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Complementarity between internal knowledge creation and external knowledge sourcing in developing and least developed countries

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Abstract: In order to catch up with the technological frontier, firms in developing and least developed countries have been striving hard to promote technological advancement through internal R&D effort (make) as well as through external sourcing (buy). The adoption and learning process requires firms to set up effective strategies to catalyze the speed of their catching-up. This study uses the complementarity approach to investigate the relationships between in-house R&D and external technological sourcing. Our empirical evidences highlight the significant effects of external technological acquisition, particularly for firms in least developed countries. But complementarity appears only in the context where firms have a compatible level of technological capability.

Keywords: R&D, adoption, make and buy, complementarity.

1. Introduction

Innovation is a process of discovery, learning, and application of new technologies and techniques. It aims at continuing economic and productivity growth through transforming knowledge into a variety of economic activities, and ultimately at the improvement in living standards. Unambiguously, much of the economic and social progress of the past few centuries has been benefited from technology inventions and achievements. The significant role of innovation which is thought to be brought about through research and development (R&D) activities carried out by profit-seeking entrepreneurs in the productivity performance was elaborated in the endogenous growth theory (Aghion and Howitt, 1998; Grossman and Helpman, 1991). According to Coe, Helpman and Hoffmaister (1997) a large part of the world's R&D activity is carried out by firms located in developed countries, particularly the more powerful member countries of the OECD. And the significant performance of R&D in explaining firm productivity of developed economies has been demonstrated in a number of empirical studies (Griliches and Hall, 1978. Kleinknecht and Mohnen, 2002).

However, when this framework of significant effects of R&D in productivity growth mapped in the context of developing countries, new characteristics were uncovered. Several studies had contributed to conceptualize innovation and technological change in developing economies (see Fransman, 1985). Comparing innovation in developed countries, innovation in developing countries is distinguished as a learning and adopting process. Due to the low level of human capital and vulnerable infrastructure, in-house innovative activities are severely constrained for a majority of firms. Innovation in this context is characterized as a learning and adoption process to catch-up the technology frontier. It emerges through various sources. Mostly, they rely on external acquisition such as investing in new machinery and equipments, licensing, R&D outsourcing, or the hiring of qualified personnel with relevant knowledge.

Firms are also required to build up their own technological capability to facilitate the adoption process. Cohen and Levinthal (1989) introduced the notion of "absorptive capacity" to describe the substantial role of a stock of prior knowledge to effectively absorb external know-how. The co-occurrence of in-house R&D and external innovative activities implies the existence of complementarity between them. For instance, firms' technological capability will increase the marginal return to external technological strategies. At the same time, external knowledge acquisition may facilitate the efficiency of in-house R&D outputs. Such a synergy has been formally defined by Milgrom and Roberts (1990) and is assumed to exist if the implementation of one practice or strategy increases the marginal return to other practices.

This paper will be based on firm level analysis in developing and least developed countries[1]. Two interesting findings are drawn from the empirical analysis. First, in order to search for the most important technological sources, we directly estimate the partial effects of in-house R&D and external sourcing strategies in firms' production function. Two types of technological input decision are distinguished. First of all, firms can obtain new technologies by conducting in-house R&D (we define this as "MAKE"). In addition, they can acquire new technologies which are externally accessible and attracted to them, such as licensing, hiring new personnel, or through trade fairs and study trip (we define this as "BUY"). Our results show that firms in developing and least developed countries rely more on external technological sources. And the effects of those external sources are significantly important for firms' productivity growth. Second, by adopting the correlation approach and productivity approach simultaneously, we systematically test the complementary versus the substitute relationship between MAKE and BUY. The findings generated from both methodologies imply the existence of complementarity only in developing economies. In least developed countries, we find no evidence in favour of complementarity relation between in-house R&D and external know-how.

The paper is structured in 6 sections. In the next section we review the literature about innovation strategies in developing countries and the complementarity in innovation studies. In section 3 we present the empirical model and empirical methodologies which have been adopted in assessing complementarity. And we describe our data and identify variables in section 4. In section 5 we show the empirical results and elaborate interpretations with respect to the findings. In the last section, we will present the conclusion.

2. Literature review

2.1 Innovation in developing countries as a learning and adopting process

Cooper (1989) explained considerably on differences between innovation in industrialized economies and characteristics of innovation in developing countries. He argued that it is a rather limited view of innovation theories only concerned with the initial introduction of products or processes. The catch-up phase is crucial too in any firm where innovation appears in particular for two reasons. First, the expectation of the catch-up speed has substantial influence on the behaviour of innovative firms. Firms will always put effort on strengthening their technological

[1] The classification of developing and least developed countries (LDCs) is taken from "World Bank country classification 2005".

capability in order to preempt learning and imitation. Second, it is important to consider catch-up and other processes that might be involved in the technological diffusion process. Most firms in developing countries are attempting to reach the technological frontier instead of creating products and processes which are new to the market. Thus, to understand the circumstance in developing countries, we must grasp the objective conditions determining the learning and adoption process. Unambiguously, technological sourcing strategies as input factors in innovation production function directly influence the outcome of catch-up process. Hence, the first objective of our study is to identify the effective technological strategy.

From theoretical and empirical findings from several studies by Arrow (1962), Bell et al. (1982) and Dahlman et al. (1987) it becomes clear that a learning process will not happen automatically. It requires a strong technological capability within the firm and, externally, a careful institutional condition, such as government financial policies, regulation and infrastructure of economy. In the absence of these factors, there may be no effective learning or no innovation at all. Cooper (1989) mentioned that failure of learning processes in developing countries is in fact quite common. Firms in developing countries that receive technology via external sources are quite often unconcerned about how to develop and appropriate internal capability.

Learning and adoption probably breaks down in developing countries more often than in industrialized countries due to the lack of absorptive capacity (Fransman, 1985; Cooper, 1989). Several studies have started to investigate the link between technological capabilities, innovation and productivity in firm level. So far results are mixed[2]. Most of this literature in developing countries conventionally emphasizes the link between R&D and innovation output or firm performance. In fact, innovation emerges as a result of many diversified activities, which not only include in-house R&D but also contain several other external practices. The unbalanced empirical results draw our attention on the exploration of external technological acquisition beyond merely focus on internal R&D.

2.2 Make and buy strategies: complementarity versus substitubility

When we consider the question of innovation strategies used by firms in developing countries, a good starting point is that for the most part even the most technologically advanced firms in

[2] For example, Chudnovsky et al. (2006) showed that R&D and technology acquisition raise the firms' probability in Argentina. The same results also discovered by Fernandes (2006) in the study of firms in Bangladesh. On the contrary, Goedhuys and Sleuwaegen (1999) find no significant impact of R&D activity or licensing on labour productivity for manufacturing firms in Burundi. Benavente (2006) found no significant result of R&D expenditures and firm productivity in Chile.

developing countries are committed to be imitators (Freeman, 1989). This is partly due to their limited technical resources, and partly because of their comparatively limited production experience. Literature on developing countries customarily distinguishes two main types of innovation: 'MAKE', which focuses on R&D done through in-house development or cooperative activities with suppliers, customers or university & research institutes; and 'BUY', which involves transactions of skilled personnel, new machinery (embodied buy), or license agreements with foreign innovative firms (disembodied buy). However, it does not mean that R&D is not important for firms. During the learning and catch-up process, firms are required to have a certain level of technological basis to facilitate the assimilation of new technologies. Rothwell and Dodgson (1991) stress that the successful adoption of external know-how for small and medium size firms with low levels of technological basis is conditioned on its in-house human capital, such as the employment of qualified technical specialists and engineers. The fact that firms conduct such internal and external knowledge acquisition activities simultaneously suggests the possibility of some form of complementary in these activities (Arora and Gambardella, 1990; Cockburn and Henderson, 1998; Granstrand et al., 1992).

The hypothesis in the present study is: *innovation in developing countries calls for the MAKE and BUY complementarity that depends on the stage of a country's development path.*

A growing number of empirical studies have estimated the complementarity versus substitubility between technology MAKE and BUY in developed economies (Cassiman and Veugelers, 2006; Belderbos et al., 2004; Arora and Gambardella, 1994). Arora and Gambardella (1990) test the synergetic effects among four different external sourcing strategies of large chemical and pharmaceutical firms. After controlling heterogeneity of firms, the results also show the complementarity between all types of external sourcing strategies. Mohnen and Roller (2005) use the Community Innovation Survey (CIS) data to test the complementarity between different obstacles faced by firms. Their results show that lack of internal human capital is complementary to all the other obstacles in almost all industries. In a recent study by Cassiman and Veugelers (2006), using the methodology developed by them, they systematically examined the relationship between firms' internal R&D and disembodied innovation strategies. The empirical results presented that a strong synergy effect of in-house R&D and disembodied souring strategy exists in Belgian manufacturing firms. Compared to developed countries, relevant studies in developing countries are relatively scarce. Since the learning and catch-up is the main objective in developing countries, we are hoping that our study on firms' technological strategy choosing and the performance of those strategies will help firms to address effective innovation management policies and ultimately improving benefit their performance.

3. Methodology: Measuring Complementarity

3.1 Empirical Model

In this section we present our objective function in which complementarity in technological acquisition strategies can be identified. Suppose that innovation is affected by N different acquisition strategies chosen by individual firms represented by A_{ij} =(A_{1j},…., A_{Nj}), i = 1,…N. where j denotes firms. In our case, we have two strategies MAKE and BUY, so N = 2. With substantial impacts on productivity, innovation happen in firms and is characterized by the production function Π(A_{ij}, Z)

$$\Pi(A_{ij}, Z)= (1-A_{1j})(1-A_{2j})\theta_{00}+A_{1j}(1-A_{2j})\theta_{10}+(1-A_{1j})A_{2j}\theta_{01}+A_{1j}A_{2j}\theta_{11}+Z_j\chi+\varepsilon_j \quad (1)$$

where A_{ij} is an endogenous decision to firms. So we will also have an adoption function, A_{ij} = D(W),

$$A_j^* = \gamma_j W + e_j \;,\; [A_j = 1\, if\, A_j^* > 0; A_j = 0\, if\, A_j^* < 0] \quad (2)$$

Cov(ε_j, e_j) = ρ; Cov(W, ε_j) = 0; Var(e_j) = 1

where θ in (1) is the cross-partial returns to adoption of strategies combinations. Z_j = { Z_{js}, Z_{jt}, Z_{jo}, z} is j × n vector of exogenous variables capture firm and industry-specific pre-determined factors in the production function. Z_{js} is the standard variable included in the Cob-Douglas production function, such as capital, and labor; Z_{jt} denotes a set of technological variables that present the technological capability of firms; Z_{jo} includes organization and institutional variables; z represents the unobserved heterogeneity which affects the return to technological strategies. χ stands for the parameters which measure the partial effects of elements in Z. There also exists a vector of factors W = (w, v) which affect the adoption of decision but not the productivity, where w is observed and v is unobserved effects in the adoption function (such as technological regulation and the innovation subsidies). w is the exogenous variables that have influence on returns of innovation strategies which appear in the production function. v represents the unobserved characteristics which only affect firms' adoption decision. The decision faced by the firm is to choose a set of innovation strategies A_{ij}

$=(A_{1j},\ldots,A_{Nj})$ that maximizes innovation output and consequently improve productivity, *i.e.* max $\Pi(A_{ij}, Z)$.

Even though the maximization problem is analogous for all firms, the heterogeneity across firms - elements in Z and W - substantially influences the process of production and strategy adoption, ultimately leads firms to make different choices. For instance, with different institutional endowments, the partial effects of the same strategy would be different across firms. Additionally, characteristics of firms will also vary the cost of practices and consequently leads to the divergence of decision adopting. Cross–sectional analysis such as the present one is only able to take into account observed firm heterogeneity. So we suppress "z" and "v" out. There might of course also exist unobserved heterogeneity in the production and adoption process, such as manager's managerial ability and institutional uncertainties.

3.2 Testing complementarity

The study of complementarities between practices is based on the theory of supermodularity and first employed in economics analysis by Milgrom and Robers (1990).

Definition: suppose, in our case, there are two endogenous technological acquisition practices A_{1j}, $A_{2j} \in A_{Nj}$ and Z is a vector of exogenous variables. The objective function $f(A_{Nj}, Z)$ is supermodular if the following inequality holds for all values of the other arguments of f:

$$f(A_1^h, A_2^h;Z) - f(A_1^l, A_2^h;Z) > f(A_1^h, A_2^l;Z) - f(A_1^l, A_2^l;Z) \qquad \text{(i)}$$

$$f(A_1^h, A_2^h;Z) - f(A_1^l, A_2^h;Z) < f(A_1^h, A_2^l;Z) - f(A_1^l, A_2^l;Z) \qquad \text{(ii)}$$

Supermodularity (i): A_{1j} and A_{2j} are complements. Where the superscript h(high) and l(low) denotes the level of A. This inequality restriction tells us that the incremental effect of one practice (A_{1j}) on the objective function will be increasing condition on the increasing of another practice (A_{2j}).

Substitutibility (ii): A_{1j} and A_{2j} are substitutes. The marginal return of practice A_{1j} on the objective function will be decreasing if practice A_{2j} increases its level.

If the presence of one practice is likely to raise the marginal effect on other practices, then the joint adoption of two practices together should be preferred. It implies that, if there is a co-movement phenomenon of two practices, and then it can be interpreted as the first evidence in favour of complementarity. This co-movement can firstly be tested by the positive correlation (negative if substitutes) between pair wise practices.

Correlation approach (CORR)

The CORR approach tests whether the correlation among practices is positive, conditional on observable. Athey and Stern (1998) defined it as "reduced-form test exploiting exclusion restrictions". Suppose $I(A_N, W)$ is supermodular in (A_1, W) and (A_2, W). Then the optimal choice of innovation strategies, $A^*(A_1^*(W), A_2^*(W))$, is monotone non-decreasing in W. It implies: (i) an increase in the exogenous returns to one practice will lead to mutually reinforcing increases in the other endogenously determined practices. (ii) in a two-choice model, only complementarity leads to a positive effect of W_{1j} on A_{2j}. A factor that has its sole direct effect on A1j will be uncorrelated with A_{2j} unless A_{1j} and A_{2j} interact directly in the production function.

It is important to note that without taking into account the characteristics across firms, the correlation between the technological strategy adoptions could be biased and lead to a false acceptance of the hypothesis of complementarity (Athey and Stern, 1998). For example, firms with more innovation financial sources tend to be more dynamic in innovation activities. Therefore we argue here that it might be the characteristics of firms which result in the correlation effects between MAKE and BUY. An intuitive way dealing with this drawback is to test the correlation between practices conditionally on observed heterogeneity of firms. Several empirical studies have been drawing attention to this issue and they argued if adding exogenous variables removes the correlation between practices, then these added variables will be considered as the sources of complementarity (see Cassiman and Veugelers, 2006).

In our empirical analysis, we first use unconditional correlation between MAKE and BUY to test if the association between these two strategies exists without taking into account firms' exogenous heterogeneity. The correlation coefficients suggest a strong and significant association between MAKE and BUY in both developing and least developed countries. However, the results are just suggestive and not strong enough to conclude the existing of complementarity. Then, we search the complementarity by controlling characteristics of firms by using the adoption function (2) and estimate the correlation between residuals. The findings show a considerably decreasing of correlation coefficients between MAKE and BUY in developing countries after controlling firms' heterogeneity. In least developed countries, the association between MAKE and BUY disappeared and the relation tends to be substitute.

An important point we should note is that even with controlling the observed characteristics among firms, the CORR approach still suffered the possibility of bias estimation due to ignore the unobserved heterogeneity - variable z and v in equation (1) and (2) - and the interaction between them. Consequently, the estimation results might still deliver biases. A number of empirical studies referenced on complementarity use this approach as auxiliary evidence[3].

Productivity approach (PROD)

In empirical studies, another popular approach used in applied studies to test complementarity is to direct estimating the parameter of interacting term in production function.

PORD Approach: observe the existence of complementarity directly by the regression of objective function on exclusive combinations of innovation activities. In this study (in-house MAKE and external BUY), A_{Nj} is binary choice and $A_{Nj} \in (1,0)$, then it can be interpreted as the presence of one technological source will higher the marginal returns of another practice to productivity compare to it performing in isolation. θ stand for the cross-partial returns of strategy combination in the production function (1), then A_{1j} and A_{2j} is complement if

$$\theta_{11} - \theta_{01} - \theta_{10} + \theta_{00} > 0 \qquad (3)$$

and substitutes if

$$\theta_{11} - \theta_{01} - \theta_{10} + \theta_{00} < 0 \qquad (4)$$

Several papers (see Miravete and Pernias, 2006; Cassiman and Veugelers, 2006) indicate that the searching of complementarity by adopting PROD approach should also control the heterogeneity across firms inside and outside the production function. Cassiman and Veugelers (2006) use the exogenous variables (correlated with adoption decision without affecting innovation output) in the adoption function as the instruments and apply them into the production to constitute the second least square (2SLS) regression. However, the results can be refined in favour of complementarity only if the instrumental variables are available and properly captured.

The PROD approach suffers the biases caused by unobserved elements in z and w (Athey and Stern, 1998). Three possibilities might happen: if z = 0 and elements in w are not affiliated

[3] Arora and Gambardella (1990) introduce a formal analysis of (CORR) as a test for complementarity. Brickley (1995) explicitly uses (CORR) as a test for the comparative static predictions of Holmstrom and Milgrom (1994) in the context of franchising contract provisions. Other recent studies which use this approach include Ichniowski, Shaw and Prennushi (1997), Brynjolfsson and Hitt (1998), Colombo and Mosconi (1995), Greenan et al (1993), Helper (1995), Helper and Levine (1993), Hwang and Weil (1996), Kelley, Harrison, and McGrath (1995), MacDuffie (1995), and Pil and MacDuffie (1996).

(influence both MAKE and BUY strategies simultaneously), the estimation from (3) will be in consistent in favour of complementarity; if w = 0, z ≠ 0 and elements in z are independent, the results from (3) will underestimate the synergy between the two strategies; if w = 0, z ≠ 0 and elements in z are in affiliation, the results will be overestimated the true degree of complementarity. Consequently, the estimation results from the PROD approach will still deliver biases and lead either to accepting the hypothesis of complementarity while no complementarity exists, or to rejecting the hypothesis of complementarity when activities in fact are complementary.

In this study, we restrict the assumption by not allowing unobserved heterogeneity. First, we will test the synergy effects on productivity between different combinations of MAKE and BUY by adopting the PROD approach. Simultaneously, we will also search for complementarity evidence by using the CORR approach. Second, based on the findings from adoption function, we regress the exogenous factors of adoption decision as instruments in the production function to refine our results. The bootstrap standard error will also be incorporate into 2SLS.

4. Data and variables

4.1 Data

The data used in our research is from World Bank Investment Climate Surveys (ICS)[4]. The survey conducts mostly in developing or least developed countries (LDCs) and provides us a wide range of information about the economic environment and economic activities of firms. Several aspects regarding firms' innovation activity is also covered in the survey. Such as the general information referring to firms' innovative input strategies, innovation outputs, and R&D activity. Our main goal is to identify the inter-relationship among technological sourcing strategies and their cross-partial effects attribution to firm performance. Another objective is attempting to identify the effective technological acquisition strategies in the context of developing and least developed countries.

After cleaning out missing values, twenty eight countries and 6,755 firms in manufacturing sector are included in the cross-sectional dataset from the period 2002-2004. Only countries with more than 50 observations are included. We also drop firms with its size less than 5. Table 1 gives simple descriptive statistics on some basic information with respect to countries and

[4] For more information and the methodology of the survey, please see http://www.worldbank.org

their innovativeness. Innovativeness is measured by two binary variables: product innovation and process innovation.

Table 1

Due to the different levels of economic development and size of the economies, the number of firms in the samples varies considerably across countries. Innovation of firms across developing countries are qiute dynamic with 68 percent of them claimed to be innovative during the previous production year. It should be noted that the new technologies or products from innovation activities in developing and LDCs are not traditionally defined as the one new to the market, but they are probably only new to the firm. This reflects the framework that innovation in developing countries and LDCs is a learning and adopting process.

The survey contains two main questions with respect to firms innovation input strategies. Firms were asked to choose three important methods of innovation sourcing strategy out of total twelve choices while the R&D spending of firms in last year is also addressed in the questionnaire. We give the binary variable "MAKE" value of 1 if firms have a positive R&D spending, 0 otherwise. Similarly, if firms chose at least one of the three technological sources: hiring key personnel, licensing from abroad or domestic, and trade fair/study tour; the dummy variable "BUY" will be marked as 1. Almost 45 percent firms were answering using import machinery and equipment as one of their important innovation input. Considering the difficulty of clearly defining the use of machinery and equipment as the input sourcing of innovation. We decided to leave this choice out due to the possibility that firms might confuse buying machinery as innovation sourcing or simply for the purpose of production. Table 2 shows the account statistics of the appearance of each strategy and their interactions.

Table 2

This account statistics tells us that the main technological strategies in developing countries and LDCs are from external sources. Particularly in least developed country, the percentage of firms which rely exclusively on BUY is triple compared to the percentage in "MAKEONLY". Nevetheless, external technological sources is also the main strategy of firms in developing countries even the proportion of "BUYONLY" decreases almost one third compared to low-income countries. From the occurrance of adopting MAKE and BUY, we can see that there is an increase in in-house R&D in middle-income countries while about 38 percent of firms are actually do not use MAKE or BUY at all. However, we should note that there might be other sourcing strategies adopted internally or externally by firms, such as, transferring from mother companies, cooperating with local university and institutes. The main concern of this study is the strategies which as defined in MAKE or BUY.

4.2 Variables in production function and adoption function

The dependent variable in equation (1) is LABOR PRODUCTIVITY, measured by sales per employee, in natural logarithmic terms. The standard explanatory variables (Z_s) used in the production function are: CAPITAL (capital/labor in logs, capital is the end of year total capital stock); SIZE is the degree of returns to scale represented by the coefficient of log permanent workers at end of the year.

Besides technological sourcing variables MAKE and BUY, the firms' technological capabilities (Z_t) devoted to absorption are crucial to the success of innovation. CAPACITY indicating the differences in capacity utilization (in percentage) between firms is also controlled in our analysis because of the idea that firms are able to produce more with the same amount of inputs when their production operates in a relatively high level. FOREIGN is a dummy variable with value 1 for those firm has positive share of foreign ownership. The dummy variable EXPORT tells if firms have postive export sales during the last year. EDULABOR is measured by the percentage of permanent workers who have at least a university education background. EDUMANAGER dummy variable has value 1 if the average education level of senior managers is above postgraduate level. We also include the dummy INTERNET when firms use internet in daily work because it is commonly recognized as an important technological infrastructure to improve communication and information efficiency. Variable ASSOCIATION capturs openness of firms to information if it has membership to a business association. It could be an important place for firms to attain technological information. Dummy variable ISO with value 1 indicates that the firm has received international certificates, such as ISO9000, 9002 or 14,000. It is based on the idea that the achievement of international certificates reflects to some extent the technological level of firms.

The ICS survey contains a series of information about the business environment firms operate. Our last set of exogenous variable (Z_o) in the production function (1) is trying to grasp some of them. The question which asking of lost sales (in percentage) due to power outages during last operation year constructs the variable INFRA to indicate the quality of business infrastructure. REGULATION denotes the average time of a manager dealing with government regulations. It measures the extent to which regulation is a burden in firms' operation. Dummy variable FINANCE with value 1 if accessing to finance or costs of finance is a major obstacle to firms.

Variables driving the adoption decision

Our attempt in this study is to systematically test the complementarity, and therefore the cross-equation restriction of the productivity function and strategy adoption function need to be considered. Besides the exogenous variables that appear in productivity function, it is essential to take into account the factors that influence the strategy adoption but have no direct effect on productivity. However, the cost and returns of adopting MAKE or BUY strategy are quantitatively unobserved. Therefore, the quality of instruments we adopted could limit the estimation outcomes. We search for variables from economic scale, basic absorptive capacity, and market information with reference from previous studies (Cassiman and Veugelers, 2006; Miravete and Pernias, 2005). Their findings imply that these characteristics of firms could be the driver to firm in adopting different technological strategy.

We include TAX, the dummy variable with value 1 for firms reported that they have been surffering from a heavy tax burden from the government. The tax system and regulation will have direct impacts on firms' in-house and external sourcing strategies. The issue of tax incentives on R&D activities has been addressed by previous studies (see Mohnen, 1999). Another dummy variable TRADE_RE with value 1 if firm claimed the trade regulation in their country as a problem for the operation and growth their business. With a better and trade friendly system, firms are more motivated to get technological sources from foreign companies. Finally, we include three dummy variables to reflect the technological infrastructure, ENGINEER and IT, which eaqual to 1 if they are adopted in firm. Table 4 gives the definition and summaries of variables used in our empirical analysis.

Table 3

Table 3 is a statistics of firms' technological variables. It tells us the difference in technological infrastructure and aborptive capacity between low-income and middle-income countries. Obviously, technological capability and innovation environment of firms are different across levels of development. We can find that the mean of technological-related variables are higher in developing countries while the obstacle-related variable are increased in least developed countries except ARRPO. We argue that with low levels of development, firms are constrained by a general low levels of technological capability. Hence, they mainly rely on external technological aquisitions and the synergy effect of MAKE and BUY on productivity performance will also be depressed. For example, even they adopted the same external technological strategies, firms with a low level of human capital will use these external sources less effectively. However, the increase of internal technological capability will catalyse the effective absorb external know-how. Table 4 gives the definition of variables we used in our empirical analysis.

Table 4

5. Empirical results

In this section we present an econometrical analysis of how strategy combination affects firms' productivity performance. Furthermore, we will identify the effective sourcing strategies for developing countries and LDCs.

5.1 CORR approach

Unconditional correlation

Before regressing firms' production function, we will investigate the indirect implications of the complementarity theory by estimating the pairwise association of MAKE and BUY strategies. Statistical association of any two-decision variables requires that all real valued nondecreasing functions of these two variables be statistically correlated. Here we first measure the association of MAKE and BUY regardless of any other differences in firms' characteristics. The nature of Pearson's correlation is not adequate to possibly measure nonlinear association between variables, nonparametric correlation is more robust in this case. In table 5, the first column gives the results from Kendall's rank correlation[5] (see Press and Flannery, 1986).

Table 5

In both low-income and middle-income cases, MAKE and BUY are positively related with a significant difference in magnitude. This result implies the existence of complementarity between MAKE and BUY strategies across countries with different levels of development. In the middle-income group, the correlation is significantly stronger compare to the low-income group. This evidence indicates the association between innovation strategies, which might be the result of a supermodular function in innovation strategies. However, the unconditional correlation test is not sufficient for us to conclude that MAKE and BUY should be considered complements. The heterogeneity across firms could be the cause of association and lead to the

[5] Pearson's linear correlation and Spearman's rank-order correlation are also computed. They all lead to the same qualitative results.

possitive correlation coefficients.

Conditional correlation

The evidence from unconditional correlation measures complementarity between innovation MAKE and BUY strategies without controlling for observed firms' characteristics. Table 6 presents the estimation of the determinants of firms' strategy adoption function. Because of the dichotomous nature of our strategy variable, we adopt the nonlinear Bivariate Probit model to estimate the marginal effects of determinants considering the covariance of the two strategies. The results given here, divided into low-income countries and high-income countries, have been obtained by regressing MAKE and BUY strategies respectively. As we can interpret from the estimates, large firms in terms of the number of employees tend to be more dynamic in terms of conducting R&D due to relatively more resources, such as finance and human capital. The size effect disappeared with respect to the BUY strategy in the middle-income group. On both strategy variables there are negative nonlinearities of the foreign ownership share in middle-income countries, and these negative effects become insignificant in low-income groups. Our understanding here is that technological sources in firms that share ownership with foreign companies are from their affiliated companies. Not surprisingly, EDULABOR, EDUMANAGE and IT as indicators of absorptive capacity show significant effects across developing and least developed countries. Firms with a better technological base are more prone to innovate. The ISO and CONSULT as a proxy for technological capability also stimulate firms' in-house and external strategy adoption, particularly in middle-income economies.

Table 6

The primarily purpose of regressing adoption function is to control the exogenous heterogeneity which has an influence on firms' technological strategy decisions. Moreover, we would like to see if the effects of exogenous variables are simultaneously showing significance on the regression results of both income groups. As we discussed in section 3, variables appear significantly in both MAKE and BUY strategies indirectly indicating the existence of complementarity that is consistent with the theory implied by the CORR approach. As the results table show, less variables are found pair-significance in the middle-income group than the low-income group. So we could not find any evidence to support the existence of complementarity in the middle-income group. However, the results is only suggestive but not conclusive.

The residuals of these adoption equations have been used to analyze the conditional pairwise association between MAKE and BUY strategies. The second and third column of table 5 repeats the analysis of pairwise association between firms' technological strategies conditional on their adoption characteristics. Instead of computing correlation coefficients directly from the occurrence of MAKE and BUY, we compute these correlation estimators based on the residuals of the Bivariate probit regression of MAKE and BUY adoption function. All observed exogenous variables are included. This method is derived from a modified version of Arora's (1996) approach to test correlation between pairs of decision variables. It was also adopted in several studies (For example: Miravete and Pernias, 1998; Kaiser, 2005).

Both Pearson and Kendall's correlations are significant in middle-income countries. It again implies the existence of complementarity between innovation MAKE and BUY strategies. But there is a considerable decrease in the magnitude compared to unconditional correlation coefficients. However, surprisingly, the correlation coefficients in low-income countries turn out to be siganificantly negative in Kendall's correlation. In contrast with complementarity, it indicates the evidence of substitutability relation between MAKE and BUY strategies. This is consistent with our hypothesis that complementarity between technological sourcing strategies in low-income countries might limited by their low level of absorptive capacity. Hence, it is possible that innovation strategies are substitutes when firms are constrained by financial or absorptive capacity. Another important interpretation drawn from the conditional correlation results is that the existence of synergetic effect of MAKE and BUY strategies needs to be supported by other contextual variables, such as firms' technological capability, financial constrain, or the economic environment. We conduct the same regression but without IT, APPRO, and TAX. These variables are the instruments which are correlated with adoption decision but without direct effects on firms' productivity performance[6]. The correlation coefficients are given with apostrosphe in table 6. Even the increase in the significant level suggests that these technological factors have caused parts of the association between MAKE and BUY. However, qualitatively, the magnitude is not strong enough to conclude these factors are the sources of complementarity. Furthermore this evidence also indicates the weak power of instrumental variables.

5.2 PROD approach

We regress our dependent variable (productivity) on the exclusive combinations of innovation activities, together with firm characteristics, country and industry dummies that may affect the

[6] We added these four instruments in production function and the results suggest that they have on significant direct effects on firms' productivity.

productivity performance. The results are presented in table 7.

Table 7

The results not only present us the implication of supermodularity in innovation strategies, it also generates several important ideas about innovation activities of firms in developing and least developed countries. Our findings suggest that elasticities of capital stock (CAPITAL) to output do not differ considerably between both groups but we find there are no increasing returns to scale (SIZE) in low-income countries. Export-oriented firms (EXPORT) are more efficient in term of productivity because of the more competitive environment they face. Productivity increases with capacity utilization (CAPACITY) and coefficients are highly significant. Firms that share ownership with foreign (FOREIGN) companies are also showing to be more productive but this is only significant in middle-income countries. Consistent with previous empirical studies (Benavente, 2006; Goedhuys, 1999), technological factors contribute significant effects in productivity growth. Firms' technological capability indicators are all significant.

Not surprisingly, when firms are faced with more obstacles in their production process, their productivity performance is reduced. Three institutional variables are showing negative effects on productivity performance. Financial constrains (FINANCE) depress productivity of firms in low-income countries more severely compared to middle-income countries. Estimate coefficient of REGULATION and INFRA are not significant but negative in both groups.

Now, turning to the hypothesis in our analysis. In middle-income countries, consistent with complementarity test by the CORR approach, the coefficient on MAKEBUY in OLS is highly significant whereas the other coefficients are lower and less significant. The coefficient of BUY contributes almost the same magnitude in firms' productivity in low-income countries as MAKEBUY does. This result confirmed our assumption that with low levels of technological capability, firms in low-income countries are more rely on external sourcing strategies. Contrary to developed countries, the traditional endogenous variable R&D (MAKE) does not play an important role as it does in developed countries due to the fact that innovation in developing countries and least developed countries is a process of catching-up and learning. The results on inequality restriction test[7] present us the evidence of complementarity between innovation

[7] Because we only have one restriction with two practices in our model, so we first conduct a one-way t-test on the inequality equations. In principal, it generates the same quality outcomes as F test. H_0: $\theta_{11} - \theta_{01} > \theta_{10} - \theta_{00}$ for testing complementarity; H_0: $\theta_{11} - \theta_{01} < \theta_{10} - \theta_{00}$ for testing substitutability. Then we compute a point estimate of the linear combination of these four estimators (θ_{11}-θ_{01} - θ_{10} + θ_{00}). This will enable us to check the sign of this restriction and consequently test complementarity versus substitutability.

MAKE and BUY strategies. The high significant p value in middle-income countries again indicates the complementarity between internal and external innovation strategies. Contrarily, the inequality equation does not hold in low-income countries with insignificant p value. These findings are in line with the coefficients generated in the CORR approach.

Table 8

Using the results from the adoption equations, we construct predicted values for exlusive combination of MAKE and BUY (MAKEONLY, BUYONLY, MAKEBUY) strategies in both low-income and high-income group. We use these predicted values incorporate into the production function to generate the 2SLS regression. Two important preconditions should be met in order to process the estimation. First, good instrumental variables should be independent from productivity but correlated with innovation strategy adoption. Because of the untestable nature of adoption cost and the limited information from data, the instruments we can propose are imperfect. This could be a serious constraint on our 2SLS estimation. Second, unobserved heterogeneity could also lead to biases in estimating of the adoption function. Table 8 indicates the coefficients based on 2SLS estimation. The results are qualitatively consistent with the OLS results in the middle-income countries. Accompanied with the significant effects showing in MAKEONLY, the hypothesis of no complementarity between internal R&D activities and external sourcing strategies is rejected with a high level of significance. We therefore conclude that there is a strong evidence in favor of complementarity in innovation MAKE and BUY strategies across developing counties. But when we search the synergy effects in least developed countries, the hypothesis of the existence complementarity will be rejected. Moreover, the hypothesis that there is substitutability in innovation MAKE and BUY can be accepted. This evidence confirmed the implication from the CORR approach. However, the standard errors of estimated coefficients on 2SLS in LDCs suggests the weak instrumental variables we used. Better instrumental variables are required in the futher study. We should be aware that results based on the above analysis capture the effect of the existence of complementarity conditional only on the observed firms' characteristics. Our estimations with repect to complementarity (substitutability) are under the assumption of nonexistence of significant heterogeneity of firms' unobserved characteristics.

6. Conclusion

The lack of advanced technological competencies in developing and least developed countries require innovation to occur through the adoption and learning process of already existing technologies. In order to catch up with the technological frontier, firms have been striving hard to promote technological advancement through internal R&D effort (MAKE) as well as through external sourcing (BUY). The low levels of technological capability severely constrain firms to conduct in-house R&D. For this reason, firms rely more on external knowledge acquisitions such as licensing, emboding skill labor etc. Our results highlight the significant contribution of external sourcing strategies to firm's productivity growth, particularly in least developed countries. However, firms that combine internal R&D with external innovation activities simutaneously are having a better performance in developing countries. These findings indicate that different levels of development requires government constitute different policies in order to catalyse effective innovation strategies. In the context of developing and developed countries, external sourcing strategies are essential for firms to be competent in the local and global market.

Attempting to search for evidence of complementarity between in-house and external strategies, we have applied the CORR and PROD approach to estimate different combinations of MAKE and BUY and their partial returns to productivity performance. Our results are consistent with the existence of complementarity between in-house and external innovation activities in developing countries. However, this synergy disappears in the context where firms have relatively low levels of technological capability, such as lack of educated labor and financial sources, technological infrastructure and institutional support. Once we control firms' heterogeneity in terms of technological factors and institutional obstacles, innovation MAKE and BUY strategies become substitutive. This finding suggests that combining technological with institutional factors are the foundamental sources to stimulate effective returns to innovation activities. However, without taking into account unoberved heterogeneity across firms, we can only provide suggestive findings. Panel data will enable us to control the random effects and interaction between unobserved heterogeneity across firms.

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Table 1. Descriptive statistics: Countries and Innovation

Country	Category	Number of observations	Innovative firms
			(Percentage)
Brazil	Middle-income	*1463*	*85.99%*
Ecuador	Middle-income	*273*	*75.46%*
El Salvador	Middle-income	*280*	*80.71%*
Guatemala	Middle-income	*371*	*72.78%*
Honduras	Middle-income	*323*	*66.25%*
Indonesia	Middle-income	*466*	*46.35%*
Nicaragua	Low-income	*308*	*75.00%*
Pakistan	Low-income	*845*	*missing*
Philippines	Middle-income	*582*	*59.79%*
Sri Lanka	Middle-income	*362*	*missing*
Tanzania	Low-income	*73*	*49.32%*
Thailand	Middle-income	*1336*	*64.97%*
Zambia	Low-income	*73*	*72.60%*
Total		*6755*	*68.11%*

Note: the innovation output information are not provided in five countries; Pakistan and SriLanka. The total mean percentage of innovative firms is estimated exluding these five countries.

Table 2. Technological MAKE and BUY strategies in low and middle-income counties

	MAKEONLY	BUYONLY	MAKEBUY	NON_MAKEBUY	Total sum
Low-income	*12.78%*	*35.87%*	*28.95%*	*22.40%*	*100.00%*
Middle-income	*16.22%*	*30.00%*	*22.76%*	*31.01%*	*100.00%*
Total sample	*15.56%*	*31.13%*	*23.95%*	*29.36%*	*100.00%*

Table 3. Descriptive statistics: Technological capability comparison (mean values)

	Low-income	Middle-income	Total
SIZE	*3.274*	*4.325*	*4.123*
FOREIGN	*0.050*	*0.119*	*0.106*
EXPORT	*0.166*	*0.320*	*0.290*
IT	*0.174*	*0.435*	*0.385*
ASSOCIATION	*0.625*	*0.673*	*0.664*
EDULABOR	*0.058*	*0.125*	*0.112*
ISO	*0.133*	*0.194*	*0.182*
EDUMANAGER	*0.302*	*0.135*	*0.167*
TAX	*0.396*	*0.345*	*0.355*
APPRO	*0.281*	*0.364*	*0.348*
CONSULT	*0.43*	*0.32*	*0.35*

Table 4. Definition of variables

Dependent Variable	
PROD_LABOR	Total sales /Number of long term permanent workers, in logs
Explanatory Variables	
CAPITAL	Total assets of firms (including Property, Plant and Equipment)/Number of long term permanent workers, in logs
SIZE	Number of long term permanent workers
CAPACITY	Actual output produced / Maximum output that could be produced with existing machinery and equipment and regular shifts (value between 0-1)
Technological Variables	
MAKE	Dummy variable equal to 1 if firms have own R&D activities and have a positive R&D budget
BUY	Dummy variable equal to 1 if firms acquire technology through at least one of the following external technology acquisition methods: hiring key personnel; licensing; trade fair/study tour
FOREIGN	Dummy variable equal to 1 if firm has foreign ownership
EXPORT	Dummy variable equal to 1 if firm's sales are exported
EDULABOR	Percentage of permanent workers have university or above education
IT	Dummy variable if firms use internet or have own website
ASSOCIATION	Dummy variable equal to 1 for firms being member of a business association
ISO	Dummy variable equal to 1 if firm has ISO (international certification)
TAX	Dummy variable equal to 1 for firms has suffered any heaven tax burden or tax system
APPRO	Dummy variable with value 1 if firm claimed the "anti-competitive or informal practices" as an obstacle in their business
CONSULT	Dummy variable equal to 1 if firm has technological consultancy
Organizational Variables	
INFRA	Lost value of sales due to power outages during last operation year, in percentage
REGULATION	The average time of manager dealing with government regulations
FINANCE	Dummy variable with the value 1 if accessing to finance or costs of finance is a major obstacle to firm

Table 5. Conditional Correlation: Cov(MAKE, BUY)

	Unconditional Correlation	Conditional Correlation	
	Kendall rank	Biprobit correlation	Kendall rank
Low income	*0.0807**	*0.072*	*-0.0309**
	0.0037	*0.147*	*0.000*
Middle income	*0.0901**	*0.061**	*0.0193**
	0.000	*0.011*	*0.002*

* represents significant level at 0.1 p-values are under coefficients

Table 6. Bivariate Probit regression: dependent variables MAKE, BUY

	low-income		middle-income	
	make	buy	make	buy
SIZE	*0.109*** *0.008*	*0.071** *0.087*	*0.131*** *0.000*	*0.018* *0.293*
FOREIGN	*-0.050* *0.815*	*0.003* *0.989*	*-0.302*** *0.000*	*-0.138** *0.054*
EXPORT	*0.031* *0.802*	*0.210** *0.087*	*0.014* *0.775*	*-0.091** *0.054*
IT	*-0.009* *0.936*	*0.244*** *0.032*	*0.248*** *0.000*	*0.079** *0.069*
ASSOCIATION	*0.071* *0.406*	*-0.085* *0.308*	*0.201*** *0.000*	*0.049* *0.250*
EDULABOR	*-1.098*** *0.002*	*0.888*** *0.026*	*0.269*** *0.014*	*0.083* *0.444*
ISO	*-0.075* *0.573*	*-0.060* *0.649*	*0.061* *0.283*	*0.119*** *0.039*
EDUMANAGER	*0.392*** *0.000*	*0.246*** *0.010*	*0.188*** *0.001*	*0.092* *0.100*
CONSULT	*0.368*** *0.000*	*-0.100* *0.235*		
TAX	*0.304*** *0.000*	*-0.056* *0.498*	*0.030* *0.490*	*0.149*** *0.000*
APPRO			*0.093*** *0.024*	*0.039* *0.336*
_cons	*-1.073*** *0.000*	*-0.003*** *0.000*	*-1.164*** *0.000*	*0.064* *0.515*
correlation correlation'	*0.072* *0.056*		*0.061*** *0.065***	
chi2(1) (correlation) Prob > chi2	*2.106* *0.147*		*6.477* *0.011*	
Wald chi2(50) Prob > chi2	*329.700*** *0.000*		*1696.650*** *0.000*	

Industry, country and year dummy are included
** significant level 1%, * at 5% . p-values are under coefficients
nomakebuy is the base category. We used different instrutment for two groups. TAX and CONSULT in low-income, TAX and APPRO middle-income countries.

Table 7. OLS: dependent variable sales per person (in logs)

	Low-income	Middle-income
CAPITAL	*0.426*** *0.000*	*0.488*** *0.000*
SIZE	*-0.044* *0.132*	*0.064*** *0.000*
CAPACITY	*0.449*** *0.030*	*0.295*** *0.000*
FOREIGN	*0.343*** *0.006*	*0.240*** *0.000*
EXPORT	*0.448*** *0.000*	*0.150*** *0.000*
EDULABOR	*0.601*** *0.019*	*0.172*** *0.007*
IT	*0.136** *0.086*	*0.126*** *0.000*
ASSOCIAION	*0.308*** *0.000*	*0.101*** *0.000*
ISO	*0.060* *0.519*	*0.070*** *0.041*
MAKEONLY	*0.082* *0.406*	*-0.018* *0.600*
BUYONLY	*0.164*** *0.028*	*-0.031* *0.291*
MAKEBUY	*0.165*** *0.045*	*0.059** *0.075*
INFRA	*-0.406* *0.245*	*-0.238* *0.175*
REGULATION	*-0.229* *0.294*	*-0.125* *0.245*
FINANCE	*-0.194*** *0.001*	*-0.052*** *0.040*
_cons	*0.936*** *0.000*	*-0.061* *0.451*
Adj R-squared	*0.379*	*0.606*
Complementarity H_0: $\theta_{11} - \theta_{01} <= \theta_{10} - \theta_{00}$	*p value = 0.7561*	*p value = 0.0078***
Point test: $\theta_{11} - \theta_{01} - \theta_{10} + \theta_{00}$	*-0.810* *p value = 0.488*	*0.107*** *p value = 0.061*

nomakebuy is the base category. Industry, country and year dummy are included.
** significant level 1%, * at 5%. p-values are under coefficients.
The first results of complementarity test are from one way t test. The second results are based on the point test of linear (nonlinear) combination of estimator.

Table 8. 2SLS Productivity: dependent variable sales per person (in logs)

	Low-income	Middle-income
CAPITAL	*0.424*** *0.000*	*0.484*** *0.000*
SIZE	*-0.100*** *0.009*	*0.060*** *0.001*
CAPACITY	*0.529*** *0.010*	*0.314*** *0.000*
FOREIGN	*0.349*** *0.005*	*0.260*** *0.000*
EXPORT	*0.241*** *0.018*	*0.187*** *0.000*
EDULABOR	*-0.263* *0.439*	*0.178*** *0.011*
IT	*-0.063* *0.527*	*0.111*** *0.004*
ASSOCIAION	*0.371*** *0.000*	*0.096*** *0.005*
ISO	*0.121* *0.198*	*0.051* *0.178*
MAKEONLY^	*1.669** *0.060*	*-1.555*** *0.001*
BUYONLY^	*3.799*** *0.000*	*-0.009* *0.985*
MAKEBUY^	*2.594*** *0.000*	*1.061*** *0.010*
INFRA	*-0.460* *0.188*	*-0.226* *0.198*
REGULATION	*-0.257* *0.235*	*-0.153* *0.151*
FINANCE	*-0.137*** *0.022*	*-0.066*** *0.011*
_cons	*-1.095*** *0.037*	*-0.080* *0.821*
Adj R-squared	*0.386*	*0.608*
Complementarity		
H_0: $\theta_{11} - \theta_{01} <= \theta_{10} - \theta_{00}$	*p value = 0.9916*	*p value = 0.000***
Point test: $\theta_{11} - \theta_{01} - \theta_{10} + \theta_{00}$	*-2.87*** *p value = 0.017*	*2.625*** *p value = 0.000*

nomakebuy is the base category. Industry, country and year dummy are included.
** significant level 1%, * at 5%. p-values are under coefficients.