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Foreign Direct Investment, R&D and Spillover Efficiency: Evidence from Taiwan's Manufacturing Firms

YIH-CHYI CHUANG and CHI-MEI LIN

Using Taiwanese firm-level data, we confirm that foreign direct investment and R&D have a positive impact, or spillover effect, on productivity. Furthermore, labour quality, firm size, market structure, and export orientation all affect a firm's productivity. Applying Heckman's [1976] two-stage estimation method, we find that firms self-select into R&D or non-R&D groups. After correcting for this selection bias, we find that foreign direct investment, local technology purchase, and outward foreign investment are substitutes to R&D activity. These results are mainly due to the significant effect of industry-wide technology spillovers. The major policy implications derived from this study are that governments in developing countries may first wish to adopt policies encouraging foreign direct investment to foster technology transfer and industry-wide knowledge spillovers in the short run. However, once the country's technological capability is established it appears critical to switch towards policies that provide a preferred environment to stimulate R&D investment (for example, infrastructure improvement and protection of intellectual property rights) to allow for sustainable economic growth.

I. INTRODUCTION

Many endogenous growth models have emphasised technology transfer from the North to the South as a vehicle for productivity growth of the South [e.g., *Segerstrom, 1991; Grossman and Helpman, 1991].* Among numerous channels of technology transfer, foreign direct investment (FDI) has been identified as the major contributor to the host economy's

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productivity growth[1] with one of the most significant beneficial effects of foreign investment being related to technology spillover across domestic firms and sectors.[2] Empirical studies from both developed and underdeveloped economies seem to support the positive spillover hypothesis.[3]

Recent theoretical models of endogenous growth have emphasised the allocation of resources to the R&D sector as critical in sustaining long-run economic growth through economy-wide knowledge spillovers [e.g., *Romer, 1990; Grossman and Helpman, 1991].* This R&D spillover effect reduces the marginal cost of additional innovation and encourages further innovations. Individual country studies also confirm the existence of R&D spillovers.[4]

Foreign direct investment and R&D are both important ways to increase firm's productivity; what is the likely relationship between them? Hughes [*1986*] and Kumar [*1987*] point out that subsidiaries of multinational enterprises (MNEs) can more easily acquire technological assistance from their parent company in the home country and thus reduce their incentive to undertake R&D. This suggests that foreign investment and R&D are substitutes. However, Lall [*1983*] stresses that new technologies brought in by foreign presence may stimulate local firms' investment in R&D, as these technologies generally require adaptation to meet local production conditions. Many studies have found that effective assimilation of modern technology acquired in the international market involves substantial resource costs [e.g., *Teece, 1977 and Ozawa, 1966*]. Thus, empirical evidence has not provided a clear answer.[6]

The purpose of this article is to address these issues in the form of three related questions, using Taiwan's manufacturing census data. First, does foreign direct investment increase firms' productivity? Second, does R&D activity increase investing firms' productivity, and are there spillovers to other firms in the industry? Third, what is the relationship between FDI and R&D activities?

Our findings confirm that both FDI and R&D spillover effects occur. We also confirm that labour quality, firm size, market structure and export orientation all affect firms' productivity. Applying Heckman's [*1976*] two-stage estimation method, we find that firms tend to self-select into R&D or non-R&D groupings. After correcting for this selection bias, we find that FDI, technology purchase, and outward foreign investment are substitutes to R&D activity.

The remainder of the article is organised as follows. Section II presents the empirical models used. Section III contains the data description and analysis. Section IV presents the regression results. Concluding remarks follow in section V.

II. THE EMPIRICAL MODEL AND ESTIMATION METHODS

Following Caves [*1974*], Globerman [*1979*], Blomstrom and Persson [*1983*], and Haddad and Harrison's [*1993*] formulation for incorporating additional variables such as labour quality, market structure, and export performance, our estimation equation for the impact of foreign investment on productivity is written as follows:[7]

$$TFP_{ij} = f\left(FDI\_Sec_j, LQ_{ij}, SCALE_{ij}, EX_{ij}, CR_j, OPEN_j\right), \quad (1)$$

while the estimation equation for the impact of R&D on productivity is

$$TFP_{ij} = g\left(R\&D\_Firm_{ij}, R\&D\_Sec_j, LQ_{ij}, SCALE_{ij}, EX_{ij}, CR_j, OPEN_j\right). \quad (2)$$

Indices i and j denote firm i and industry j, respectively, TFP denotes total factor productivity, FDI_Sec is the share of foreign assets at the industry level, LQ is a measure of labour quality, SCALE stands for scale economies, EX is the firm's share of exports in total output, CR is the industry's concentration ratio, OPEN represents market openness of the industry, and R&D_Firm and R&D_Sec denote the share of R&D expenditure to total sales at the firm and industry levels, respectively.[8]

As firms may self-select into R&D or non-R&D firms according to market structure and firm-level characteristics, we apply Heckman's [*1976*] two-stage estimation method to test the relationship between FDI and R&D. Thus, the first stage probit equation is defined as

$$DUM\_R\&D_{ij} = h(FDI\_Sec_j, DUM\_FOR_{ij}, DUM\_TP_{ij}, OFI_{ij}, KL_{ij}, AGE_{ij}), \quad (3)$$

where DUM_R&D is a dummy variable for doing R&D (1 for R&D firms and 0 for non-R&D firms), DUM_FOR is a dummy variable for the firm's ownership (1 for foreign-owned firms and 0 for domestically-owned firms), DUM_TP is a dummy variable for technology purchase or co-operation (1 for firms currently purchasing any amount of foreign technology, 0 for no technology purchase), OFI represents outward foreign investment, KL is the capital-labour ratio, and AGE denotes the age of the firm since establishment. The second stage OLS regression for R&D firms is then written as follows:

$$R\&D\_Firm_{ij} = k(FDI\_Sec_j, DUM\_for_{ij}, DUM\_TP_{ij}, OFI_{ij}, KL_{ij}, AGE_{ij}, IMR_{ij}), \quad (4)$$

where the inverse Mills ratio (denoted as IMR) obtained from equation (3) is now included to correct for possible selection bias.[9] Moreover, the

estimated coefficient for IMR will enable us to infer the nature of the self-selection.

Equations (1)–(4) are our empirical models for regression analysis. Estimation is based upon Ordinary Least Squares (OLS) method. Where the problem of heteroskedasticity is present, we apply White's [*1980*] correction for the estimated standard deviations in hypothesis testing.

III. DATA DESCRIPTION AND ANALYSIS

The empirical data for this study are taken from the random sampling data file of The Report on 1991 Industrial and Commercial Census for Taiwan-Fukien Area published by the Directorate-General of Budget, Accounting and Statistics, Executive Yuan, Republic of China. The random sampling data consists of 13,330 manufacturing establishments, about nine per cent of all officially registered firms.[11] However, due to limited data for some of variables used in this study, our final sample consists of a total of 8,846 establishments. Following Blomstrom and Persson [*1983*], we define those establishments of which at least a 15 per cent share is foreign-owned as foreign-owned. Output is measured by gross product, labour by total number of workers employed, and capital input includes building, machinery and equipment, and works in process. Labour quality is another important factor capturing the human capital investment of the workers employed. Three proxies are utilised: the employment share of white-collar workers, the ratio of skilled to unskilled labour, and the relative wage of white to blue-collar workers.[12] The concentration ratio of an industry is measured by the market share of the four largest firms or by the Herfindahl index at the three-digit industry level. Finally, market openness is measured by the share of exports to total output for a three-digit industry.

With reference to the dependent variable in equations (1) and (2), we calculate two measures for a firm's total factor productivity, TFP1 and TFP2. TFP1 is derived from traditional growth accounting under a constant returns to scale assumption, while TFP2 allows for the existence of variable returns to scale.[13] The simple correlation coefficient between TFP1 and TFP2 is 0.67. Further explanation of all the variables used in the empirical regressions appears in Appendix A. The correlation coefficients between independent variables, which are not shown here, show little problem of multicollinearity.

Table 1 shows that indices of labour productivity, technical efficiency, capital intensity, scale of production, the share of white-collar workers, export share, and R&D intensity, are in general greater for foreign-owned than for domestically-owned firms. However, domestically-owned firms on average have higher value-added ratios and higher ratios of skilled to

unskilled labour. The standard deviations of the two productivity indices are smaller for foreign-owned firms than that for domestically-owned firms. This implies that compared to domestically-owned firms, foreign-owned firms not only have higher productivity levels but also possess similar (less dispersed) technologies. The average wage gap between white and blue-collar workers is 37 per cent higher in foreign-owned firms than in domestically-owned ones. As Taiwan's labour market is considered close to a competitive market for unskilled labour, the high wage gap implies that foreign-owned firms are actually paying a higher wage premium for white collar workers.

If we further distinguish foreign ownership by complete and partial foreign ownership, the shares of the two ownership forms are 52 per cent and 48 per cent, respectively. Table 2 shows that the difference in productivity between the two types of ownership is insignificant. However, completely foreign-owned firms have larger production scale, higher export-orientation, and less capital and R&D intensity. In the latter case, the share of total sales devoted to R&D is roughly twice as large in partially foreign-owned. For those firms that have exports, performance comparisons are similar to those in Table 1 except that the gap in productivity between foreign-owned and domestically-owned firms is insignificant.

If we concentrate on domestically-owned firms, Table 3 shows that more export-oriented firms are more productive and incur higher R&D intensity but less capital intensity than domestic market-oriented ones. This result implies that in Taiwan large enterprises tend to concentrate on the domestic market, while small and medium enterprises (SMEs) focus on the export market. However, SMEs are more productive and engage in more R&D than large ones do.[14] Regardless of ownership type, Table 3 shows that firms engaged in R&D tend to be correlated with higher productivity, white-collar wages, and are more capital-intensive and export-oriented across firms.

IV. THE ESTIMATION RESULTS

In this section we present and discuss the regression results of the models set out in section II. The preceding data analysis discussion suggested that the characteristics of domestically- and foreign-owned firms are distinct. Thus, in testing the impact of FDI and R&D spillovers on productivity, we first further divide our sample by ownership type, and then run regressions on each of the subsamples.

The Effect of FDI on Productivity

Tables 4 and 5 show regression results for domestically-owned and foreign-owned firms, respectively.

TABLE 1
SUMMARY STATISTICS

	Domestically-owned Obs. = 8502		Foreign-owned Obs. = 344		All Firms Obs. = 8846	
	Means	Std. Dev.	Means	Std. Dev.	Means	Std. Dev.
Labour productivity (NT$1,000/person)	407.52	(340.37)	596.84	(444.38)	414.89	(346.91)
Total factor productivity TFP1*	7.66	(1.35)	7.97	(1.14)	7.67	(1.34)
Total factor productivity TFP2*	9.40	(0.86)	9.67	(0.69)	9.41	(0.85)
Capital labour ratio (NT$1,000/person)	546.67	(929.18)	794.99	(1579.30)	556.33	(963.75)
Rate of value added (%)	33.71	(19.45)	33.37	(15.25)	33.70	(19.30)
Scale of Production*	0.187	(0.46)	0.745	(1.51)	0.208	(0.55)
Employment share of white-collar workers*	0.266	(0.15)	0.299	(0.15)	0.267	(0.15)
Ratio of skilled to unskilled labour*	0.293	(0.38)	0.165	(0.28)	0.288	(0.38)
Relative wage of white- to blue-collar workers*	1.37	(0.96)	1.88	(0.82)	1.39	(0.96)
Share of exports	0.217	(0.37)	0.586	(0.42)	0.231	(0.38)
Share of R&D expenditure to total sales	0.00154	(0.01)	0.00762	(0.03)	0.0018	(0.01)

Note: * See Appendix A for the relevant definitions.

TABLE 2
CHARACTERISTICS OF FIRMS BY TYPES OF OWNERSHIP

	Foreign-owned				Domestically-owned					
	Partial Ownership Obs. = 178		Complete Ownership Obs. = 166		Domestically Oriented Obs. = 5577		Partially-Exported Obs. = 2055		Fully-Exported Obs. = 870	
	Means	Std. Dev.	Means	Std. Dev.	Means	Std. Dev.	Means	Std. Dev.	Means	Std. Dev.
Labour productivity (NTS1,000/person)	655.55	(508.10)	533.89	(354.78)	384.14	(330.10)	473.67	(843.64)	400.97	(265.30)
Total factor productivity TFP1*	7.98	(1.09)	7.96	(1.19)	7.55	(1.35)	7.76	(1.32)	8.13	(1.27)
Total factor productivity TFP2*	9.70	(0.70)	9.64	(0.69)	9.35	(0.88)	9.44	(0.79)	9.62	(0.80)
Capital labour ratio (NT$1,000/person)	939.96	(2064.00)	639.55	(750.00)	531.58	(949.10)	635.64	(949.50)	433.28	(707.50)
Rate of value added (%)	33.09	(14.34)	33.69	(16.20)	35.82	(21.36)	29.48	(14.03)	30.17	(15.03)
Scale of Production*	0.58	(1.10)	0.92	(1.84)	0.11	(0.31)	0.34	(0.64)	0.31	(0.58)
Employment share of white-collar workers*	0.32	(0.15)	0.28	(0.15)	0.26	(0.16)	0.29	(0.14)	0.25	(0.13)
Ratio of skilled to unskilled labour*	0.20	(0.32)	0.12	(0.23)	0.33	(0.41)	0.23	(0.32)	0.18	(0.31)
Relative wage of white- to blue-collar workers*	1.90	(0.88)	1.85	(0.75)	1.28	(1.00)	1.55	(0.84)	1.54	(0.85)
Share of exports	0.52	(0.42)	0.66	(0.41)	0	–	0.47	(0.32)	1.0	–
Share of R&D expenditure to total sales	0.010	(0.035)	0.005	(0.013)	0.001	(0.010)	0.003	(0.017)	0.003	(0.023)

Note: * See note in Table 1.

TABLE 3
CHARACTERISTICS OF R&D AND NON-R&D FIRMS

	R&D Firms				Non-R&D Firms			
	Foreign-owned Obs. = 116		Domestically-owned Obs. = 563		Foreign-owned Obs. = 228		Domestically-owned Obs. = 7939	
	Means	Std. Dev.	Means	Std. Dev.	Means	Std. Dev.	Means	Std. Dev.
Labour productivity (NT$1,000/person)	783.32	(604.52)	584.91	(420.63)	501.97	(295.40)	394.95	(330.38)
Total factor productivity TFP1*	7.92	(1.03)	7.75	(1.33)	8.00	(1.19)	7.65	(1.35)
Total factor productivity TFP2*	9.80	(0.59)	9.50	(0.78)	9.60	(0.73)	9.40	(0.86)
Capital labour ratio (NT$1,000/person)	1073.15	(2489.82)	832.29	(1003.01)	653.47	(754.09)	526.42	(920.42)
Ratio of value added (%)	31.30	(14.36)	31.92	(15.54)	34.43	(15.60)	33.80	(19.69)
Scale of Production*	1.15	(2.17)	0.51	(0.85)	0.54	(0.97)	0.16	(0.41)
Employment share of white-collar workers*	0.34	(0.15)	0.35	(0.16)	0.28	(0.15)	0.26	(0.15)
Ratio of skilled to unskilled labour*	0.15	(0.25)	0.25	(0.31)	0.17	(0.30)	0.30	(0.39)
Relative wage of white- to blue-collar workers*	1.96	(0.67)	1.59	(0.89)	1.84	(0.88)	1.36	(0.97)
Share of exports	0.65	(0.38)	0.44	(0.41)	0.55	(0.43)	0.20	(0.36)
Capital share of foreign-ownership	0.80	(0.26)	0	–	0.76	(0.28)	0	–
Share of R&D expenditure to total sales	0.023	(0.042)	0.023	(0.048)	0	–	0	–

Note: *See note in Table 1.

(a) FDI spillover effect: For domestically-owned firms, looking at the results in Table 4, we find that the estimated coefficients of the spillover variable, FDI_Sec, are positive and significant regardless of which definition of productivity is used. A one per cent increase of the foreign investment ratio in the industry increases domestic firms' productivity by 1.40 per cent to 1.88 per cent. This result is consistent with the findings of Caves [*1974*], Globerman [*1979*], and Blomstrom and Persson [*1983*] that FDI spillovers exist and lead to increases in firms' labour productivity. As for foreign-owned firms (see Table 5), the FDI spillover effect appears significant and positive for TFP2 but negative for TFP1 and coefficient magnitudes are smaller than in the regressions for domestically-owned firms. These results imply that a FDI spillover effect does exist for domestically-owned firms, but its effect on foreign-owned firms is considerably smaller. The reason may be that in foreign-owned firms most of their technologies are directly adopted from their parent companies in the home country and thus are less sensitive to local spillovers. By contrast, domestically-owned firms, whose technology levels are both more scattered and relatively backward on average, have more room for and are more sensitive to learning and adapting technology spillovers.

(b) Scale of production: In both of the sub-sample groups, the production scale of a firm has a positive and significant effect on its productivity. This implies that in both categories most firms are smaller than the size of the most efficient firm in the industry and can take advantage of scale economies.

(c) Share of exports: For domestically-owned firms, the effect of exports on a firm's productivity is positive and significant for TFP1, but insignificant for TFP2. As for foreign-owned firms, the effect of exports is always insignificant. As argued before, foreign firms rely heavily on their parent companies abroad for technology. However, for domestically-owned firms, trade-induced learning by doing appears to be an important channel to upgrade domestic production, management, and marketing technologies.[15]

(d) Labour quality: For domestically-owned firms, the effect of the share of white-collar workers (LQ1) is ambiguous: it appears negative for TFP1 and positive for TFP2. Intuitively, a higher share of white-collar workers may imply higher quality of labour employed and hence may improve management and operation efficiency. However, an excess number of white-collar workers may also imply excessive bureaucratisation and red tape, reducing production efficiency. In contrast to these ambiguous results, the effect of the skilled relative to unskilled labour ratio (LQ2) has a

TABLE 4
REGRESSION RESULTS OF FDI SPILLOVER EFFECT
FOR DOMESTICALLY-OWNED FIRMS

	Dep. Var. = TFP1				Dep. Var. = TFP2			
	(1)	(2)	(3)	(4)	(1′)	(2′)	(3′)	(4′)
Constant	7.04**	7.38**	7.18**	7.40**	8.98**	9.23**	9.19**	9.41**
	(0.037)	(0.041)	(0.037)	(0.041)	(0.026)	(0.029)	(0.026)	(0.031)
FDI_Sec	1.48**	1.85**	1.76**	1.80**	1.40**	1.72**	1.69**	1.77**
	(0.089)	(0.099)	(0.099)	(0.099)	(0.063)	(0.062)	(0.061)	(0.061)
SCALE	0.46**	0.40**	0.40**	0.40**	0.33**	0.28**	0.29**	0.29**
	(0.048)	(0.045)	(0.045)	(0.045)	(0.033)	(0.031)	(0.031)	(0.032)
LQ1	-0.29**	-0.31**			0.09	0.076		
	(0.093)	(0.092)			(0.061)	(0.060)		
LQ2			0.30**				0.26**	
			(0.036)				(0.022)	
LQ3				-0.087**				-0.096**
				(0.020)				(0.018)
CR4		-1.94**	-1.86**	-1.92**		-1.95**	-1.89**	-1.94**
		(0.150)	(0.150)	(0.150)		(0.096)	(0.095)	(0.095)
HI	-2.95**				-7.7**			
	(0.760)				(1.540)			
EX	0.17**	0.18**	0.21**	0.20**	-0.01	-0.0055	0.024	0.016
	(0.041)	(0.041)	(0.041)	(0.041)	(0.027)	(0.027)	(0.027)	(0.027)
OPEN	0.95**	0.71**	0.78**	0.74**	0.45**	0.24**	0.28**	0.25**
	(0.041)	(0.045)	(0.045)	(0.045)	(0.028)	(0.028)	(0.028)	(0.028)
Adj R-sq	0.1093	0.1282	0.1338	0.1307	0.1262	0.1595	0.1724	0.1707
N	8502	8502	8502	8502	8502	8502	8502	8502

Notes: Numbers in the parentheses are White's heteroscedastic-consistent standard deviations.
** indicates statistical significance at the 5% level.

TABLE 5
REGRESSION RESULTS OF FDI SPILLOVER EFFECT
FOR FOREIGN-OWNED FIRMS

	Dep. Var. = TFP1				Dep. Var. = TFP2			
	(1)	(2)	(3)	(4)	(1′)	(2′)	(3′)	(4′)
Constant	7.51**	7.48**	7.50**	7.65**	9.21**	9.26**	9.50**	9.64**
	(0.280)	(0.300)	(0.260)	(0.260)	(0.160)	(0.170)	(0.150)	(0.180)
FDI_Sec	-0.79**	-0.81**	-0.78**	-0.74**	0.91**	0.95**	1.04**	1.09**
	(0.330)	(0.390)	(0.390)	(0.390)	(0.220)	(0.230)	(0.230)	(0.240)
SCALE	0.17**	0.17**	0.17**	0.17**	0.069**	0.069**	0.071**	0.70**
	(0.036)	(0.037)	(0.037)	(0.037)	(0.019)	(0.018)	(0.019)	(0.018)
LQ1	0.22	0.23			0.74**	0.74**		
	(0.440)	(0.450)			(0.250)	(0.250)		
LQ2			0.17				0.081	
			(0.240)				(0.160)	
LQ3				-0.05				-0.063
				(0.060)				(0.060)
CR4		0.53	0.58	0.51		-0.40	-0.35	-0.41
		(0.690)	(0.690)	(0.690)		(0.390)	(0.390)	(0.390)
HI	9.01*				-4.95			
	(4.990)				(3.340)			
EX	0.22	0.25	0.25	0.25	0.009	-0.008	-0.051	-0.042
	(0.170)	(0.170)	(0.170)	(0.170)	(0.110)	(0.110)	(0.110)	(0.110)
OPEN	0.86**	0.88**	0.89**	0.87**	0.37**	0.34**	0.30**	0.30**
	(0.180)	(0.190)	(0.190)	(0.190)	(0.120)	(0.120)	(0.120)	(0.120)
Adj R-sq	0.1181	0.112	0.1128	0.1124	0.1122	0.1088	0.0871	0.0914
N	344	344	344	344	344	344	344	344

Notes: Numbers in the parentheses are White's heteroscedastic-consistent standard deviations.
*, ** indicate statistical signfiicance at 10% and 5% levels, respectively.

TABLE 6
REGRESSION RESULTS OF R&D SPILLOVER EFFECT FOR NON-R&D FIRMS

	Dep. Var. = TFP1				Dep. Var. = TFP2			
	(1)	(2)	(3)	(4)	(1′)	(2′)	(3′)	(4′)
Constant	7.18**	7.46**	7.27**	7.48**	9.07**	9.34**	9.25**	9.47**
	(0.037)	(0.042)	(0.038)	(0.041)	(0.027)	(0.031)	(0.028)	(0.032)
R&D_Sec	19.1**	25.82**	25.59**	26.11**	31.25**	37.03**	37.01**	38.77**
	(2.890)	(3.060)	(3.050)	(3.070)	(1.900)	(1.840)	(1.830)	(1.850)
SCALE	0.46**	0.40**	0.40**	0.40**	0.34**	0.29**	0.30**	0.30**
	(0.053)	(0.049)	(0.049)	(0.050)	(0.039)	(0.36)	(0.036)	(0.37)
LQ1	-0.24**	-0.25**			0.096*	0.084		
	(0.097)	(0.096)			(0.064)	(0.063)		
LQ2			0.31**				0.28**	
			(0.038)				(0.023)	
LQ3				-0.076**				-0.093**
				(0.020)				(0.018)
CR4		-1.55**	-1.48**	-1.53**		-1.68**	-1.63**	-1.67**
		(0.150)	(0.150)	(0.150)		(0.100)	(0.100)	(0.100)
HI	-2.22**				-7.20**			
	(0.690)				(1.420)			
EX	0.21**	0.23**	0.26**	0.25**	0.0088	0.014	0.045	0.037
	(0.042)	(0.041)	(0.042)	(0.042)	(0.028)	(0.028)	(0.028)	(0.027)
OPEN	0.93**	0.74**	0.80**	0.76**	0.41**	0.24**	0.28**	0.25**
	(0.042)	(0.046)	(0.046)	(0.046)	(0.030)	(0.030)	(0.030)	(0.030)
Adj R-sq	0.0893	0.1017	0.1086	0.1038	0.0989	0.1222	0.1372	0.1326
N	8167	8167	8167	8167	8167	8167	8167	8167

Note: See notes in Table 5.

TABLE 7
REGRESSION RESULTS OF R&D SPILLOVER EFFECT FOR R&D FIRMS

	Dep. Var. = TFP1				Dep. Var. = TFP2			
	(1)	(2)	(3)	(4)	(1′)	(2′)	(3′)	(4′)
Constant	6.58**	6.54**	6.66**	7.02**	8.73**	8.68**	8.83**	9.13**
	(0.170)	(0.200)	(0.180)	(0.190)	(0.096)	(0.120)	(0.110)	(0.120)
R&D_Sec	-14.50*	-13.71	-6.02	-4.54	33.79**	32.81**	39.42**	41.67**
	(8.420)	(8.600)	(8.560)	(8.770)	(5.080)	(5.050)	(5.020)	(5.100)
R&D_Firm	-0.89	-1.00	-1.17	-0.46	-0.93	-0.89	-0.91	-0.39
	(0.950)	(0.950)	(0.960)	(0.930)	(0.620)	(0.620)	(0.620)	(0.600)
SCALE	0.23**	0.23**	0.23**	0.23**	0.11**	0.12**	0.12**	0.12**
	(0.041)	(0.042)	(0.044)	(0.042)	(0.025)	(0.026)	(0.027)	(0.026)
LQ1	1.01**	1.02**			0.93**	0.94**		
	(0.300)	(0.300)			(0.170)	(0.170)		
LQ2			0.61**				0.43**	
			(0.170)				(0.091)	
LQ3				-0.094				-0.098**
				(0.058)				(0.042)
CR4		0.74	0.86	0.67		-0.02	0.06	-0.08
		(0.460)	(0.460)	(0.460)		(0.290)	(0.300)	(0.290)
HI	12.90**				-4.86			
	(4.430)				(2.96)			
EX	0.20*	0.19	0.23*	0.17	0.042	0.04	0.061	0.019
	(0.120)	(0.120)	(0.120)	(0.120)	(0.075)	(0.075)	(0.075)	(0.075)
OPEN	1.41**	1.44**	1.46**	1.39**	0.51**	0.54**	0.54**	0.49**
	(0.140)	(0.160)	(0.160)	(0.160)	(0.093)	(0.100)	(0.100)	(0.098)
Adj R-sq	0.1677	0.1613	0.1661	0.1512	0.1922	0.1882	0.1818	0.1663
N	679	679	679	679	679	679	679	679

Note: See notes in Table 5.

positive and significant effect for all domestically-owned firms. The effect of the relative wage of white- to blue-collar workers (LQ3) is also positive and significant. These results across various dimensions of labour quality seem to suggest that higher labour quality improves production efficiency and thus raises productivity. However, for foreign-owned firms, all the labour quality indices except LQ1 are insignificant.

(e) Market concentration: For domestically-owned firms, both concentration ratios, whether measured by the four largest firms (CR4) or by the Herfindahl index (HI), have negative and significant coefficients. This implies that the higher the concentration of the market, the less the competition between firms and thus the less incentive for firms to engage in technology enhancement and cost reduction. However, the market concentration effect for foreign-owned firms is insignificant.

(f) Market openness: For all subsample groups, the coefficients of market openness (OPEN), are all positive and significant, which implies that the more open the industry is to foreign markets and keen international competition, the greater the productivity of those firms which survive. Furthermore, openness of an industry to international markets appears to be associated with access to a larger pool of knowledge for domestically-owned firms; access to new technologies, in turn, promotes domestic technology transfer and spillovers.[16]

In sum, the regression results from Taiwan's manufacturing firm data support the hypothesis of a beneficial spillover effect from FDI. Moreover, the productivity of domestically-owned firms also depends on labour quality, production scale, market structure and export performance. However, for foreign-owned firms, evidence of a spillover effect is very weak. Moreover, within this pool of firms there appears little relationship between productivity and the local market structure in the host country. It is argued that this dichotomy reflects the tendency of the latter group to adopt most production technologies directly from their parent companies in the home country.

The Effect of R&D on Productivity

Tables 6 and 7 show the regression results for non-*R&D* and *R&D* firms, respectively. For both R&D and non-R&D firms, the estimated coefficients for R&D_Sec are all positive and significant except in the case of TFP1 of R&D firms, where most coefficients are negative but insignificant. A one percentage point increase in R&D intensity of the industry will result in 19.1 per cent to 41.7 per cent increase in firms' productivity. This finding

confirms that the R&D spillover effect exists. That is, the creation of new knowledge by any single firm will spill over to other firms in the industry. However, Table 7 shows that for R&D firms the coefficients of R&D_Firm are negative and insignificant.[17] The reason may be that R&D usually takes time and thus it should be the stock rather than the flow of R&D that is more important for firms' productivity. Moreover, a year of R&D expenditure is usually considered as a cost of that year to the firm and hence temporarily reduces the firm's productivity figures.

As for other variables like labour quality, production scale, industry concentration ratio, and market openness, the estimation results are similar to those found for FDI, and hence the discussion is omitted here.

The Relationship Between FDI and R&D: Substitutes or Complements?

Among our random sample of 8,846 firms surveyed in 1991, only 679 firms (7.7 per cent) undertake R&D. By nature, firms may self-select into R&D or non-R&D firms according to market structure and unobserved firm characteristics. Thus, tests of the relationship between FDI and R&D using firms from the R&D group alone are likely to be subject to the problem of selection bias which is mainly generated by the truncation of the error term. In turn, straightforward OLS estimates will be biased and inconsistent. To deal with selection bias, we apply Heckman's [*1976*] two-stage estimation method: first, we construct a probit model to estimate the probability of a firm doing R&D, by using all sample observations. Second, we run OLS for R&D firms only by including an additional variable of the inverse Mill's ratio (IMR) obtained in the first stage probit regression to correct for the selection bias.

The results of probit regression in equation (1) of Table 8 shows that, other things being equal, the higher the ratio of FDI in the industry, the greater the tendency of the firm to do R&D. Foreign-owned firms have a greater inclination to do R&D than domestically-owned firms. Moreover, firms which engage in technology cooperation/purchase, have outward foreign investment, are more capital-intensive, or have a longer history of establishment tend to perform more R&D. The second stage estimation of a negative and significant coefficient of variable IMR implies that firms do self-select into R&D or non-R&D groups according to their underlying comparative advantage. Without correcting for the selection bias, OLS coefficients will tend to be overestimated.

Results of second stage OLS estimation in equation (3) of Table 8 show a negative and insignificant coefficient of FDI_Sec which implies that there is no clear relationship between FDI and R&D.[18] As pointed out by Cohen and Levinthal [*1989*], in order to absorb and digest new technology from abroad, local firms need to enhance their technical capability via their own

TABLE 8
DETERMINANTS OF FIRM'S R&D EFFORTS

	Probit Model	OLS Model	
	Dep. Var. = DUM_R&D	Dep. Var. = R&D_Firm	
	(1)	(2)	(3)
Constant	–2.266**	0.022**	0.125**
	(0.052)	(0.005)	(0.050)
FDI_Sec	1.880**	0.040**	–0.019
	(0.139)	(0.011)	(0.031)
DUM_FO	0.650**	–0.004	–0.022**
	(0.081)	(0.005)	(0.010)
DUM_TP	1.650**	0.002	–0.044**
	(0.109)	(0.005)	(0.023)
OFI	0.410**	0.0003	–0.011*
	(0.064)	(0.0004)	(0.007)
KL	1.23E-7**	2.03E-9	–1.31E-10
	(1.66E-8)	(1.31E-9)	(1.67E-9)
AGE	0.022**	–0.0008**	–0.0015**
	(0.002)	(0.0002)	(0.0004)
IMR			–0.042**
			(0.020)
Adj R-sq		0.041	0.045
N	8846	679	679

Note: See notes in Table 5.

R&D first. Therefore, FDI and R&D are complements. However, evidence of a positive FDI spillover in the previous section implies that a foreign presence should foster knowledge spillover, labour turnover, and technology transfer, which in turn reduces local firms' incentives to strengthen their technical capability by unilateral investing in R&D. As a result, these two diametric forces may tend to offset each other, thus explaining the negative though insignificant coefficient observed.

The negative and significant coefficients of the dummy variables for foreign ownership (DUM_FOR) and technology purchase (DUM_TP) provide strong evidence that they are substitutes to R&D. These results confirm the finding of Hughes [*1986*] and Kumar [*1987*] that the

subsidiaries of MNEs acquire technology assistance from their parent companies in the home country and thus have little incentive to do R&D. In addition, technology purchase is another alternative to gain new technology. The coefficient of outward foreign investment (OFI) is also negative and significant. This R&D contraction effect by OFI may come from two channels. First, OFI in developing countries enables the firm to take the advantage of cost saving while extending the life cycle of its products, and hence weakens its need to invest in R&D in the home country. Second, OFI in developed countries enables the firm to rely upon the international division of labour by having R&D conducted in advanced countries: itself concentrating only on production in the home country. Moreover, the negative and significant coefficient of AGE variable implies that firms with older age invest less in R&D activity. Intuitively, older firms have a better reputation and should have an incentive to engage in more R&D investment to sustain their position in the market. However, older firms tend to be large and usually enjoy certain types of monopoly powers.[19] Moreover, at least in Taiwan, firms in the modern or high-tech industries tend to be small and medium size and are relatively younger in age than that in the traditional or low-tech ones. If this is the case, we may expect the sign of AGE to be negative as estimated.

V. CONCLUDING REMARKS

Using firm data for Taiwan, we confirm the existence of beneficial spillovers from both FDI and R&D. A one per cent increase in an industry's FDI ratio produces a 1.40 per cent to 1.88 per cent increase in domestic firms productivity, while a one percentage point increase in industry's R&D intensity will generate a 19.1 per cent to 41.7 per cent increase in firms productivity. Furthermore, labour quality, firm size, market structure and export orientation all affect a firm's productivity. Applying Heckman's [*1976*] two-stage estimation method, we find that firms do self-select into R&D or non-R&D groups.[20] After correcting for this selection bias, we find that foreign direct investment, technology purchase, and outward foreign investment are substitutes to R&D activity. These results are mainly due to the significant effect of industry-wide technology spillovers.

The results of our firm-level study in Taiwan may shed important light on government policies for technology and economic development. During the early development stage, technology transfer, especially through direct foreign investment of MNEs, can facilitate industry-wide technological learning and diffusion, and thus may be the most effective way for the developing country to strengthen its technical capability and to absorb appropriate technologies. However, our empirical study of Taiwan shows

that this rapid technical diffusion will in turn attenuate local firms' incentive to do their own R&D. As R&D is the engine of innovations and technological progress and because imitation and learning by doing have their own limits, the major policy implications derived from this study are that governments in developing countries may at first adopt policies encouraging foreign direct investment to foster technology transfer and industry-wide knowledge spillovers. It is important to note that once the country's technological capability has progressed to a certain degree, that switching policies provides an environment conducive to R&D investment. In other wards, national strategies including infrastructure improvement and protection of intellectual property rights may become increasingly critical to sustain economic growth.

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NOTES

1. See Haddad and Harrison [*1993*] for a discussion of different avenues of technology transfer and the relative importance of foreign investment.
2. Blomstrom and Persson [*1983*] list three potential sources of spillover efficiency from foreign investment: competition; the training of labour and management or investment in human capital; and acceleration of the transfer of technology.
3. Using Australian and Canadian manufacturing data, respectively, Caves [*1974*] and Globerman [*1979*] both find support for positive spillovers from foreign presence. Using data for Mexican manufacturing firms, Blomstrom and Persson [*1983*] find a positive relationship between the labour productivity of domestic plants and foreign participation in various industries and conclude that there is a spillover of technical efficiency in Mexican manufacturing industry. Using Moroccan manufacturing data, Haddad and Harrison [*1993*] find that domestic firms exhibit higher levels of productivity in sectors with a larger foreign presence.
4. Bernstein and Nadiri [*1989*] find evidence of R&D spillovers effects for four US industries. Bernstein [*1989*] reaches the same conclusion for Canadian industries. Using panel data of private manufacturing firms in India, Raut [*1995*] and Basant and Fikkert [*1996*] both find evidence for the R&D spillover hypothesis.
5. Using Indian data, Deolalikar and Evenson [*1989*] estimate the demand function for patents and find that in the chemical industry the higher the foreign presence, the lower the number of patents in the industry.
6. Using data from Indian firms, Siddharthan [*1992*] shows that foreign direct investment has a positive effect on R&D intensity and Katrak [*1989, 1990*] finds that foreign-owned firms and domestically-owned firms have *insignificant* R&D expenditure. Braga and Willmore [*1991*] find that the probability of making R&D expenditure is insignificant between different ownership even after controlling for the spillover effect.
7. We follow Haddad and Harrison [*1993*] in using total factor productivity, whereas the others cited use one component of TFP, namely labour productivity, as the dependent variable in their estimates.
8. The detailed description and definition of the variables will be discussed in section III, see also Appendix A.
9. See, for example, Johnston and DiNardo [*1997: 448–9*] for the derivation of the inverse Mill's ratio.

10. See, for example, Greene [*1993: 391–2*] for explanation of the White test of heteroscedasticity. Leamer [1994] points out that with a large sample size, the problem of heteroscedasticity only affects the width of the confidence interval, and not the point estimate itself.
11. All firms with annual sales in 1990 above NT$50,000,000 were surveyed, while the remaining (smaller) firms were sampled by using the stratified random sampling method; five strata have been classified according to annual sales and approximately five per cent of firms from each stratum were drawn.
12. White-collar workers are defined as professionals, technicians and clerks, while blue-collar workers include skilled and unskilled labour. Skilled labour are mechanics, while unskilled labour are non-technical and manual labourers.
13. See Szpiro and Cette [*1994*] for a detail formulation and calculation of TFP by allowing for variable returns to scale.
14. See Chou [*1995*] for a detailed discussion on this so-called 'dichotomous' industrial structure. Using Taiwanese firm-level data, Aw and Hwang [*1995*] also find that firms that engage in export market have higher levels of productivity.
15. See Chuang [*1998*] for a detailed discussion on the process of trade-induced learning by doing for the developing countries.
16. See, for example, Grossman and Helpman [*1991*] and Chuang [*1997*] for models of technological change through international knowledge spillovers.
17. Albach [*1980*] also finds a negative effect of R&D intensity for US data.
18. Note that without correcting for the selection bias, the estimated coefficient of FDI_Sec is positive and significant, which is apparently erroneous and overestimated, see equation (2) of Table 8.
19. In Taiwan, large firms tend to concentrate on protected local market, while small- and medium-size firms concentrate on competitive international market. See also note 14.
20. Note that there are some cautionary limitations to the use of Heckman correction model [*Johnston and DiNardo, 1997: 449–50*].

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APPENDIX

VARIABLES AND DEFINITIONS

Variable	*Definition*
TFP1	Firm's total factor productivity under constant returns to scale assumption
TFP2	Firm's total factor productivity allowing for variable returns to scale
FDI_Sec	The share of foreign-owned assets to the total industry's assets at the two-digit industry level
R&D_Sec	The share of R&D expenditure to total sales at the two-digit industry level
R&D_Firm	The share of R&D expenditure to total sales at the firm level
SCALE	The ratio of the firm's average gross product to the minimum efficient scale (MES)[a] in the industry.
LQ1	The share of white-collar workers[b] of a firm's total employment
LQ2	The relative ratio of skilled to unskilled labour[c]
LQ3	The relative wage between white-collar to blue-collar workers[d]
CR4	The market share of the four largest firms in the three-digit industry
HI	Herfindahl index[e] measured at the three-digit industry level
EX	The share of exports to total output for a firm
OPEN	The share of exports to total output for a three-digit industry
OFI	Number of cases of outward foreign investment
KL	Capital–labour ratio
AGE	The age of the firm since establishment
DUM_R&D	Dummy variable for R&D performance – 1 for R&D firms and 0 for non-R&D firms
DUM_FOR	Dummy variable for the firm's ownership – 1 for foreign-owned firms and 0 for domestically-owned firms
DUM_TP	Dummy variable for technology purchase – 1 for firms with technology purchase and 0 for firms without

Notes:

[a] As the larger plants in an industry exhaust available economies of scale [e.g., *Blomstrom and Persson, 1983*], we use the average size of the larger plants that account for 50 per cent of the industry's output as a proxy for MES.

[b] White-collar workers include managers, engineers, technicians and clerks.

[c] Skilled labour are mechanics, while unskilled labour are non-technical and manual labourers.

[d] Blue-collar workers include skilled and unskilled labour.

[e] The Herfindahl index is calculated as [e.g., *Scherer and Ross, 1990: 72*],

$$HI = \sum_{i=1}^{n} \left(\frac{x_i}{X} \right)^2$$

where x_i represents the employment of the ith individual firm and X represents the total employment of the industry.