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R&D, Human Capital Investment and Productivity: Firm-level Evidence from China's Electronics Industry

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Abstract

Using firm-level panel data covering 2005–2007, the present paper examines the effects of R&D and human capital investment on productivity in China's electronics industry. It is found that both R&D and on-the-job training positively contribute to total factor productivity (TFP). Firms' investment in employees' health insurance and pensions, which are components of workers' compensation, generate a productivity-enhancing effect, supporting the efficiency wage hypothesis. The estimated impact of R&D on productivity varies among different forms of ownership, and foreign-owned enterprises experience higher R&D efficiency than state or private enterprises. After controlling for potential endogenous causality between TFP and R&D, the above findings remain unchanged. We also find that on-the-job training can improve the quality of human capital and is helpful in promoting productivity. Therefore, establishing indigenous technological capability through various technological sources is quite important, and the government should devote further effort to investing in human capital.

Key words: insurance, productivity, R&D, training
JEL codes: J24, M52, O30

I. Introduction

Embracing the globalization of production by utilizing the advantage of cheaper endowments and increased foreign direct investment (FDI), China has become the "world factory" for a variety of manufactured goods and has long experienced high rates of economic growth. To move towards becoming a knowledge-driven economy, China has begun to develop high-

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technology industries to ensure that its economic growth is sustainable. Along with the policy of "State Development through Promoting Science and Technology" announced in 1998, both the public and private sectors have aggressively engaged in R&D activity to promote indigenous technological capability and meet the needs of industrial transformation. For example, the amount of R&D expenditure has increased more than sevenfold, from RMB50.92bn in 1997 to RMB371.02bn in 2007. Over the same period, the ratio of R&D spending to gross national product has increased from 0.64 to 1.49 percent (NBS, 2008a). This rising trend suggests that R&D activity has been an increasing focus in China.[1] Some recent studies examine the impact of R&D on economic growth using provincial-level datasets and reach the conclusion that domestic R&D has a significantly positive effect on regional economic growth in China (e.g. Lai *et al*., 2006; Kuo and Yang, 2008).

Among the high-technology industries, the electronics industry is the most important industry in China's manufacturing sector in terms of exports and R&D activity. In 2007, the electronics industry contributed 28.56 percent of total exports and accounted for 21.55 percent of R&D expenditure to the manufacturing sector (NBS, 2008b). The electronics industry is a technologically dynamic industry, and R&D activity is crucial to a firm's performance, in particular for its productivity. Moreover, after China's accession to the WTO in 2001, Chinese firms have had to face more intense market competition from multinationals and foreign firms in both domestic and international markets. Therefore, it is important to analyze the productivity-enhancing effect of R&D for Chinese electronics firms in the post-WTO accession period. Although the issue of the relationship between R&D and firm-level productivity is a longstanding research question in developed countries, relatively few empirical studies investigate the impact of R&D on productivity in China.

The quality of human capital is important for firms to absorb, assimilate and manage new technologies in developing countries. Aw *et al*. (2007) point out the critical role of human capital investment undertaken by firms in terms of improving productivity in developing countries, such as on-the-job training.[2] This point is particularly relevant to the productivity effect of R&D in China because Chinese firms have tended to favor physical capital investment over human capital investment (Heckman, 2005) and have preferred to use low-cost labor to produce low-end products. Higher-quality workers can not only directly contribute to promote productivity, but can also be complementary to R&D investment by fostering productivity indirectly. The efficiency wage hypothesis proposed by Stiglitz (1976) claims that wages are

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[1] Indeed, China's R&D intensity was higher than that of some developed countries in 2007, such as Italy (1.09 percent), Ireland (1.33 percent) and Spain (1.22 percent) (OECD, 2008).

[2] Borensztein *et al*. (1998) also highlight the importance of human capital as a carrier of learning and assimilating newly-acquired technology from abroad.

determined through more than simple supply and demand and that some firms pay their employees more than the market-clearing wage to increase their productivity. In China, there is an additional and important form of wage; namely, social security as health insurance and pensions. However, it was not mandatory for employers to pay for employees' social security before the Labor Contract Law went into effect in January 2008.[3] In addition, the cost of medical treatment is considerably high relative to the general income level in China. Therefore, these workers' benefits might increase the loyalty of employees and induce a higher level of productivity. Despite the potential importance of human capital investment in terms of the productivity of firms in China, related studies on this issue are almost nonexistent.

A series of ownership reforms were sped up in the late 1990s and have led to a shift from a presence of state-owned enterprises (SOEs) to shareholding companies and foreign-owned enterprises (FOEs) in the manufacturing sector. However, the effectiveness of corporatization has been widely criticized in that the government has continued to maintain a tight control over most of the shareholding enterprises transformed from SOEs (Watanabe, 2002; Qu, 2003). Most studies find that SOEs have lower productivity compared with FOEs and private-owned enterprises (POEs) (e.g. Zheng *et al*., 1998; Jefferson *et al*., 2000; Li *et al*., 2007) . Therefore, it is important to explore whether enterprise reforms and tough competition brought about by the accession to the WTO have had a significant impact on improving SOEs' productivity. Moreover, another key question is whether there are differences in the productivity-enhancing effects of R&D and human capital investment among firms of various types of ownership.

The present paper analyzes the impacts of R&D and human capital investment on firm-level productivity in China's electronics industry using the panel dataset from the National Bureau of Statistics of China. It attempts to contribute to the empirical literature by providing three distinct types of empirical evidence. First, as the firm-level evidence on the productivity-enhancing effect in China remains minimal and inconclusive, the present study aims to shed new light on the potential importance of R&D in promoting productivity in China using firm-level panel data. Second, and importantly, the present paper is the first to examine the direct and indirect productivity-enhancing effects of human capital investment in Chinese firms. Third, we test whether there are differences in the productivity-enhancing effect of R&D among firms of various types of ownership.

The remainder of the present paper is organized as follows. Section II provides a review of the empirical literature on the potential impact of R&D and human capital investment on productivity, with a special focus on studies related to Chinese firms. Section III describes

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[3] The new law significantly impacts small and medium-sized enterprises and those enterprises investing in low-end manufacturing in the short run who cannot abuse low-cost labor and must contribute a considerable amount of money to social security.

the dataset and presents empirical models. Section IV reports and analyzes the estimation results. The final section concludes the paper and provides some policy implications.

II. Literature Review and Discussion of the Influences of R&D and Human Capital on Productivity

The important roles of R&D and human resources in promoting productivity have been widely recognized in many econometric analyses using firm-level data.[4] In order to enhance the technological capability of developing countries, R&D can be developed internally (in-house R&D) or acquired externally (technology imports). Because technology imports offer immediate access to desirable technologies and can contribute to establishing indigenous technological capability in China (Zhao, 1995), they usually come with certain restrictions and can eventually result in technological reliance. Therefore, the most important way to improve indigenous technological capability is to devote more long-run effort to R&D. In fact, the critical role of R&D in sustaining economic and productivity growth has been widely emphasized in studies concerning endogenous growth theory (e.g. Grossman and Helpman, 1991; Aghion and Howitt, 1992; Jones, 1995).

The positive impact of human-capital investment, such as education and employer-provided training, on productivity has also been claimed over the long term (e.g. Barron *et al*., 1987; Black and Lynch, 1996; Aw *et al*., 2007). However, does offering health insurance and pensions to workers improve firms' productivity? Investment in employees' health insurance and pensions can be treated as a component of salary compensation, and the efficiency wage theory states that the productivity of employees increases as their wages increase. According to O'Brien (2003), employers might benefit from providing insurance if it enables them to recruit and retain high-quality workers. By offering insurance benefits, a firm can attract employees who anticipate establishing a long-term employment relationship. Although many employers believe that health insurance and health affect employees' productivity and firms' performance, based on the arguments of O'Brien (2003), economists often overlook and rarely measure the firms' returns on health-related investments in their empirical studies, especially for emerging markets like China.[5] Pensions also play an important role in the internal labor market. With populations aging around the world, especially with the implementation of the one-child policy in China, the demand for pension

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[4] See Aw *et al*. (2007) for a brief review and discussion on the relationships among R&D, worker training and productivity.

[5] Wojcik (2007) and Freeman *et al*. (2008) discuss the issue of the relationship between workers' health and firms' productivity.

plans will obviously continue to increase. The question is whether employers who offer pension plans in workers' compensation contracts enjoy gains in productivity or not. There is little empirical research on the relationship between pension benefits and productivity, apart from Dorsey *et al*. (1998) who estimate the effect of defined benefit plans on productivity and find higher labor productivity to be associated with defined benefit plans. However, the results in terms of a firm's overall productivity are still ambiguous.

Workers' benefits, such as health insurance and pension plans, are not implemented without criticism. The principal–agent problem suggests that the desires or benefits of the principals often conflict with those of agents, which gives rise to a potential moral hazard problem. Because health insurance and pension plans are in some ways like a "constant" bonus to employees, workers view them as automatic payments regardless of their performance. However, flawed compensation packages could not serve as a good instrument in motivating employees. In the case of China, the provision of pension plans by employers is considered to be insufficient given the rapid economic growth in recent years. In 2004, the Chinese Government started to encourage employers to provide supplementary retirement benefits to employees by issuing two documents: the Provisional Rules on Enterprise Annuities and the Provisional Rules on Enterprise Annuity Management. The pension system is similar to the 401(k) plan in the USA.[6]

Although a large number of studies have focused on examining the impact of R&D on productivity in China using regional-level datasets (see Yang, 2009 for a review), very few studies have been conducted at the firm-level because of the limitation of a reliable micro dataset. To be specific, thus far, there is no empirical study that examines the role of human capital investment in terms of health insurance and pensions on promoting firm-level productivity in China.

Hu (2001) first examines the relationship between R&D and productivity in China's enterprises. Using cross-sectional data for Chinese enterprises of various types of ownership, his empirical results show that the direct contribution of private R&D to firm productivity is insignificant, while government R&D contributes indirectly to productivity by promoting private R&D. The results of studies on the impact of ownership on innovation are mixed. Using survey data for 8341 large and medium-sized enterprises operating in 33 industries, Zhang *et al*. (2003) investigate the influence of ownership on the R&D efficiency of Chinese firms. They find that ownership is an unneglectable factor in the cross-sectional variance of both R&D and productive efficiencies. Moreover, the state sector is found to have significant lower efficiencies than the non-state sector in both R&D and productive activities. Li *et al*. (2007) use a cross-sectional firm-level survey conducted by the World Bank in 2001 to investigate the major sources of

[6] For detailed information of the 401(k) plan, please see the website of the Department of Labor, USA. Available from: http://www.dol.gov/dol/topic/retirement/index.htm.

improvements in production and the growth of innovation among Chinese enterprises. Their findings indicate the importance of production networks and R&D for production improvements. Moreover, ownership does matter to firm performance and the SOEs generally perform worse than FOEs and POEs. Motohashi and Yuan (2009) use a large-scale firm-level dataset from the NBS to analyze the productivity performance of Chinese manufacturing firms from 1995 to 2003. They find that information technology and R&D intensity are positively correlated with firm-level productivity growth. However, neither information technology nor R&D has any significantly positive impact on productivity after controlling for the reverse causality of productivity on information technology and R&D investments. More importantly, the structural changes in the Chinese industry sectors as a result of accelerated privatization and the increasing number of FOEs have positively contributed to aggregate productivity growth.

As is evident from this brief literature review, Motohashi and Yuan (2009) is the only study that uses firm-level panel data to examine the R&D-productivity nexus, suggesting the need for more empirical studies. Importantly, the role of human capital investment in promoting productivity in China has never been investigated. These insufficiencies inspire what follows in the present study.

III. Data and Empirical Specification

1. Data and the Measure of Total Factor Productivity

The dataset used in the present study is based on an enterprise dataset from the NBS covering the period from 2005 to 2007. The annual survey covers almost all SOEs and the large and medium-sized non-SOEs (with sales of over RMB5m). The survey questionnaires contain both information related to financial statements and some non-financial information, such as the entry date, the district code, the industry code and the main products of the enterprise. The electronics industry selected in this study is the two-digit manufacturing industry coded 40: "manufacture of electronic and telecommunication equipments," which is composed of nine three-digit industries.[7] Because information on R&D expenditure are only available from 2005, in the present survey, we have to limit the study period to the years of 2005–2007. Moreover, this survey is conducted based on a minimum sales threshold of RMB5m, implying that the sample of surveyed firms may vary each year, especially for medium-sized enterprises. After cleaning the dataset by deleting observations with unreasonable variables, such as negative values and

[7] The nine three-digit industries include: telecommunications equipment (401), radar and peripheral equipment (402), broadcast and television equipment (403), electronic computer (404), electronic apparatus (405), electronics components (406), household audiovisual equipment (407), electronic and telecommunication equipment repair (408) and other electronics equipment (409).

zero values for sales, capital, R&D and wages variables, we finally obtain a balanced panel dataset of 5695 firms, yielding a total of 17 085 observations for the years 2005–2007. In terms of human capital investment, in addition to the firm's expenditure on on-the-job training, data on health insurance and pensions are also available.

In the dataset, each firm reports its registration ownership type, which falls into the following ownership categories: SOEs, collectively-owned enterprises, Hong Kong-owned, Macau-owned and Taiwan-owned enterprises, FOEs, shareholding enterprises and POEs. Because ownership types might play a significant role in our analysis, we classify the firms into three types of ownership: SOEs include SOEs and collectively-owned enterprises; FOEs include Hong Kong-owned, Macau-owned and Taiwan-owned enterprises and FOEs; and shareholding enterprises and private enterprises, which are classified as POEs.

The following question will be investigated: Do investments in R&D and human capital lead to higher productivity in China's electronics firms? The concept of productivity is the unobserved firm-specific effect that can be recovered from an estimated production function as the difference between the actual and predicted value-added. As the Chinese micro data is sometimes not being sufficiently reliable, it can induce certain calculated absolute values of total factor productivity (TFP) to be serious biased. Therefore, the present study adopts the relative index of TFP developed in Baily *et al*. (1992). The TFP index is calculated as follows:

$$\begin{aligned}\ln TFP_{it} = \ln VA_{it} - \overline{\ln VA_{jt}} - s_{EMP_t}(\ln EMP_{it} - \overline{\ln EMP_{jt}}) \\ - (1 - s_{EMP_t})(\ln CAP_{it} - \overline{\ln CAP_{jt}})\end{aligned} , \tag{1}$$

where *VA* is the value-added, which is measured as output minus intermediate inputs. *EMP* and *CAP* denote the wage payment and capital stock. Subscripts *i* and *t* denote firm and time, respectively. s_{EMP_t} is the value-added elasticity of labor in each year and is based on regressing ln*VA* on ln*EMP* and ln*CAP*. $\overline{\ln VA_{jt}}$, $\overline{\ln EMP_{jt}}$ and $\overline{\ln CAP_{jt}}$ represent the average of ln*VA*, ln*EMP* and ln*CAP* in the *j* (electronics) industry. The TFP index indicates the relative productivity of each firm within an industry and is widely adopted in the literature investigating firms' productivity dynamics (Baily *et al*., 1992).

2. Empirical Specification and Estimation Technique

In this subsection, regression analysis is performed to determine whether investments in R&D and human capital contribute to productivity. Based on the above discussion regarding the importance of R&D and human capital in term of productivity, the empirical models are developed as follows:

$$\begin{aligned}\ln TFP_{it} = a_0 + a_1 \ln RD_{it} + a_2 TRAINR_{it} + a_3 INSURR_{it} + a_4 \ln RD_{it} * TRAINR_{it} + \\ a_5 SOE_{it} + a_6 FOE_{it} + b \cdot location\_dummies + g \cdot industry\_dummies + e_{it}\end{aligned} . \tag{2}$$

The dependent variable is the relative TFP index calculated in Equation (1). As for the independent variables, *RD* denotes R&D expenditure; *TRAINR* is training intensity; and *INSURR* represents insurance intensity. *SOE* and *FOE* are dummy variables for SOEs and FOEs. Two series of location dummies and industry dummies are also included. The definition and measure of explanatory variables are discussed below. α, β and γ are estimated coefficients; ε is an error term.

RD is a firm's R&D expenditure and is in the form of a logarithm in Equation (2). R&D investment is directly devoted to producing new products or new processes and, in the theoretical and empirical literature, is widely recognized as the major source of technological change. Therefore, we expect a positive sign to be attached to the estimated coefficient. Two variables for human capital investment are included in this study: the term *TRAINR* denotes training intensity, which is measured by the ratio of on-the-job training expenditure to the total wage. Because of the possible complementary effect of R&D and human capital on productivity, the present study also includes their interaction term ($\ln RD * TRAINR$). The other human capital investment variable is insurance intensity (*INSURR*), which is measured by the ratio of expenditure on employees' social security (health insurance and pensions) to the total wage. From the perspective of employees, this expenditure is considered as one type of wage compensation and, according to the efficiency wage hypothesis, it is expected to induce higher labor productivity. However, because insurance expenditure is not compulsory for firms before the implementation of the new Labor Contract Law, firms with the additional cost of insurance expenditure might exhibit lower productivity compared with those firms without this expenditure.

Another dimensional factor affecting the difference in firms' productivity is the type of firm ownership, which is the focus of the present study. Therefore, we include two ownership dummies: *SOE* and *FOE* (see the definitions in Table 1). Using POEs as the reference group, the estimated coefficients of these two variables can be used to measure the potential difference in TFP between ownership types in terms of their management and incentive schemes. Moreover, two sets of controlling dummy variables are included. The first is a vector of location dummies. The geographical locations of Chinese electronics firms are mainly concentrated in Beijing, Yangtze River Delta and Pearl River Delta areas; we therefore adopt other regions as the base and include three location dummies (*BEJ*, *YZRDELTA* and *PRDELTA*) to test whether there are productivity gains as a result of industry clustering (Oosterhaven and Broersma, 2007). The dummy variables refer to firms located in Beijing, the Shanghai area and Guangdong, respectively.[8] Second, six three-digit industry dummies are included to capture the unmeasured industry-specific feature and its effect on

[8] The regional variable *YZRDELTA* includes firms located in Shanghai and Jiangsu Province.

Table 1. Variable Definitions and Basic Statistics

Variables	Definitions	Mean (standard deviation)
VA	Value added: measured by output minus intermediate inputs (RMBm)	72.764 (584.977)
WAGE	Wage expenditure (RMBm)	14.014 (85.360)
CAP	Fixed capital (RMBm)	54.832 (266.763)
RD	R&D expenditure (RMBm)	4.441 (90.743)
TRAIN	On-the-job training expenditure (RMBm)	0.064 (0.393)
INSUR	Insurance expenditure: including health care and unemployment insurance expenditure (RMBm)	1.584 (23.070)
TRAINR	Ratio of on-the-job training expenditure to wage expenditure (%)	0.461 (0.461)
INSURR	Ratio of insurance expenditure to wage expenditure (%)	11.293 (27.026)
SOE	Ownership dummy: a state-owned enterprise	0.049 (0.216)
FOE	Ownership dummy: a foreign-owned enterprise	0.516 (0.500)
BEJ	Location dummy: a firm located in Beijing	0.051
YZRDELTA	Location dummy: a firm located in Shanghai or Jiangsu (Yangtze River Delta)	0.229
PRDELTA	Location dummy: a firm located in Guangdong (Pearl River Delta)	0.345
SIZE	Firm size: logarithm of sales	10.821 (1.524)
KL	Capital-to-sales ratio	0.358 (1.793)
PROFIT	Profitability ratio (%)	4.051 (15.211)
MKTSHR	Market share: the share of a firm's sales to the four-digit industry's sales (%)	1.756 (12.072)
CR4	Four-firm concentration within the four-digit industry (%)	25.385 (14.877)

Note: The means and standard errors are calculated by pooling data for the 2005–2007 period.

productivity. The definitions and basic statistics of the variables are listed in Table 1.

To estimate Equation (2) with a panel dataset, we allow for the existence of individual effects that are potentially correlated with the right-hand side regressors:

$$e_{it} = u_i + v_{it} \ , \tag{3}$$

where ε is composed of individual effect and pure white noise. The term u_t is an individual firm effect corresponding to permanent, unobserved heterogeneity across firms but not within a firm over time, and v_{it} is a white noise error term, representing a period-specific shock for firm *i*, which is assumed to be independent across firms and over time. Using a "within" panel estimator, fixed effect or random effect techniques are standard estimation methods used to eliminate the individual effect. The three sets of dummy variables, including ownership, location and industry dummies, are time invariant and they will be dropped in the fixed effect model. Therefore, we report the estimates obtained from the random effect model.

IV. Empirical Results and Discussions

1. Empirical Results

A series of estimations for Equation (2) are shown in Table 2. The estimates without including

Table 2. Random Effect Estimates of R&D, Human Capital Investment and Productivity

	Model (1)	Model (2)	Model (3)	Model (4)
Constant	–0.139***	–0.138***	–0.141***	–0.051
	(0.013)	(0.017)	(0.021)	(0.045)
lnRD	0.023***	0.023***	0.020***	0.016***
	(0.003)	(0.003)	(0.003)	(0.003)
TRAINR	0.014***	0.014***	0.013***	0.014***
	(0.003)	(0.003)	(0.003)	(0.003)
INSURR	0.005***	0.005***	0.004***	0.004***
	(0.687E-03)	(0.692E-03)	(0.692E-03)	(0.691E-03)
*lnRD*TRAINR*	0.402E-03	0.402E-03	0.462E-03	0.456E-03
	(0.624E-03)	(0.624E-03)	(0.623E-03)	(0.621E-03)
Ownership_ dummies	[a]			
SOE		–0.007	–0.016	–0.019
		(0.042)	(0.042)	(0.042)
FOE		–0.0006	0.015	0.009
		(0.020)	(0.020)	(0.020)
Location_ dummies	[a]			
BEJ			0.360***	0.283***
			(0.050)	(0.050)
YZRDELTA			0.161***	0.166***
			(0.028)	(0.028)
PRDELTA			–0.132***	–0.168***
	[a]		(00.26)	(0.026)
Industry_ dummies		[a]	[a]	Yes
Log-likelihood	–23 000	–23 000	–22 920	–22 840
Number of observations	17 085	17 085	17 085	17 085

Notes: Figures in parentheses are standard deviations. *** represents significance at the 1-percent statistical level. [a] Denotes that dummy variables are excluded.

the ownership, location and industry dummies are displayed in model (1), which serves as the benchmark model. Then we add the ownership, location and industry dummies to the empirical estimations and present the results in models (2)–(4).

In the benchmark model (1), the coefficient on ln*RD* is significantly positive at the 1-percent statistical level, indicating that R&D expenditure has a positive impact on firm-level TFP in China's electronics industry. This finding is consistent with those previous studies using a firm-level panel dataset in developed countries and is an encouraging result because Chinese firms have been engaged in R&D more intensively since the early 2000s. The magnitude of the estimated R&D elasticity hovers around 0.020 for all models, which is similar to that found in Li *et al*. (2007) using a sample of firms located in Beijing, but it is relatively low compared with those for advanced economies.[9] This suggests that there is room for Chinese enterprises to improve R&D productivity. Despite the lower R&D elasticity, the positive impact of R&D expenditure on productivity suggests that R&D is an important factor in raising China's technological capability.

Another possible factor influencing firms' productivity is the improvement in the quality of human capital. In all models, we find a significantly positive coefficient for ***TRAINR***, implying that an electronics firm with a higher intensity of on-the-job training expenditure is associated with relatively higher TFP. This finding is consistent with the research conducted by Black and Lynch (1996) and Aw *et al*. (2007). As claimed by Aw *et al*. (2007), human capital investment might play an important role in improving productivity in developing countries. The government has been aggressively extending higher education to provide more highly-educated graduates in the labor market. To meet the needs of industrial transformation, on-the-job training could be more directly relevant to firms in promoting TFP.

The estimates for the social security expenditure variable are of particular interest in this study. All estimated coefficients in Table 2 are positive and significant at the 1-percent statistical level, after controlling for other factors. This result indicates that firms with a higher intensity of employees' social security expenditure are associated with higher relative TFP. As discussed previously, firms had no obligation to pay employees' insurance before 2008, and their expenditure on employees' social security can be treated as part of a compensation package. Therefore, the estimated positive relation between social security expenditure and productivity supports the efficiency wage hypothesis that higher workers' compensation can induce higher productivity.

A higher quality of human capital might indirectly contribute to productivity through the complementary effect of R&D. However, the complementarity is not justified in our study because none of the estimated coefficients for the interaction term between R&D

[9] Mairesse and Sassenou (1991) summarize the estimation of R&D elasticity from nine studies conducted in developed countries based on firm-level data, where the estimated coefficient lies between 0.05 and 0.21.

and training intensity are significantly positive. A possible interpretation is that the on-the-job training might focus on the operation of advanced imported technologies rather than R&D activity in China's electronics industry. Therefore, there is no additional productivity-enhancing effect brought about by the interaction between R&D and on-the-job training.

In models (2)–(4) of Table 2, we include two ownership dummies (*SOE* and *FOE*) but find no significant impact on TFP. This implies that, after controlling for other variables, there is no significant difference in TFP across firms of various ownership types. This result contradicts findings in previous studies that examine the role of ownership on productivity. Although SOEs and FOEs are widely argued to have lower and higher TFP, respectively, relative to private firms in existing studies (e.g. Jefferson *et al*., 2000; Li *et al*., 2007; Motohashi and Yuan, 2009), our findings suggest a convergence in TFP across ownership types in China's electronics industry, as surviving SOEs might have improved their TFP through incentive schemes brought about by ownership reforms.

Some informative and interesting results can be drawn from the estimates of the regional dummy variables. As there is an obvious industrial clustering phenomenon among electronics firms in China that are concentrated in Beijing, Yangtze River Delta and Pearl River Delta areas, it is of interest to examine the potential difference in TFP as the result of the industry clustering effect. Models (3) and (4) show significantly positive coefficients for variables *BEJ* and *YZRDELTA*, suggesting that firms located in Beijing and Yangtze River Delta areas have higher productivity compared to the reference group of firms located in places outside of these regions. This finding supports the existence of a cluster effect on productivity. However, firms clustered in the Pearl River Delta are found to exhibit significantly lower TFP than firms in other regions. Although this result seems to contradict the hypothesis of cluster economies, it is a reasonable reflection of actual practice. Cities located in Pearl River Delta were the first opened up to attract FDI at the beginning of the reform period in 1979. This assisted in the advancement of many labor-intensive firms that were seeking to take advantage of low-cost labor. Even for the electronics industry, firms located in the Pearl River Delta region are relatively labor-intensive, especially compared with those located in Beijing and Shanghai. Labor-intensive firms usually exhibit lower TFP than their capital-intensive counterparts, which might explain why firms located in Pearl River Delta experienced lower TFP.

2. Further Investigation and Robustness Estimations

Given that there are no significant differences in TFP across firms of various ownership types, one interesting and important concern worth investigating further is whether the productivity-enhancing effect of R&D varies across ownership types. Table 3 provides a series of estimations. In addition to the interaction terms of R&D expenditure and ownership dummies, the location dummies and industry dummies are included in models (2) and (3) of Table 3.

Table 3. Random Effect Estimates of R&D Efficiency across Ownerships

	Model (1)	Model (2)	Model (3)
Constant	–0.140***	–0.133***	0.042
	(0.013)	(0.019)	(0.045)
*lnRD*SOE*	0.012*	0.010	0.007
	(0.007)	(0.007)	(0.007)
*lnRD*FOE*	0.030***	0.029***	0.026***
	(0.004)	(0.004)	(0.004)
*lnRD*POE*	0.017***	0.013**	0.009**
	(0.004)	(0.004)	(0.004)
TRAINR	0.014***	0.013***	0.014***
	(0.003)	(0.003)	(0.003)
INSURR	0.005***	0.004***	0.004***
	(0.642E-03)	(0.689E-03)	(0.688E-03)
*lnRD*TRAINR*	0.473E-03	0.545E-03	0.537E-03
	(0.624E-03)	(0.623E-03)	(0.621E-03)
Ownership_ dummies	[a]	[a]	[a]
Location_ dummies	[a]		
BEJ		0.368***	0.290***
		(0.050)	(0.050)
YZRDELTA		0.158***	0.162***
		(0.028)	(0.028)
PRDELTA		–0.134***	–0.170***
		(0.025)	(0.025)
Industry_ dummies	[a]	[a]	Yes
Log-likelihood	–22 993	–22 912	–22 853
Number of observations	17 085	17 085	17 085

Notes: Figures in parentheses are standard deviations. *, ** and *** represent significance at the 10, 5 and 1-percent statistical levels, respectively. [a] denotes that dummy variables are excluded.

Although the estimates obtained in the three models are quite similar, there are some interesting findings worth addressing. First, ownership indeed plays an important role in influencing the productivity effect of R&D in the FOEs relying on R&D to promote productivity more efficiently than the SOEs and POEs.[10] Second, for the domestic firms, the

[10] The R&D efficiency for FOEs might be overvalued, because they can use technologies and knowledge of their parent firms to promote productivity.

productivity effect of the R&D of POEs is a little higher than that of SOEs. To be specific, the estimated R&D coefficient for SOEs turns out to be statistically insignificant after including location and industry dummies in models (2) and (3) of Table 3. Third, the expenditure on investment in training and employee insurance has a significantly positive impact in terms of promoting productivity, whereas the interaction between R&D and on-the-job training remains statistically insignificant.

The above analysis indicates that foreign firms experienced a higher productivity effect of R&D than domestic enterprises, and that non-SOEs tend to have higher R&D productivity than SOEs. The findings regarding the influence of ownership on the productivity-enhancing effect of R&D are consistent with the findings in Zhang *et al.* (2003). However, the content of the policy implications varies. Zhang *et al.* (2003) argue that the higher productivity effect of the R&D of foreign firms is the result of higher R&D intensity, which, in turn, leads to higher productivity. This suggests that foreign-owned electronics firms can utilize R&D investments more efficiently possibly because of their superior technological and management knowledge to produce higher value-added products. By contrast, SOEs have the highest R&D intensity on average but exhibit the lowest productivity. Their poor performance in utilizing R&D to promote productivity may be attributed to the lack of alluring incentive mechanisms.

In the random effect estimations in Tables 2 and 3, R&D investment is treated as an exogenous variable in terms of the productivity level. However, a firm with higher productivity might invest more in R&D, implying that such reverse causality might lead to biased estimates of the coefficients. Therefore, we adopt two alternatives to deal with the endogeneity problem. The first involves replacing R&D expenditure by 1-year lagged R&D expenditure to avoid the simultaneous relationship between R&D and productivity. The other is the instrumental variables approach, which regresses ln*RD* by including TFP, firm-specific characteristics and industry characteristics as explanatory variables at the first stage.[11] Table 4 presents the robustness estimates for the various specifications.

Using 1-year lagged R&D expenditure as an explanatory variable and applying the instrumental variables approach, the estimates in models (1)–(4) of Table 4 are quite similar to the findings drawn from the results in Tables 2 and 3. Not only does R&D have a significantly positive impact on productivity, but investments in training and employee social security are also positively related to the productivity level. Moreover, as the estimates of the productivity-enhancing effects of R&D for SOEs and POEs are very close, the FOEs experience the highest R&D productivity among the firms of various ownership types.

[11] Another typically used method is the generalized method of moments approach. However, the short panel (only three periods) prevents us from adopting this approach.

Table 4. Robustness Estimations of R&D, Human Capital Investments and Productivity

	Model (1) 1-year lagged ln*RD*	Model (2) 1-year lagged ln*RD*	Model (3) ln*RD* instrument	Model(4) ln*RD* instrument
Constant	–0.121**	0.107**	0.045	0.506***
	(0.048)	(0.048)	(0.044)	(0.043)
lnRD	0.032***		0.016***	
	(0.003)		(0.003)	
*lnRD*SOE*		0.018**		0.097***
		(0.008)		(0.007)
*lnRD*FOE*		0.046***		0.121***
		(0.005)		(0.003)
*lnRD*POE*		0.020***		0.096***
		(0.005)		(0.003)
TRAINR	0.019***	0.019***	0.029***	0.017***
	(0.003)	(0.003)	(0.003)	(0.003)
INSURR	0.004***	0.004***	0.004***	0.004***
	(0.843E-03)	(0.853E-03)	(0.686E-03)	(0.653E-03)
*lnRD*TRAINR*	–0.001	–0.001	0.004***	0.001***
	(0.001)	(0.001)	(0.663E-03)	(0.644E-03)
Ownership_dummies	[a]	[a]	[a]	[a]
Location_ dummies				
BEJ	0.171***	0.183***	0.283***	0.289***
	(0.054)	(0.054)	(0.050)	(0.045)
YZRDELTA	0.191***	0.180***	0.164***	0.066***
	(0.029)	(0.030)	(0.028)	(0.025)
PRDELTA	–0.165***	–0.172***	–0.170***	–0.186***
	(0.027)	(0.027)	(0.025)	(0.023)
Industry_ dummies	Yes	Yes	Yes	Yes
Log-likelihood	–15 519	–15 504	–22 825	–22 073
Number of Observations	–11 390	–11 390	–17 085	–17 085

Notes: Figures in parentheses are standard deviations. ** and *** represent significance at the 5 and 1-percent statistical levels, respectively. In models (3) and (4), the first-stage instrumental variable equation for lnRD are estimated using the Tobit model, including the independent variables of ln*TFP*, firm size, *KL* (capital to sales ratio), *PROFIT* (the profit ratio), *MKTSHR* (market share) and *CR*4. [a] denotes that dummy variables are excluded.

Interestingly, after controlling for the endogenous choice of R&D, the coefficient of the interaction term between R&D and on-the-job training turns out to be positive and significant at the 1-percent statistical level, as shown in models (3) and (4) of Table 4. This indicates that human capital investment plays a critical role in improving productivity.

V. Concluding Remarks and Policy Implications

With the increased emphasis on a knowledge-based economy, how R&D and human capital investments affect the productivity of firms is an important issue for China, but has been inadequately investigated. The present paper aims to analyze the impacts of R&D and human capital investments on firm-level productivity in China's electronics industry by using a panel dataset of 5695 electronics firms during 2005–2007. The empirical estimates reveal that R&D significantly contributes to enhancing productivity in China's electronics industry. In addition, investments in human capital, including on-the-job training and employees' health insurance and pensions, are positively related to firm-level productivity, suggesting the importance of human capital and workers' compensation in promoting firm-level productivity in China. Although ownership does matter to R&D efficiency, no significant difference in productivity across firms with various forms of ownership is found in China's electronics industry. We find that FOEs have the highest R&D efficiency for various specifications, whereas state-owned and privately-owned electronics firms tend to appear to be similar to each other in terms of R&D efficiency.

After controlling for the reverse causality of productivity and R&D investments, the above findings remain unchanged. Importantly, investments in both physical (R&D) and human capital (on-the-job training) tend to induce an additional productivity-enhancing effect as a result of the coordination of well-trained employees and R&D efforts.

Several important policy implications can be drawn from our analysis. First, because R&D is widely recognized as one of the major driving forces behind the growth of productivity, the government might consider devoting more effort to public R&D investment and to transferring new technologies for industrial usage. Moreover, policies to encourage R&D, such as tax incentives and subsidies, should be implemented. Second, investment in on-the-job training is found to have both direct and indirect impacts on productivity, thereby highlighting the importance of human capital to productivity and sustainable growth. Firms should recognize the critical role of human capital in firms' operations and put more effort into increasing on-the-job training, especially in the technologically dynamic industries. Third, although investments in employees' health insurance and pensions are positively related to productivity, they became compulsory expenditures as a result of the enactment of the Labor Contract Law in 2008. The productivity-enhancing effect of these expenditures will disappear because every employee will enjoy such benefits. However, as predicted by the efficiency wage hypothesis, firms will need to provide more competitive compensation to attract higher quality employees to coordinate future advanced technologies and R&D investment efficiently.

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