ADBI Working Paper Series

Do Exporting Firms in the People's Republic of China Innovate?

Ganeshan Wignaraja

No. 365
July 2012

Asian Development Bank Institute

Ganeshan Wignaraja is director of research at the Asian Development Bank Institute (ADBI).

The author is grateful for comments from Peter Petri, Mike Plummer, Garry Jefferson, and Xingmin Yin, and for research assistance from Anna-Mae Tuazon and editorial assistance from Kevin Donahue. He would also like to thank other participants at the International Conference on Investments, Technology Spillovers, and East Asian FTAs (co-organized by Fudan University and Brandeis University in Shanghai). The views expressed in this article are those of the author and do not necessarily reflect the views and policies of the Asian Development Bank (ADB) or its Board of Governors or the governments they represent.

The Working Paper series is a continuation of the formerly named Discussion Paper series; the numbering of the papers continued without interruption or change. ADBI's working papers reflect initial ideas on a topic and are posted online for discussion. ADBI encourages readers to post their comments on the main page for each working paper (given in the citation below). Some working papers may develop into other forms of publication.

Suggested citation:

Wignaraja, G. 2012. Do Exporting Firms in the People's Republic of China Innovate? ADBI Working Paper 365. Tokyo: Asian Development Bank Institute. Available: http://www.adbi.org/working-paper/2012/07/03/5135.exporting.firm.prc.innovate/

Please contact the author for information about this paper.

Email: gwignaraja@adbi.org

Asian Development Bank Institute
Kasumigaseki Building 8F
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

Abstract

With international trade spluttering amidst the Great Recession, there is renewed interest in the factors driving firm-level export performance in Asia's super exporter—The People's Republic of China (PRC). While early studies suggested that innovation was important, there has been little research on opening up the black box of technology at firm-level in the PRC. This paper undertakes econometric analysis of innovation, learning, and exporting in automobiles and electronics firms in the PRC using a large-scale dataset to identify the most appropriate innovation proxy. Drawing on recent literature on innovation and learning in developing countries, it tests two alternative proxies: (i) a technology index (TI) to capture a variety of minor activities involved in using imported technologies efficiently; and (ii) the research and development (R&D)-to-sales ratio, which represents formal technological efforts to create new products and processes, often at world frontiers. A higher TI (representing minor technological activities) increases the probability of exporting in both industries, while the R&D-to-sales ratio was not significant. Foreign ownership, technical manpower, and the characteristics of the general manager/chief executive officer also matter. The findings suggest that the PRC's remarkable success in the export of automobiles and electronics since initiating an open-door foreign direct investment (FDI) policy in 1978 is linked to technology transfer from multinationals; systematic investments in and upgrading of minor technological activities (like search, engineering, quality management, and design); and human capital. As the PRC's per capita income rises over time, however, formal R&D activities are likely to become more important to sustain competitiveness and technological upgrading in automobiles and electronics.

JEL Classification: F23, O31, O32, L63, O57

Contents

1. INTRODUCTION

The existing theoretical literature recognizes the importance of innovation and learning for exporting manufactures, especially in developing countries. Innovation and learning at the firm-level in developing countries is often defined as the acquisition of technological capabilities, i.e., the skills and information needed to use imported technologies efficiently (Lall 1992; Bell and Pavitt 1993; Westphal 2002). This typically spans a wide spectrum of technological activities including acquisition, use, modification, improvement, and creation of technology. Firms in developing countries generally lack domestic capabilities and rely instead on a range of mechanisms to import technology, including technology transfer by multinational corporations (MNCs) and foreign buyers of output. The evolutionary theory of technical change emphasizes that difficult firm-specific processes are involved in building technological capabilities as well as complex interactions among firms, institutions, and incentives (Nelson and Winter 1982; Metcalfe 1994; Lundvall ed. 1992; Nelson 2008). Differences in the efficiency with which capabilities are created are themselves a major source of competitiveness between countries.

The bulk of the empirical analysis—based on detailed, qualitative, micro-level case studies of innovation and learning in developing countries—suggests that formal research and development (R&D) aimed at creating new products and processes, often at world frontiers, is only one of several technological activities required to absorb imported technologies. (This vast literature includes Lall 1987; Lall et al. 1994; Hobday 1995; and Mathews and Cho 2002). Minor technological activities—search, engineering, quality management, and design—were found to be more important and widespread than formal R&D activities. Unfortunately, this valuable insight from case studies of innovation and learning is not captured in the growing body of econometric literature on firm-level exporting and innovation in developing countries, which has used the ratio of R&D expenditure to sales as the key proxy for innovation (Lall, 1986; Zhao and Li, 1997; and Van Dijk, 2002). Accordingly, existing econometric studies typically understate a large part of innovation and learning activities conducted at the firm-level in developing countries. In a landmark development in the literature on technological capabilities, a technology index (TI) based on technical functions performed by enterprises was developed see the pioneering work by Westphal et al. 1990, and variants by Romijn 1997; Dominguez and Brown 2004; and Lammarino et al., 2008). A few studies have begun using variants of this tool to commence econometric testing of the relationship between innovation, learning, and exporting in developing countries (Guan and Ma 2003; Rasiah 2003 and 2004; Bhadhuri and Ray 2004; and Wignaraja 2002 and 2008a and b). Nonetheless, there has been little attempt in this literature to test the empirical validity of alternative proxies for innovation and learning, including comparing a TI to the ratio of R&D to sales.

Such research is particularly lacking for the PRC, which emerged as the world's largest exporter in 2009 in the aftermath of the global financial crisis, three decades after adopting an open-door policy to export-oriented foreign direct investment (FDI) in 1978. Facilitated by massive technology transfer and significant access to the marketing networks of MNCs, the PRC's share of world automobile exports increased from 0.6% to 2.8% between 2001 and 2009, while that for electronics increased from 5.8% to 9.7%.[1] Spectacular export success has encouraged empirical investigation of various macro and micro determinants, including trade and industrial policies as well innovation and learning in PRC firms (Lardy 2002; Rodrick 2006; Lin 2009; Wignaraja 2011 and 2012). Recent attention has focused on mapping innovation activities in the manufacturing sector since the open-door policy was adopted, as well as technology spillovers

[1] Estimated from International Trade Center TradeMap (www.trademap.org) accessed January 2011.

from MNCs to local firms in the automobile and electronics industries (Zhao and Li 1997; Guan and Ma 2003; Cheung and Lin 2004; Guan et al. 2009; Motohashi and Yuan 2010). Guan et al. (2009) drew attention to the fact that minor technological activities dominated PRC firms' innovation and learning activities during the economic transition of the 1990s.[2] Motohashi and Yun (2005) suggest that some firms built technological capabilities by collaborating with universities and public research institutes in the aftermath of economic reforms in PRC. Critical questions for further research include whether this finding about the centrality of minor technological activities at the firm-level also holds for the early 2000s, and whether minor technological activities influence export behavior.

This paper undertakes econometric analysis of the relationship between innovation, learning, and exporting in a sample of automobile and electronics firms in the PRC using both a TI and the ratio of R&D to sales. As the dataset relates to 2003, the paper updates previous research on minor vs. major technological activities in PRC firms and explores possible links with exporting. The central research question addressed here is whether a TI or the ratio of R&D to sales is a better innovation proxy in econometric analysis of firm-level exporting behavior in the PRC in the early 2000s. For each industry, comprehensive firm-level export functions were estimated separately for the TI and the ratio of R&D to sales (along with foreign ownership and other control variables) using a Probit model. Prior to this, a broad-based TI was constructed and exploratory data analysis was conducted including a T-test for exporters and non-exporters. The large-scale dataset covers 194 automotive firms and 524 electronics firms in the PRC.

The paper is structured as follows. The literature on innovation, learning, and exporting is reviewed in Chapter 2 with a view to formulating hypotheses for econometric research. Empirical results are presented and evaluated in Chapter 3. Chapter 4 concludes. Appendix 1 explains how the TI was constructed for automobile and electronics firms in the PRC.

2. LITERATURE ON INNOVATION, LEARNING, AND EXPORTING

2.1 Theories

There is a growing empirical literature on innovation, learning, and exporting at the firm-level. Much of this literature is rooted in two distinct branches of applied economics: (i) international trade and investment, and (ii) technological capabilities and national innovation systems. This conceptual framework for the paper draws on both branches of literature, but particularly focuses on (ii).

Nearly three decades ago, applied international trade 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, respectively, stimulated subsequent empirical

[2] A large scale survey of 1,244 PRC firms in Beijing conducted in 1996 provides rare insights on innovation performance and development for the first decade and a half of transition (Guan et al. 2009). It concludes that "innovation activities of Chinese firms were still confined to the domestic sphere and mainly directed to quality improvements and cost reductions for existing products" (Guan et al. 2009: 811). The study also suggests that firms with government support (e.g., the high-tech firm accreditation system) performed better. They have begun to move from a reliance on imported equipment and are using indigenous R&D efforts to innovate for the market economy.

work on developing countries.[3] This literature, which has roots in the neo-Heckscher–Ohlin model and neo-technology 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. Therefore, conditions of imperfect markets with widespread oligopolies—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.

More recently, Melitz (2003) constructed a model in which only a few highly productive firms are engaged in export. His model showed that only highly productive firms are able to make sufficient profits to cover the large fixed-costs required for export operations. Helpman, Melitz, and Yeaple (2004) extended the Melitz model to incorporate FDI and showed that the productivity of exporting firms is lower than that of firms engaged in local production overseas. This rests on the theory that only productive firms can cover the large fixed-costs involved in local production overseas. The Melitz model and its extension have stimulated empirical research at the firm-level (see Bernard, Jensen, Redding, and Schott 2011 for a survey).

The other group is the literature on technological capabilities and national innovation systems. Focusing on innovation and learning processes in developing countries, proponents emphasize the acquisition of technological capabilities as a major source of export advantage at the firm-level (Lall 1987 and 1992; Bell and Pavitt 1993; 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 (1994) 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 technology 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 ed. 1992). Hence, differences in the efficiency with which firm-level capabilities are created are themselves a major source of competitive advantage.

---

[3] This growing literature includes Lall (1986), Wilmore (1992), Van Dijk (2002), and Correa et al. (2007).

[4] The major trade theories—Heckscher–Ohlin Model, theories of economies of scale and oligopolistic competition, neo-technology theories, and theories of economic geography—attribute the export performance of an open, developing economy to its comparative advantage over another in terms of access to certain factor inputs, including capital, labor, economies of scale, technology, and geography (Grossman and Helpman 1994; Baldwin 2008). Empirical applications to developing countries have sought to explain the export performance of each industry/product in terms of their various characteristics.

2.2 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 and learning. Studies include a proxy for innovation and standard control variables in the firm-level exporting literature such as ownership, firm size and age, and human capital. Regressions were run relating export achievements to particular enterprise characteristics using different econometric methods. Early studies relied on ordinary least squares (OLS) regressions, 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 broad types according to the proxy for innovation.

First, a long research tradition has used an 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 include wages and salaries of R&D personnel (such as scientists and engineers), as well as 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 the PRC 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 PRC 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. Guan et al. (2009) examine the relationship between innovation strategy and performance in PRC firms, focusing on separate innovation objectives (including production innovations, cost-cutting, and process improvement) rather than a TI. They find that innovation activities in PRC firms were largely oriented towards minor technological activities (e.g., quality improvement and cost reductions for existing products) and that this was positively linked to innovation performance. 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, while the firm's age was not.

Third, and more recently, a comprehensive TI 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. (For more detail, 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

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

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 PRC industrial firms, reveal that export performance is positively related to an index of innovative capability and firm size. In a comparative study of PRC 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 of electronics from firms in Malaysia and Thailand. The process TI and the other four 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 (new products developed, technical reports published, and development of new designs and processes). R&D capability, foreign ownership, and raw material imports were all significant.

2.3 Specification and Hypothesis

Drawing on the above theoretical and empirical studies, the following econometric model is estimated for separate export functions for automobile and electronics firms:

$$\boldsymbol{Y} = \beta \boldsymbol{X} + \boldsymbol{\varepsilon}, \qquad (1)$$

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 Table 1.

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.

Human Capital. Within a given activity, a higher level of human capital is expected to have a 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 the development of effective business strategies that are likely to provide a competitive edge at the firm-level. Accordingly, human capital is represented by three variables: (i) share of technically qualified employees in employment (ETM), (ii) level of education of the general manager (EDUC), and (iii) years of experience of the general manager (GMEXP).

Table 1: Definition of Variables

Variable	Description
CAP	Net value of production machinery and equipment per employee, local currency
ETM	Share of technical professionals 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
FOR	Share of foreign equity, %
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 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
AGE	Number of years in operation
SIZE	Number of permanent employees
Binary dependent variable = EXPORTER	1 if exporter (exports to total sales ratio is > 0); 0 otherwise

Source: Author.

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 the 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 benefits from economies of scale in production, R&D, and marketing. A large firm

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

will be better able to exploit such economies of scale and enjoy greater efficiency in production, thereby 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 also includes more conscious investments in creating skills and information to operate imported technology efficiently (Westphal et al. 1990; 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 in the previous section, two alternative proxies—R&D to sales ratio and a firm-level TI—are used in the econometric analysis. The R&D-to-sales ratio represents formal technological efforts to create new products and processes, often at world frontiers. It 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 firm's competence across a series of technical functions, and the results were normalized to give a value between 0 and 1. (For more detail on the TI see Appendix 1).

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 build-up of capabilities (van Dijk 2002; Rasiah 2003; Bhaduri and Ray 2004).

3. DATA AND EMPIRICAL FINDINGS

3.1 Exploratory Data Analysis

The dataset for this study of PRC firms was drawn from the World Bank's Investment Climate Survey undertaken in 2003. Our sample consists of 718 firms—194 automobile and 524 electronics firms. The majority of the sample firms are domestically owned, with only 38 automobile and 113 electronics firms having foreign equity. Tables 2 and 3 show the sample profile and descriptive statistics.

Firms in the sample differ in export behavior as measured by the share of exports to total sales. There are 35 exporters in automobiles and 152 in electronics. The samples show some of the stylized facts reported in the literature in the previous section. In particular, exporters have higher levels of innovation and learning, are generally foreign-owned, and are larger than non-exporters. Table 4 shows the mean values of certain characteristics of exporters and non-exporters for automobiles and electronics firms in the sample, along with the t-values.

Table 2: Sample Profile

	All		Automobiles		Electronics	
	No.	% Dist.	No.	% Dist.	No.	% Dist.
No. of firms	718	100.00	194	27.02[e]	524	72.98[e]
By export orientation[a]						
Exporter	187	26.04	35	18.04	152	29.01
Non-exporter	531	73.96	159	81.96	372	70.99
By ownership structure[b]						
Foreign	151	21.03	38	19.59	113	21.56
Domestic	567	78.97	156	80.41	411	78.44
By technological intensity[c]						
High	371	51.67	98	50.52	273	52.10
Low	347	48.33	96	49.48	251	47.90
By size[d]						
Large	444	61.84	125	64.43	319	60.88
SME	274	38.16	69	35.57	205	39.12

Notes: [a] A firm is an exporter if shares of exports to total sales is greater than zero during the sample period; a firms is non-exporter otherwise. [b] A firm is foreign if the share of foreign equity is greater than zero; a firm is domestic otherwise. [c] A firm has high-technological intensity if TIO is 0.50 or higher; a firm has low-technology intensity otherwise. [d] A firm is large if it has more than 100 employees; a firm is a small and medium-sized enterprise (SME) otherwise. [e] Percent distribution across electronics and automotive firms.

Source: Computed from Enterprise Surveys, The World Bank Group.

Table 3: Descriptive Statistics

Firm characteristics	Automobiles		Electronics	
	Mean	Std. dev.	Mean	Std. dev.
CAP	55.19	7.14	46.04	7.39
ETM	6.85	1.41	12.24	2.98
EDUC	3.94	0.05	4.06	0.02
GMEXP	5.60	0.32	5.86	0.20
FOR	10.82	1.73	14.17	1.32
RDSALES	0.53	0.13	1.45	0.38
TI	0.41	0.02	0.52	0.01
AGE	14.95	1.02	14.29	0.57
SIZE	777.42	139.55	421.33	36.77

Note: See Table 1 for definition of variables.

Source: Computed from Enterprise Surveys, The World Bank Group.

Table 4: T-tests of Differences of Means for Exporting and Non-exporting Firms in the PRC

	Automobiles			Electronics		
Firm Characteristics	Exporter	Non Exporter	t-values	Exporter	Non Exporter	t-values
CAP	89.28	47.64	2.27**	95.55	25.54	4.38***
ETM	10.61	5.93	1.32	18.18	10.34	1.13
EDUC	4.23	3.88	3.03***	4.16	4.01	2.98***
GMEXP	6.12	5.49	0.76	5.56	5.99	0.98
FOR	23.32	8.06	3.49***	35.34	5.52	11.47***
RDSALES	0.62	0.52	0.29	1.08	1.60	-0.61
TI	0.60	0.37	5.15***	0.55	0.50	3.64***
AGE	11.00	15.83	-1.84*	11.85	15.29	-2.77***
SIZE	2026.57	502.45	4.39***	865.29	239.93	8.19***

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, * at 10% level; See Table 1 for definition of variables.

Source: Computed from Enterprise Surveys, The World Bank Group.

Most strikingly, there is a significant difference in innovation and learning activities between exporters and non-exporters in both industries. Our TI indicates the various technological functions needed to use imported technology efficiently. According to this measure, exporters had higher TI scores (0.60 in automobiles and 0.55 in electronics) than non-exporters. Furthermore, the gap in TI scores between exporters and non-exporters is wider in automobiles than in electronics, which may indicate that more limited technology spillovers from export activity have occurred in automobiles than in electronics. The technology gap between exporters and non-exporters in the two industries may be due to structural issues such as the organization of production (modular architecture in electronics vs. integrated production of mutually interdependent components in electronics), the number of parts and component suppliers, and the length of supply chains (Motohashi and Yuan 2010). However, the R&D-to-sales ratio is not significant in either industry.

Exporters have higher shares of foreign equity than non-exporters. Exporters in automobiles have an average foreign equity share of 23%; in electronics, the figure is 35%. These are significantly higher than the foreign equity shares of non-exporters: 8% in electronics and 6% in electronics. Underlining the link between foreign ownership and firm size, exporters are also significantly larger (in terms of employment) than non-exporters. On average, exporters in automobiles and electronics have 2,027 and 865 employees, respectively, while non-exporters have 503 and 240 employees, respectively.

There is also a significant difference in the average level of education of the general manager/chief executive officer (CEO) between exporters and non-exporters. However, other human capital variables (number of years of experience of the general manager/CEO, share of technical professionals in employment) are not significant. Furthermore, exporters have higher capital intensity (as measured by the net value of production machinery and equipment per employee) and are younger (in terms of years of operation) than non-exporters.

3.2 Econometric Results

While t-tests are a useful descriptive device, they do not shed much light on causation. Thus, a Probit model was used to estimate the export function specified in Section 2.3 The empirical model was estimated twice for each industry to account for the alternative measures of innovation—TI and the R&D-to-sales ratio—with the same binary dependent variable and other firm characteristics. A general model was estimated initially and was followed by a reduced-form model with significant variables from the general model.

Table 5 reports the results of our estimated export functions for automobiles and electronics. Estimated equations (1), (2), (5), and (6) use TI as a measure of innovation while (3), (4), (7), and (8) use the R&D- to-sales ratio. Equations (2) and (6) are the reduced-form equations for TI with variables that have coefficients significantly different from zero, while (4) and (8) relate to the R&D-to-sales ratio.

Table 5: Probit Estimates of Firm-Level Export Performance in the PRC

Independent variables	Automobiles				Electronics			
	TI General (1)	TI Reduced (2)	R&D/Sales General (3)	R&D/Sales Reduced (4)	TI General (5)	TI Reduced (6)	R&D/Sales General (7)	R&D/Sales Reduced (8)
CAP	-0.0019		-0.0005		0.0048	0.0048	0.0046	0.0048
	(-1.27)		(-0.37)		(2.52)**	(2.55)**	(2.57)**	(2.61)**
ETM	0.0111	0.0099	0.0031	0.0032	0.0001	0.0001	0.0001	0.0001
	(1.96)*	(1.75)*	(2.34)**	(2.03)**	(2.60)**	(2.59)**	(3.08)***	(3.04)***
EDUC	0.2083		0.4019		0.2915	0.2785	0.3625	0.3470
	(0.63)		(1.20)		(1.79)*	(1.75)*	(2.23)**	(2.21)**
GMEXP	0.0483	0.0444	0.0293		0.0083		0.0069	
	(1.74)*	(1.78)*	(0.97)		(0.49)		(0.40)	
FOR	0.0126	0.0129	0.0100	0.0134	0.0176	0.0176	0.0172	0.0170
	(2.18)**	(2.53)**	(1.89)*	(2.98)***	(5.46)***	(5.67)***	(5.39)***	(5.55)***
R&D			-0.0082				0.0010	
			(-0.17)				(0.18)	
TI	2.4030	2.3418			1.4013	1.3747		
	(4.3)***	(4.3)***			(2.70)***	(2.56)***		
AGE	-0.0191		-0.0168		0.0001		-0.0003	
	(-1.63)		(-1.58)		(0.03)		(-0.50)	
Constant	-3.0733	-2.5348	-2.6709	-1.1772	-3.1025	-2.9932	-2.6364	-2.5393
	(-2.34)**	(-7.63)***	(-1.96)**	(-7.95)***	(-4.27)***	(4.52)***	(-3.75)***	(-3.99)***
N	162	162	162	163	352	356	351	356
Wald χ^2	40.31***	38.52***	15.97**	13.05***	54.57***	54.38***	48.42***	48.20***
Pseudo R^2	0.23	0.20	0.14	0.09	0.22	0.22	0.20	0.20
Log likelihood	-60.54	-63.98	-68.13	-73.56	-153.90	-154.74	-155.85	-157.95

Dependent variable: EXPORTER

Notes: z-values are in parenthesis; *** significant at 1% level, ** significant at 5% level, and * significant at 10% level; See Table 1 for definition of variables.

Source: Computed from Enterprise Surveys, The World Bank Group.

The R&D-to-sales ratio as a measure of innovation shows no significance in either industry. Estimating the same empirical model using TI as a measure of innovation shows a positive and highly significant result for both industries. The lack of significance of the R&D-to-sales ratio is puzzling. There may be a 1–2 year lag before R&D expenditures impact export behavior at the firm-level in the PRC automobiles and electronics industries. However, the lack of lagged data on R&D expenditures from the World Bank Investment Climate Survey meant that this explanation could not be pursued empirically.

Continuing with TI as a measure of innovation, the empirical model was estimated to keep the variables that show significance in the general model. The results are provided in equations (2) and (6) for automobiles and electronics, respectively.

The TI is positive and highly significant at the 1% level in automobiles and electronics. This result indicates that difficult firm-specific processes are involved in building firm-level technological capabilities to use imported technology efficiently. Conscious investments in skills and information to operate imported technologies efficiently increase the probability of exporting. It is noteworthy that the magnitude of effect of TI is more than those of the other explanatory variables in the empirical model.

Foreign ownership (FOR) plays a role in explaining the probability of exporting in both industries. FOR is positive and significant at the 5% level in automobiles and at the 1% level in electronics. This confirms the hypothesis that foreign ownership has a positive influence on the probability of exporting. Several factors—access to marketing connections of parent firms, accumulated learning experience of producing for overseas markets, and larger firm size—combine to give foreign firms an export advantage.

Apart from TI and FOR, the proxies for human capital also exert some influence on the probability of exporting. ETM is positive in both industries with varying significance: 10% in automobiles and 5% in electronics. Meanwhile, GMEXP and EDUC are positive and significant (10% level) in automobiles and electronics. Accordingly, the share of technical manpower matters in both industries. The characteristics of the general manager/CEO also matter, with experience being relevant in automobiles and education in electronics.

Finally, capital intensity (CAP) shows up as a significant determinant of the probability of exporting in electronics, but not in automobiles. The absolute age of the firm (AGE) is not significant in either industry.

4. CONCLUSION

This study examines innovation, learning, and exporting in PRC automobiles and electronics firms using a TI and R&D-to-sales ratio as alternative innovation proxies. The empirical analysis suggests that innovation and learning was the principal determinant of the probability of exporting in automobiles and electronics in the early 2000s. The TI—a broad measure of innovation covering several firm-level technical functions needed to use imported technology efficiently—is significant with a positive sign. However, the R&D-to-sales ratio—a narrower measure of innovation focusing on new products and processes often at world frontiers—is not significant. Foreign ownership and technical manpower are the other key significant determinants of the probability of exporting in both industries. Finally, the characteristics of the firm's general manager/CEO are relevant, with experience mattering in automobiles and education in electronics. Capital intensity is significant in electronics.

Some inferences can be drawn from the analysis. First, the PRC's remarkable ascent in the rankings of world exports of automobiles and electronics since it initiated an open-door policy to FDI in 1978 was underpinned by technology transfer from MNCs as well as systematic investments in innovation and learning. Minor technological activities—search, engineering, quality management, and design—remained crucial for absorbing imported technologies efficiently in the early 2000s as they were in the mid-1990s. While formal R&D activities are not statistically associated with the probability of exporting in our study, they remain an important element of innovation and learning processes in both industries under review in the PRC.

As per capita income rises, the focus of technological activity tends to shift from minor activities to formal R&D at world frontiers. Accordingly, the development of new products and processes will become even more essential to sustaining industrial competitiveness and technological upgrading in PRC firms. Coordinated public policy support to strengthen the PRC's national innovation system to reach Organisation for Economic Co-operation and Development (OECD) levels of performance and efficiency may also be needed to facilitate a shift in the nature of innovation and learning activities. Such support could include additional tax incentives for R&D activities, developing performance-based financing instruments for risky technological activities, increasing the numbers of scientists and engineers, and encouraging closer collaboration between the different actors in the national innovation system (i.e., firms, technology institutions, and universities). Measures to improve intellectual property rights are also useful but may take time to implement effectively.

Second, the TI offers a tool to expand the scope and scale of case study research on innovation and learning at the firm-level in developing countries. It provides a convenient summary measure to map technological behavior across large enterprise samples and conduct econometric testing of the determinants of enterprise performance and technological activity. Refining the TI to better include technical functions performed in specific industries and undertaking large sample panel data analysis are fruitful avenues for further study.

REFERENCES

Auquier, A. 1980. Sizes of firms and exporting behaviour, and the structure of French industry. *The Journal of Industrial Economics* XXIX(2): 203–218.

Baldwin, R. E. 2008. *The Development and Testing of Hecksher-Ohlin Trade Models: A Review*. Cambridge, MA: MIT Press.

Bell, M. and K. Pavitt. 1993. Technological accumulation and industrial growth. *Industrial and Corporate Change* 2(2): 157–209.

Bernard, A. B, J. B Jensen, S. J. Redding and P. K. Schott. 2011. The Empirics of Firm Heterogeneity and International Trade, NBER Working Papers no 17627. Cambridge, MA: National Bureau of Economic Research.

Bhaduri, S. and A. Ray. 2004. Exporting through technological capability: Econometric evidence from India's pharmaceutical and electrical/electronics firms. *Oxford Development Studies* 32(1): 87–100.

Cheung, K. and P. Lin. 2004. Spillover Effects of FDI on Innovation in China: Evidence from Provincial Data. *China Economic Review* 15(1): 25–44.

Correa, P., M. Dayoub, and M. Francisco. 2007. Identifying Supply-Side Constraints to Export Performance in Ecuador: An Exercise with Investment Climate Survey Data. *World Bank Policy Research Working Paper* 4179. March.

Dominguez, L. and F. Brown. 2004. Measuring technological capabilities in Mexican industry. *CEPAL Review* 83(August): 129–144.

Du, J. and S. Girma. 2007. Finance and firm export in China. *Kyklos* 60(1): 37–54.

Dunning, J. H. 1993. *Multinational Enterprises and the Global Economy.* Wokingham, United Kingdom: Addison-Wesley.

Grossman, G. and E. Helpman. 1994. Technology and Trade. *NBER Working Paper* No. W4926.

Glejser, H. A., A. Jaquemin, and J. Petit. 1980. Exports in an imperfect competition framework: An analysis of 1446 exporters. *Quarterly Journal of Economics* XCIV: 507–524.

Guan, J. and N. Ma. 2003. Innovative Capability and Export Performance of Chinese firms. *Technovation* 23:(9): 737–747.

Guan, J. C., R. C. M. Yam, E. P. Y. Tang, A. K. W. Lau. 2009. Innovation strategy and performance during economic transition. *Research Policy* 38: 802–812.

Helpman, E., M. J. Meltiz, and S. R. Yeaple. 2004. Export versus FDI with heterogeneous firms. *American Economic Review* 94(1): 300–316.

Hirsch, S. and Z. Adar. 1974. Firm size and export performance. *World Development* (2)7: 41–46.

Iammarino, S., R. Padilla-Perez, and N. von Tunzelmann. 2008. Technological capabilities and global-local interactions: The electronics industry in two Mexican regions. *World Development* 36(10): 1980–2003.

Lardy, N. R. 2002*. Integrating China into the Global Economy*. Washington, DC: Brooking Institution Press.

Lall, S. 1986. Technological development and export performance in LDCs: Leading engineering and chemical firms in India. *Weltwirtschaftliches Archiv* 122: 80–91.

Lall, S. 1987. *Learning to Industrialize*. Basingstoke, United Kingdom: Macmillan Press.

Lall, S. 1992. Technological Capabilities and Industrialization. *World Development* 20: 165–86.

Lall, S., G. Barba-Navaretti, S. Teitel, and G. Wignaraja. 1994. *Technology and Enterprise Development: Ghana Under Structural Adjustment*. Basingstoke, United Kingdom: Macmillan Press.

Lin, J. 2009. *Economic Development and Transition: Thought, Strategy and Viability*. New York, NY: Cambridge University Press.

Lundvall, B. A. 1992 (ed.). *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Mathews, J.A and D. Cho. 2002. *Tiger Technology: The Creation of a Semiconductor Industry in East Asia*. Cambridge, United Kingdom: Cambridge University Press.

Melitz, M. J. 2003. The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity. *Econometrica* 17(6): 1695–1725.

Metcalfe, J. S. 1994. Evolutionary Economics and Technology Policy. *Economic Journal* 104(425): 931–944.

Motohashi, K. and Y. Xiao. 2005. China's Innovation System Reform and Growing Industry and Science Linkages. RIETI Discussion Paper Series 05-E-011. Tokyo: The Research Institute of Economy, Trade and Industry).

Motohashi, K. and Y. Yuan. 2010. Productivity impact of technology spillovers from multinationals to local firms: Comparing China's automobiles and electronics industries. *Research Policy* 39: 790 –798.

Nelson, R. R. and S. G. Winter. 1982. *An Evolutionary Theory of Economic Change*. Cambridge, MA: Belknap-Harvard University Press.

Nelson, R. R. 2008. Economic development from the perspective of evolutionary economic theory. *Oxford Development Studies* 36(1): 9–21.

Rasiah, R. 2003. Foreign ownership, Technology and electronics exports from Malaysia and Thailand. *Journal of Asian Economics* 14: 785–811.

Rasiah, R. 2004. *Foreign Firms, Technological Intensities and Economic Performance, Evidence from Africa, Asia and Latin America*. Cheltenham, United Kingdom: Edward Elgar.

Rodrick, D. 2006. What's So Special About China's Exports? NBER Working Paper, no. 11947. Cambridge, MA: National Bureau of Economic Research..

Romjin, H. 1997. Acquisition of technological capability in development: A quantitative case study of Pakistan's capital goods sector. *World Development* 25(3): 359–377.

Van Dijk, M. 2002. The Determinants of Export Performance in Developing Countries: The Case of Indonesian Manufacturing. *Eindhoven Centre for Innovation Studies Working Paper* 02.01.

Westphal, L. E., K. Kritayakirana, K. Petchsuwan, H. Sutabutr, and Y. Yuthavong. 1990. The Development of Technological Capability in Manufacturing: A Macroscopic Approach to Policy Research. In: *Science and Technology: Lessons for Development Policy,* edited by R. E. Evenson and G. Ranis. London: Intermediate Technology Publications.

Westphal, L. E. 2002. Technology strategies for economic development. *Economics of Innovation and New Technology* 11: 275–320.

Wignaraja, G. 1998. *Trade Liberalization in Sri Lanka: Exports, Technology and Industrial Policy London*: Macmillan Press and New York, NY: St. Martins Press.

Wignaraja, G. 2002. Firm size, technological capabilities and market-oriented policies in Mauritius. *Oxford Development Studies* 30(1): 87–104.

Wignaraja, G. 2008a. Ownership, technology and buyers: Explaining exporting in China and Sri Lanka. *Transnational Corporations* 17(2) (August): 1–15.

Wignaraja, G. 2008b. Foreign ownership, technological capabilities and clothing exports in Sri Lanka. *Journal of Asian Economics* 19: 29–39.

Wignaraja, G. 2011. Economic Reforms, Regionalism and Exports: Comparing China and India. East-West Center. Policy Studies No. 60. Available at http://www.eastwestcenter.org/publications/publications-home

Wignaraja, G. 2012. Commercial Policy and Experience in the Giants: China and India. Iin: *The Oxford Handbook of International Commercial Policy*, edited by M. E. Kreinin and M.G. Plummer. Oxford, UK: Oxford University Press.

World Bank. 2011. *Enterprise Surveys*. Available: http://www.enterprisesurveys.org.

Wilmore, L. 1992. Transnationals and foreign trade: Evidence from Brazil. *Journal of Development Studies* 28(2): 314–335.

Zhao, H. and H. Li. 1997. R&D and exports: An empirical analysis of Chinese manufacturing firms. *The Journal of High Technology Management Research* 8(1): 89–105.

APPENDIX: THE TECHNOLOGY INDEX (TI)

The Lall (1987 and 1992) taxonomy of technological capabilities provides a comprehensive matrix of technical functions required for firms in developing countries to set up, operate, and transfer imported technology efficiently. Lall groups these functions under three sets of capabilities: investment, production, and linkages. The Lall taxonomy of technological capabilities has been successfully used by case study research to assess firm-level technological development in developing countries (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 (Westphal et al*,* 1990; Romijn 1997; Rasiah 2003 and 2004; and Wignaraja 1998, 2002, 2008a, and 2008b).

The application of the Lall (1987 and 1992) taxonomy in this study was influenced by data availability on technical firms contained in the 2003 World Bank Investment Climate Surveys on the PRC. Nine technical functions were common to all three samples. The TI used here was based on firms' competence in the following: (i) upgrading equipment, (ii) licensing technology, (iii) International Organization for Standardization (ISO) quality certification, (iv) process improvement, (v) minor adaptation of products, (vi) introduction of new products, (vii) research and development (R&D) activity, (viii) subcontracting, 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 TI 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, iv, v, vi, and vii). Investment is represented by two activities (items i and ii), while linkages are also represented by two activities (items viii and ix).

APPENDIX TABLES

Table 1a: Correlation Matrix of Variables for the Automotives Sample

Variables	EXPORTER	CAP	ETM	EDUC	GMEXP	FOR	RDSALES	TI	AGE
EXPORTER	1.0000								
CAP	0.1077	1.0000							
ETM	0.1038	0.0395	1.0000						
EDUC	0.2072	0.3125	-0.0140	1.0000					
GMEXP	0.0902	-0.1525	0.0355	-0.0567	1.0000				
FOR	0.2613	0.4555	0.0149	0.3082	-0.0931	1.0000			
RDSALES	0.0068	0.0481	-0.0527	0.0083	-0.0033	0.0565	1.0000		
TI	0.3429	0.2878	-0.0139	0.3641	-0.0416	0.2228	0.1049	1.0000	
AGE	-0.1459	-0.2021	0.0450	-0.0003	0.1446	-0.2232	-0.0719	-0.0479	1.0000

Source: Author.

Table 1b: Correlation Matrix of Variables for the Electronics Sample

Variables	EXPORTER	CAP	ETM	EDUC	GMEXP	FOR	RDSALES	TI	AGE
EXPORTER	1.0000								
CAP	0.2915	1.0000							
ETM	0.0885	0.0083	1.0000						
EDUC	0.1834	0.1442	0.0199	1.0000					
GMEXP	-0.0598	-0.0457	-0.0427	-0.2894	1.0000				
FOR	0.4305	0.1967	-0.0221	0.1464	-0.1121	1.0000			
RDSALES	-0.0135	-0.0295	-0.0116	0.0352	-0.0298	-0.0393	1.0000		
TI	0.1540	0.0549	0.0990	0.1572	-0.0529	0.0000	0.0835	1.0000	
AGE	-0.1311	-0.1325	-0.0519	-0.0647	0.0550	-0.2453	-0.0059	0.0091	1.0000

Source: Author.