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# Complementarity between in-house R&D and technology purchasing: evidence from Chinese manufacturing firms

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**Abstract:** In order to catch up with the technological frontier, firms, especially in developing countries, try to acquire technological advancement through internal R&D efforts as well as through external technology sourcing activities. This study tests the existence of a complementarity between in-house R&D and external technology acquisition in Chinese manufacturing firms. We show that the two sources of technological upgrading are complementary in stimulating product innovation across small and medium size manufacturing firms in China, but not in generating process innovation nor in achieving higher levels of labor productivity.

**Keywords:** R&D, technology purchasing, complementarity, China, manufacturing

**JEL codes**: O33

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## 1. Introduction

In order to catch up with the technological frontier, firms in developing countries have been striving to promote technological advancement through internal research and development efforts (in-house R&D) as well as through external technology purchasing (TP). In-house R&D expenditure includes the capital, labour and design costs associated with research and development. TP involves purchasing, transferring or licensing new technologies from the domestic or the international market. For firms in developing countries, establishing efficient innovation strategies will accelerate their catching-up to the technological frontier and contribute to their economic development.

In China, the central government has established a series of policy incentives to encourage firms to carry out in-house R&D activities, and these policies have greatly increased China's capability to develop its own technology, and to assimilate and improve upon technology transferred from advanced economies (Lu and Lazonick, 2001). However, given shortcomings inherited from the pre-reform planned economic mechanism, the efficiency of innovation of the manufacturing sector as a whole is still severely constrained. With great emphasis placed on 'indigenous innovation'[1], do Chinese firms still need external technology sourcing? Is there a synergy in engaging in both internal and external innovation activities? The goal of this research is to answer these questions and provide an empirical framework to investigate the role of these innovation input strategies in fostering productivity in Chinese manufacturing firms.

The modeling is based on the notion of complementarity, which will be estimated using continuous measures of innovation inputs in the innovation and productivity functions. The data applied in the empirical analysis comes from the World Bank Investment Climate Surveys (ICS)[2] concerning China in the year 2003. The result exhibits evidence of complementarity between in-house R&D and TP in stimulating product innovation across small and medium size Chinese manufacturing firms. In-house R&D accelerates the assimilation of external know-how while external technology sourcing enhances the efficiency of in-house innovation activities. However, despite the fact that in-house R&D and TP each contribute significantly to product innovation, we find no sign of synergy between them in raising productivity.

The next section sets the background by reviewing the existing evidence on complementarity between own and external technology acquisition in innovation studies and by tracing the history of Chinese technology policy in the last 30 years. Section 3 defines the notion of complementarity and the specification of the model used in the empirical analysis. The data and the variables used will be presented in section 4. The results are interpreted in section 5. Section 6 summarizes and concludes.

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[1] Indigenous innovation means "to develop the capability of conducting R&D or create innovation internally".

[2] For more information on the Investment Climate Survey, see http://www.worldbank.org

## 2. Background

### 2.1 In-house R&D and technology purchasing: complements or substitutes?

A growing number of empirical studies have estimated the relationship between innovation sourcing strategies in developing countries. One view is that internal R&D and external technology are substitutes. Firms decide to make technology by themselves and/or buy it from outside given a limited budget. An increase in either of the two choices, therefore, tends to lower the spending incurred on the other one. Mytelka (1987) found that external imports of technology discouraged Andean group countries to undertake in-house innovation activities. Fikkert (1993) regressed technology imports on in-house R&D efforts and also found a negative relationship between technology imports and R&D efforts in Indian manufacturing firms. Basant and Fikkert (1996) estimated the return of R&D, technology imports and their interaction using Indian firm level panel data. They found that the estimated rate of return of technology imports is much higher than the return to in-house R&D. They also concluded that there is a substitutability between R&D effort and external technology in the production of knowledge. Katrak (1997) found that the probability of importing technology is only weakly influenced by R&D efforts, and Blonigen and Taylor (2000) also conclude that firms either make or buy technology.

An alternative view is that in-house R&D and external technology purchasing are complementary strategies. Based on the notion of absorptive capacity proposed by Cohen and Levinthal (1989), it argues that the successful use of external technology requires the ability to assimilate external technology and apply it internally. As argued by Fu, Pietrobelli and Soete (2010), a crucial condition to obtain effective technology transfer to developing countries is their level of absorptive capacity. In this sense, parallel indigenous innovation efforts are complementary with international technology diffusion. The studies by Desai (1989), Lall (1989) and Mowey and Oxley (1995) confirm this view that technological capability is needed in order to understand the tacit components of foreign technology. On the other hand, acquiring technology externally helps improving the efficiency of doing in-house R&D. As Aggarwal (2000) points out, external technology sourcing plays two important roles in developing economies: filling gaps in domestic technological capability and upgrading the existing technologies to international standards. By enhancing the technological capability, it may consequently stimulate in-house R&D. Braga and Willmore (1991) found that there is a robust complementary relationship between technology buying and firm technology effort in Brazilian industry. Deolalikar and Evenson (1989) and Kim and Nelson (2000) conclude the same on Indian firm data. A certain number of studies have tested a slightly different but related hypothesis on data from developed countries, namely the complementarity between internal and external R&D: Arora and Gambardella (1990) for large US, European, and Japanese biotechnology firms, Veugelers (1997) and Cassiman and Veugelers (2006) for Belgian manufacturing firms, Bönte (2003) for West-German industry data, and Berlderbos et al. (2008) for Dutch firm data. Most of the studies share the view that internal and external R&D are complementary, although Audretsch, Menkveld and Thurik (1996) find that the complementarity only holds for high-technology industries.

### 2.2 Country background

China has been the fastest growing major economy in the past 30 years with an average annual GDP growth rate of over 10%. Around 8% of the total manufacturing output in the world comes from China, and it ranks third worldwide in industrial output[3]. The extraordinary performance of the Chinese economy makes it very interesting to study its technology acquisition behaviour and to examine whether it contributed to the growth performance of its manufacturing firms.

In the 1950s, China began to acquire technology externally. At first, the major source of technology was the former Soviet Union. Then, western countries and Japan became the main technology suppliers in heavy industry. After the economic open-door policy launched in 1976, importing external technology constituted an essential component of the Four Modernisation Programmes (Zhao, 1995). Technology transfer became diversified through the purchase of turnkey plants and equipment, foreign direct investment (FDI), and in the form of disembodied technology including licensing, technical consulting, technical service and co-production. Another feature is that the source of technology widened. Five countries - the US, Japan, Germany, France and the UK – dominated the supply of technology to China at that time. After the 1980s, other industrial countries and regions, such as Canada, Italy, Taiwan and Hong Kong, played an increasing role in providing technology to China (Zhang, 1990; Liu, 1992; Zhao, 1995). Meanwhile, the central government created incentives and provided support for firms to establish R&D departments, and these units increased dramatically, from 7000 in 1987 to over 24,000 by 1998 (China Science and Technology Statistics, 1992, 1998)[4]. These changes have greatly improved China's indigenous innovative capability to develop and utilize technology (Lu and Lazonick, 2001).

Like other developing countries, China has two main objectives in acquiring foreign technology: enhancing technological capability and facilitating economic growth by increasing productivity. Zhao (1995) finds that imported technology complemented the establishment of Chinese indigenous technological capability by analyzing the time series data from 1960 to 1991. Hu et al. (2005) conclude that the foreign transferred technology does not play a positive role in stimulating productivity without in-house R&D efforts in Chinese medium and large size firms. This finding implies a complementary relationship between technology buying and in-house R&D. A recent empirical study (Li, 2010) based on a panel of 21 high-tech sectors over the period 1995-2004 shows that investing in external knowledge sourcing alone does not enhance innovation performance in domestic firms, unless in-house R&D is also conducted. It is interesting to re-examine this issue ten years after China's transition to a market economy, a period during which it experienced unprecedented changes in its social, legal, and economic institutions (Zhou, Yim and Tse, 2005). In the current research, we look at the innovation sourcing strategies of small and medium Chinese manufacturing firms in the 2000-2002 period. What distinguishes this study from

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[3] For more detailed information the reader is referred to http://en.wikipedia.org/wiki/Economy_of_the_People%27s_Republic_of_China

[4] Source: Ministry of Science and Technology of the People's Republic of China: http://www.most.gov.cn/eng/

previous studies is the analysis of the complementarity between internal and external knowledge sourcing in terms of two measures of performance: innovation output and total factor productivity. Moreover, the availability of panel data enables us to control for unobserved heterogeneity (at least for one of the two measures).

## 3. Empirical model and testing of complementarity

### 3.1 Definitions

A pair of economic activities is complementary if (1) adopting one does not preclude adopting the other one and if (2), whenever it is possible to implement each activity separately, the sum of the benefits to do just one or the other is not greater than the benefit of doing both together. An equivalent understanding of the second condition is that the incremental return to implementing any one of the activities is greater if the other one is already implemented. A theorem states that if each pair of activities in a group is complementary, then implementing any subset of the activities in the group raises the incremental return to implementing the remaining ones (Topkis 1978). This notion of complementarity between activities was introduced in economics by Vives (1990) and Milgrom and Roberts (1990, 1995).

More formally, suppose there are two technology acquisition practices, R&D and TP, and Z is a vector of exogenous variables. If R&D and TP are discrete variables, they are complementary if the presence of one strategy (R&D) increases the marginal return of adopting the other strategy (TP) controlling for other effects. In other words, the objective function f (R&D, TP, Z) is defined as supermodular if the following inequality holds for all values of the other arguments of f(.) (Milgrom and Robert, 1990):

$$f(1, 1; Z) - f(1, 0; Z) > f(0, 1; Z) - f(0, 0; Z) \quad (1)$$

If R&D and TP are continuous variables, this inequality restriction implies that the incremental effect of one practice on the objective function increases conditionally on increasing another practice.

$$\frac{\partial^2 f(r_b, r_m, Z)}{\partial r_b \partial r_m} > 0 \quad \text{; where } r_b \text{ is TP and } r_m \text{ is in-house R\&D expenditure} \quad (2)$$

Conversely, R&D and TP are substitutes if the inverse of inequality (1) or (2) holds.

In the rest of this section, we are going to introduce the two empirical models that link the technology acquisition strategies to measures of performance.

### 3.2 Testing complementarity in terms of innovation output

Testing complementarity among activities in an objective function has been done in several empirical studies (Cassiman and Veugelers, 2006; Mohnen and Röller, 2003; Belderbos et al., 2008). This approach aims at testing the complementarity in achieving a specific economic goal. It refers to a synergy between activities that will lead to a better performance in terms of this goal. In the first model we estimate the complementarity between R&D and TP in terms of innovation performance.

Here, innovation output $P_i$ is a dichotomous variable equal to 1 if the firm claims to have introduced either a product or a process innovation in the period under review and zero otherwise. The one (zero) corresponds to a positive (negative) value of a latent variable $P_i^*$ that is determined by innovation inputs and firm specific variables:

$$P_i^* = \delta_b r_{b,i} + \delta_m r_{m,i} + \delta_{bm} r_{bm,i} + \phi W_i + \eta_i \quad (3)$$

where $r_{b,i}$ and $r_{m,i}$ are the levels of innovation inputs (TP and R&D respectively), expressed as expenditure per capita and $r_{bm,i}$ is the interaction term that captures the synergy effect. W is a vector of exogenous variables that affect the probability of innovating. $\delta(=\delta_b, \delta_m, \delta_{bm})$ and $\varphi$ are coefficients that need to be estimated. $\eta$ is the error term due to measurement errors and omitted variables. If $\delta_{bm}$ is positive and statistically significant, then there is complementarity between R&D and TP. Due to the fact that the innovation output indicator is only available for the year 2002, the innovation probit model will be estimated on cross-sectional data. For the innovation input and the other explanatory variables in equation (3) the average values over 2000-2002 will be used (see section 4.2 for more detail), since innovation relates to this three-year period.

### 3.3 Testing complementarity in terms of total factor productivity

Rather than just looking at the effect of innovation strategies on innovation output, we will go one step further and also investigate whether there exists a synergy between R&D and TP in promoting firms' productivity performance. Firms carry out several types of investment, such as capital, labour, innovation and material inputs. We derive our model from a simple extended Cobb-Douglas production function for firm i at time t:

$$Y_{it} = A_{it} K_{it}^{\beta_k} L_{it}^{\beta_l} M_{it}^{\beta_m} e^{\varepsilon_{it}} \quad (4)$$

where $Y_{it}$ is the total sales of firm *i* in period *t*, $K_{it}$ , $L_{it}$ and $M_{it}$ represent the inputs physical capital, labour and materials. The coefficients $\beta_k$, $\beta_l$, $\beta_m$ are the output elasticities of capital, labour and materials. $A_{it}$ is the total factor productivity, which is driven by technological innovation, industry specifics and ownership characteristics, and $\varepsilon_{it}$ is a random error term. We decompose productivity $A_{it}$ in the following way:

$$\ln A_{it} = \gamma_0 + \gamma_b r_{b,it} + \gamma_m r_{m,it} + \gamma_{bm} r_{b,it} r_{m,it} + \gamma_s S_{it} + \gamma_f F_{it} + \Sigma_j \gamma_j I_j + \Sigma_t \gamma_t T_t \quad (5)$$

where $r_{b,it}$ and $r_{m,it}$ are again defined as expenditure per capita for R&D and TP respectively, $S_{it}$ and $F_{it}$ are dummies accounting for the state ownership and foreign ownership status of the firms. The industry dummies $I_j$ represent differences in technological opportunity across industries. The year dummies $T_i$ capture year-to-year fluctuations in productivity. It should be noted that the coefficient $\gamma_{\mathrm{m}}$ captures the partial effects of in-house R&D expenditure; $\gamma_{\mathrm{b}}$ is the returns of TP; and $\gamma_{\mathrm{bm}}$ the additional return of doing both together. After substituting (5) into (4), taking logarithms, and normalizing by labor, we obtain the labor productivity function:

$$\begin{aligned} \ln(Y_{it}/L_{it}) &= \gamma_0 + \beta_k(K_{it}/L_{it}) + (\beta_l + \beta_k + \beta_m - 1)L_{it} + \beta_m m_{it} + \\ &\gamma_b r_{bit} + \gamma_m r_{mit} + \gamma_{bm} r_{bit} r_{mit} + \gamma_s S_{it} + \gamma_f F_{it} + \Sigma_j \gamma_j I_j + \Sigma_t \gamma_t T_t + \omega_i + \varepsilon_{it} \end{aligned} \tag{6}$$

The disturbance term has two orthogonal components: the time-invariant individual effects $\omega_i$, that are unobserved by the econometrician but known to the firm (such as managerial ability or organizational ability) and the idiosyncratic productivity shocks $\varepsilon_{it}$ that are unobserved by the econometrician and by the firm. We assume the idiosyncratic error term to be sequentially exogenous, i.e. always exogenous with respect to past values of the explanatory variables.

The problem here is that the inputs, especially the traditional inputs, labor, capital and materials, but also the innovation related inputs $r_{b,it}$ and $r_{m,it}$ - may be correlated with $\omega_i$. The endogeneity of input practices makes OLS fail to generate consistent estimators. To tackle the endogeneity problem we use the system-GMM estimation from the dynamic panel literature (Arellano and Bond, 1991, Blundell and Bond, 1998).[5] Taking the first differences of equation (6) will remove the unobserved individual effect $\omega_i$, thus eliminating a potential source of omitted variable bias in the estimation. Then it instruments the differenced variables that are not strictly exogenous with all their available lags in level (Difference GMM). However, lagged levels are poor instruments for its first differences if the variables are close to a random walk (Holtz-Eakin, Newey, and Rosen, 1988; Arellano and Bover, 1995). Therefore, Blundell and Bond (1998) suggest to add another set of orthogonality conditions, namely between the levels of the error term and the first-differences in the sequentially exogenous variables under the assumption of stationarity. This is the idea behind System GMM.

## 4. **Data and variables**

### 4.1 Data description

[5] We prefer to use the dynamic panel GMM approach to the proxy-based approach introduced by Olley and Pakes (1996) and generalized by Levinsohn and Petrin (2003) because of the assumed presence of fixed effects. Ackerberg et al (2006) compare the two approaches and discuss their respective advantages and disadvantages.

The data used in our empirical analysis are from the World Bank Investment Climate Surveys (ICS)[6] - China 2003. The survey is conducted in 24 industrial cities and provides us with a wide range of information about the economic environment and activities of the firms. The majority of firms included in the ICS China 2003 are of small and medium size[7]. After removing missing values, cleaning for outliers and removing the large size firms, we are left with 3332 observations of small and medium size firms from 18 cities and 10 manufacturing industries for the period 2000 to 2002[8]. Several aspects regarding firms' innovation activity are covered in the survey; such as the firms' innovative input strategies and innovation outputs. We deflated annual sales, profits, capital, materials and innovation expenditure to 2000 price values[9].

**4.2 Variables in the innovation equation**

The dependent variable in the innovation equation is a dichotomous variable that equals 1 if the firm claims to have had either a product or a process innovation in the years 2000 to 2002. There are two categories of variables that might affect the probability of having a successful innovation.

The first category captures firm specifics. With more profits in previous periods, firms have more cash on hand and are therefore more likely to invest in innovation and be successful innovators (Katrak, 1997). PROFIT_worker is the average ratio of profit (before tax) per employee from 2000 to 2002. Larger firms are expected to have a higher propensity of innovation. Firm size is proxied by CAPITAL_worker, which is the average capital/labor ratio from 2000 to 2002. Company ownership can be a crucial variable in innovation performance in the case of China, as it affects the motivation to innovate and the continuity of business strategy. State-owned enterprises (SOEs) are usually reluctant to undertake changes. However, with more solid financial and infrastructure support from the government, they might have more resources to carry out innovation activities. So the effect of SOEs on innovation output is ambiguous. Foreign controlled firms tend to concentrate their research and development in their home countries. A negative sign is expected. FOREIGN and SOE indicate respectively foreign and state ownership. The dummy EXPORT tells if firms have positive exports in 2002. We use EXPORT to indicate the level of openness of the economy. Openness is expected to lead to greater competition in product markets and increasingly in markets for services. More vigorous competition exerts discipline on firms. It therefore tends to strengthen incentives for innovation in their economy. So we expect a positive

[6] See footnote 3.

[7] Small size firms have less than 500 employees, medium size firms have between 500 and 2000 employees, and large size firms have more than 2000 employees. The classification is based on the number of long-term employees according to "The classification of small, medium and large Chinese manufacturing firms" from the National Bureau of Statistics of China: http://www.stats.gov.cn/. The large size firms included in the sample, after dropping missing values, represent about 3.5 percent of the total sample (33 firms). We decided to drop these firms and look only at the small and medium size firms.

[8] Firms with no information on financial outcomes are dropped. The service sector is not included because the innovation outputs are not reported. Furthermore, following Hall and Mairesse (1995), we only keep observations for which the capital-labor ratio was within three times the inter-quartile range (the difference between the 75% value and the 25% value) above or below the median. This removed 129 observations, or 2.1% of the sample. The remaining sample is an unbalanced panel with 3332 observations for the period 2000 to 2002.

[9] For the annual sales and profits, we use the wholesale price deflators at the industry level. For capital, material and innovation expenditure, the industry input deflators are used (Chinese Bureau of Statistics, 2000-2003).

relationship between export activities and innovation performance. AGE is calculated as the number of years evolved since the enterprise started production up to 2002. Young firms are expected to be more dynamic and innovative all other things equal. Innovation activities tend to be relatively more intensive in the technologically more advanced industries, such as pharmaceuticals, electrics and electronics. Thus industry dummies are also included.

The second category of explanatory variables is the set of innovation inputs. The survey contains two main questions on innovation input strategies. Firms are asked to report their annual in-house R&D expenditure. In-house R&D spending is the relevant capital, labor and design costs associated with research and development. The other strategy is for firms to buy or import technology directly from external channels, on both the domestic and international markets. Technology purchasing is defined in the questionnaire as the amount firms spend on purchasing technology externally. The two variables are respectively denoted by R&D and TP. Both of them are measured in spending per employee on average in 2000–2002. More investment in in-house R&D and external technology purchasing will not only strengthen the firms' technological capability, but also directly contribute to the innovation output. We expect both estimated parameters to have a positive sign. The interaction term of R&D and TP captures their complementarity. Dummy variables R&D_PRIs, R&D_UNIVERSITY and R&D_FIRMS are equal to 1 if firms have any R&D cooperation with public research institutes, universities and other firms. The Chinese government has strongly encouraged Public Research Institutes (PRIs) and universities to create more effective links with industry since the 1980s. In 2004, about one-third of large and medium-sized companies' R&D spending went to universities and PRIs as contracted R&D (National Bureau of Statistics of China, 2006). We use these three variables to proxy the technological opportunity. Any form of cooperation constitutes an information source for new technologies and could lead to innovativeness.

**4.3 Variables in the production function**

In the production function, the dependent variable is PRODUCTIVITY. It is measured by sales per employee, in natural logarithmic terms. The three conventional inputs are CAPITAL, measured as the total book value of fixed assets, LABOR, measured as the number of full time employees, and MATERIAL, measured as the costs of raw materials, energy and other related costs reported by the firm. The innovation inputs R&D and TP and their interaction will also enter the productivity equation as endogenous variables. We control for several variables (FOREIGN, SOE and EXPORT) that capture the firms' competitiveness and technological capability. Foreign owned firms are characterized by higher capital intensity, high quality of human capital and efficient management. Many previous studies suggest that foreign owned firms are more productive (Globerman et al, 1994; Doms and Jensen, 1998; Kimura and Kiyota, 2007). State-owned enterprises (SOEs) are usually characterized by redundant workers and inefficient management. As we can see from table 1, the mean val number of long-term employees for SOEs is much higher than the sample average while their productivity is below the sample average. They are not motivated to perform efficiently since the local government takes full responsibility for their production and profit. For this reason, we expect SOEs to have a negative effect on the productivity performance. Exporting firms face fiercer competition on the international market.. It stimulates firms to be more productive and efficient, so we expect a positive effect. Besides, we also control for industry and year specifics by using industry and year dummies.

Table 1 gives the descriptive statistics on the conventional inputs, the productivity performance and the technology variables across industries. In general, high-tech industries such as electronic equipment, household electronics and biotechnology are more productive and spend more on innovation activities. It has been postulated that it is in new and dynamic industries that companies in developing countries can most readily catch up (Gerschenkron, 1962). The ICT industry is relatively new, having entered its boom stage in the 1990s, and China has been catching up very rapidly. As is shown in table 1, electronic equipments, auto & auto parts and biotech have more spending on conducting innovations both internally and externally compared to traditional industries, such as chemicals, garment & leather, food processing and transportation equipments, where the expenditure on innovation is smaller and hence the the gap between Chinese and leading world companies narrows down at a much slower pace.

As the variable EXPORT shows in table 1, high-tech industries in China are more likely to sell their products abroad. Compared to all the firms in the sample, SOEs are less productive and less likely to export.

*Insert table 1 here*

Innovation output by Chinese companies is relatively poor compared with advanced economies. Their innovation capability is most often focused on incremental innovation and their capacity for radical innovation is small (OECD 2007). As presented in table 3 approximately 46 percent of the firms claim to have introduced a new product, and 25 percent a new process, in the period under review[10]. It should be noted that the product and process innovations in developing countries are not conventionally defined as new to the market, but rather as new to the firm. Table 3 presents the summary of technological variables across industries.

*Insert table 2 here*

The second last line of table 2 shows us the innovation performance of SOEs in the data. In general, SOEs are relatively bigger in terms of capital and labor. They are more dynamic in both internal and external innovation activities. The proportion doing in-house R&D is higher than the average and the proportion doing TP is almost as high as for the overall sample. Additionally, the innovation output is also above average. This might be due to the fact that SOEs are in general prioritized in getting financial support from the government. Many policy instruments from the central government during that period

[10] R&D dummy is equal to 1 if the firm has had R&D spending sometimes during the last three years. TP dummy is equal to 1 if firm had spending on external technological acquisition in 2002.

have been targeted to motivate reform and innovation in the SOEs. Another point that should be noted is that the two innovation output measures in table 2 are binary variables which do not take into account the relative level of innovation spending (in terms of labor or total sales) and the quality of innovation (market value).

## 5. Empirical results

In this section we shall present an econometric analysis of how innovation strategies affect firms' innovation and productivity performances. The results will also highlight the role of R&D and TP play in the innovation and production process for Chinese small and medium size manufacturing firms.

### 5.1 The role of R&D and TP in stimulating innovation

We first look at the determinants of firms' innovation output and test the complementarity between R&D and TP by estimating the interaction term in the innovation propensity.

*Insert table 3 here*

Table 3 presents the estimates of the probit model (3). The second column exhibits the estimated coefficients and the last column gives the corresponding marginal effects calculated from the estimated coefficients. As expected, firms with higher profit tend to be more innovative. An increase of 1000 RMB in profit per employee increases by 3 percent the probability that a firm is an innovator. Any kind of cooperation activity will encourage firms to become more innovative as well. As shown in table 3, cooperation with other firms increases the propensity of having product or process innovation by almost 20 percent compared to firms with no cooperation activities. Cooperation with universities and research institutes increase the propensity of innovation by 18% and 14% respectively. The estimated coefficient of age is not significant. Foreign ownership also does not play a significant role in stimulating innovation. State-owned enterprises are 12% more likely to innovate compared to other firms. As we explained in the previous section, this might due to the fact that SOEs have it relatively easier to take advantage of financial and policy support from the central government.

Turning to the primary interest of this research, we find complementarity between R&D and TP in making firms innovative: the estimated coefficient for R&D*TP is positive and significant. Investing 100 more RMB per person in R&D increases the probability of innovating by 0.6% in the absence of technology purchase. The marginal effect of technology purchasing is not significant. Increasing R&D by 100 RMB per person when the technology purchasing are at their sample mean value of 450 RMB per person increases the probability of innovating by 1.32% (=0.6+0.72) Table 4 presents the results of the probit model for product and process innovation. Profitability and R&D cooperation with research institutes tend to increase the propensity of product innovation only (not of process innovation). On the other hand, exporting firms have a higher probability to have process innovation, but not product innovation. State ownership and other R&D cooperation activities encourage both product and process innovation. In-house R&D is critical in stimulating innovation in both product and process innovation while TP does not appear significant in either one. Any complementary effect between R&D and TP is confined to product (not process) innovation.

*Insert table 4 here*

**5.2 The role of R&D and TP in promoting productivity**

Table 5 presents the results of the productivity equation (6) obtained using ordinary least squares (OLS) and the system GMM method. The system GMM exploits the orthogonality conditions between the first differences in the error term and the explanatory variables in levels lagged by one period, once for 2002 and once for 2001, and the orthogonality conditions between the error terms in levels and the lagged first differences of the explanatory variables. Hence in total there are 45 orthogonality conditions, 21 estimated coefficients, and consequently 24 overidentifying restrictions[11]. The OLS estimates are likely to be inconsistent because of the endogeneity of the conventional inputs and the innovation strategy variables. They are only shown as a benchmark. In the presence of a positive technology shock we expect firms to increase their inputs, but the existence of adjustment costs for labor and capital will have them increase materials more than the two quasi-fixed inputs. Hence we would expect an upward bias in the estimate of the output elasticity of materials and a downward bias in the estimates of the output elasticities of labor and capital. R&D is probably more quasi-fixed than technology purchases and hence we expect an upward bias for the latter and a downward bias for the former. The directions of bias are confirmed by our estimates. Our interpretation will be based on the system GMM estimation, which tackles the endogeneity problem. The instruments used in the GMM estimation are acceptable by the Hansen test of overidentifying restrictions, which is only significantly different from zero at a p-value of 0.17. The Difference-in-Hansen test also accepts the 12 additional orthogonality conditions of the level equations that differentiate the System GMM from the First-difference GMM.

*Insert table 5 here*

[11] The number of orthogonality conditions equals the number of instruments used for the endogenous variables plus the number of pre-determined variables (used as their own instruments). In our case, six variables are considered to be endogenous (labor, capital, materials, R&D, TFP and the interaction between R&D and TP). We consider the first differences in the error term of the productivity equation to be orthogonal to the one and two-period lagged levels of the endogenous variables for the year 2002 and to the one-period lagged levels of the endogenous variables for the year 2001 (remember, we have no data prior to 2000). That makes 18 orthogonality conditions so far. As to the level of the error term, we consider it to be orthogonal to the first differences in the endogenous variables for 2002 and for 2001. That makes 12 additional orthogonality conditions (6 for each year). So, in total the system GMM exploits 30 orthogonality conditions to instrument for the endogenous variables, plus 15 orthogonality conditions using the predetermined variables of our model (the time, industry, ownership and exporting status dummies) in the first difference equations, which makes a grand total of 45 orthogonality conditions.

In the last column of table 5, the two-step system GMM estimates with robust standard errors are reported[12]. The output elasticity of physical capital is about 0.18 and that of materials is about 0.46. The two magnitudes are quite reasonable. Returns to scale are slightly increasing (coefficient of labour). As expected, the foreign-owned firms are more productive, SOEs tend to be less productive compared to firms with other ownership structures, and exporting firms are 15.9% more productive than non-exporting firms. A 100 RMB increase in R&D and external technology purchasing raises total factor productivity by resp. 0.5% and 1.5 %. There is no more any sign of complementarity between R&D and outside technology purchasing in achieving higher productivity.

Our result may seem to contradict those obtained by Bönte (2003) and Belderbos et al (2008), who concluded to a complementarity between internal (i.e. in-house) and external (i.e. contracted-out) R&D in West-Germany and the Netherlands respectively. But first of all, our measure of purchased technology relates to the purchase of existing technology, from domestic or foreign sources, and not to the execution of R&D outside of the firm's R&D facilities. We do not investigate the complementarity between ways of performing R&D but between R&D and the purchase of existing technology. Secondly, we examine firm data from a developing country and not from developed countries. It may well be that small and medium size firms in China do not have sufficient absorptive capacity to benefit from a synergy between own research and purchased technology. Our results are more comparable and in line with those reported by Fikkert (1993) and Basant and Fikkert (1996).

## 6. Conclusion

This paper explores the impact of internal and external technology sourcing on firms' innovation and productivity performance in Chinese small and medium size manufacturing firms. In particular, it investigates whether there exists a complementarity between in-house R&D and external technology sourcing.

R&D is found to contribute significantly to the occurrence of product or process innovation whereas technology purchasing has no significant direct effect on the two measures of innovation output and affects the creation of new products and processes only by raising the knowledge acquired from own R&D. The two technology acquisition strategies are complementary in making firms innovative, but when innovation is split into product and process innovation, complementarity only shows up in product innovation. When it comes to explaining labor productivity, technology purchases yield higher returns than own R&D efforts in Chinese small and medium manufacturing enterprises. There is no sign of complementarity between own and outside knowledge acquisition in fostering labor productivity.

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12 The two-step system GMM performed in stata using the xtabond2 command automatically corrects the standard errors for heteroskedasticity and autocorrelation (Roodman, 2006).

Our results suggest that Chinese government policies should stimulate both in-house R&D and external technology-purchasing activities. One reason why we may not find any complementarity between in-house R&D and technology purchasing is that there is insufficient absorptive capacity in Chinese small and medium size manufacturing firms. Besides the need for acquiring and transferring new technologies from outside, it is crucial for Chinese small and medium size firms to raise their indigenous innovation capabilities so as to reap positive returns from outside technology adoption. It may also be that this absorptive capacity is lacking in small and medium size but not in large firms in China. To check this hypothesis we would need to get access to large Chinese firm data from the Statistical Bureau of China.

Another shortcoming of our analysis is that it can only rely on cross-sectional data to estimate the innovation output equation, and might therefore be plagued by endogeneity, reverse causality and unobserved heterogeneity. The complementarity in product innovation should be re-examined with panel data to make sure that any complementarity we have uncovered is not simply a reflection of unobserved individual effects. Unfortunately, the ICS data, even if more waves of the survey become available, will provide repeated cross-sectional data rather than true panel data. Hence another source of data needs to be tapped.

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Table 1 Descriptive statistics across industries

| Industry | N. obs | Productivity | Capital | Material | Labor | R&D | TP | R&D & TP | SOE dummy | Foreign dummy | Export dummy |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Garment & leather | 778 | 3.871 | 3.091 | 3.059 | 4.953 | 0.560 | 0.047 | 0.204 | 0.090 | 0.193 | 0.391 |
| Electronic equipment | 375 | 5.044 | 3.851 | 4.080 | 4.957 | 5.641 | 1.057 | 31.580 | 0.200 | 0.224 | 0.195 |
| Electronic parts | 614 | 4.210 | 3.690 | 3.321 | 4.860 | 1.526 | 0.559 | 9.435 | 0.259 | 0.137 | 0.176 |
| Household electronics | 128 | 4.525 | 3.825 | 3.273 | 5.216 | 2.725 | 1.472 | 34.298 | 0.047 | 0.367 | 0.445 |
| Auto & auto part | 734 | 4.344 | 3.716 | 3.560 | 5.261 | 1.574 | 0.466 | 17.897 | 0.228 | 0.113 | 0.108 |
| Food processing | 144 | 4.483 | 3.624 | 3.603 | 4.898 | 0.913 | 0.294 | 9.193 | 0.250 | 0.146 | 0.069 |
| Chemical product | 134 | 4.287 | 3.935 | 2.980 | 4.865 | 0.657 | 0.405 | 2.308 | 0.261 | 0.045 | 0.104 |
| Biotech products | 60 | 4.764 | 4.106 | 2.986 | 4.901 | 8.295 | 1.443 | 74.535 | 0.200 | 0.050 | 0.067 |
| Metallurgical product | 327 | 3.601 | 3.534 | 2.601 | 4.765 | 0.700 | 0.066 | 0.402 | 0.312 | 0.092 | 0.064 |
| Transportation equipment | 38 | 3.100 | 2.565 | 1.887 | 4.216 | 12.589 | 0.072 | 0.178 | 0.237 | 0.079 | 0.000 |
| SOE firms | 195 | 3.845 | 4.066 | 2.901 | 5.666 | 1.482 | 0.137 | 0.585 | 1.000 | 0.000 | 0.107 |
| Total | 3332 | 4.219 | 3.565 | 3.301 | 4.981 | 1.926 | 0.455 | 12.474 | 0.201 | 0.153 | 0.201 |

Note: Productivity is in logarithm of sales (in 1000 RMB) per person; Capital and material are also in logarithm of 1000RMB/person; R&D expenditure and technology purchasing are expressed in 1000 RMB per person. R&D&TP is the product of R&D expenditure per person and technology purchasing per person. Labor is the logarithm of the number of employees.

Table 2 Descriptive statistics of technological variables across industry

| Industry | Innovation | Product innovation | Process innovation | R&D dummy | TP dummy | R&D &TP dummy |
|---|---|---|---|---|---|---|
| Garment & leather | 0.269 | 0.246 | 0.122 | 0.243 | 0.078 | 0.076 |
| Electronic equipment | 0.667 | 0.643 | 0.384 | 0.573 | 0.224 | 0.216 |
| Electronic parts | 0.573 | 0.539 | 0.316 | 0.448 | 0.207 | 0.197 |
| Household electronics | 0.648 | 0.648 | 0.438 | 0.547 | 0.273 | 0.273 |
| Auto & auto part | 0.535 | 0.527 | 0.260 | 0.446 | 0.187 | 0.187 |
| Food processing | 0.542 | 0.542 | 0.250 | 0.382 | 0.208 | 0.208 |
| Chemical product | 0.425 | 0.425 | 0.224 | 0.269 | 0.194 | 0.187 |
| Biotech products | 0.700 | 0.700 | 0.200 | 0.600 | 0.350 | 0.350 |
| Metallurgical product | 0.404 | 0.385 | 0.220 | 0.275 | 0.107 | 0.098 |
| Transportation equipment | 0.132 | 0.132 | 0.079 | 0.132 | 0.053 | 0.053 |
| SOE firms | 0.560 | 0.556 | 0.325 | 0.438 | 0.165 | 0.162 |
| Total | 0.480 | 0.462 | 0.250 | 0.390 | 0.167 | 0.163 |

Note: Product (process) innovation: dummy variable equal to 1 if a firm has introduced a new product (process) in the period of 2000 to 2002. R&D&TP: product of R&D dummy and TP dummy

Table 3 Estimation results of innovation function

| Variables | Estimated Coef. | Marginal effects |
|---|---|---|
| **Innovation dummy** | | |
| R&D expenditure per person* | 0.017** | 0.006** |
| | *0.008* | *0.003* |
| TP expenditure per person* | -0.018 | -0.006 |
| | *0.068* | *0.023* |
| Product of R&D and TP expenditure per person* | 0.047** | 0.016*** |
| | *0.018* | *0.005* |
| State ownership dummy | 0.360*** | 0.117*** |
| | *0.120* | *0.039* |
| Foreign ownership dummy | 0.203 | 0.067 |
| | *0.127* | *0.041* |
| Age | -0.003 | -0.001 |
| | *0.003* | *0.001* |
| Capital-labor intensity* | 1.16e-4 | -4.02e-5 |
| | *0.001* | *2.6e-4* |
| Profit per person* | 0.008*** | 0.003*** |
| | *0.003* | *0.001* |
| Export dummy | 0.172 | 0.058 |
| | *0.113* | *0.037* |
| R&D cooperation with university | 0.598*** | 0.179*** |
| | *0.142* | *0.045* |
| R&D cooperation with research institute | 0.446*** | 0.139*** |
| | *0.145* | *0.044* |
| R&D cooperation with other firms | 0.663*** | 0.198*** |
| | *0.121* | *0.042* |
| Constant | -0.430 | |
| | *0.358* | |
| Industry dummies | Included | |
| Number of observations | 1115 | |

*** P – value 99%, ** P – value 95%, * P – value 90%

Variables with a star are averages over 2000-2002.

Table 4 Estimation results of product innovation and process innovation

| Variables | Product innovation | | Process innovation | |
|---|---|---|---|---|
| **Product/Process dummy:** | **Estimated Coef.** | **Marginal effects** | **Estimated Coef.** | **Marginal effects** |
| R&D expenditure per person* | 0.017** | 0.007** | 0.015** | 0.004** |
| | *0.008* | *0.003* | *0.006* | *0.002* |
| TP expenditure per person* | 1.56e-4 | 6.01e-5 | 0.019 | 0.006 |
| | *0.066* | *0.026* | *0.035* | *0.010* |
| Product of R&D and TP expenditure per person* | 0.029** | 0.011** | -1.92e-4 | -5.66e-5 |
| | *0.014* | *0.005* | *6.65e-4* | *2e-4* |
| State ownership dummy | 0.413*** | 0.152*** | 0.326** | 0.103** |
| | *0.123* | *0.043* | *0.127* | *0.043* |
| Foreign ownership dummy | 0.145 | 0.056 | 0.133 | 0.041 |
| | *0.129* | *0.048* | *0.129* | *0.041* |
| Age | -0.001 | -4.69e-4 | -0.003 | -1.14e-4 |
| | *0.004* | *0.001* | *0.004* | *0.001* |
| Capitallabor intensity* | -6.09e-4 | -2.34e-4 | -3.81e-4 | -1.15e-4 |
| | *7.81e-4* | *3e-4* | *7.75e-4* | *2.3e-4* |
| Profit per person* | 0.009*** | 0.003*** | -6.69e-4 | -1.97e-4*** |
| | *0.003* | *0.001* | *0.001* | *3.2e-4* |
| Export dummy | 0.145 | 0.055 | 0.297** | 0.093** |
| | *0.123* | *0.046* | *0.124* | *0.039* |
| R&D cooperation with university | 0.439*** | 0.159*** | 0.496*** | 0.165*** |
| | *0.141* | *0.048* | *0.132* | *0.048* |
| R&D cooperation with research institute | 0.368** | 0.135*** | 0.175 | 0.054 |
| | *0.144* | *0.050* | *0.137* | *0.044* |
| R&D cooperation with other firms | 0.630*** | 0.222*** | 0.297** | 0.094*** |
| | *0.121* | *0.041* | *0.115* | *0.039* |
| Constant | -1.338** | | -2.096*** | |
| | *0.631* | | *0.485* | |
| Industry dummies & city dummies | Included | | | |
| Number of observations | 1115 | | | |

*** P – value 99%, ** P – value 95%, * P – value 90%

Variables with a star are averages over 2000-2002.

Table 5 Estimation results of the productivity equation

| Variable | OLS | GMM |
|---|---|---|
| **Productivity: sales per person, in logarithm** | Coef.<br>*SE* | Coef.<br>*SE* |
| Capital-labor intensity, in logarithm | 0.146***<br>*0.011* | 0.181***<br>*0.021* |
| Labor: total number of employees, in logarithm | 0.042***<br>*0.012* | 0.047***<br>*0.018* |
| Material-labor intensity, in logarithm | 0.568***<br>*0.009* | 0.458***<br>*0.039* |
| R&D expenditure per person | 0.003*<br>*0.001* | 0.005***<br>*0.001* |
| Technology purchasing per person | 0.032***<br>*0.009* | 0.015*<br>*0.008* |
| Product of R&D and TP expenditure per person | -2.59e-4*<br>*1.47e-4* | -8.07e-5<br>*1.046e-4* |
| State ownership dummy | -0.282***<br>*0.034* | -0.371***<br>*0.062* |
| Foreign ownership dummy | 0.237***<br>*0.037* | 0.289***<br>*0.052* |
| Export dummy | 0.168***<br>*0.035* | 0.159***<br>*0.046* |
| Constant | 1.490***<br>*0.127* | 1.684***<br>*0.211* |
| Industry and year dummies | included | |
| Number of observations | 3332 | |
| Hansen test of overidentifying restrictions (24) | 21.13 (p-value 0.173) | |
| Difference in Hansen test (12 additional orthogonality conditions from the level equations) | 10.45 (p-value 0.235) | |

*** P – value 0.001, ** P – value 0.05, * P – value 0.01

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