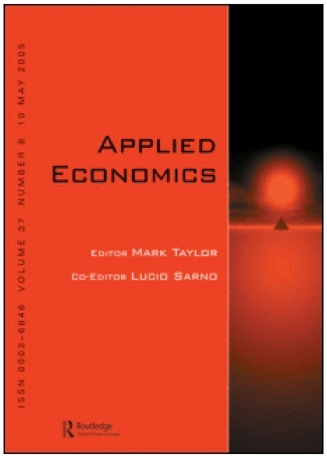

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The interdependence between FDI and R&D: an application of an endogenous switching model to Taiwan's electronics industry

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Foreign direct investment (FDI) and research & development (R&D) are mutually dependent and should be treated as endogenous variables in empirical studies. An endogenous switching regression model is used to examine the mutual effect of FDI and R&D in Taiwan's electronics industry. The empirical results show that FDI and R&D are positively related and do reinforce each other. Unbiased coefficients are obtained as they are compared to those estimates if FDI and R&D are treated as exogenous variables. The results have a strong public policy implication for Taiwan's foreign direct investment and can be further used to estimate the difference in R&D expenditures between FDI and non-FDI firms.

I. Introduction

There are two schools of thought on the relationship between foreign direct investment (FDI) and research and development (R&D) in the literature. The first school focuses on the determinants of FDI, of which R&D is an important factor, contending that a firm has to have a firm-specific advantage in order to engage in foreign direct investment. The second school shifts its attention to the effect of FDI, debating whether there is a positive or negative effect of FDI on the home or host economy. It focuses on the economic effect of R&D, trade, employment, and industrial structure at the national level. At the firm level, a research question arises as to what would happen to a firm's investment, R&D, and other activities after it engages in FDI. Empirically, research tends to examine the effect of R&D on FDI or FDI on R&D by treating them as exogenous variables. However, as just discussed above, if these two schools of thinking are integrated, then FDI and R&D have no longer a one-way cause–effect relationship. As in the contention of the causality between physical investment and R&D (Lach and Schankerman, 1989; Lach and Rob, 1996; Chiao, 2001), FDI and R&D are actually mutually dependent upon each other. They should not be treated as exogenous variables as they are in most empirical studies.

In this article we take a position of treating FDI and R&D as being interdependent upon each other and thus adopt an endogenous switching regression model to examine the mutual effect of FDI and R&D in Taiwan's electronics industry. The reason we choose this industry is that it is the most important industry in Taiwan's economy

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and Taiwan's foreign direct investment, especially the investment towards mainland China. The island's FDI in mainland China has become a public concern, because it may create an industrial hollowing-out effect on Taiwan's economy. We expect that this research will provide empirical evidence that FDI has a positive effect on R&D, and a greater effect will be obtained if FDI and R&D are treated as endogenous variables.

II. Literature Review

There are many theories explaining why a firm goes abroad. Conventional FDI theory views that FDI is jointly determined by three-interrelated advantages – namely, ownership advantages, location advantages, and internalization advantages (Dunning, 1981, 1988). A firm goes abroad or moves its production overseas in order to exploit firm-specific advantages or ownership advantages, which include tangible and intangible properties such as capital, patent, technology, managerial or marketing skills, production differentiation, and trademarks (Hymer, 1960; Vernon, 1966; Kinderberge, 1969; Caves, 1971; Horst, 1972; Dunning, 1988, 1998; Love, 2003). The choice of location is based on location advantages of such factors as consumer preference, resource endowment, relative wage rate, and government policies in tax, tariff, foreign exchange, and incentive schemes (Smith, 1981; Dunning, 1988, 1998). A firm that has firm-specific advantages and faces location advantages may not engage in FDI if its firm-specific advantages are able to be licensed or sold in the international market at fair prices in host countries. However, there is not a perfect market, especially for intermediate inputs, for a fair evaluation of firm-specific advantages. A firm thus has to internalize or control them under its management through FDI (Rugman, 1981; Dunning, 1988, 1998).

Contrary to conventional FDI theory, the linkage approach views FDI as a conduit for asset-seeking in management, technology or marketing expertise to reinforce or complement or build up new firm-specific advantages of the investors (Buckley and Ghauri, 1989; Buckley and Clegg, 1991; Chen and Chen, 1998; Hoesel, 1999). A firm's network linkages may be either firm specific or industry specific, and are especially important for the internationalization of small and medium enterprises (Fujita, 1995; Chen and Chen, 1998). Because of the complexity of FDI theory, researchers, however, tend to focus on few factors so as to conduct empirical tests, especially examining firm-specific or ownership advantages. The firms that engage in FDI are generally large in size, superior in technology, or unique in product lines (Horst, 1972; Caves, 1974; Fukao *et al.*, 1994). In short, R&D has been confirmed to have a positive relationship with FDI and is often viewed as a proxy of many firm-specific advantages.

With regard to the effect of FDI on R&D, this has been conversely debated at the macro and micro levels. From a macro-perspective, it is related to the issue of de-industrialization or industrial hollowing-out. Singh (1977) and Thirlwall (1982) argue that FDI is a substitute for domestic investment, because it reduces domestic investment, employment, and exports, and the share of manufacturing sector will then decrease, which creates an industrial hollowing-out effect. However, Rowthorn and Wells (1987) and Robert and Ramana (1997) contend that the shrinking in the manufacturing sector is a natural process, which will not affect employment and international competitiveness. Productivity will increase in the manufacturing sector, because technology will be upgraded, and a better resource allocation will stimulate the service sector that then absorbs employment released from the manufacturing sector. This natural process is what most developed countries have experienced in the last two centuries.

From a micro-perspective, the concern focuses on the effect of FDI on R&D at the firm level. What happens to a firm's R&D after it engages in FDI? The effect of FDI on a firm's home R&D can be indirectly derived from its FDI motivation or strategic intention. According to the linkage approach, a growing number of studies have suggested that the purpose of FDI is to develop firm-specific advantages or to acquire strategic assets in the host countries (Teece, 1992; Dunning, 1993; Chang, 1995; Almeida, 1996; Lall, 1996; Shan and Song, 1997; Walz, 1997; Kuemmerle, 1999). Thus, FDI has a positive effect in various ways on a firm's home R&D. Empirically, Japanese firms in the USA were found attracted to knowledge creators (Park, 2003; Co and List, 2004) or R&D intensive sectors (Love, 2003) or to form joint ventures with US firms so as to source US technology or develop capability (Kogut and Chang, 1991; Chang, 1995). The same results were found in foreign firms in the US semiconductor industry (Almeida, 1995). A similar pattern was found in the outward FDI of less-developed countries (Lecraw, 1993; Chen and Chen, 1998; Kumar, 1998; Makino *et al.*, 2002). Investors use the capital earned in their home countries or FDI in other low-wage countries to acquire management, technology and marketing expertise in developed countries.

A more direct empirical examination of the effect was conducted by Lipsey (1994), who investigated the effect of FDI on employment and R&D activities for American manufacturing firms. He found that firms that have a higher ratio of overseas production will employ more worker than those with a lower ratio, because the overseas production increases the need for administrative, financial, and R&D personnel. If the number of skilled labour is used as an indicator of R&D activities, then the firms tend to upgrade their R&D activities at home when they move their low technological production to low-cost countries. The same results are found in Fors' (1997) study of 121 Swedish manufacturing MNEs and Chuang and Lin's (1999) study of Taiwanese manufacturing firms. Swedish firms tend to supply R&D-generated knowledge at home to their overseas production, which implies that the more overseas production there is, the more R&D activities there are that are conducted at home. Taiwanese firms having foreign direct investment tend to be more capital intensive and have more and longer-term R&D activities. In summary, FDI has a positive effect on a firm's home R&D.

At the firm level, the above discussions, either R&D as a determinant of FDI or FDI as a factor affecting R&D, all focus on a one-way causal-effect, treating them separately as exogenous variables. They ignore the fact that FDI and R&D are mutually dependent upon each other and should be treated as endogenous variables as in the mutual causality between R&D and physical investment of firms in US science-based industries (Chiao, 2001). The effect of FDI on R&D or R&D on FDI tends to be under-estimated in most current empirical studies. From a public policy perspective, the under-estimated effect reduces the importance in supporting the argument that FDI has a positive effect on R&D.

III. Methodology

Model specification: endogenous switching regression model

To correct the bias of the mutual effect between FDI and R&D, an endogenous switching regression model is specified. Since firms that engage in FDI are very different from those that do not, we first specify a firm's FDI decision equation and then separate its R&D decisions – one for the firm engaging in FDI (FDI firm) and one for that not engaging in FDI (non-FDI firm). Three simultaneous equations are thus created, in which R&D is one of the independent variables in the FDI decision and the effects of FDI on R&D are accounted for in the two R&D decisions. This endogenous switching regression model specified as follows will then give us an unbiased estimation of the effects between FDI and R&D.

$$Y_i^* = Z_i'\gamma + \delta RD_i^* + \varepsilon_i \qquad (1)$$
$$Y_i = 1 \quad \text{if } Y_i^* > 0, \quad Y_i = 0 \quad \text{if } Y_i^* \le 0$$

$$\begin{aligned} RD_{1i}^* &= X_i'\beta_1 + U_{1i} && \text{if } Y_i^* > 0 \\ RD_{1i} &= RD_{1i}^* && \text{if } RD_{1i}^* > 0 \\ &= 0 && \text{if } RD_{1i}^* \le 0 \end{aligned} \qquad (2)$$

$$\begin{aligned} RD_{2i}^* &= X_i'\beta_2 + U_{2i} && \text{if } Y_i^* \le 0 \\ RD_{2i} &= RD_{2i}^* && \text{if } RD_{2i}^* > 0 \\ &= 0 && \text{if } RD_{2i}^* \le 0. \end{aligned} \qquad (3)$$

In Equation 1, Y_i^* is the potential FDI, but is unobservable:

- Y_i observable FDI, equal to 1 or 0;
- $Y_\text{i} = 1$ a firm engaging in FDI;
- $Y_\text{i} = 0$ a firm not engaging in FDI;
- Z_i determinants of FDI;
- RD_i^* firm's R&D, indicating a firm's technological advantage and it is an endogenous variable affecting the FDI decision.

In Equation 2, we have:

- RD_{1i}^* R&D of the FDI firm; a latent variable being censored; when $RD_{1i}^* \le 0$, $RD_{1i} = 0$, indicating that a firm does not engage in R&D, and is censored as 0; when $RD_{1i}^* > 0$, $RD_{1i} = RD_{1i}^*$, indicating that a firm engages in R&D, and is not censored;
- X_i determinants of the R&D decision.

In Equation 3, we have:

- RD_{2i}^* R&D of the non-FDI firm; a latent variable being censored; when $RD_{2i}^* \le 0$, $RD_{2i} = 0$, indicating that a firm does not engage in R&D, and the data is censored as 0; when $RD_{2i}^* > 0$, $RD_{2i} = RD_{2i}^*$, indicating that a firm engages in R&D, and is not censored;
- X_i determinants of the R&D decision.

Here, assume $[U_1\ U_2\ \varepsilon] \sim$ iid trivariate normal $(0, \Sigma)$,

$$\Sigma = \begin{bmatrix} \sigma_1^2 & \sigma_{12} & \sigma_{1\varepsilon} \\ \sigma_{21} & \sigma_2^2 & \sigma_{2\varepsilon} \\ \sigma_{\varepsilon 1} & \sigma_{\varepsilon 2} & 1 \end{bmatrix}.$$

Estimation

The fully-maximum likelihood method is employed to estimate the endogenous switching regression model specified in Equations 1, 2 and 3. Depending on the sign combination of Y_i^* and RD_1^*, RD_2^*, the firms' decision can be grouped into four mutually exclusive decision combinations.

$$I_1 = \{i | Y_i^* > 0, RD_1^* > 0\}$$
$$I_2 = \{i | Y_i^* > 0, RD_1^* \le 0\}$$
$$I_3 = \{i | Y_i^* \le 0, RD_2^* > 0\}$$
$$I_4 = \{i | Y_i^* \le 0, RD_2^* \le 0\}$$

To construct the likelihood function, let

$$\varepsilon = Y^* - Z'r - \delta RD^*, \quad a_0 = Z'r + \delta RD^*$$
$$V_1 = \frac{RD_1^* - X'\beta_1}{\sigma_1}, \qquad a_1 = \frac{X'\beta_1}{\sigma_1}$$
$$V_2 = \frac{RD_2^* - X'\beta_2}{\sigma_2}, \qquad a_2 = \frac{X'\beta_2}{\sigma_2}$$

Thus, the likelihood firms can be shown as follows:

$$L(\gamma, \delta, \beta_1, \beta_2, \sigma_1, \sigma_2, \sigma_{1\varepsilon}, \sigma_{2\varepsilon}) = L_1 \times L_2 \times L_3 \times L_4 \quad (4)$$

where

$$L_1 = \prod_{I_1} \int_{-a_0}^{\infty} \phi_2(V_1, \varepsilon) \mathrm{d}\varepsilon = \prod_{I_1} \frac{1}{\sigma_1} \phi(a_1) \times \Phi\left[\left(1 - \frac{\sigma_{1\varepsilon}^2}{\sigma_1^2}\right)^{-1/2} \left(-a_0 - \frac{\sigma_{1\varepsilon}}{\sigma_1} a_1\right)\right]$$

$$L_2 = \prod_{I_2} \int_{-a_0}^{\infty} \int_{-\infty}^{-a_1} \phi_2(V_1, \varepsilon) \mathrm{d}V_1 \,\mathrm{d}\varepsilon = \prod_{I_2} \Phi_2(-a_1, a_0)$$

$$L_3 = \prod_{I_3} \int_{-\infty}^{a_0} \phi_2(V_2, \varepsilon) \mathrm{d}\varepsilon = \prod_{I_3} \frac{1}{\sigma_2} \phi(a_2) \times \Phi\left[\left(1 - \frac{\sigma_{2\varepsilon}^2}{\sigma_2^2}\right)^{-1/2} \left(a_0 + \frac{\sigma_{2\varepsilon}}{\sigma_2} a_2\right)\right]$$

$$L_4 = \prod_{I_4} \int_{-\infty}^{-a_0} \int_{-\infty}^{-a_2} \phi_2(V_2, \varepsilon) \mathrm{d}V_2 \,\mathrm{d}\varepsilon$$

here $\phi(\cdot)$ and $\Phi(\cdot)$ are the univariate standard normal density and cdf respectively; similarly, $\phi_2(\cdot,\cdot)$ and $\Phi_2(\cdot,\cdot)$ are the bivariate standard normal density and cdf. The parameters $\{\gamma, \delta, \beta_1, \beta_2, \sigma_1, \sigma_2, \sigma_{1\varepsilon}, \sigma_{2\varepsilon}\}$ are obtained by maximizing the log likelihood function indicated in Equation 4. Finally, we are able to compare the estimated coefficient $\hat{\beta}_1$, $\hat{\beta}_2$ to understand what determines R&D for FDI firms and non-FDI firms.

Table 1. Descriptive statistics for electronics firms

	Without R&D	With R&D	Total
No FDI	5611 (85.25%)	971 (14.75%)	6582 (100%)
FDI	275 (36.47%)	479 (63.53%)	754 (100%)
Total	5886	1450	7336

Source: Statistical Dept. of the Ministry of Economic Affairs, 1998 Survey Data.

Data

There are 7336 firms in the electronics industry (CISC 31) taken from two surveys (1997 and 1998) conducted by the Department of Statistics of the Ministry of Economic Affairs. Firms that have completely left Taiwan are not included in the surveys. The size of the exclusion is small and its effects can therefore be ignored. The surveyed firms are further classified into four groups by whether they engaged in FDI or whether they conducted R&D activities in 1998. Table 1 shows that 6582 firms are not engaging in FDI, of which 85.25% do not have R&D and 14.75% have R&D. There are 754 firms engaging in FDI, of which 36.47% do not have R&D and 63.53% have R&D. Of the firms that do not have R&D, there only 4.67% engage in FDI. Of the firms that have R&D, 33.03% are engaged in FDI. The statistics conclude that firms that have R&D tend to have overseas engagement.

The descriptive statistics of the four groups of firms are presented in Tables 2 and 3. Table 2 shows that, for non-FDI firms, if the firms that have R&D and those that do not have R&D are compared with each other, then the former tend to be larger and older, and have higher sales growth, labour technical capability, technology imports, export ratio, concentration ratio, and market growth, but they have a relatively lower profit rate. Table 3 shows a similar pattern, whereby as compared to firms without R&D, for FDI firms, the firms that do have R&D tend to be higher or better in all of the averages including the profit rate. The statistics conclude that R&D activities are generally related to all the averages shown in the tables, with the exception of the profit rate (which is uncertain in its direction with R&D).

IV. Empirical Tests and Results

Variable selection for FDI decision

The FDI decision is affected not only by R&D, but also by other factors. Based on empirical literature and the nature of our data, firm size, profitability, the sales growth rate, export ratio, firm age, and

Table 2. Descriptive statistics for non-FDI firms

Variable	Without R&D	With R&D	Total firms
No. of firms	5611	971	6582
Average no. of employees	24	127	39
Average sales (NT $1 000)	65 917	657 788	53.253
Average profitability	7.84%	5.78%	5.48%
Average sales growth rate	3.42%	6.5%	3.81%
Average technical ability (NT $1 000)	330	429	345.40%
Average technology import (NT $10 000 000)	53	12 740	0.1924%
Average age	7.91	8.26	7.97
Average export ratio	37.23%	45.24%	38.42%
Average concentration ratio	0.0464	0.0599	0.0484
Average market growth rate	12.05%	13.57%	12.28%

Source: Statistical Dept. of the Ministry of Economic Affairs, 1998 Survey Data.

Table 3. Descriptive statistics for FDI firms

Variable	Without R&D	With R&D	Total firms
No. of firms	275	479	754
Average no. of employees	67	379	265.94
Average sales (NT $1 000)	323 588	2 476 568	1 691 330
Average profitability	5.32%	6.43%	6.533%
Average sales growth rate	9.99%	62.97%	40.37%
Average technical ability (NT $1 000)	420	485	461.98
Average technology import (NT $10 000 000)	138	32,038	2,0404
Average age	8.67	9.47	9.18
Average export ratio	41.09%	49.12%	46.20%
Average concentration ratio	0.0426	0.0701	0.0601
Average market growth rate	12.28%	15.81%	14.52

Source: Statistical Dept. of the Ministry of Economic Affairs, 1998 Survey Data.

a dummy indicating sub-industry type are selected as the control variables. Each variable is briefly explained as follows:

Y. Coded as 0 if a firm does not engage in FDI and 1 if a firm engages in FDI by 1998.

R&D quantity. A proxy for a firm's specific advantages, indicating a firm's technical ability, product differentiation, and innovations (Caves, 1974; Helpman, 1984). We expect R&D to be positively related to FDI.

Firm size. Indicated by number of employees. The larger the firm size is, the more market and production power the firm enjoys, and thus the firm has a greater tendency to engage in FDI (Hymer, 1960).

Profitability. Measured by profits before taxes/sales. Generally, a more profitable firm will have a better ability to undertake FDI (Vernon, 1966). This may be the case for MNEs, but may not be the case for Taiwanese firms, of which many are small and medium-sized and are pushed to engage in FDI, especially towards mainland China (Yeh and Lin, 1999).

Sales growth rate. Sales growth rate between 1997 and 1998. A firm enjoying high sales growth tends to have a high ability to engage in FDI (Chen, 1992).

Firm age. A firm's age up to 1998. It is expected that the older a firm is, the more experience the firm has for engaging in FDI.

Export ratio. Indicated by export sales/total sales. The higher the export ratio a firm has, the higher the motivation is for the firm to undertake FDI so as to protect its export market, overcome trade barriers imposed by host countries, and/or take advantage of incentives or lower factor costs in host countries.

Industry type. A dummy variable. There are five sub-industries in the electronics industry. The 'other' industry is used as the reference industry, and the other four industries – information-computer, telecommunication-equipment, electronic-parts, and semiconductor industry – are coded 1 or 0 as dummy variables.

Variable selection for R&D decision

Similar to the FDI decision, ten variables are selected to separately estimate R&D decisions for FDI and non-FDI firms. Dependent and independent variables are briefly explained as follows.

R&D quantity. Measured by R&D expenditure for year 1998.

Firm size. Indicated by number of employees. R&D involves a high risk and only a large company is able to support this risk (Schumpeter, 1950). Therefore, a larger firm size implies it has higher investment, market share, and profits and thus has a higher ability to support R&D activities.

Profitability. Measured by profits before tax/sales. R&D requires investment. A firm having a higher profit rate means that it is more affordable for the firm to conduct R&D.

Sales growth rate. Sales growth between 1997 and 1998. If other things are equal, then a firm having a higher sales growth rate implies a higher return for R&D and hence more R&D will be conducted.

Labour's technical ability. Measured by the average wage rate. A higher wage rate means a higher labour technical capability. The higher a firm's labour technical capability is, the more R&D that will be conducted (Lall, 1983).

Technology import. Total expenditure for technology imports. The imported technology may substitute or supplement for R&D activities. The relationship between technology imports and R&D is thus uncertain.

Firm's age. A firm's age up to 1998. The older a firm is, the more technical and administrative capability the firm has (Lall, 1983).

Export ratio. Exports/total sales. Exports expand market share, which create high profits and thus induce R&D activities (Pugel *et al*., 1996).

Concentration ratio. Measured by the Herfindabl–Hirschman Index (HHI). The relationship between HHI and R&D is uncertain. Some argue that the more power over the market a firm has, the higher incentive the firm has for R&D activities (Schumpeter, 1950). On the contrary, some argue that competition induces R&D (Scherer, 1992).

Market growth rate. Industry sales growth rate between 1997 and 1998. The higher a market expands, the higher incentive the firm has for R&D activities.

Industry type. A dummy variable. There are five sub-industries in the electronics industry. The 'other' industry is used as the reference industry, and the other four industries – information-computer, telecommunication-equipment, electronic-parts, and semiconductor industry – are coded 1 or 0 as dummy variables.

Results

The results reported in Table 4 are estimates of the endogenous switching regression model specified in Equations 1, 2 and 3. They are obtained using the fully maximum method. The results shown in column 1 are the estimates for the FDI model specified in Equation 1 which as predicted show that R&D, firm size, profitability, sales growth rate, firm age, and export ratio are positively and significantly related to the FDI decision. The more a firm conducts R&D activities, the higher is the firm's tendency to engage in FDI. In addition, a firm that is a larger scale, older, and owns a higher export ratio has a higher tendency to engage in FDI. With regard to the effect of sub-industry, the information and computer industry, the telecommunication equipment industry, and the electronic-parts industry all have a positive relationship with the FDI decision, while the semiconductor industry has no effect on the FDI decision.

Columns 2 and 3 in Table 4 show the regression results for the two R&D expenditure equations that are corrected for bias due to the mutual FDI and R&D decisions. Column 2 concerns the firms that are a foreign direct investor, while column 3 deals with those that do not invest abroad. The importance of taking into account endogenous FDI can be seen from the statistical significance of the correlation terms, $\rho_{1\varepsilon}$ and $\rho_{2\varepsilon}$. Moreover, the overall performance of the model seems satisfactory as the equations have a higher log-likelihood value than the log-likelihood of the equations, which do not consider the endogenous FDI (see the appendix).

The coefficients of firm size in columns 2 and 3 are both positive and significantly greater than zero at the 1% level, indicating that an increase in firm size

Table 4. Estimated coefficients for FDI and R&D: endogenous switching regression model

Variable	FDI decision	R&D decision (non-FDI firm)	R&D decision (FDI firm)
Constant	−1.7912***	−0.1130	−63.750***
	(0.8088E − 01)	(0.1087)	(3.7953)
R&D	0.2927E − 01***		
	(0.2236E − 02)		
Firm size	0.8622E − 03***	0.2842E − 01***	0.4599E − 01***
	(0.5703E − 03)	(0.5162E − 04)	(0.1247E − 02)
Profitability	0.2397***	−0.4484***	3.6737***
	(0.1371E − 01)	(0.3112E − 02)	(1.3027)
Sales growth rate	0.6509E − 02*	0.6237E − 02*	0.3403E − 01***
	(0.2637E − 02)	(0.2783E − 02)	(0.1181E − 01)
Firm age	0.3855E − 01***	−0.1317E − 01***	0.5922***
	(0.3708E − 02)	(0.4072E − 02)	(0.1624)
Export ratio	0.4728***	0.6598E − 01	10.974*
	(0.1991)	(0.1927)	(6.2302)
Technology import		0.2067***	0.1962***
		(0.6507E − 03)	(0.4744E − 01)
Technical ability		0.4969E − 01***	0.2961***
		(0.7915E − 01)	(0.2727E − 01)
Concentration ratio		0.3414	−3.0748
		(0.2467)	(9.9148)
Market growth ratio		31.872**	62.25
		(15.153)	(83.49)
Industry			
Information-computer	0.6225***	−0.3024***	9.0302**
	(0.1485)	(0.1148)	(3.2401)
Communication-equipment	0.2335**	−0.1389E − 01	7.5930*
	(0.1202)	(0.11052)	(4.5924)
Electronic-parts	0.1829***	−0.12638	6.4276**
	(0.6287E − 01)	(0.1063)	(2.5943)
Semiconductor	−0.1126	0.7817***	2.4901*
	(0.1096)	(0.1064)	(1.8264)
σ		1.4914***	32.470***
		(0.3662E − 02)	(0.9125)
ρ		0.8540	0.9878
		(0.3674E − 02)	(0.1366E − 02)
Log-likelihood	−8042.25		

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively; standard errors are in parentheses.

leads to an increase in R&D expenditures for both FDI and non-FDI firms. The results support the Schumpeter hypothesis and are similar to the finding of Katrak (1985, 1989) for Indian enterprises.

The coefficient of profitability is negatively significant for non-FDI firms, but it is positively significant for FDI firms. The contrasting results of the profitability coefficients suggest that even though non-FDI firms have less profit, they are more likely to perform R&D. The results may imply that although technology of non-FDI firms is relatively low, they are pushed by strong competitive pressure from the international market of electronics products to perform R&D. For FDI firms, profitability turns out to be quite large and positive, implying that a large proportion of profitable firms perform R&D, promoting competitiveness in international markets.

The sales growth variable and sales growth rate variable are significant, with a positive sign in both columns 2 and 3, implying that firms' R&D expenditure is positively associated with firm growth. However, market growth is less significant with R&D expenditure.

The technology ability is found to be positively related to R&D expenditures, indicating that the R&D absorption capacity may depend heavily on high levels of technical employees in Taiwan. For Indian firms, Lall (1983) found a negative relationship between these two variables, whereas a positive relationship was found by Kumar (1987).

The other variables, firm age, export ratio, and technology import as expected have a positive association with R&D expenditures. The industry dummy variable, information-computer, communication equipment, electronic-parts, and semiconductor

Table 5. Estimated result on the difference of R&D expenditure (US million dollars)

Comparison formula	Estimated result
(1) $E(RD_1^*\|Y=1,\bar{X}_1)-E(RD_2^*\|Y=0,\bar{X}_1)$	8.25***
(2) $E(RD_1^*\|Y=1,\bar{X}_2)-E(RD_2^*\|Y=0,\bar{X}_2)$	0.09375***

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.
$\bar{X}_1$: mean of explanatory variables of FDI firms.
$\bar{X}_2$: mean of explanatory variables of non-FDI firms.
The value of $\bar{X}_1$ and $\bar{X}_2$ is referred to the last columns of Table 2 and Table 3. $\bar{X}_1$ indicates ''large firms'' and $\bar{X}_2$ indicates ''small firms''.

are all positive in column 3. Obviously, firms' R&D expenditures in those industries are higher than those of other electronics firms for FDI firms. For non-FDI firms, except in the semiconductor industry, other industries show negative signs.

It is interesting to note that the results are quite different for FDI and non-FDI firms. As shown in Table 4, columns 2 and 3, the coefficients of variables for FDI firms' R&D are larger than for non-FDI firms. This demonstrates that FDI firms and non-FDI firms have very different R&D behaviours.

A question that arises is whether the level of R&D expenditure is higher for FDI firms than for non-FDI firms. The difference between FDI and non-FDI firms can be properly calculated with a conditional mean given that they have the same characteristics.[1] Two levels of characteristics of firms are used to compute the difference of R&D expenditures. One is the mean of characteristics for FDI firms ($\bar{X}_1$), while the other is the mean of characteristics for non-FDI firms ($\bar{X}_2$). For the values of $\bar{X}_1$ and $\bar{X}_2$, refer to the last column of Tables 2 and 3. Since FDI firms are of a much larger size than non-FDI firms, $\bar{X}_1$ represents large firms and $\bar{X}_2$ represents small firms. Both $\bar{X}_1$ and $\bar{X}_2$ are used to estimate the difference in R&D expenditures of FDI firms and non-FDI firms. Table 5 reports the R&D difference between FDI firms and non-FDI firms. All estimates in Table 5 are positive and significant at the 1% level. It is thus evident that the average level of R&D expenditures is higher for FDI firms than for non-FDI firms. In addition, this reflects the existence of the scale effect, namely that large firms input more R&D expenditures than small firms after investing in foreign countries.

V. Conclusions and Implications

R&D is an important determinant of the FDI decision while FDI is also a factor that affects the R&D decision. For different research interests, either one of them is often treated as exogenous in empirical studies. Since they are mutually dependent upon each other, both should be treated as endogenous variables in an empirical study in order to obtain unbiased estimates. We thus use an endogenous switching regression model to examine the mutual effect of FDI and R&D in Taiwan's electronics industry. In the model, three simultaneous equations – FDI decision and R&D decisions for firms that do not engage in and do engage in FDI – are specified and estimated. For comparison, we also present the estimates for FDI and R&D decisions with consideration of FDI and R&D as exogenous variables. Our results show that R&D is positively related to FDI and reinforces greatly the effects of FDI on R&D. The effect of FDI on R&D is demonstrated by the difference between the R&D decision for firms not having FDI and the decision for firms having FDI.

For those who are interested in estimating the extent of R&D expenditures between firms with FDI and those without FDI, our results are able to provide the tools for estimation. We have demonstrated here the usage of the estimation, which also helps estimate the effect of FDI on R&D for large or small-size firms.

With regard to the current debate, the effects of FDI on Taiwan's economy can be examined from many perspectives such as trade, employment, production, investment, and R&D. Our empirical results provide only partial evidence that FDI has a positive effect on R&D in the electronics industry. Our results are unable to determine the direct effects of FDI on trade, employment, production, and investment. However, the increase in R&D as part of a company's investment caused by an increase in FDI may in turn

[1] $$E(RD_1^*|Y=1)-E(RD_2^*|Y=0)=\left[\bar{X}'\beta_1+\sigma_{1\varepsilon}\frac{\phi(a_0)}{\Phi(a_0)}\right]-\left[\bar{X}'\beta_2+\sigma_{2\varepsilon}\frac{-\phi(a_0)}{1-\Phi(a_0)}\right]$$
$$=\bar{X}'(\beta_1-\beta_2)+\sigma_{1\varepsilon}\frac{\phi(a_0)}{\Phi(a_0)}-\sigma_{2\varepsilon}\frac{-\phi(a_0)}{1-\Phi(a_0)}.$$

stimulate trade, employment, production, and investment in equipment and machinery. Furthermore, R&D may not have a quantity effect on a firm's product – it may, however, upgrade the firm's quality. Will the results apply to other industries such as the textile and cloth industry, the plastics industry, and other traditional labour-intensive industries? Some of them may even close factories entirely when they move to mainland China. For this purpose, further research should be conducted in other industries.

References

Almeida, P. (1996) Knowledge sourcing by foreign multinationals: patent citation analysis in the U.S. semiconductor industry, *Strategic Management Journal*, **17**, 155–65.

Buckley, P. J. and Clegg, J. (1991) *Multinational Enterprises from Less Developed Countries*, St. Martin's Press, New York.

Buckley, P. J. and Ghauri, P. (1989) *The Internationalization of the Firm: A Reader*, Academic Press, London.

Caves, R. E. (1971) International corporations: the industrial economics of foreign investment, *Economica*, **38**, 1–27.

Caves, R. E. (1974) Causes of direct investment: foreign firm's shares in Canadian and United Kingdom manufacturing industries, *Review of Economics and Statistics*, **56**, 279–93.

Chang, S. J. (1995) International expansion strategy of Japanese firms: capability building through sequential entry, *Academy of Management Journal*, **38**, 383–407.

Chen, T. J. (1992) Determinants of Taiwan's direct foreign investment: the case of a newly industrializing country, *Journal of Development Economics*, **39**, 397–407.

Chen, H. and Chen, T. J. (1998) Network linkages and location in choice in foreign direct investment, *Journal of International Business Studies*, **29**, 445–568.

Chiao, C. (2001) The relation between R&D and physical investment of firms in science-based industries, *Applied Economics*, **33**, 23–35.

Chuang, Y. C. and Lin, C. M. (1999) Foreign direct investment, R&D and spillover efficiency: evidence from Taiwan's manufacturing firms, *The Journal of Development Studies*, **35**, 117–37.

Co, C. Y. and List, J. A. (2004) Is foreign direct investment attracted to 'knowledge creators'?, *Applied Economics*, **36**, 1143–9.

Dunning, J. H. (1981) *International Production and the Multinational Enterprises*, Allen & Unwin, London.

Dunning, J. H. (1988) The eclectic paradigm of international production: a restatement and some possible extensions, *Journal of International Business Studies*, **19**, 1–31.

Dunning, J. H. (1993) *Multinational Enterprises and the Global Economy*, Addison-Wesley, New York.

Dunning, J. H. (1998) Location and the multinational enterprise: a neglected factor?, *Journal of International Business Studies*, **29**, 461–91.

Fors, G. (1997) Utilization of R&D results in the home country and foreign plants of multinationals, *The Journal of Industrial Economics*, **45**, 341–58.

Fujita, M. (1995) Small and medium-sized transnational corporations: salient features, *Small Business Economics*, **7**, 251–71.

Fukao, K., Izawa, T., Kuninori, M. and Nakakita, T. (1994) R&D investment and overseas production: an empirical analysis of Japan's electric machinery industry based on corporate data, *Boj Monetary and Economic Studies*, **12**, 1–60.

Helpman, E. (1984) A simple theory of international trade with multinational corporation, *Journal of Political Economy*, **92**, 451–71.

Hoesel, R. V. (1999) *New Multinational Enterprises from Korea and Taiwan: Beyond Export-led Growth*, Routledge, New York.

Horst, T. (1972) Firms and industry determinants of the decision to invest abroad: an empirical study, *Review of Economics and Statistics*, **54**, 258–66.

Hymer, S. (1960) The international operations of national firms: a study of direct foreign investment, PhD thesis, MIT Press, Cambridge, MA.

Katrak, H. (1985) Imported technology, enterprise size and R&D in a newly industrializing country: the Indian experience, *Oxford Bulletin of Economics and Statistics*, **4**, 213–29.

Katrak, H. (1989) Imported technology, enterprise size and R&D in a newly industrializing country: the experience of India, *Journal of Development Economics*, **31**, 123–39.

Kinderberge, C. P. (1969) *American Business Abroad*, Yale University Press, New Haven, CT.

Kogut, B. and Chang, S. J. (1991) Technological capabilities and Japanese foreign direct investment in the United States, *Review of Economics and Statistics*, **73**, 401–13.

Kuemmerle, E. K. (1999) The drivers of foreign direct investment into research and development: an empirical research, *Journal of International Business Studies*, **30**, 1–24.

Kumar, N. (1987) Technology imported and local research and development in Indian manufacturing, *The Developing Economies*, **25**, 220–33.

Kumar, N. (1998) *Globalization, Foreign Direct Investment and Technology Transfers: Impacts on Prospects for Developing Countries*, Routledge, New York.

Lach, S. and Rob, R. (1996) R&D investment and industry dynamics, *Journal of Economics and Management Strategy*, **5**, 217–49.

Lach, S. and Schankerman, M. (1989) Dynamics of R&D and physical investment in the scientific sector, *Journal of Political Economics*, **97**, 880–904.

Lall, S. (1983) Determinants of R&D in an LDC — the Indian engineering industry, *Economics Letters*, **13**, 379–83.

Lall, S. (1996) *The Investment and Governments: Catalysts for Economic Restructuring*, Routledge, London.

Lecraw, D. J. (1993) Outward direct investment by Indonesian firms: motivation and effects, *Journal of International Business Studies*, **24,** 589–600.

Lipsey, R. E. (1994) Outward direct investment and the U.S. economy, NBER Working Paper #4691.

Love, J. H. (2003) Technology sourcing versus technology exploitation: an analysis of US foreign direct investment flows, *Applied Economics*, **35**, 1667–78.
Makino, S., Lau, C. M. and Yeh, R. S. (2002) Asset exploitation versus asset seeking: implications for location choice of foreign direct investment, *Journal of International Business Studies*, **33**, 403–21.
Park, K. H. (2003) Pattern and strategies of foreign direct investment: the case of Japanese firms, *Applied Economics*, **35**, 1739–46.
Pugel, T. A., Kragas, E. S. and Kimura, Y. (1996) Further evidence on Japanese direct investment in US manufacturing, *The Review of Economics and Statistics*, **78**, 208–13.
Robert, R. and Ramana, R. (1997) Re-industrialization: causes and implications, IMF Working Paper.
Rowthorn, R. E. and Wells, J. R. (1987) *Re-industrialization and Foreign Trade*, Cambridge University Press, New York.
Rugman, A. M. (1981) *Inside The Multinationals*, Columbia University Press, New York.
Scherer, F. M. (1992) *International High-Technology Competition*, Harvard University Press, Cambridge, MA.
Schumpeter, J. (1950) *Capitalism, Socialism and Democracy*, Harper Row, New York.
Shan, W. and Song, J. (1997) Foreign direct investment and the sourcing of technological advantages: evidence from biotechnology industry, *Journal of International Business Studies*, **28**, 267–84.
Singh, A. (1977) UK industry and the world economy: a case of de-industrialization?, *Cambridge Journal of Econo*mics, **1**, 113–6.
Smith, D. M. (1981) *Industrial Location: An Economic Geographical Analysis*, 2nd edn, John Wiley, New York.
Teece, D. J. (1992) Foreign direct investment and the technological development in silicon valley, *California Management Review*, **34**, 88–106.
Thirlwall, A. P. (1982) De-industrialization in the UK, *Lloyds Bank Review*, **134**, 22–37.
Vernon, R. (1966) International investment and trade in the product cycle, *Quarterly Journal of Economics*, **80**, 190–207.
Walz, U. (1997) Innovation, foreign direct investment and growth, *Economica*, **64**, 63–79.
Yeh, R. and Lin, H. (1999) The investment of Taiwanese small and medium enterprises in China: past and the future, *Global Focus*, **XI**, December.

Appendix

Estimated coefficients when FDI and R&D treated as exogenous variable: three independent regression models

Variable	FDI decision	R&D decision (non-FDI firms)	R&D decision (FDI firms)
Constant	−2.2848***	−8.8362***	−20.399***
	(0.7979E–01)	(0.3805)	(3.0587)
R&D	0.2077E–01***		
	(0.6278E–02)		
Firm size	0.1389E–02***	0.9933E–02***	0.3719E–01***
	(0.1203E–03)	(0.5332E–03)	(0.1549E–02)
Profitability	0.2697**	0.1384E–01	−0.3345
	(0.1126)	(0.3257E–01)	(0.3838)
Sales growth rate	0.2259E–02*	0.2786E–01**	0.2926E–02
	(0.1247E–02)	(0.1270E–01)	(0.6596E–02)
Firm age	0.9661E–02***	0.1205E–01	−0.2207**
	(0.3363E–02)	(0.1323E–01)	(0.1114)
Export ratio	0.4702***	2.2545***	10.579*
	(0.1589)	(0.6373)	(5.5923)
Technology import		0.1927***	0.1525***
		(0.1072E–01)	(0.3760E–01)
Technical ability		0.5603***	1.0015**
		(0.4430E–01)	(0.3948)
Concentration ratio		2.7367*	−6.5173
		(1.4792)	(13.248)
Market growth ratio		−39.381	1115.7
		(84.163)	(812.06)
Industry			
Information-computer	0.2719***	1.4920***	0.2430
	(0.8625E–01)	(0.3969)	(3.1432)
Communication- equipment	0.2215**	1.4535***	3.2141
	(0.1079)	(0.4888)	(3.8480)

(*continued*)

Appendix Continued.

Variable	FDI decision	R&D decision (non-FDI firms)	R&D decision (FDI firms)
Electronic-parts	0.1853***	0.2769	−4.0194
	(0.5273E–01)	(0.2656)	(2.6884)
Semiconductor	−0.8902E–01	2.2848***	9.5557***
	(0.1334)	(0.48040)	(3.7038)
σ		4.0953***	18.516***
		(0.9692E–01)	(0.5890)
Log-likelihood	−2060.475	−4025.783	−2202.508
Chi-squared statistic	737.6893		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively; standard errors are in parentheses.