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FDI and Innovation as Drivers of Export Behaviour:
Firm-level Evidence from East Asia

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Abstract
This paper examines the links between ownership, innovation and exporting in electronics firms in three late industrializing East Asian countries (China, Thailand and the Philippines) drawing on recent developments in applied international trade and innovation and learning. Technology-based approaches to trade offer a plausible explanation for firm-level exporting behavior. The econometric results (using probit) confirm the importance of foreign ownership and innovation in increasing the probability of exporting in electronics. Higher levels of skills, managers' education and capital also matter in China as well as accumulated experience in Thailand. Furthermore, a technology index composed of technical functions performed by firms emerges as a more robust indicator of innovation than the R&D to sales ratio. Accordingly, technological effort in electronics in these countries mostly focuses on assimilating and using imported technologies rather than formal R&D by specialized engineers.

JEL Codes: F23, O31, O32, L63, O57
Key words: foreign direct investment, innovation, technological capabilities, R&D, firm-level exports, electronics, East Asia, China, Thailand and the Philippines

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I. INTRODUCTION

There is growing empirical testing of the relationship between foreign direct investment (FDI) innovation and exports at firm-level. This literature has been empirically led through econometric analysis of firm-level data sets in individual countries. An important question is whether firms' efficiency is considerably enhanced by the experience of competing in overseas markets. It has generally emerged that the characteristics of firms that export are significantly different from firms that do not. Specifically, exporting firms are larger, have higher foreign equity and are more innovative than non-exporters (for a recent selection see Bleaney and Wakelin, 2002; Barrios *et al*. 2003; Bhaduri and Ray, 2004; Raisah, 2004; Correa *et al.*, 2007). These findings from studies on developed and developing countries have been rationalised in terms of the neo-Heckscher-Ohlin Model, the neotechnology theories, the technological capabilities approach and the national innovation systems approach, among others.

The first aim of this paper is to replicate tests of the links between foreign ownership, innovation and exporting in individual countries for a sample of electronics firms in China, Thailand and the Philippines. A comprehensive firm-level export function was estimated (which includes foreign ownership, innovation and other control variables) using a Probit model. This is one of a handful of firm-level cross-country econometric studies on these issues using a common framework.[2] The dataset used in this paper is a relatively large one, covering 524 firms in China, 166 firms in Thailand and 117 firms in the Philippines. The industry and East Asian countries selected are particularly fascinating. The technologically sophisticated electronics industry is one of the East Asia's largest exports and plays a crucial role in the region's industrial development (Mathews and Cho, 2002). The giant Chinese economy has successfully attracted significant FDI inflows and has rapidly emerged as one of world's largest exporters of electronics. Thailand and the Philippines have also relied on FDI to emerge as notable electronics exporters. Much remains unknown about the export and technological behaviour of enterprises in these three countries.

The second aim is the testing of alternative measures of innovation at the firm-level – the dominant research and development (R&D) to sales ratio and a broader based technology index. The econometric results confirm the findings of earlier firm-level studies that foreign ownership and innovation increase the likelihood of exporting in all three countries. Interestingly, the technology index performs better as a proxy for innovation in the three countries than the R&D to sales ratio. This seems to suggest that only a small part of the technological effort takes the form of formal R&D by specialized engineers. It mainly consists of minor changes and adaptations to technologies from abroad.

The paper is structured as follows. The literature on firm-level exporting, FDI and innovation is reviewed in Section II. Empirical results are presented and evaluated in Section III. Section IV concludes.

II. WHY DO FIRMS EXPORT?

A. Theories

The analysis of firm-level export performance, FDI and innovation has attracted the attention of two related schools of applied economics. Nearly three decades ago, applied international trade

[2] Others include: Rasiah (2003) on Malaysia and Thailand and Wignaraja (2008a) on China and Sri Lanka.

and investment specialists began to explore the effects of the theoretical determinants of comparative advantage on firm-level export performance. Influential early papers by Hirsch and Adar (1974), Auquier (1980) and Glejser *et al.* (1980) on Dutch, French and Belgian firms stimulated subsequent empirical work.[3] This literature (which has roots in the neo-Heckscher-Ohlin Model and the neotechnology theories) suggests that the theoretical determinants of comparative advantage, which are traditionally recognized as industry-level factors[4], can also operate at the firm-level. This literature suggests that conditions of imperfect markets with widespread oligopoly as well as differences in technologies, learning and tastes underlie the notion of firm-specific advantages. It follows that almost all the theories of comparative advantage can be firm-specific determining not only which countries will enjoy a comparative advantage in international markets but also which firms can exploit that comparative advantage better than others. Incorporating the notion of firm-specific advantages, somewhat modifies the predictions of the theories of international trade as follows: (i) there are country-specific and industry-specific advantages that apply to all firms equally; and (ii) within this, some advantages will be firm-specific since certain managerial, organizational, marketing and other skills will be peculiar to each firm as will production methods, technologies and experience based know-how.

The other group with an interest in firm-level exporting is the literature on technological capabilities and national innovation systems. Focusing on innovation and learning processes in developing countries, this literature puts emphasis on the acquisition of technological capabilities as a major source of export advantage at the firm-level (see Lall, 1987 and 1992; Bell and Pavitt, 1993; Ernst *et al.*, 1998; Mathews and Cho, 2002; Rasiah, 2004; Iammarino *et al.*, 2008). Drawing on the evolutionary theory of technical change by Nelson and Winter (1982) and updates by Metcalfe (1998) and Nelson (2008), this literature underlines the difficult firm-specific processes involved in building technological capabilities to use imported technology efficiently. The central argument is that firms have to undertake conscious investments in search, training, engineering and, even R&D, to put imported technologies to productive use. Technological knowledge cannot be readily transferred internationally across firms like a physical product because it has a large “tacit” element that is difficult to codify in a meaningful way. The transfer of tacit elements of knowledge is slow and costly since it requires the acquisition of experience. Furthermore, capability building in firms rarely occurs in isolation and typically involves close and intense technological interactions between firms and institutions within a national innovation system (Lundvall, 1992). Hence, differences in the efficiency with which firm-level capabilities are created are themselves a major source of competitive advantage.

B. Empirical Studies

The available empirical studies have generally confirmed the importance of the theoretical determinants of comparative advantage and the role of firm-level innovation. Studies include a proxy for innovation and standard control variables in the firm-level exporting literature like ownership, firm size, age and human capital. Regressions were run relating export achievements to particular enterprise characteristics using different econometric methods. Early

[3] This is a large, growing literature on developed and developing countries. See Lall (1986); Wilmore (1992); Ito and Pucik (1993), Kumar and Siddharthan (1994); Bleaney and Wakelin (2002); and Barrios *et al*., (2003).

[4] The major trade theories (the Heckscher-Ohlin Model, theories of economies of scale and oligopolistic competition, the neotechnology theories and theories of economic geography) attribute the export performance of a open developing economy to its comparative advantage over another in terms of access to certain factor inputs – capital, labour, economies of scale, technology and geography (for surveys see Dosi *et al.* 1988, Grossman and Helpman, 1994; and Deardorff, 2005). Empirical applications to developing countries have sought to explain the export performance of each industry/product in terms of their various characteristics.

studies relied on OLS while recent studies have employed more refined techniques such as Tobit, Probit and Heckman selection models. Empirical studies on developing countries can be classified into three types according to the proxy for innovation employed (see Appendix Table 1).

First, a long research tradition has used R&D expenditures to sales ratio (or a dummy variable for R&D expenditures) as a proxy for innovation. The R&D to sales ratio, which captures the firm's expenditures on design and R&D, is usually available in an enterprise's accounts. R&D expenditures includes wages and salaries of R&D personnel (such as scientists and engineers); materials, education costs, and subcontracting costs. In an early study of Indian engineering and chemical firms, Lall (1986) found evidence for technological determinants of enterprise exporting. Foreign equity was found to be significant in chemicals, licenses were highly significant in engineering (1% level), and R&D was significant in both industries (but with opposite signs). Zhao and Li (1997), tested the relationship between R&D and export propensity in manufacturing firms in China and found R&D and firm size to be positive and significant determinants. Capital intensity was also significant but with a negative sign. In a study of Indonesian manufacturing firms, van Dijk (2002) found that foreign ownership and skills influenced exporting in most industries. However, R&D expenditure was only significant in mature industries while age had a negative sign in supplier dominated sectors.

Second, a few attempts have been made to include other innovation measures (e.g. patents or a measure of product innovation). Du and Girma (2007), in a regression model of exporting by Chinese manufacturing firms, used an indicator representing new product innovation with several determinants (e.g. age, training expenditures and self-raised finance). Product innovation and most explanatory variables were significant. In a study of firm-level exporting in Ecuador, Correa *et al.* (2007) use separate dummy variables to represent aspects of innovation and technology (e.g. R&D, process innovation, quality certification) that are found to be positively associated with exporting. Foreign ownership and firm size were significant but age was not.

Third and more recently, a comprehensive technology index to represent innovation has come from the technological capabilities literature in developing countries. Studies have developed a simple summary measure of technological capabilities by ranking the technical functions performed by enterprises (see the pioneering work on Thailand by Westphal *et al.* 1990).[5] The ranking procedure integrates objective and subjective information into measures of a firm's capacity to set up, operate and transfer technology. The typical approach is to highlight the various technical functions performed by enterprises and to award a score for each activity based on the assessed level of competence in that activity. An overall capability score for a firm is obtained by taking an average of the scores for the different technical functions. As discussed below, the overall capability score (often referred to as a technology index or TI) has proved robust in statistical analysis of firm-level exporting. Guan and Ma (2003), in their study of Chinese industrial firms, reveals that export performance is positively related to an index of innovative capability and firm size. In a comparative study of Chinese and Sri Lanka garment firms, Wignaraja (2008a) showed that exporting is positively correlated with an index of technological capability, learning from buyers (represented by a dummy variable) and foreign ownership. Rasiah (2003) examined the influence of an index of process technology as well as several control variables (ownership, R&D expenditure, age, and skills) in determining exports in electronics firms in Malaysia and Thailand. The process technology index and the other four

[5] Other applications of TI include: Pakistan by Romijn (1997), Mauritius by Wignaraja (2002), and Mexico by Dominguez and Brown (2004) and Iammarino *et al.* (2008).

variables were significant. In a study of Indian pharmaceuticals and electrical/electronics firms, Bhaduri and Ray (2004) used an output-based measure of R&D capability (e.g., new products developed, technical reports published, development of new designs and processes). R&D capability, foreign ownership, and raw material imports were all significant.

C. Specification and Hypothesis

Drawing on the above studies, the following econometric model is estimated for separate export functions for Chinese, Thai and Philippines electronics firms:

$$\boldsymbol{Y} = \beta \boldsymbol{X} + \boldsymbol{\varepsilon}, \tag{1}$$

where ***Y*** is the vector denoting the probability of exporting at the firm-level, ***X*** is the matrix of explanatory variables, β is the matrix of coefficients, and ε is the matrix of error terms. The dependent variable is a binary variable, taking a value of 1 if the firm is an exporter (exports to sales ratio>0) and zero if it is a non-exporter (exports to sales ratio=0). The hypotheses and explanatory variables in ***X*** in equation (1) are described below. A description of the variables is provided in Appendix Table 2.

Foreign ownership, the share of foreign equity (FOR), is expected to have a positive influence on the probability of exporting (Lall, 1986; Wilmore, 1992; Raisah, 2003; Correa *et al.* 2007; and Du and Girma, 2007). There are two *a priori* reasons. First, access to the marketing connections and know-how of their parent companies as well as accumulated learning experience of producing for export make foreign affiliates better placed to tap international markets than domestic firms.[6] Second, foreign firms tend to be larger than domestic firms and therefore better placed to reap economies of scale in production, R&D and marketing. A large firm will be better able to exploit such scale economies and enjoy greater efficiency in production, enabling it to export more.

Innovative activity at the firm-level leading to greater cost-efficiency is expected to be positively associated with the probability of exporting. As the literature on technological capabilities in developing countries indicates, the innovation and learning process in enterprises is not just a simple function of years of production experience but of more conscious investments in creating skills and information to operate imported technological efficiently (see Westphal *et al.* 1990; Ernst *et al.* 1998; Rasiah, 2003; Wignaraja, 2002 and 2008b; Guan and Ma, 2003). Such investments would include technology search, training, engineering and possibly R&D activities. Accordingly, following the empirical literature on innovation, two alternative proxies - R&D to sales ratio *and* a firm-level technology index (TI) – are used in the econometric analysis. The R&D to sales ratio captures the firm’s expenditures on design and R&D (includes wages of R&D personnel, materials and training costs). The TI which is based on the Lall (1987 and 1992) taxonomy is designed to represent a broad range of technological capabilities. It was constructed by ranking a clothing firm’s competence across a series of technical functions and the results were normalized to give a value between 0 and 1. Appendix 1 contains the details.

Age is represented by the absolute age of the firm (AGE). As firms with experience are regarded as enjoying greater experimental and tacit knowledge, age is considered to be positively associated with the probability of exporting and the building capabilities (van Dijk, 2002; Rasiah, 2003; Bhaduri and Ray, 2004).

[6] See Dunning (1993) for a discussion of the ownership advantages of multinationals.

***Human Capital**.* Within a given activity, a higher level of human capital is expected to have positive relationship with the probability of exporting (van Dijk, 2002; Wignaraja, 2008a). Higher levels of human capital (in terms of a better stock of technically qualified manpower as well as educated and experienced general managers) are associated with more rapid technological learning and development of effective business strategies which are likely to provide a competitive edge at the firm-level. Accordingly, human capital is represented by three variables – the share of technically qualified employees in employment (ETM), the level of education of the general manager (EDUC) and years of experience of the general manager (GMEXP).

Capital is represented by the value of production machinery per employee (CAP). Within a given activity, a higher level of physical capital in the form of modern equipment is expected to give a firm a competitive advantage. Thus, CAP is expected to be positively associated with the probability of exporting.

III. DATA AND EMPIRICAL FINDINGS

A. Firm-level Dataset

The analysis in this paper uses data from the Investment Climate Survey conducted by the World Bank in collaboration with location institutions in 2003 for China and the Philippines and 2004 for Thailand.[7] This survey collected data using direct interviews with a questionnaire and firms were selected using a stratified random sampling methodology. The dataset is a relatively large one totaling 807 electronics firms in the three countries (524 firms in China, 166 firms in Thailand and 117 firms in the Philippines). This is the most detailed firm-level dataset currently available for these countries and is relatively recent. The data are not publicly available but it is possible to apply for firm-level data for research purposes from the World Bank. The sample contains a mix of firms of different ownership and size classes.

B. Exploratory Data Analysis

Appendix Table 3 reports t-test results on the mean values for some firm characteristics in the three countries. Exporters are those that continue to export and new exporters while non-exporters are the rest. The main findings, which confirm those of earlier empirical studies, are as follows:

- There is a significant difference in foreign equity between exporters and non-exporters in the three countries. Exporters in the Philippines have the highest share of foreign equity in total equity, followed by Thailand and China.
- The TI significantly differs between exporters and non-exporters in all three countries but the R&D to sales is not significant in any country. This seems to suggest that the TI is likely to be a better predictor of the probability of exporting in the econometric analysis than the R&D to sales ratio.
- The general manager's education level is significantly different between exporters and non-exporters in all three countries.

[7] The Investment Climate Survey aims to better understand and thus help to improve the investment climate and its effect on business performance. It collects information about the business environment, how it is perceived by individual firms, how it changes over time, and about the various constraints to firm performance and growth (World Bank, 2008).

- The value of production machinery per employee is significantly different between exporters and non-exporters in China and Thailand.

Table 1 Average Technology Index (TI) Scores

	China	Thailand	Philippines
All Firms	0.517	0.505	0.406
Exporters	0.554	0.560	0.464
Non-Exporters	0.502	0.388	0.284
t-values	*3.643****	*5.032****	*4.780****
Foreign firms	0.544	0.577	0.429
Local firms	0.510	0.388	0.333
t-values	*2.088***	*5.876****	*2.184***
Large firms	0.543	0.586	0.437
SMEs	0.478	0.313	0.319
t-values	*5.019****	*8.790****	*2.770****

Notes: SMEs = small and medium enterprises. Exporters have >0 exports to sales ratio; foreign firms have >0% foreign equity or have a foreign partner and large firms have >100 permanent employees. t-values refer to test of differences between means of top and bottom figures; *** significant at 1%, ** at 5%, and * at 1% levels.

Table 1 provides average TI scores for all electronics firms and by exporting, ownership and firm size. Two major findings emerge. First, China has the highest average TI scores (0.517) and is closely followed by Thailand. The Philippines lags behind. Second, the gaps between the TI scores of all three categories (exporters and non-exporters, foreign and local, large and small firms) are narrower in China than in the other two countries. This seems to suggest that technology spillovers are taking place between different types of firms in the China at a faster rate than in the other two countries. Our preliminary finding seems to support the argument of Wei, Liu and Wang (2008) that mutual productivity spillovers are taking place between foreign and local firms in China due to diffusion of technology and local learning. Further empirical investigation is needed to verify this interesting finding and the factors underlying it.

Table 2 Frequency Distribution of Technology Index (TI) Scores

TI Scores	China		Thailand		Philippines	
	No. of firms	% of total firms	No. of firms	% of total firms	No. of firms	% of total firms
0.00 – 0.20	3	0.6	17	10.2	23	19.7
0.21 – 0.40	89	17.0	24	14.5	31	26.5
0.41 – 0.60	306	58.4	68	41.0	38	32.5
0.61 – 0.80	115	22.0	53	31.9	25	21.3
0.81 – 1.00	11	2.0	4	2.4	0	0.0
Total	524	100.00	166	100.00	117	100.00

Table 2 shows the frequency distribution of the TI scores in the electronics firms in the three countries. The data suggest a wide variation in TI scores between electronics firms within each country. There are only a handful of firms with a high degree of technical competence (with a score in excess of 0.81) and some firms with a medium to high degree of technical competence (with scores of in the range of 0.61 to 0.80). The remaining firms, which form the largest group, have scores below 0.60. Interestingly, the data suggest that the China and Thailand have a larger share of firms with TI scores in excess of 0.60 which is indicative of technological strengths.

C. Econometric Results

The t-tests and frequency distributions are useful descriptive devices but do not shed much light on causation. Hence, a two-stage modeling strategy was adopted to estimate an export function using the alternative proxies for innovation but the same binary dependent variable and other firm characteristics. Initially a general model was estimated followed by a reduced form model with significant variables from the general model.

Table 3 Probit Estimates: Using the R&D/Sales Ratio

Binary Variable: Exporter (1) and Non-exporter (0)

Independent Variables	China		Thailand		Philippines	
	General (1)	Reduced (2)	General (3)	Reduced (4)	General (5)	Reduced (6)
R&D	0.0010		0.0510		0.6172	
	(0.18)		(0.74)		(1.64)	
FOR	0.0172	0.0170	0.0141	0.0142	0.0194	0.0224
	(5.39)***	(5.55)***	(4.14)***	(5.76)***	(4.13)***	(5.41)***
AGE	-0.0003		0.0883	0.0387	-0.0143	
	(-0.05)		(2.75)***	(1.96)**	(-0.68)	
ETM	0.0001	0.0001	0.0003		0.0115	
	(3.08)***	(3.04)***	(0.02)		(0.81)	
EDUC	0.3625	0.3470	0.4990		0.3420	
	(2.23)**	(2.21)**	(1.65)*		(1.21)	
GMEXP	0.0069		0.0543		0.0304	
	(0.40)		(1.57)		(1.62)	
CAP	0.0046	0.0048	0.0000		0.0001	
	(2.57)**	(2.61)**	(0.74)		(0.30)	
Constant	-2.6364	-2.5393	-112.5106	-0.6258	-2.8726	-0.7350
	(-3.75)***	(-3.99)***	(-1.64)	(-2.33)**	(-1.76)*	(-2.69)***
n	351	356	134	166	77	79
Wald χ^2	48.42***	48.20***	35.99***	35.40***	34.06***	29.29***
Pseudo R^2	0.20	0.20	0.25	0.18	0.44	0.37
Log likelihood	-155.85	-157.95	-60.32	-84.91	-26.88	-30.38

Note: z-values are in parenthesis; *** significant at 1% level, ** significant at 5% level, and * significant at 10% level.

Table 3 shows the general and reduced form probit regression for the binary exporter/non-exporter variable for all firms in the three countries against the R&D to sales ratio and other firm characteristics. Most strikingly, the R&D to sales ratio is not significant (even at the 10% level) in any country. The reduced form regressions indicate the importance of other firm characteristics in explaining the probability of exporting. In China, higher foreign equity, technical skills, general manager's education level and value of production machinery per employee increase the probability of exporting. In Thailand, foreign equity and age are influential. In the Philippines, only foreign equity is significant and positive in sign. This underlies the fact that foreign firms make up the bulk of the electronics exporters in the Philippines. The R&D to sales ratio, which focuses on formal technological activity by engineers, is insufficient to capture the full range of technological effort taking place at the firm-level.

A broad based TI may be more useful in representing firm-level technological activity in developing countries. The econometric evidence underlines the value of using a broad based TI (made up of technical functions undertaken by firms) to represent innovation. Table 4 shows the general and reduced form probit regression estimates for the binary exporter/non-exporter variable for firms in the three countries against the TI and other firm characteristics. In contrast with the results for the R&D to sales ratio, the TI turns out to be significant and positive in sign in all three countries in both the general and reduced form models.

Table 4 Probit Estimates: Using the Technology Index
Binary Variable: Exporter (1) and Non-exporter (0)

Independent Variables	China		Thailand		Philippines	
	General (7)	Reduced (8)	General (9)	Reduced (10)	General (11)	Reduced (12)
TI	1.4013 (2.70)***	1.3747 (2.65)***	1.6988 (2.88)***	1.7339 (3.21)***	5.58 (4.73)***	5.2691 (5.25)***
FOR	0.0176 (5.46)***	0.0176 (5.67)***	0.0103 (3.50)***	0.0118 (4.48)***	0.0188 (3.74)***	0.0204 (4.22)***
AGE	0.0001 (0.03)		0.0896 (2.93)***	0.0505 (2.67)***	-0.0276 (1.50)	
ETM	0.0001 (2.60)**	0.0001 (2.59)**	0.0005 (0.04)		0.0017 (0.11)	
EDUC	0.2915 (1.79)*	0.2785 (1.75)*	0.2587 (1.00)		0.0246 (0.09)	
GMEXP	0.0083 (0.49)		0.0353 (1.07)		0.0182 (0.89)	
CAP	0.0048 (2.52)**	0.0048 (2.55)**	0.0000 (0.87)		-0.0000 (-0.57)	
Constant	-3.1025 (-4.27)***	-2.9932 (-4.52)***	-73.9628 (-1.11)	-1.4921 (-3.97)***	-2.7651 (-2.03)**	-2.6820 (-5.47)***
n	352	356	156	166	77	79
Wald χ^2	54.57***	54.38	38.29***	39.87***	54.35***	53.94***
Pseudo R^2	0.22	0.22	0.23	0.23	0.58	0.56
Log likelihood	-153.90	-154.74	-72.69	-79.75	-19.82	-21.19

Note: z-values are in parenthesis; *** significant at 1% level, ** significant at 5% level, and * significant at 10% level.

There are some interesting differences in the reduced form results by country. In China, TI, and foreign ownership are both significant at the 1% level and with the correct signs. Meanwhile, human capital variables (technical skills and the general manager’s education level) as well as capital are also significant and positive in sign. In Thailand, TI, foreign ownership and age are significant with the expected signs at the 1% level. In the Philippines, TI and foreign ownership are both significant at the 1% level with the expected signs. It is noteworthy that TI and foreign ownership are good predictors of export propensity in all three countries. In the case of China, higher levels of technical skills, managerial education and capital increase the likelihood of exporting. In Thailand, accumulated experience affects firms' likelihood to export.

IV. CONCLUSIONS

This paper used data from electronics firms in China, Thailand and the Philippines to replicate tests of the relationship between exporting, ownership and innovation conducted for other countries. In all three countries, there is significant evidence of the correlation between exporting, ownership and innovation as has been found elsewhere. The results indicate that higher levels of foreign equity and technological capabilities increase export propensity of firms in all three coiuntries. Furthermore, in the case of China, the probability of exporting is influenced by higher levels of skills, managers' education and capital. Accumulated experience affects Thai firms' likelihood to export. More generally, the findings suggest that technology-based approaches to trade offer a plausible explanation for firm-level exporting in developing countries.

Interestingly, the R&D to sales ratio – the dominant proxy for innovation in most empirical studies – is not significant in any of the three countries in the reduced form regressions. Nonetheless, an alternative broad based technology index (which includes R&D as one of eight components) emerges as a strong indicator of innovation at the firm-level. This result confirms the argument made by Westphal *et al.* (1990), Guan and Ma (2003) and Bhadhuri and Ray (2004) that an innovation measure based on a range of technical functions performed by firms is a robust proxy for innovation at the firm-level in late industrializing East Asian countries. Typically, little R&D is performed at the firm-level in such economies (particularly towards the development of new products and processes at the frontiers of technology) and most of the technological effort is directed towards learning to use imported technologies efficiently.

The availability of a methodology to compute a firm-level technology index and the greater availability of survey data makes it easier to develop micro-level innovation indicators particularly in developing countries. Further work is needed to refine this useful innovation tool for wider applicability in studies of innovation in developing countries. In this vein, tailoring the technology index to better capture the technical functions performed in different industries, application of more complex econometric estimation methods (e.g. panel data estimation) and improved data availability and quality would be useful ways forward.

It may be appropriate to conclude with an interesting insight from a recent survey of science, technology and innovation indicators by Freeman and Soete (2007):

"The science-technology-innovation system is one that is continuously and rapidly evolving. …, frontiers and characteristics that were important in the last century may no longer be so relevant today and indeed may even be positively misleading. The sky of STI indicators is indeed without horizons" (Freeman and Soete, 2007, p. 14).

Appendix 1: The Technology Index (TI) for Electronics Firms in China, Thailand and the Philippines.

The Lall (1987 and 1992) taxonomy of technological capabilities provides a comprehensive matrix of technical functions required for a developing country firm to set up, operate and transfer imported technology efficiently. Lall groups these functions under the three sets of capabilities - investment, production and linkages. The Lall taxonomy of technological capabilities has been successfully used by case study research to assess levels of firm-level technological development in developing countries (for a selection see Lall, 1987, Lall, Barba-Navaretti, Teitel and Wignaraja, 1994, Wignaraja, 1998; and Romijn, 1997). Subsequently, a technology index (TI) based on the Lall taxonomy (or its variants) has been developed for econometric testing in several developing countries (see, for instance, Westphal *et al.* 1990; Romijn, 1997; Wignaraja 1998, 2002 and 2008a and 2008b; and Wignaraja and Olfindo, forthcoming).

The application of the Lall (1987 and 1992) taxonomy in this study was influenced by data availability on technical firms performed by firms contained in recent World Bank Investment Climate Surveys on the three countries.[8] Nine technical functions were common to all three samples. Hence, the TI used here was based on firms' competence in the following - (i) upgrading equipment, (ii) licensing of technology, (iii) ISO quality certification, (iv) process improvement, (v) minor adaptation of products, (vi) introduction of new products, (vii) R&D activity, (viii) sub-contracting and (ix) technology linkages. A firm is given a score of 1 for each technical function it undertakes and the result is normalized to give a value between 0 and 1. This figure can be interpreted as the overall capability score for a firm.

The largest category, production, is represented by five activities that range from ISO certification to R&D activity (items iii to iv). Investment represented by two activities (items i and ii) while linkages is also represented by two activities (items viii and ix).

[8] The 2003 Investment Climate Surveys of China and the Philippines and the 2004 Investment Climate Survey for Thailand.

Appendix Table 1: Selected Studies of Exports and Measures of Innovation

Studies	Country	Sample	Measure of Technology	Model	Results/Main Findings [/a]
Using R&D expenditures					
Lall (1986)	India	100 engineering and 45 chemical firms; 1978-1980 data	R&D expenditure	OLS	Export incentives (+), product differentiation (+), and internal technological effort (+) [/c]
Willmore (1992)	Brazil	17,053 industrial firms; 1980 data	Dichotomous variable: 1 if firm has R&D program; 0 otherwise	Logit	Foreign ownership (+), advertising (+), non-wage value-added per employee (-), value-added to output ratio (-), firm's value-added (+), and geographic concentration of industry's output (+)
Kumar and Siddharthan (1994)	India	640 corporations; 1988-1990 survey data	Intensity of in-house R&D activity	Tobit	Technological activity (+ for LT and MT), firm size (U-shaped), advertising (+), and capital intensity (- for LT and MT, + for HT) [/b]
Zhao and Li (1997)	China	1,562 manufacturing firms; 1992 survey data	Dichotomous variable: 1 if firm has reported R&D; 0 otherwise	Logit and simultaneous equations	R&D expenditures (+), profitability (-), and firm size (+)
Van Dijk (2002)	Indonesia	20,239 manufacturing plants; 1995 data	R&D expenditure to sales ratio	Tobit and Generalized Least Squares (GLM) model	Firm size (U-shaped), foreign ownership (+), age (-),human capital (+ for SD and – for SI), R&D (+ for SD and SI)
Using Other Measures of Innovation					
Du and Girma (2007)	China	28,000 manufacturing enterprises; 1999-2002 data	New product innovation to total output	Tobit	Product innovation (+), training (+), firm size (+), productivity growth (+), age (-), bank loans (+), and self-raised finance (+)
Correa, Dayoub, and Francisco (2007)	Ecuador	441 manufacturing firms; 2003 survey data	Dichotomous variable: 1 if firm has in-house R&D; 0 otherwise	Heckman selection	Technology (+), firm size (+), and foreign ownership (+)
Using a Technology Index					
Westphal, *et al.* (1990)	Thailand	119 firms in 18 industries	Index using 5 technological capabilities: productive, major change, minor change, and investment capabilities, and technological resources	OLS	Foreign ownership (+), BOI promotion (+), and firm size (+)

Guan and Ma (2003)	China	213 industrial firms; 1996-1998 survey data	Index using 7 dimensions of innovation capabilities: learning, R&D, manufacturing, marketing, organizational, resources exploiting, and strategic capabilities.	Multiple regression	Innovative capability (+) and firm size (+)
Rasiah (2003)	Malaysia and Thailand	71 electronic firms; survey data	Index for process technology capability using 4 components (also used R&D expenditure to sales ratio as another variable)	OLS	Foreign ownership (+), wage (+), age (+), process technology (+), and R&D (+)
Bhaduri and Ray (2004)	India	124 pharmaceutical and electronics firms; 1994-1995 data	Index of R&D output consisting of products, technical reports, new processes, new designs and import substitutes developed, consultancy services rendered, and research papers published.	Tobit	Firm size (+), R&D (+), foreign ownership (+), raw material import (+), and technological capability (+)
Wignaraja (2008a)	China and Sri Lanka	558 firms (353 in China and 205 in Sri Lanka)	Index using 5 technical functions: search for technology, ISO quality certification, process adaptation, minor adaptation of products; and introduction of new products.	Probit	Foreign ownership (+), technology index (+), buyer links (+), skill-adjusted wage rate (-), and capital intensity (- for China sample)
Wignaraja and Olfindo (forthcoming)	China	858 firms (506 electronics and 352 automotive)	Same index as Wignaraja (2008a)	Tobit	Education level of the general manager (+), foreign ownership (+), technology index (+), firm size (+), and share of skilled and technically qualified professionals in employment (+ for automotive)

OLS = ordinary least squares, R&D = research and development, GLM = generalized least squares, BOI = Board of Investment.
a/ Reports selected significant factors that affect export performance.
b/ SD=scale dominated firms; SI=scale intensive firms; LT=low-technology; MT=medium-technology; HT=high technology
c/ Shows significant results for both engineering and chemical firms.

Appendix Table 2: Description of Variables

Variable	Description
SIZE	Number of permanent employees
FOR	Share of foreign equity, %
AGE	Number of years in operation
ETM	Share of technical manpower (technical and vocational level qualifications) in employment, %
EDUC	Level of education of general manager/chief executive officer: 1 No education 2 Primary school education 3 Secondary education 4 Vocational training/some university training 5 Bachelor degree 6 Graduate degree
GMEXP	Number of years the general manager/chief executive officer has held the position
CAP	Net value of production machinery and equipment per employee, Yuan
R&D	Share of total R&D expenditure to total sales, %
TI	The technology scoring scale is based on 9 technical functions, graded according to two levels (0 and 1) to represent different levels of competence. Thus, a given firm is ranked according to a total capability score of 9 and the result is normalized to give a value between 0 and 1. The technical functions are as follows: • Upgrading equipment • Licensing of technology • ISO certification • Process improvement • Upgrade/adaptation of products • Introduces new products • R&D activity • Subcontracts • Technology linkages
Binary Dependent Variable	1 if exporter (exports to total sales ratio is > 0); 0 otherwise

Appendix Table 3: Mean Characteristics of Exporters and Non-Exporters in Electronics

Country	Variables	Mean		t-values
		Exporters	Non-Exporters	
China (152 exporters and 372 non-exporters)	Foreign ownership, %	35.34	5.52	11.47***
	R&D to sales ratio, %	1.08	1.60	-0.61
	Technology Index	0.55	0.50	3.64***
	Education level of the General Manager	4.16	4.01	2.98***
	Value of production machinery per employee, local currency	95.55	25.54	4.38***
Thailand (113 exporters and 53 non-exporters)	Foreign ownership, %	66.67	23.17	6.23***
	R&D to sales ratio, %	0.39	0.45	-0.21
	Technology Index	0.56	0.39	5.03***
	Education level of the General Manager	5.93	5.79	1.98**
	Value of production machinery per employee, local currency	443.46	143.92	1.66*
Philippines (79 exporters and 28 non-exporters)	Foreign ownership, %	81.25	17.50	8.93***
	R&D to sales ratio, %	0.95	0.12	1.02
	Technology Index	0.44	0.23	4.77***
	Education level of the General Manager	5.20	4.74	2.29**
	Value of production machinery per employee, local currency	554.23	252.94	1.05

Notes: t-values for two-sample t-test with equal variance: mean(exporter) – mean(non-exporter); *** t-values are significant at 1% level, ** at 5% level, and * at 10% level.

Appendix Table 4: Correlation Matrix for Electronics Sample

China

(obs=351)

	exporter	for	age	etm	educ	gmexp	cap	r&d	ti
exporter	1.0000								
for	0.4305	1.0000							
age	-0.1311	-0.2453	1.0000						
etm	0.0885	-0.0221	-0.0519	1.0000					
educ	0.1834	0.1464	-0.0647	0.0199	1.0000				
gmexp	-0.0598	-0.1121	0.0550	-0.0427	-0.2894	1.0000			
cap	0.2915	0.1967	-0.1325	0.0083	0.1442	-0.0457	1.0000		
r&d	-0.0135	-0.0393	-0.0059	-0.0116	0.0352	-0.0298	-0.0295	1.0000	
ti	0.1540	0.0000	0.0091	0.0990	0.1572	-0.0529	0.0549	0.0835	1.0000

Thailand

(obs=134)

	exporter	for	age	etm	educ	gmexp	cap	r&d	ti
exporter	1.0000								
for	0.4509	1.0000							
age	0.1124	-0.1293	1.0000						
etm	-0.1097	-0.2810	-0.0189	1.0000					
educ	0.1647	0.1041	-0.1618	-0.0610	1.0000				
gmexp	-0.0090	0.0721	-0.6794	0.1782	0.1346	1.0000			
cap	0.1462	0.0483	-0.0592	0.1040	0.0724	0.0032	1.0000		
r&d	-0.0339	-0.1905	0.0580	-0.0170	0.0575	-0.1310	-0.0410	1.0000	
ti	0.3626	0.3737	-0.0924	-0.0748	0.2553	0.0473	-0.0321	0.0726	1.0000

Philippines

(obs=78)

	exporter	for	age	etm	educ	gmexp	cap	r&d	ti
exporter	1.0000								
for	0.6626	1.0000							
age	-0.2612	-0.2892	1.0000						
etm	0.1711	0.2043	0.1181	1.0000					
educ	0.2548	0.2296	-0.1037	0.1541	1.0000				
gmexp	0.2511	0.2070	-0.0743	-0.0426	0.0094	1.0000			
cap	0.1213	0.1529	-0.0249	0.1620	0.0403	0.1256	1.0000		
r&d	0.0791	0.0971	-0.0726	-0.0682	-0.0097	0.0508	0.0124	1.0000	
ti	0.6133	0.4238	-0.0463	0.2223	0.2626	0.2873	0.1552	-0.0576	1.0000

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