International R&D Deployment and Locational Advantage of Developing Countries:

A Case Study of Taiwan

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Abstract

Although it is evident that R&D has undergone the process of internationalization and the developing country is increasingly involved in this process, the substantial body of literature in this area is based mainly on the experience of the developed country. This paper aims to contribute to the understanding of this issue by examining the R&D internationalization of a newly-industrializing country, Taiwan being a prime example, and with a special focus on factors underlying locational advantage for attracting multinationals' offshore R&D. We begin with an examination of the literature on R&D internationalization and globalization, based upon which we emphasize the significance of "first-tier supplier advantage" in the Taiwanese context. We take advantage of an official database to reveal the patterns of foreign corporate R&D in Taiwan and to systematically examine the determinants of foreign affiliates' R&D intensities at the industrial level. Our empirical results show that foreign affiliates in Taiwan with a higher R&D-intensity tend to be more export-oriented, localized in Taiwan in terms of sourcing of materials and capital goods, and to belong to sectors with a larger pool of R&D labor force.

Keywords: R&D internationalization, locational advantage, foreign affiliate, Taiwan, first-tier supplier advantage

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1. Introduction

The last few decades have witnessed the surge of East Asia as a major manufacturing base in the developing world thanks initially to the catching-up of Asian Newly Industrializing Countries (NICs) and more recently to that of newly developing countries in the region, China in particular. This has much to do with both indigenous innovation and the relocation of multinationals' (MNCs) value chain activities. Lall (2003) elaborates on these points and argues that the performance of such countries as Taiwan and Korea can be attributed more to the former, while other developing countries in the region may gain momentum more from the latter.

However, it has become a rising trend that countries in East Asia are seeking to attract MNCs' R&D facilities. On the one hand, not all foreign direct investment is equally valuable because many of MNCs' subsidiaries are as footloose as "branch plants", which can lead to the so-called "branch plant syndrome" (Firn, 1975). By contrast, MNCs' subsidiaries with strong R&D mandates as well as strategic geographical or product range responsibilities tend to be stickier to the host economy and hence considered to be highly desirable in terms of their effects on local wealth generation.

On the other hand, there is a matching trend, as part of the process of globalization, that MNCs have been consolidating the R&D activities of their subsidiaries on the global scale (Petrella, 1989; OECD, 1997; Patel and Pavitt, 1998; Guellec et. al., 2001; Kaufmann and Tödtling, 2001). More importantly, the outreach of MNCs' R&D activities was initially geared to the developed country, but more recently to the developing world (Reddy, 2000). In particular, countries such as India (Reddy, 2000) and China (Xue and Wang, 2001; Chen et al., 2002; Walsh, 2003) have been documented as the high-profile developing host countries for MNCs' offshore R&D facilities. The literature on R&D internationalization has proliferated over the last decade and has focused mainly on its trend (OECD, 1997; Patel and Pavitt, 1998; Cantwell and Santangelo, 1999; Gerybadze and Reger, 1999; Voelker and Stead, 1999;

Patel and Pavitt, 2000; Kumar, 2001; Guellec et. al., 2001), evolution of organization (Zedtwitz, 2002; Gassman and Zedtwitz, 2002), motives of MNCs (De Meyer, 1993; Paoli and Guercini, 1997; Cantwell and Santangelo, 1999; Gerybadze and Reger, 1999; Zander, 1999) etc. More recent research has addressed the locational aspect of MNCs' R&D facilities, especially within a host country (Cantwell and Mudambi, 2000; Cantwell and Iammarion, 2000; Frost and Zhou, 2000). However, the relevant literature remains based mainly on the experience of the developed country.

In addition, less attention has been paid to research issues concerning the deepening of foreign corporate R&D activities in host countries, especially for a developing host country. Foreign corporate R&D deepening has been recognized as a means for the host country to anchor foreign-owned firms (Kearns and Ruane, 2001). This is particularly important for a developing country to enhance the MNCs' commitments to its domestic economy even as its comparative advantage shifts. Moreover, the deepening of foreign corporate R&D in the domestic regions is useful to capitalize on the agglomeration effect of corporate R&D activities (Carrincazeaux, et al, 2001). Nonetheless, the substantial body of the "site-selection" literature has focused mainly on the geography of new R&D facilities and investment by MNCs, neglecting that it may involve a cumulative process of expansion, contraction, and adaptation by firms of existing facilities in host-country locations (Frost and Zhou, 2000).

Set against the above background, the paper aims to contribute to the current understanding of R&D internationalization by exploring factors underlying R&D activities in a developing country, with Taiwan being the prime example. The authors are aware that such countries as China and India have drawn considerable attention in this issue (for example Reddy, 2000; Xue and Wang, 2001; Chen et al., 2002; Walsh, 2003), but on the one hand, not much systematic evidence on this issue has yet been produced and, on the other hand, their unique attributes, such as huge market potentials, may undermine the applicability of these two countries' experience to other developing countries. By contrast, Taiwan, like the majority of the developing countries, has a small domestic market, and our empirical analyses will focus on the industrial and/or

micro aspect of the issues concerned. In particular, our studies are set to identify industrial conditions in a developing country that may lead to the deepening of offshore R&D of MNCs. While the determinants of foreign R&D have been explored by the current research at the aggregate macro-level country-specific data, the role played by industrial conditions in a developing host country has remained less explored to date. For our empirical work, we draws on "Statistics on Overseas Chinese & Foreign Investment", a Taiwanese government database concerning foreign corporations' business operation activities in Taiwan, which enables us to utilize the aggregate industrial level and time-series data to examine the issue concerned.

The paper is organized as follows. The next section begins with an examination of the literature on R&D internationalization to highlight factors that may be considered as locational advantages for a developing host country to attract MNCs' offshore R&D. We borrow the concept "locational advantage" from Dunning's well-known eclectic paradigm and emphasize the significance of "first-tier supplier advantage" in the Taiwanese context. In Section 3, we take advantage of an official database to reveal the patterns of foreign corporate R&D in Taiwan. Section 4 describes the research strategy employed in the paper in terms of model specifications and data source. The empirical results are presented and discussed in Section 5. The final section provides some conclusions drawn from this study.

2. Locational Advanatage of R&D Internationalization

In the studies on R&D globalization, the bottom line appears to be that although not yet truly globalized, R&D is undergoing a process of globalization (Howells, 1992) and that progress varies across sectors and economies (Casson and Singh, 1993; Dunning, 1994). More recent literature (OECD, 1997; Patel and Pavitt, 1998; Guellec et. al., 2001; Cantwell and Santangelo, 1999; Gerybadze and Reger, 1999) has also confirmed that this is an escalating trend, but despite this trend, the globalization of R&D has largely been considered as a developed country-centric phenomenon.

However, Reddy (2000), amongst others, has in fact revealed a rising trend in

terms of the R&D operations of MNCs in the developing world. The factors underlying this trend, as highlighted by Reddy, can be summarized as followed. In specific terms, MNCs are themselves faced with an increasing need to monitor and learn the new global trends and hence to engage in multi-sourcing of technology inputs, partly because of rising R&D costs, the increasing demand for R&D personnel and a shortage of R&D personnel in the industrialized countries. Conversely, some, if not a great many, of the developing countries are able to provide an abundant supply of R&D personnel or skills, especially with regard to the so-called 'non-core' R&D areas. This match of supply and demand has been facilitated by factors such as improved information and communication technologies, the flexibility of new technologies which allows de-linking of manufacturing and R&D, and the comparative advantages of the developing host countries.

For our empirical work, we propose a concept framework for further analysis which is essentially based on Dunning's (1993) eclectic paradigm, with a strong flavor of the evolutionary approach to technology (Nelson and Winter, 1982; Frost and Zhou, 2000). According to Dunning, where firms possess advantages of ownership and internalization, and host countries enjoy locational advantages, international production may take place. In our view, Dunning's paradigm can be useful for analyzing the offshore R&D activities of multinationals if one interprets ownership, internalization and locational advantages in the context of R&D, with these advantages being related mainly to the technological routines and trajectories of the firms and the host countries (Dosi, 1982). In short, what a firm and an economy can do, or is about to do, is linked strongly to their routines and previous bases.

In our opinion, the ownership advantages of MNCs generally lie in their core technology and world-class brand names. Their core technologies allow them to set the agenda, at an international level, and influence the way in which technology will progress, whilst their world-class brand names enable them to gain direct access to customers and marketplaces, which in turn facilitate their initiation of concepts for product development and the means of further exploiting market potential elsewhere.

The internalization advantages of MNCs may include systems integration capabilities, product planning capabilities, market access advantages and information and communication networks. In particular, with systems integration capabilities and information and communication networks at their disposal, they may be able to deploy core and non-core R&D across boundaries, whilst maintaining control over the profits generated during the whole process. Likewise, the possession of product planning capabilities and market access advantages means that MNCs have control over the two ends of the 'smiling curve', and hence, have the final say in the benefits derived from the entire value-chain they face.

With regard to Taiwan as a location for offshore R&D by MNCs, we have to refer to the way in which economic development has evolved on the island, since it is well-known as a typical example of the export-oriented industrialization paradigm. Although this goes hand in hand with the process of migration from labor-intensive sectors towards high-technology and capital-intensive industries, Taiwan's major sectors are characterized by their vertical disintegration and the pursuit of OEM/ODM contracts for brand marketers, without direct access to the final market. In terms of R&D, local firms may, in general, lack systems integration capabilities and the ability to take the initiative in product and technology development; however, some of the industrial players may be positioned as 'first-tier suppliers', possessing innovation capabilities in certain areas and industrial segments, which could be considered as Taiwan's main locational advantage in offshore R&D. A notable example at issue is Intel which has recently set up an R&D and innovation center in Taiwan dedicated to product innovation in WLAN partly because Taiwan has been the major global supplier of WLAN sets. Others examples involving Sony and HP seem to follow the same logic. This is particularly feasible for such a sector as the information technology (IT) industry because Taiwanese's IT firms have evolved from pure manufacturers towards integrated service providers, giving rise to intensified interdependence between the network flagships and their Taiwanese subcontractors (Chen, 2002). Having said that, even in such an industry as footwear, we can find the collocation of Nike's main offshore R&D center and its main supplier, Pao Cheng Industrial Corporation, in Taichung.

To elaborate on this point, for such an economy as Taiwan, her industrial clusters co-evolve with the international industrial structure of the sectors concerned. In addition, whether or not her industrial clusters are sustainable depends heavily on the extent of "localization", which may involve at least two things: first, the presence of indigenous firms with substantial innovation capabilities; and second, the ability to "anchor" the "network flagships". With regard to the latter, we mean more than the local operations or investments of the network flagships because they can be as footloose as "branch plants", as compared to "performance plants". Instead, we mean something like international linkages that are so enduring as to enable those indigenous firms to leverage for industrial upgrading.

Moreover, the trend of globalization involves a process of increased disintegration in production and even innovation capabilities around the globe (Feenstra, 1998), with the result that some, if not many, of the indigenous firms and/or industrial clusters in the developing world nowadays are able to shoulder important functions that used to be undertaken by their counterparts in the developed world. For one thing, outsourcing has become a widely adopted practice in quite a number of industries for the brand marketers to stay cost-competitive. As a result, many network flagships have become "hollowing-out" corporations, focusing their operations on the two ends of the "Smiling Curve", namely the R&D and marketing functions (Chen and Ku, 2000; Kotabe, 1996; Swamidass and Kotabe, 1993; Venkatesan, 1992), leading to certain degree of de-linking of R&D and manufacturing for the sector concerned; and typical examples at issue include Ericsson in the handset industry and IBM in the PC industry. Within this process, the brand marketers are increasingly linked up with other firms that may not be in the neighborhood.

In addition, innovations in many cases involve technical systems that are inherently large, comprising of a set of jointly-consumed interdependent products (Windrum, 1999). Because of network effects and product compatibility, successful innovations for technical systems entail intensive interfaces between multiple actors with different knowledge and skills bases, termed as 'innovation networks'. By

implication, not only does such an innovation often result from the collective efforts of inter-related firms, but it also demonstrates that the value chain does not need to be completely internalized within individual firms. Therefore, in many cases, industrial competition takes place between rival technological and production networks that contain a multiplicity of differentiated firms, rather than between vertically integrated oligopolists.

In a sense, the evolutionary approach to technology (Nelson and Winter, 1984) is a constructive building block underlying the concept of international linkages. The essence of this approach, in short, is that what a firm and an economy can do, or is about to do, is linked strongly to their routines and previous bases. In technological terms, a firm can be considered as a producer, repository, and user of knowledge, producing or acquiring knowledge and putting it to use efficiently. Each firm's competitive advantage lies in its stock of knowledge, and because firms possess idiosyncratic knowledge they are likely to be heterogeneous. Product innovation involves an assortment of knowledge related to various stages of the value chain. Knowledge applied to manufacturing, marketing, and customer services is complementary to the knowledge used in product innovation. Vertical integration of the innovation function in the value chain is only justified, however, if internalization is the best way to acquire the relevant knowledge, and this is not often the case. Since product innovations address the needs of customers, the knowledge most valuable to product innovation is that obtained from interacting with customers, in other words, marketing. Therefore, product innovation combined with marketing may be the optimal mix of services offered by a firm, which may involve interactions between firms and their customers and suppliers.

Relevant studies on this issue highlight some more additional motives for MNCs' offshore R&D. The substantial part of the literature together suggests that the location decisions of MNCs' offshore R&D are generally determined by the following four major factors: First, MNCs intend to be close to their clients for the purpose of offshore R&D. The host country's industrial advantages can therefore be regarded as a driving

force to anchor offshore R&D of MNCs. In this regard, accumulated production experience and capabilities of a host country may serve as an important local condition to attract MNCs' R&D facilities. For example, Fors and Zejan (1996) suggest that MNCs' offshore R&D to a large extent is found in locations where overseas production is taking place. These expatriated R&D investments generally support the local use of production-technology and products, which are designed or created outside the home country.

Second, MNCs may undertake offshore R&D to access to new foreign technologies for developing new products and production processes. Due to the dynamics of technology, some R&D oriented firms based in Asia and Europe, for example, have set labs in the US to take advantage of 'centers of excellence' (Dambrine, 1997; Voelker and Stead, 1999). Fors and Zejan (1996) argue that MNCs tend to locate their R&D in the host regions which are relatively specialized technologically in the firms' own areas, for gaining access to foreign centers of excellence and to take advantage of localized knowledge spillover. Similarly, Niosi (1999) indicates that learning is a critical element in the new trend of international R&D, which often entails locating closely to major innovatory centers in order to broaden the scope of the parent's technological portfolio.

Third, it is regarded as increasingly important for MNCs to relocate their R&D overseas for hiring foreign R&D labor force. Through looking at locational choice of overseas R&D investment by MNCs based in the US and Japan, Kumar (2001) argues that a country with abundant R&D labor forces will enjoy a locational advantage in attracting MNCs' R&D investment.

Fourth, the locational choice of MNCs' overseas R&D can be motivated by the serving of local markets. Through examining determinants of foreign affiliates' R&D investment in 16 OECD countries, Gao (2000) highlights the market size of host countries as one of the critical factors. Besides stressing the significance of foreign market size, Kumar (2001) summarizes three locational advantages of host countries in driving foreign R&D investment: large domestic market, abundance of low cost R&D

manpower, and the scale of national technological effort.

To put it in another way, Westney (1992) has identified four research mandates in terms of vertical technology scope: technology transfer, product modification, new product development, and basic research. And each research mandate has its own geographic scope. In general a mandate of basic research will require close linkages with local basic research centers, such as universities and research institutions. A mandate of local product modification requires a close linkage to consumers.

The foregoing research relies mainly on case studies, questionnaire surveys or aggregate country data to examine the determinants of locational choice of MNCs' offshore R&D, and most of the studies are based on the experience of the advanced countries. In light of these, we are therefore motivated to apply the industrial level data to examine the determinants of MNCs' R&D oversea in a developing country, like Taiwan.

3. Foreign Corporations' R&D in Taiwan

Against this backdrop, many countries in East Asia, including Taiwan, have orchestrated programs to attract foreign-owned R&D units, jumping on the bandwagon of promoting their local economies as international innovation 'hubs'. This gives rise to an important question concerning factors that may drive MNCs' offshore facilities to become engaged in R&D activities. As a matter of fact, although it is well-documented that foreign direct investment (FDI) has played an important role in Taiwan's economic development, it is seldom realized that to some degree, some of the MNCs in Taiwan have also invested in R&D. Calculated from the data set of Investment Commission, MOEA, Taiwan's estimated average R&D intensities for foreign-owned subsidiaries are 1.22%, 1.48%, and 2.49% respectively over the periods 1996-91, 1992-96, and 1997-2000, perhaps indicating that Taiwan's mandate has significantly improved in terms of MNCs' regional or global innovation network. The last figure becomes more significant if we take into account the fact that Taiwan's total R&D expenditures just accounted for 2.16% of GDP in 2001.

Table 1 R&D intensity of Foreign Corporations and capital inflow in Taiwan's manufacturing sector

	1987-91	1992-96	1997-2000
R&D intensity ratio (%)	1.22	1.48	2.49
Capital inflow (US$1,000)	5,737,184	5,026,103	7,305,936

Source: Investment Commission, MOEA, R.O.C., Statistics on Overseas Chinese & Foreign Investment.

As Table 2 shows, the survey for the 1987-2000 period reveals that the electrical and electronic machinery industry registers the highest R&D intensity of foreign corporations, followed by the primary metal and products and machinery industry. By contrast, both the food and beverages, and lumber, wood products and furniture sectors are the industries with lowest R&D intensity of foreign corporations in Taiwan. Not surprisingly, these industries with high foreign R&D activities tend to fall in the category of the so-called high-tech industries, while traditional industries registered a relatively lower foreign R&D intensity.

Table 2 R&D Intensities and capital inflow of Foreign corporations at an industry level, 1987-2000

Manufacturing Industry	R&D Intensities (%)	Capital inflow distribution (%)
Electrical and electronic machinery	2.72	23.83
Primary metal and products	2.47	4.96
Machinery	1.47	5.65
Leather and related products	1.18	0.42
Pulp, paper and allied products	0.97	0.32
Chemicals and chemical products	0.87	8.22
Rubber and plastic products	0.46	1.31
Textile and apparel	0.32	1.18
Food and beverages	0.26	2.90
Nonmetallic mineral products	0.24	1.10
Lumber, wood products, and furniture	0.17	0.22
Mean/Total	1.80	100.00

Source: Investment Commission, MOEA, R.O.C., Statistics on Overseas Chinese & Foreign Investment.

Moreover, Pearson correlation ratio shown in Table 2 reaches the level of 0.725, pointing out a high and positive correlation between foreign corporate R&D intensity

and the distribution of capital inflow within the manufacturing industry. Similarly, OECD (2001), based on its members' data, has revealed a positive correlation between share of foreign affiliates in manufacturing turnover and that in manufacturing R&D on the international scale. On the one hand, this may mean the former is a necessary condition for the latter. On the other hand, in the Taiwanese context, this may suggest that those industries characterized by a higher foreign R&D investment has become the major FDI targets in recent decades. And these industries with high R&D intensity, such as the electrical and electronic machinery and machinery sectors Taiwanese's IT firms have evolved from pure manufacturers towards integrated service providers are also indeed Taiwan's primary export industries.

4. The Research Strategy

For our empirical work, we draw on an official databank and employ a regression technique to explore the factors determining R&D intensity of foreign affiliates in Taiwan. This section discusses the research strategy and the key features of the empirical studies.

4.1. Model

The principal aim of our empirical enquiry is to explore features which characterize foreign affiliates with a higher R&D intensity. The dependent variable is therefore denoted as **Rdr**, R&D intensity of foreign corporations at the industry level. $\mathbf{Rdr}_i$ is measured as the logarithm of ratio of foreign corporations' total R&D expenditure performed to total sales in industry *i*. By doing so, the total R&D expenditures by foreign subsidiaries are normalized by their sales to control for the size effect. In terms of explanatory variables, the study follows Varsakelis (2001) to incorporate the local procurement ratio in both materials (LOCMR) and capital goods (RAT1), and export orientation (EXR) into our regression equation of foreign corporations' R&D intensity (RDR). In addition, we examine the impact of R&D labor force (LRDP) and local industrial R&D capabilities (IRDR) on the foreign corporate

R&D activities. The definitions and measurements of explanatory variables in the empirical model are described as follows:

KLR: Capital labor ratio, measured by the ratio of the book value of fixed capital stock to total labor expenditures. We attempt to examine whether **KLR** has a statistically significant coefficient in the R&D intensity equation. This variable is to characterize the attributes of production technologies employed by foreign affiliates. Ramstetter (1999) compared foreign multinationals and indigenous firms in Asian manufacturing industries and found that MNCs generally adopt relatively high capital-intensive production technologies, which may suggest MNCs' endowments of firm-specific assets. However, to some extent, high KLR may indicate the homogeneity of products. An industry with high KLR provides high homogenous products with lower product differentiation. For this reason, we presume that a foreign firm associated with high capital intensity has low incentive to making R&D investment in host countries.

LOCMR: is a local contents ratio, measured by the share of value of local materials to value of purchased materials. A square term of LOCMR, $\mathbf{LOCMR}^2$, is used in this model to take into account a possible non-linear influence on RDR. These variables are designed to examine the locational advantage of a host country in terms of industrial capability. As argued Reddy (2000), one of the main factors for R&D investment by MNCs in developing countries is the local industrial capability to produce advanced manufactured products. This will be helpful for MNCs to exploit their innovation assets and enhance the market competitiveness. LOCMR may reflect the local dependency of foreign affiliates' in terms of supply chains, underlining the industrial capabilities of host countries. Thus, the coefficients of both variables are presumed to be statistically significant and positive in the model.

RAT1: Local capital investment ratio, measured by the ratio of local capital purchased to sales by controlling size effect. Similar to **LOCMR, RAT1** in

this paper is intended to examine whether the industrial capability of a host country can be a locational advantage to leverage R&D investment of foreign affiliates. The host countries' excellent industrial infrastructure in terms of vertical industrial linkage may attract foreign affiliates to undertake R&D activities in order to effectively interact with the local suppliers of capital goods for innovation. In addition, this research compares the effects of **RAT1** with **RAT2**, which is the imported capital investment content, measured by the ratio of imported capital purchased to sales, on foreign corporate R&D intensity. We presume that the coefficient of RAT1 is positive in equation (1) and higher than the one of **RAT2**.

EXR: Export propensity, measured by the logarithm of ratio of exports to sales. It is well-documented that the market size of a host country plays an important role as a locational advantage in attracting foreign R&D in order to serve the local market and/or customize products for the local market. However, In some cases, foreign affiliates may function simply as an export outpost for their parent companies (Kumar, 2001). This may be particularly true for such a country as Taiwan given its small market size. Therefore, it is possible that R&D operations of MNCs' subsidiaries in Taiwan may capitalize on Taiwan's locational advantage in order to serve the international market. Thus, we presume that the coefficient of EXR in the equation is statistically positive and significant.

LRDP: local industrial R&D capabilities, measured by the logarithm of numbers of R&D employees for each industry. This variable is a proxy for the availability of R&D labor force in the local industries. As shown in many studies, seeking for available R&D labor force may motivate MNCs to locate R&D operations abroad (Kumar, 2001). Thus, we presume that the coefficient of **LRDP** in the R&D intensity equation is positive.

To examine the determinants of the foreign corporate R&D intensity, industrial-specific attributes are also taken into consideration in the paper, with the

summary of the variable definitions being provided in Table 3. It should be noted, however, that this model does not consider certain omitted variables, including Taiwanese corporations' R&D investment and coordination costs of cross-border R&D, which are emphasized by many studies, such as Camtwell and Iammarino (2000) and Fischer and Behrman (1979). Take into account the attribute of pooling data, we need to specify the fixed effects and random effects models. In addition, in the estimation of the regression models, we consider the influence of 10 manufacturing industries, but not including the leather sector because of too many missing observations.

Table 3 Definitions of Variables Used in the Statistical Analysis

Variable	Definition	Impact on RDR
RDR	R&D intensity of foreign subsidiaries	
KL	Capital to labor ratio	+
RAT2	Imported capital content ratio	+
RAT1	Local capital content ratio	+
EXPR	Export ratio	+
LOCMR	Local material content ratio	+
EXPER* LOCMR	Cross-term of EXPER and LOCMR	+
LR&DP	Availability of R&D labor force	+

Based on the above discussion, the study derives a set of regressions for the industry *i*. The equation is

$$Rdr_{it} = a_0 + a_1 EXPR_{it} + a_2 LOCMR_{it} + a_3 EXPR_{it} * LOCMR_{it} + a_4 RAT1_{it} + a_5 RAT2_{it} + a_6 KL + a_7 LRDP_{it} \quad (1)$$

where $LOCMR_{it}$ is the ratio of local material expenditures to total material expenditures in terms of percentage; $EXPR_{it}$ denotes the portion of exports to total sales in terms of percentage; $LOCMR_{it} * EXPR_{it}$ refers to the cross-term of $LOCMR_{it}$ and $EXPR_{it}$; Klr_{it} is the ratio of capital stock to total labor costs; RAT1 and RAT2 denote local capital investment ratio and imported capital investment ratio respectively; and $LRDP_{it}$ denotes the number of R&D labor in industry *i* in year *t*. All the variables are taken in terms of the derivative of natural logarithm in the empirical models. And other industrial specific

attributes are reflected in the fixed effects or random effects model.

In the literature, equation (2) is known as the fixed effects model if the intercept may differ across individual groups (here the 10 industries) and each individual intercept does not vary over time. Thus, equation (1) can be rewritten as

$$Rdr_{it} = a_0 + a_1 EXPR_{it} + a_2 LOCMR_{it} + a_3 EXPR_{it} * LOCMR_{it} + a_4 RAT1_{it} + a_5 RAT2_{it} + a_6 KL + a_7 LRDP_{it} + \sum \lambda_i IND_i + \varepsilon_{it} \qquad (2)$$

In other settings, we may view each individual specific constant term as randomly distributed across individual groups. It follows that equation (1) can be reformulated as the following equation,

$$Rdr_{it} = a_{0i} + a_1 EXPR_{it} + a_2 LOCMR_{it} + a_3 EXPR_{it} * LOCMR_{it} + a_4 RAT1_{it} + a_5 RAT2_{it} + a_6 KL + a_7 LRDP_{it} + \varepsilon_{it} \qquad (3)$$

where a_{0i} is the intercept with random disturbance characterizing the *i*th observation and can be expressed as $a_{0i} = a_0 + u_i$, i=1,2,…,10. And u_i is a random error term with a mean value of zero and variance of σ_u^2.

4.2. The Data

The Industrial-level data set used in the study is collected by the Investment Commission, MOEA, Taiwan, which contains information on foreign affiliates' production and R&D in the manufacturing sector. Industry-specific R&D data is taken from the National Science Council. The industrial data are available over the period 1987-2000, and we pool together data for these 14 years to gain our sample.

Table 4 Summary of Statistics

Variables*	Mean	Std.Dev.	Minimum	Maximum	#of observations
RDR	-5.409	1.451	-11.614	-0.938	137
EXPR	-1.404	0.860	-4.765	-0.007	137
LOCMR	-0.784	0.518	-4.184	-0.007	137
LOCMRS	0.882	1.912	0.000	17.507	137
LOCMR* EXPR	1.019	0.808	0.006	5.359	137
LRATIO	-5.314	0.862	-8.164	-3.549	137
KL	1.401	0.904	-5.888	4.031	137
RAT1	-3.504	1.256	-8.662	-0.566	137
RAT2	-4.200	1.348	-10.094	-0.946	134

*: all variables are taken in terms of natural logarithm

Source: Calculated from Investment Commission, MOEA, R.O.C., *Statistics on Overseas Chinese & Foreign Investment.*

Table 4 provides the summary of descriptive statistics of these variables with 141 available observations. Table 5 presents the correlation coefficients for all the variables used in our empirical model, with the statistics showing that both high correlations exists between EXPR*LOCMR and EXPR, and LOCMR and LOCMRS where the correlation coefficient is over 0.5. However, all the other correlation coefficients are rather small, suggesting that no serious problem of multicollinearity exists within our empirical model

Table 5 Correlation Analysis

	EXPR	LOCMR	LOCMRS	LOIM	RAT1	RAT2	LRDP
LOCMR	-0.185						
LOCMRS	0.168	-0.930					
LOCMR*EXPR	-0.667	-0.401	0.251				
RAT1	0.194	0.035	-0.016	-0.209			
RAT2	0.134	0.112	-0.121	-0.149	0.351		
LRDP	0.115	0.063	-0.102	-0.186	0.247	0.142	
KL	-0.119	-0.038	0.015	0.090	0.170	0.065	0.140

Source: Calculated by the authors

5. Emprical results

This section presents and discusses the empirical results, which are summarized in Table 6. The specification in columns (1) – (4) in Tables 6 generally include the export dependence, local input content and their cross-term, while columns (5) – (8) further take capital labor ratio into account. Based on the OLS residuals, we have undertaken Lagrange multiplier test statistics of χ^2 for each regression equations. The statistics for each equation are significant at the 5 percent level of significance. It is therefore necessary for us to apply Hausman test to each equation to examine the statistical robustness of the fixed effects model or the random effects model. The statistics Chi-square values of equations (1), (2), (3) and (6) in Tables 6 are statistically significant, suggesting that these models are in favor of the fixed effects model against the random effects model. Most importantly, the overall results suggest that six of the explanatory variables: EXPR, LOCMR, LOCMRS, EXPR*LOCMR, RAT1, LRDP are each significant (all at the 5 per cent level) in some, if not all of the equations.

Foreign-owned subsidiaries with higher R&D intensity are found to be characterized by higher extent of localization in terms of sourcing of both production materials and capital goods. To interpret this finding, one can refer to Westney's (1990) arguments that MNCs' offshore R&D units are given higher hierarchical mandates if their ties with the local scientific and technical community are gaining strength (and probably, therefore, greater R&D intensity). To put this another way, Reddy (2000) championed the concept of 'first-tier supplier advantage' as a locational advantage for attracting MNCs' R&D units, which may imply that foreign-owned subsidiaries with a higher degree of localization may need to devote more effort to R&D in order to effectively interact with their local suppliers.

By controlling the variable Localmr, we also find that in Taiwan, foreign-owned electronics firms with higher export propensity tend to be more R&D intensive. As is widely known, quite a substantial part of the manufacturing industry in Taiwan is internationally competitive and export-oriented, with local players in many of the sub-sectors enjoying first-tier supplier status. By analogy, their MNC counterparts in

Taiwan may have to act in the same way in order to exploit Taiwan's advantages.

In addition, we find that where Taiwanese industrial sectors have a larger pool of R&D employees, their constituent foreign affiliates tend be more R&D intensive. On the one hand, this seems to imply that foreign affiliates in Taiwan are driven by local technology pool to undertake R&D. On the other hand, assuming that a larger pool of R&D employees in a sector implies its local firms are more technology aggressive, one can argue that indigenous R&D efforts serve as a complement to, rather than a substitute for, foreign affiliates' R&D activities. Below we categorize three main effects, namely the local industrial capability effect, market linkage effect, and R&D labor resource effect, for further discussion.

Table 6 Regression Results of Foreign Affiliates's R&D Intensity at industry leve

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Fixed Effect	Fixed Effect	Fixed Effect	Random Effect	Random Effects	Fixed Effects	Random Effects	Random Effects
EXPR	1.336 (3.898)**	0.941 (2.499)**	1.014 (2.785)**	0.915 (2.997)**	1.021 (2.989)**	1.318 (3.876)**	0.889 (2.436)**	0.927 (2.655)**
LOCMR	2.638 (2.837)**	2.292 (2.347)**	2.058 (2.173)**	2.091 (2.313)**	2.040 (2.216)**	2.590 (2.807)**	2.153 (2.231)**	1.890 (2.029)**
LOCMRS	0.511 (2.612)**	0.456 (2.230)**	0.395 (1.988)	0.371 (1.949)	0.371 (1.924)*	0.505 (2.603)**	0.428 (2.115)**	0.362 (1.850)*
EXPR*LOCMR	1.015 (2.860)**	0.859 (2.375)**	0.827 (2.311)**	0.860 (2.584)**	0.882 (2.550)**	1.018 (2.895)**	0.828 (2.328)**	0.779 (2.229)**
RAT1		0.257 (2.332)**	0.238 (2.324)**	0.303 (3.296)**	0.268 (2.755)**		0.270 (2.503)**	0.261 (2.624)**
RAT2		0.098 (1.200)					0.090 (1.102)	
LRDP				0.498 (4.248)**	0.476 (2.807)**			
KL					-0.231 (-2.016)**	-0.209 (-1.763)	-0.173 (-1.481)	-0.200 (-1.732)
constant				-6.137 (-6.216)**	-5.693 (-4.376)**		-2.221 (-2.501)**	-2.612 (-3.333)**
LMT $\chi^2(1)$	115.15**	79.38**	82.42**	15.63**	10.23**	117.20**	66.82**	73.40**
Hausman	$\chi^2(4)$=42.99**	$\chi^2(6)$=58.16**	$\chi^2(5)$=26.02**	$\chi^2(6)$=9.18	$\chi^2(7)$=3.43	$\chi^2(5)$=66.17**	$\chi^2(7)$=2.82	$\chi^2(6)$=4.39
#of observations	137	134	137	137	137	137	134	137

Notes:

[a] Dummy variable proxy three industries: the primary metal and products, machinery, and electrical and electronic machinery sectors.

[b] ** represents statistical significance at the 5 per cent level.

5.1 LOCAL INDUSTRIAL CAPABILITY EFFECT

Columns one and two in Table 6 includes the LOCMR and $LOCMR^2$ measures. Both coefficients are positive and statistically significant, revealing that foreign affiliates in Taiwan using more local materials in their production have higher R&D investment. Two aspects of these empirical results stand out. First, the result support our hypotheses in the previous section that host country's excellence in production capabilities in terms of industrial value chain can be regarded as one of the locational advantages to leverage foreign corporations to increase their R&D investments, even in a developing host country. Due to severe global competition, MNCs may need to establish their offshore R&D centers close to their production partners for the purpose of time to market. Second, the extent of local sourcing in terms of both production materials and capital goods not only reflects the degree to which MNCs' offshore facilities are localized in the host country, but also may prompt them to upgrade their local operations in terms of R&D.

Consistent with this, we also compare the effects of RAT1 and RAT2 on foreign corporate R&D intensity. From Columns (2) and (6) in Tables 6, the coefficients of RAT1 are not only statistically significant and positive, but also larger than those of RAT2, further demonstrating that local industrial infrastructure matters in driving foreign corporate R&D in a host country.

5.2 Market Linkage EFFECT

While much of the literature on R&D internationalization emphasizes the importance of market access for MNCs' offshore R&D, for a country, like Taiwan with small domestic market size, the market linkage effect may mean more to this issue hence may be regarded as a location-specific advantage for such a host country to leverage foreign R&D investment. For all specifications we find that foreign-owned firms in Taiwan with higher export propensity tend to be more R&D intensive. As a country characterized by internationally competitive and export-oriented, Taiwan may

be able to host some MNCs to capitalize on its comparative advantages to serve the international market. Indeed, in a questionnaire survey undertaken for a separate study (Liu, Chen and Lin, 2002), we asked R&D performers of foreign affiliates to identify their highest level R&D activities in Taiwan. The results showed that predominant level appeared to be the modification and development of products for the international market. Without denying the importance of market access to R&D internationalization, the evidence gleaned from the paper suggests that given accumulated comparative advantage in production and industrial value chain, developing host countries can still attract foreign R&D investment by playing the role of a hub for access to the international markets, even without large domestic market size.

It is interesting to note that the coefficient of the cross term EXPR*LOCMR is positive at the 5% level of statistical significance, indicating that there exits animportant interaction effect between foreign affiliates' export propensity and local content ratio in enhancing foreign affiliates' incentive to local R&D.

5.3 R&D LABOR RESOURCE EFFECT

Finally, turning to the explanatory variable, LRDP, the estimated parameter has the expected positive sign in the regression model and is significant at the 5% level in both the fixed effects and random effects models. It therefore follows that the local R&D labor pool on the industrial level is positively and significantly related to the corresponding foreign affiliates' R&D intensity, confirming our hypothesis that MNCs tend to locate their overseas R&D investment to countries with abundant R&D resources. This result is also consistent with much research that emphasizes the escalating importance of the supply-side force in driving R&D internationalization. By implication, it can be argued that a host country needs to demonstrate its technological strengths in certain industrial segments in order to attract MNCs' offshore R&D.

6. Conclusions

In the process of globalization, international economic development has much to

do with relocation of MNCs' value chain and indigenous innovation. These two factors however are inter-related. In light of the footlooseness of MNCs' cross-border operations, it is increasingly deemed important for a host country to attract MNCs' facilities with strategic mandates, such as that of R&D. Therefore, R&D internationalization has become a trend that is no long confined within the developed world and the developing country is increasingly getting involved in this process. This gives rise to an important question as to what locational advantage a developing country may have and develop in order to attract MNCs' R&D activities.

In studying this issue, Taiwan appears to provide an interesting case. While such high-profile countries in this issue as China and India each have a large domestic market and a large pool of R&D labor force, Taiwan is obviously not the case, making the Taiwanese case more meaningful to many developing countries. In addition, the paper goes a step forward than the previous research by exploring the issue at the industrial level, which appears to be more insightful.

Our empirical results show that foreign affiliates in Taiwan with a higher R&D-intensity tend to be more export-oriented and localized in Taiwan in terms of sourcing of materials and capital goods. In addition, we are able to prove with statistical robustness that those sectors with a larger pool of R&D labor force tend to attract more foreign affiliates' R&D activities. While some of our results are consistent with the previous findings, others may need to be interpreted in the context of Taiwan's economy. For example, the size of local R&D labor force may reflect Taiwan's technological strengths in certain industrial sectors which may in turn attract MNCs' to invest in R&D in Taiwan. This is in line with the so-called technology-related motive, namely to tap into foreign science and technology resources. Of interest is the finding that foreign affiliates with a higher degree of localization in terms of sourcing of materials and capital goods tend to be more R&D-intensive. To interpret this finding, one can refer to Westney's (1990) arguments that MNCs' offshore R&D units are given higher hierarchical mandates if their ties with the local scientific and technical community are gaining strength (and probably, therefore, greater R&D intensity). To

put this another way, Reddy (2000) championed the concept of 'first-tier supplier advantage' as a locational advantage for attracting MNCs' R&D units, which may imply that foreign-owned subsidiaries with a higher degree of localization may need to devote more effort to R&D in order to effectively interact with their local suppliers. Moreover, we also find that not only foreign affiliates with a higher export propensity tend to be more R&D-intensive, but also the effect of export propensity positively interact with the effect of local sourcing of materials. This may have something to with the heritage of Taiwan's economic development, which is widely known as export-oriented industrialization. Specifically speaking, some of the Taiwanese industries have successfully penetrated into the international market, giving rise to a sound industrial infrastructure and capability. As a result, their foreign affiliate counterparts may be driven by this to invest more in R&D in order to capitalize on the Taiwanese comparative advantage, especially when they are reliant more on local materials.

Throughout the paper, there is a focus on the concept of the evolutionary approach to technology in interpreting Taiwan's inward R&D internationalization. Without denying the possibility of leapfrogging development, we would like to emphasize the significance of a cumulative process of expansion to developing countries' efforts to anchor MNCs' offshore R&D. As Ernst puts (2000), an ideal location for knowledge-intensive activities is characterized by three conditions: attractive lead markets, a highly developed production structure and excellent research environments, but not all of the criteria can be met at the same time by many locations in the developing country. The experience of Taiwan seem to suggest that a developing country, even without world-leading R&D centers of excellence, can still build up a competitive production base as a starting-point to take part in a global production networks and in due course this accumulated production capability can become an incentive for foreign affiliates to invest in R&D..

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