present value of future profits is maximized. Under certain assumptions about the structure of the market and demand function, it can be shown that at the steady state the growth rate of firm-specific capital H is positively related to $rG^\varphi - \rho$ (where ρ is the discount factor) and the amount of managerial time devoted to current production is negatively related to G .⁷ The economic intuition is straightforward. The optimal allocation of managerial time is given by M^* and $1 - M^*$ so that the marginal profits of managerial time from the two productive activities, in present value terms, are in balance. The presence of foreign-invested firms with advanced technologies raises the level of knowledge from the external source (G), which in turn raises the productivity and marginal profit (in present value terms) of managerial time in the production of firm-specific capital. As a result, the firm will allocate more managerial time to the accumulation of firm-specific capital and less to directing current production of outputs. The former will raise the growth rate of firm-specific capital and hence the long-term rate of productivity growth of the firm. The latter, less managerial time to directing current production, will lower the short-term productivity level of the firm.

To see this in terms of production function, we can derive from Eq. (1) the firm's total factor productivity at time t as

$$TFP_t = \frac{Q_t}{L_t^\alpha K_t^\beta} = A_t B_t [H_t M_t]^\gamma, \quad (3)$$

and the growth rate of total factor productivity as

$$T\hat{F}P = \hat{A} + \hat{B} + \gamma\hat{H}, \quad (4)$$

where the steady state growth rate of firm-specific capital is given by

$$\hat{H} = r(1 - M^*)^\delta G^\varphi. \quad (5)$$

Since the level of TFP is determined in part by M and the current stock of firm-specific capital (H), a reduction in the steady state M due to an increase in G leads to a drop in the level of TFP . But, because the growth rate of H is now higher due to an increase in managerial time allocated to accumulating H , the steady state growth rates of H and TFP are both increased. In other words, a higher G propels domestic firms, through its effect on the accumulation of firm-specific capital, to a steeper path of productivity growth.

3. Empirical methodology

One important implication of the theoretical analysis is that if the effects of spillovers are to lower the short-term level but raise the rate of productivity growth of domestic firms, then an empirical analysis focusing only on the changes in the level of productivity could yield misleading results. While the rate effect will dominate the level effect in the long run because a small increase in the rate of productivity growth will translate into a huge gain in the level of productivity in the future, this is not guaranteed for samples with relatively short time series. Indeed, if the sample period is short, it is possible for the negative level effect to dominate the positive rate effect of spillovers. Therefore, it is crucial for us to specify an empirical model that allows for the separation of the level from the rate effect of technology spillovers.

A natural starting point is to estimate a model in which the logarithm of firm i 's productivity ($\ln p_{ij}$) is assumed to depend on foreign equity share in the firm ($F\text{DL}_{\text{firm}_{ij}}$), foreign investments

⁷ Proof is available upon request.

in industry j (FDI_sector_j , to be defined later), a time trend (Time), an interaction term between the time trend and FDI_sector_j , and other relevant control variables, X :

$$\begin{aligned} \ln fp_{ij} = & \alpha_0 + \alpha_1 FDI_firm_{ij} + \alpha_2 FDI_sector_j + \alpha_3 Time + \alpha_4 Time * FDI_sector_j \\ & + \alpha_5 X_{ij} + u_i + \varepsilon_i, \end{aligned} \quad (6)$$

where u_i denotes the unobservable firm specific effect and ε_i denotes the remainder stochastic disturbance. Whereas parameter α_2 captures the effect of spillovers on the short-term level of productivity, α_4 captures the effect of spillovers on the long-term rate of productivity growth of the firm. The implicit assumption of the regression analysis is that the time trend of productivity can serve as an indicator of the long-term rate of productivity growth, which is determined in part by endogenous, firm-specific productivity growth.

The fixed-effects specification is important for our econometric model for two reasons. First, since the effects of spillovers FDI depend on within-firm variations in FDI_sector , the fixed-effects specification avoids the possible reverse causality that industries with higher productivity levels or higher rates of productivity growth attract more foreign investments. The fixed-effects specification with firm dummies also helps avoid the possible reverse causality that regions that have more productive firms attract more foreign investments. Second, the fixed-effects specification can mitigate the impacts of some forms of nonrandom measurement error. Suppose, for instance, that a firm overstates its output by a certain percentage each year. This will have no bearing on the estimated effects of spillovers.

Using Eq. (6), we conduct two sets of empirical estimations. First, we estimate the effects of intraindustry spillovers at the four-digit industry level—the most disaggregated sector level that the sample firms can be identified. This type of spillovers has been the primary focus of the existing empirical literature on technology spillovers associated with FDI. Second, we expand Eq. (6) to estimate the effects of interindustry or vertical spillovers in conjunction with those of intraindustry spillovers. We consider two types of interindustry spillovers. One takes place through backward linkages where domestic firms are suppliers of intermediate inputs used by foreign-invested firms in downstream industries. The other occurs via forward linkages where domestic firms purchase intermediate inputs from foreign-invested firms in upstream industries. Because the input–output matrix that is required for constructing proxies (to be defined later) for interindustry spillovers is available only for the two-digit industries, we are restricted to the estimation of the effects of interindustry spillovers across two-digit industries.

4. Data and definitions of key variables used

4.1. Data

The empirical analyses in this study are based on a sample of manufacturing firms in China. The data were obtained from the National Bureau of Statistics of China (NBSC), which collects and maintains a computerized firm-level database covering over 20,000 industrial firms in China.⁸ Our sample, randomly drawn from the database, is an unbalanced panel consisting of 17,675 manufacturing firms over a period of 5 years from 1995 to 1999 with a total of 50,667 observations.⁹

⁸ These firms are classified as medium-size and large-size enterprises accounting for about one third of China's industrial output. China had nearly 8 million industrial enterprises in 1999.

⁹ At the time we obtained our sample from the NBSC, 1999 was the most recent year for which the database was available.

Table 1
Definitions and summary statistics of key variables used

Variable	Definition	Mean (standard deviation)
Output (million yuan)	Value-added in constant price	453.29 (1842.21)
Capital (million yuan)	Real values of capital stock	110.06 (699.85)
Labor (persons)	Total number of employees	1453 (3983)
lfp	Log of total factor productivity	2.647 (1.529)
FDL_firm (%)	The percentage of firm's equity owned by foreign investors	10.33 (23.93)
FDL_sector (%)	The weighted average of the percentage of firm's equity owned by foreign investors among firms in the same four-digit industry ^a	11.83 (20.03)
FDL_sector2 (%)	The weighted average of the percentage of firm's equity owned by foreign investors among firms in the same two-digit industry ^a	13.12 (17.15)
FDL_downstream_sector (%)	The weighted average of FDL_sector2 of upstream two-digit industries ^a	5.69 (7.36)
FDL_upstream_sector (%)	The weighted average of FDL_sector2 of downstream two-digit industries ^a	5.67 (6.51)
HI	Herfindhal index	0.10 (0.133)
Sample size		50,667

Firms included in the sample come from the following two-digit manufacturing sectors: food processing, food manufacturing, beverage manufacturing, tobacco processing, textile, garments and other fiber products, leather (including furs and related products), timber processing, furniture, paper and paper products, printing and record medium, educational and sports goods, petroleum processing, chemical material and products, medical and pharmaceutical products, chemical fiber, rubber products, plastic products, nonmetal mineral products, processing of ferrous metals, processing of nonferrous metals, metal products, ordinary machinery, special purpose equipment, transportation equipment, electric equipment and machinery, electronic and telecommunications equipment, instruments, and other manufacturing.

^a See discussions about Eqs. (8)–(10) for the specific weight used.

The data contain information on the gross value of output in current and constant (1990) prices, value added in current prices, work force, total wage bill and employment benefits, original value of fixed assets, net value of fixed assets, sales revenue, registered foreign equity share, and so on. Table 1 presents definitions and summary statistics of the key variables used in the empirical estimations.

Output is measured in terms of real value-added. We obtain real value-added by deflating the value-added figures at current prices using implicit deflators, which are the ratios of gross output in current price to gross output in constant price.¹⁰ Labor is measured by the total number of employees rather than hours worked due to lack of data on the latter.

In constructing the real capital stock series, we follow closely the method used by Chow (1993), Li (1997), and Liu (2001). First, we derive the nominal value of newly added fixed assets from the difference in the reported original value of fixed assets between the current and preceding years. Second, we deflate the series by a price index of investment in fixed assets to obtain annual gross investments in constant (1990) prices, I . The price index is a weighted average of separate cost indexes for investments in construction and installation, purchases of equipment and instrument, and others.¹¹ Third, assuming that the initial real capital stock is the

¹⁰ We also tried to use ex-factor price index as the deflator. It made very little difference.

¹¹ The price index varies across provinces and is obtained from *China Statistical Yearbook*. When province-specific price index is not available, (e.g., for Guangdong) the national average is used.

deflated net value of fixed assets in 1995,¹² we use the perpetual inventory method to obtain the real capital stock in year t as

$$K_t = (1-d)K_{t-1} + I_t, \quad (7)$$

where d is the rate of depreciation.¹³

4.2. Constructing proxies for spillovers

We follow Aitken and Harrison (1999) to measure for each province the presence of foreign investment in manufacturing sectors at the four-digit level by the average of the percentage of firm's equity owned by foreign investors, weighted by each firm's share in sector j 's output (OS_{ij}):¹⁴

$$FDI_sector_j = \sum_i OS_{ij} \times FDI_firm_{ij} \quad (8)$$

where FDI_firm_{ij} , as noted earlier, is firm i 's equity share owned by foreign investors.

We believe that spillovers are likely to occur within industries at the four-digit level because the constituting firms produce similar products and the technology and management know-how employed by foreign-invested firms are more directly applicable to domestic firms in the same sector. If FDI facilitates technology spillovers, we expect such external effects to benefit firms operating in the same or closely related product markets. As such, FDI_sector captures the intraindustry or horizontal spillovers.

We also believe that spillovers can take place across firms in different industries. In this case, technology or management know-how may be transferred from foreign to domestic firms as one becomes a business client of the other. We explore interindustry spillovers using proxies that reflect the extent of backward and forward linkages between industries. Following Javorcik (2004) we proxy the presence of FDI in industries k ($k \neq j$) that are being supplied by sector j by

$$FDI_downstream_sector_j = \sum_k \theta_{jk} \times FDI_sector2_k \quad (9)$$

where θ_{jk} is the share of sector j 's output used as an intermediate input by sector k taken from the 1997 input–output matrix,¹⁵ $FDI_sector2_k$ is the equivalent of FDI_sector_j of Eq. (8) defined at the two-digit industry level. A higher $FDI_downstream_sector$ indicates a greater potential for spillovers

¹² For firms that we do not have their information for 1995, the real capital stock for the first year in which data are available is defined as the deflated net value of fixed assets in that year.

¹³ Due to data constraint, we cannot use strictly the perpetual inventory method to construct the real capital stock series, which requires historical information on annual gross investments going back at least 15 years prior to our sample period. Our treatment of the initial real capital stock is similar to the approach adopted in Lichtenberg (1992). Following Young (2000), we assume that the annual depreciation rate on real capital stock is 6%. To check the sensitivity of our main results to alternative measures of capital stock, we tried to apply different depreciation rates (7% and 10%) and to distinguish capital used for production from capital used for non-production purposes. The main results are fairly robust to these changes.

¹⁴ We also experimented with alternative weighting schemes, such as capital share or labor share, and found that they lead to very similar results.

¹⁵ The share is calculated excluding products for final consumption and exports but including imported intermediate products. Ideally, imports should be excluded and different input–output matrices should be used for each year. Unfortunately, input–output matrix pertaining to domestic outputs does not exist and comparable input–output matrices are not available for the rest of our sample years. This is also an issue in Javorcik (2004).

from FDI in downstream sectors to firms in upstream sectors. Similarly, we capture the potential spillovers from FDI in upstream industries to firms in downstream sectors by the following proxy

$$\text{FDI_upstream_sector}_j = \sum_l \tau_{jl} \times \text{FDI_sector}_l \quad (10)$$

where τ_{jl} is the share of intermediate inputs purchased by industry j from industry l in total inputs sourced by sector j , and $l \neq j$.

4.3. Estimating total factor productivity

Consider the following Cobb-Douglas production function:

$$q_{it} = \alpha + \beta_l l_{it} + \beta_k k_{it} + \omega_{it} + \varepsilon_{it} \quad (11)$$

where q , l , and k are the logarithm of output (in value-added terms), labor and capital inputs, respectively, ω is total factor productivity which is known to the firm but not to the researcher, ε stands for random productivity shocks, and subscripts i and t index firm and time. It is obvious that obtaining consistent input elasticity estimates from the production function is crucial for getting proper estimates of total factor productivity. However, since inputs are endogenously determined, OLS estimates from Eq. (11) are susceptible to simultaneity bias. To overcome this problem, we obtain consistent elasticity estimates by employing the semiparametric estimation procedure originally developed by Olley and Pakes (1996) and implemented in Pavcnik (2002) and Javorcik (2004). A simplified version of the procedure involves the following assumptions and steps.¹⁶ Labor is assumed to be a variable input. Capital is treated as a fixed input and is assumed to be a function of unobservable productivity, ω . The firm's investment at time t is assumed to depend on the capital input and productivity,

$$i_{it} = i(\omega_{it}, k_{it}) \quad (12)$$

By inverting (12), the unobservable productivity can be expressed as a function of observable investment and capital:

$$\omega_{it} = h(i_{it}, k_{it}) \quad (13)$$

Substituting (13) into (11), we obtain the production function to be estimated in the first step of the Olley and Pakes procedure:

$$q_{it} = \alpha + \beta_l l_{it} + \beta_k k_{it} + h(i_{it}, k_{it}) + \varepsilon_{it} \quad (14)$$

Since the functional form of $h(i_{it}, k_{it})$ is unknown, the coefficient on capital cannot be estimated from (14). However, approximating $h(i_{it}, k_{it})$ by a third-order polynomial expansion in investment and capital, we can obtain consistent estimates for β_l and the third-order polynomial function, which is:

$$\Psi_{it} = \alpha + \beta_k k_{it} + h(i_{it}, k_{it}) \quad (15)$$

Accordingly,

$$h(i_{it}, k_{it}) = \Psi_{it} - \beta_k k_{it} - \alpha, \quad (16)$$

¹⁶ We use Javorcik's (2004) notation.

The second step of the procedure involves estimating the following nonlinear regression model:

$$q_{it+1} = \beta_l l_{it+1} = \beta_k k_{it+1} + g(\Psi_{it} - \beta_k k_{it} - \alpha) + \xi_{it+1} + \varepsilon_{it+1}, \quad (17)$$

where g is a third-order polynomial of $\Psi_{it} - \beta_k k_{it} - \alpha$ and ξ_{it+1} is mean independent of k_{it+1} .¹⁷ A nonlinear least squares method can be used to obtain a consistent estimate for β_k . We estimate (14) and (17) for each two-digit industry to obtain consistent input elasticity estimates. These estimates are then used to compute firm-specific total factor productivity, which is the difference between the actual and predicted outputs.

5. Results

5.1. Replicating empirical models of previous studies

To establish a point of reference, we begin with the estimation of productivity models commonly used in the literature. The log of total factor productivity ($\ln tfp$) is typically specified as a function of percentage of firm equity capital owned by foreign investors (FDL_{firm}), weighted average of foreign equity share across firms in the industry (FDL_{sector}), and the interaction term between FDL_{firm} and FDL_{sector} . If foreign equity participation increases the firm's productivity, the coefficient on FDL_{firm} should be positive. If technology spills over from foreign-invested to domestic firms, we should expect the coefficient on FDL_{sector} to be positive. The sign of the coefficient on the interaction term indicates whether or not foreign equity participation affects the firm's ability to benefit from spillovers emanating from other foreign-invested firms in the industry.

As correctly pointed out by Aitken and Harrison (1999),¹⁸ studies that based on aggregate industry-level data might generate biased estimated effect of spillovers. This will be true if the amount of FDI that an industrial sector receives is positively correlated with the productivity of the sector. In this case, even though spillovers are in fact absent, one is likely to find a positive relation between productivity and foreign investment in the industry. Column 1 of Table 2 presents the results from the productivity regression without industry or firm dummies that closely resembles the specification adopted by some previous studies that analyzed industry-level data. In this specification, the estimate for foreign equity participation is positive and statistically significant, indicating that foreign investment improves the firm's productivity. The positive and statistically significant estimate for the average foreign equity participation in the sector suggests that technology spills over from foreign-invested to domestic firms. The negative estimate for the interaction term means that, although foreign-invested firms also benefit from the presence of other foreign investment in the industry, they benefit less than domestic firms do. Furthermore, the benefit diminishes as the foreign equity share in the firm increases. However, when we introduce industry dummies in column 2, all estimated coefficients and that on FDL_{sector} in particular switch signs. The latter suggests that spillovers are detrimental, rather than beneficial, to domestic firms. This seems to be consistent with the notion that industries with high productivity

¹⁷ For a more detailed discussion, see Javorcik (2004).

¹⁸ Aitken and Harrison (1999) estimated log-linear production functions using plant-level data and introduced these three variables related to FDI into the production functions to capture their effects on plant's productivity. Since our TFP measure has netted out the effect of changes in input factors (labor and capital), TFP regressions are equivalent to production function regressions. One advantage of the TFP regressions is that firms from different industries are not constrained to have the same input elasticity parameters.

Table 2
Estimating the level effect of intraindustry spillovers

Variables	(1)	(2)	(3)	(4)
FDL_firm	0.00605*** (0.000530)	-0.00173*** (0.000384)	-0.00166** (0.000350)	-0.00386*** (0.000484)
FDL_sector	0.00517*** (0.000546)	-0.00174*** (0.000355)	-0.00199*** (0.000351)	-0.00191*** (0.000382)
FDL_firm * FDL_sector	-0.0000431*** (0.0000103)	0.0000670*** (0.00000779)	0.0000721*** (0.00000750)	0.000102*** (0.00000858)
Firm dummy	No	No	Yes	No
Industry dummy	No	Yes	No	No
Year dummy	Yes	Yes	Yes	No
Adj- R^2	0.02	0.91	0.91	0.005
Sample size	50,667	50,667	50,667	30,225

Figures in parentheses are standard errors corrected for heteroskedasticity. The dependent variable is $\ln tfp$ for columns (1) through (3). For column (4), the dependent variable is $\ln tfp_t - \ln tfp_{t-1}$ and independent variables are in first-difference form. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

tend to attract more foreign investment. In column 3, we introduce firm dummies, which account for time-invariant industry-, province- and firm-specific factors. The resulting estimates are very comparable to those reported in column 2. As an alternative way of controlling for firm-specific characteristics, we also estimate the productivity regression in first-difference form. The resulting estimates reported in column 4 further suggest a negative effect of spillovers on the productivity of domestic firms. Based on the estimates of Table 1, one would have concluded that FDI generates negative externalities hampering the productivity of domestic firms. As we demonstrate below, this is an erroneous inference.

5.2. Estimating the level and rate effects of intraindustry spillovers

If technology spillovers have a negative level effect and a positive rate effect on the productivity of firms in the industry, the productivity level regressions presented in Table 2 capture the combined level and rate effects of spillovers and, as a result, may yield either a negative or a positive spillover estimate. The estimated effect is likely to be negative if the sample period is too short to allow sufficient time for the positive rate effect to compensate the negative level effect of spillovers. It is therefore important to distinguish the level from rate effect of spillovers. We now implement the regression model given by Eq. (6) that allows us to estimate separately these two effects.

Column 1 of Table 3 presents the estimates based on the full sample. The estimated coefficients on FDL_sector and Time * FDL_sector are statistically significant at the 1% level and have opposite signs, indicating that the presence of foreign-invested firms has significant but different effects on the short-term level and the long-term rate of productivity growth of firms in the industry. The level effect, -0.00116, implies that the productivity level of average firms would fall by about 1.16% following an increase in FDI in the industry, say, from 0% to 10%. The rate effect, 0.000374, suggests that the rate of productivity growth of average firms would increase by about 0.374 percentage points in response to the same amount of change in FDI. According to these estimates, the increase in the rate of productivity growth will enable the affected firms to recover the initial loss in the productivity level in about 3 years, and thereafter the net effect of spillovers is positive and growing over time.

Table 3

Estimating the level and rate effects of intraindustry spillovers, dependent variable: *ltpf*

Variables	(1) Full sample	(2) Full sample	(3) Domestic sample	(4) Domestic sample
FDL_firm	0.000256 (0.000374)			
FDL_firm (lagged)		0.000359 (0.000425)		
FDL_sector	-0.00116*** (0.000408)		-0.00346*** (0.000573)	
FDL_sector (lagged)		-0.00140** (0.000607)		-0.00375 (0.000915)
Time * FDL_sector	0.000374*** (0.000107)		0.000292* (0.000159)	
Time * FDL_sector (lagged)		0.000324** (0.000158)		0.000356 (0.000257)
Time	0.0122*** (0.00185)	0.0139*** (0.00267)	0.0123*** (0.00196)	0.0139*** (0.00288)
HI	-0.0359 (0.0472)	-0.000589 (0.0608)	-0.120** (0.0531)	-0.0823 (0.0700)
Firm dummy	Yes	Yes	Yes	Yes
Obs.	50,667	30,225	39,140	23,555
Adj- R^2	0.91	0.93	0.91	0.93

Figures in parentheses are standard errors corrected for heteroskedasticity. Lagged indicates the independent variable is lagged by 1 year. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

The estimate for foreign equity share in foreign-invested firms is positive but statistically insignificant indicating that the productivity of foreign-invested firms is not necessarily higher than that of domestic firms.¹⁹ The positive and significant estimate for the time trend implies that our sample firms experienced positive productivity growth over the sample period. The estimate for HI, the Herfindahl index, is negative. This suggests an inverse relationship between firms' productivity and market concentration.²⁰

It is conceivable that a substantial period of time may pass between the change in foreign investment at either the firm or industry level and its final impacts on productivity. To allow for such a possibility, we use FDL_firm and FDL_sector lagged by 1 year in column 2. In this specification, all estimates are fairly comparable to their counterparts reported in column 1. The only noticeable change is that the estimated level and rate effects of spillovers are statistically significant at the 5% level, instead of the 1% level.

It should be noted that the estimated level and rate effects of spillovers reported in columns 1 and 2 are for average firms including both domestic and foreign-invested firms in the industry. While these results lend strong support to the predictions of our theoretical model, they do not necessarily imply that domestic firms benefit from the presence of FDI in their industries. In fact, if foreign-invested firms are the main beneficiaries of spillovers it is possible that FDI has no effect or even an overall negative effect on the productivity of domestic firms.

One way of isolating the effects of spillovers on the productivity of domestic firms is to expand the regression models to include two additional interaction terms, namely, FDL_firm * FDL_sector and Time * FDL_firm * FDL_sector. In this specification, FDL_sector and Time * FDL_sector

¹⁹ Liu and Plehn-Dujowich (2005) offer an explanation on why joint-venture firms may not have a productivity advantage over their domestic counterparts.

²⁰ We also used the Entropy index and obtained virtually the same results.

capture respectively the level and rate effects of spillovers on the productivity of domestic firms, whereas the newly introduced interaction terms capture whether these effects are intensified or diminished by the presence of foreign equity in joint-venture firms. Implementing this regression model, we obtain estimates of -0.00276 for FDL_sector and 0.000244 for $Time * FDL_sector$, which are statistically significant at the 1% and 10% level, respectively.²¹ Although these estimates are smaller in absolute terms than their counterparts in column 1, their signs are conforming to theoretical expectations. Together, they indicate that the presence of FDI benefits domestic firms in the long run.

Another way of estimating the effects of spillovers on the productivity of domestic firms is to perform the regression analyses using the subsample of domestic firms. As foreign equity participation is zero in domestic firms, interaction terms involving FDL_firm are eliminated as explanatory variables. Columns 3 and 4 present the regression results. In column 3, the estimates for FDL_sector and $Time * FDL_sector$ have opposite signs (again, consistent with the theoretical expectations) and are statistically significant at the 1% and 10% level, respectively. They imply that the increase in the rate of productivity growth due to an increase in FDI in the industry will allow domestic firms to recover the initial loss in the productivity level in about 11 years. This result is further corroborated by the estimates reported in column 4, where lagged FDL_sector and $Time * FDL_sector$ are used. It is worth noting that in this specification, the estimated rate effect of spillovers is quantitatively comparable to those obtained based on the full sample, albeit not statistically significant at conventional levels of significance.²²

5.3. Estimating the level and rate effects of intraindustry and interindustry spillovers

Our empirical analyses so far restrict spillovers to take place horizontally within an industry at the four-digit level. However, spillovers may occur vertically across industries through either backward linkages where domestic firms supply intermediate inputs to foreign-invested firms or forward linkages where domestic firms purchase intermediate inputs from foreign-invested firms. In this section we extend the regression models presented in Table 3 to allow for vertical spillovers as well.

The first two columns of Table 4 present the results based on the full sample. In column 1 the spillover proxies are contemporaneous, whereas in column 2 they are lagged by 1 year. Qualitatively, these estimates are consistent with our theoretical predictions. The estimated level effects of all three forms of spillovers are negative, and their estimated rate effects are all positive. This indicates that while spillovers can occur through multiple channels, their effects are similar—a negative effect on the short-term level and a positive effect on the long-term rate of productivity growth. Also, the estimates associated with intraindustry or horizontal spillovers are somewhat smaller in absolute terms than their counterparts reported in Table 3, presumably because the latter pick up partly the effects of vertical spillovers which we include here but not in the previous regressions. However, in terms of statistical significance, the estimated rate effects are not uniform. In column 1 where the spillover proxies are introduced into the regression in contemporaneous form, the estimated rate effects of horizontal and backward spillovers are significant at the 5% and 1% levels, respectively, whereas the estimated rate effect of forward spillovers is not significant. By contrast, in column 2 where lagged spillover proxies are used, only the estimated rate effect of forward spillovers is significant at the 10% level.

²¹ We also run this regression using the spillover proxy lagged by 1 year and obtained quantitatively similar results. However, the estimate for $Time * FDL_sector$ becomes statistically insignificant.

²² The estimate is statistically significant at the 15% level.

Table 4

Estimating the level and rate effects of intraindustry and interindustry spillovers, dependent variable: Itfp

Variables	(1) Full sample	(2) Full sample	(3) Domestic sample	(4) Domestic sample	(5) Domestic sample	(6) Domestic sample
FDL_firm	0.000312 (0.000375)					
FDL_firm (lagged)		0.000412 (0.000438)				
FDL_sector	-0.000990** (0.000416)		-0.00338*** (0.000580)			
FDL_sector (lagged)		-0.00102 (0.000643)		-0.0000404 (0.000927)		
Time * FDL_sector	0.000231** (0.000118)		0.000212 (0.000169)			
Time * FDL_sector (lagged)		0.000196 (0.000179)		0.0000613 (0.000266)		
FDL_downstream_sector	-0.00269** (0.00128)		-0.000963 (0.00146)		-0.000468 (0.00146)	
FDL_downstream_sector (lagged)		-0.0101** (0.00462)		-0.00833*** (0.00197)		-0.00824*** (0.00198)
Time * FDL_downstream_sector	0.000696*** (0.000272)		0.000421** (0.000209)		0.000632** (0.000316)	
Time * FDL_downstream_sector (lagged)		0.00107 (0.000821)		0.000989** (0.000445)		0.000953** (0.000451)
FDL_upstream_sector	-0.000480 (0.00145)		0.00160 (0.00157)		0.000908 (0.00158)	
FDL_upstream_sector (lagged)		-0.00581 (0.00379)		-0.00446** (0.00232)		-0.00434* (0.00234)
Time * FDL_upstream_sector	0.000324 (0.000346)		0.000156 (0.000389)		0.000243 (0.000404)	
Time * FDL_upstream_sector (lagged)		0.00131* (0.000819)		0.000761 (0.000600)		0.000697 (0.000625)
Time	0.00857*** (0.00227)	0.00827* (0.00467)	0.0104*** (0.00247)	0.0104*** (0.00360)	0.0116*** (0.00247)	0.0102*** (0.00361)
HI	-0.0344 (0.0473)	-0.00655 (0.257)	-0.118** (0.0532)	-0.0840 (0.0702)	-0.112** (0.0531)	-0.0844 (0.0703)
FDL_sector2					-0.000979 (0.000536)	
FDL_sector2 (lagged)						-0.000144 (0.000872)
Time * FDL_sector2					-0.000383 (0.000365)	
Time * FDL_sector2 (lagged)						0.0000255 (0.000256)
Firm dummy	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	50,667	30,225	39,140	23,555	39,140	23,555
Adj- R^2	0.914	0.932	0.914	0.932	0.914	0.93

Figures in parentheses are standard errors corrected for heteroskedasticity. Lagged indicates the independent variable is lagged by 1 year. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

In columns 3 and 4, we report the estimates based on the subsample of domestic firms. While these estimates are broadly in line with those based on the full sample, there are two important differences. First, the estimated rate effect of backward spillovers is statistically significant at the 5% level and is insensitive to whether contemporaneous or lagged spillover proxies are

introduced into the regression model. At the range of point estimates the positive rate effects associated with backward spillovers overtake the negative level effects between 2.5 and 8 years. By contrast, none of the estimated rate effects of horizontal and forward spillovers is statistically significant. This suggests that the backward linkage is statistically the most important channel through which technology spills over from FDI to domestic firms. This result is consistent with Javorcik (2004), who finds a positive and statistically significant relationship between the productivity level of domestic firms and FDI in downstream industries in Lithuania. However, we differ from Javorcik in one critical aspect: we find that an increase in FDI in a downstream industry results in a decrease in the productivity level but an increase in the rate of productivity growth of domestic firms in upstream industries. Second, the estimated rate effect of horizontal spillovers is sensitive to whether the current or lagged spillover proxy is used—the estimated coefficient on $\text{Time} * \text{FDL_sector}$ in column 3 is three times as large as that in column 4, though neither is statistically significant at the conventional level.

Note that, in columns 3 and 4 while the proxy for horizontal spillovers is defined at the four-digit industry level, the proxies for vertical spillovers are defined at the two-digit level. This raises the question that to what extent the apparent robustness of the estimated rate effect of backward spillovers and the insignificant rate effect of horizontal spillovers are the result of including in the same regression the spillover proxies defined at different levels of industry aggregation.²³ One way of looking into this question is to substitute FDL_sector with its counterpart defined at the two-digit industry level, i.e., FDL_sector2 . Columns 5 and 6 present results from such regressions. In both specifications, the estimated rate effect of backward spillovers remains positive and statistically significant at the 5% level. But these regressions are incapable of offering a definitive assessment of the rate effect of horizontal spillovers across four-digit industries.²⁴

5.4. Simultaneity issues

So far we have assumed that all our FDI variables are exogenous. However, it is arguable that the direction of causality may go from productivity or its growth rate to foreign equity share in the firm. Suppose, for example, if foreign investors select only the more productive domestic firms with whom to form joint ventures (i.e., FDL_firm is endogenously determined), our estimates will suffer from simultaneity bias. Recall, however, the regression analyses based on the subsample of domestic firms (columns 3 and 4 of Table 3 and columns 3–6 of Table 4), in which foreign equity participation is zero, yield generally a negative level effect and a positive rate effect of spillovers associated with FDI on the productivity of domestic firms. Simultaneity bias, even if foreign investments at the firm level are truly endogenous, does not seem to have any significant bearing on our main findings.

At a more aggregate level, FDI may be endogenous if some industries are more attractive than others to foreign investors. Factors such as the growth potential of the industry or domestic demand and the overall competitiveness of domestic firms in the global market are likely to

²³ Obviously, this question can also be raised in the context of the regressions based on the full sample. We address this issue using the domestic sample because we are more interested in spillovers that affect the productivity of domestic firms.

²⁴ A better alternative is to use spillover proxies that are all defined at the four-digit industry level. However, as mentioned earlier, the input–output matrix required for constructing backward and forward spillover proxies is not available for four-digit industries. Nevertheless, based on the estimates reported in Tables 3 and 4 it seems fair to conclude that there is suggestive evidence for horizontal spillovers from foreign-invested to domestic firms within industries at the four-digit level.

influence foreign investors' entry decision. However, from the standpoint of an individual domestic firm, foreign entries are largely exogenous in that the performance or characteristics of the individual domestic firm have a very minimum, if any, impact on the amount of FDI received by its own industry or by its upstream and downstream industries. If FDI at the industry level and the productivity of domestic firms are statistically correlated, the causal relation is more likely to go from FDI to the productivity of domestic firms than the other way around. Furthermore, in all our regressions we have included firm dummies which control effectively for industry-specific characteristics.

One method that can be used to deal with the potential simultaneity bias is to use the lagged values of the variables in question. Under the assumption that the lagged variables are uncorrelated with the error term in the regression model, using lagged values of the endogenous variables can mitigate simultaneity bias.²⁵ Recall from [Tables 3 and 4](#), the estimated level and rate effects of spillovers are fairly robust, at least quantitatively, with respect to whether contemporaneous or lagged values of spillover proxies are used as explanatory variables.

6. Conclusion

It is now generally recognized that FDI brings multiple benefits to its recipient country. But many of them are short-term gains. For example, FDI is alleged to promote economic growth of its recipient country by filling the savings gap. According to the neoclassical growth theory, however, economic growth based on capital accumulation is not sustainable because of diminishing marginal returns to capital. Therefore, for FDI to promote long-term economic growth, it must lead the recipient country to adopt policies that are conducive to economic growth (such as encouraging human capital investments) or policies that facilitate technology transfer. In this paper, we focus on the latter by addressing the question whether FDI generates spillovers that benefit domestic firms in the host country.

Within the endogenous growth framework, we offer an explanation on how technology spillovers take place at the firm level. Our theoretical analysis suggests that spillovers associated with FDI could cause a decrease in the short-term productivity level but an increase in the long-term rate of productivity growth of domestic firms. The negative level effect of spillovers underscores the fact that technology transfer (even through externalities) does not occur automatically and is a costly learning process. The positive rate effect of spillovers is in accordance with the central thesis of the endogenous growth literature that identifies human capital or knowledge as the ultimate engine of economic growth. Serving as a source of knowledge, FDI promotes sustainable productivity growth among domestic firms.

The empirical evidence gleaned from a large panel of Chinese manufacturing firms is by and large consistent with the theoretical predictions. The estimates show that an increase in FDI in the industry at the four-digit level lowers the short-term productivity level but raises the long-term rate of productivity growth of domestic firms. Since the level effect results in a loss in the productivity level and the rate effect leads to a gain in productivity applicable to all future periods, the latter dominates the former in the long run and domestic firms benefit from the presence of FDI in their industries (i.e., intraindustry spillovers). When we do not distinguish between the level and rate effects of spillovers, the estimated effect of spillovers, which is a mixture of the level and rate effects, is often negative. These results may explain at least partly why previous studies that focus on the relation between productivity levels and FDI have yielded conflicting

²⁵ Incidentally, the serial correlations in the residuals from these specifications are generally weak.

results. They also highlight the importance of separating the level from rate effect of spillovers in empirical investigations, especially when the sample used covers a relatively short time span—a fact applies virtually to all studies.

We also expand our model to allow for interindustry or vertical spillovers that take place through backward or forward linkages between foreign and domestic firms in different industries. The empirical results, based on our spillover proxies that reflect the extent of linkages between industries at the two-digit level, are generally consistent with our theoretical expectations. While there is some evidence for positive rate effects associated with all three forms of spillovers, the estimates associated with intraindustry spillovers in particular are not always statistically significant at conventional levels of significance. Among the three spillover channels, we find that backward linkages are statistically the most important channel through which technology spills over from foreign-invested to domestic firms.

Although our model features technology spillovers as a costly process which is supported by our empirical findings, learning costs may vary across domestic firms depending on firms' managerial and technical capacities as well as their ability to finance the adoption of advanced technology. There is also the question whether some domestic firms have a structure of incentives that leads their managers to focus on the long-term, rather than short-term, profitability of their firms. The incentive structure may differ across firms of different ownership types. While the existing literature has recognized the importance of human capital in facilitating technology transfer, the financial capability and incentive structure of domestic firms may be equally important. We will address these issues in future studies.

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