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# A study of the R&D efficiency and productivity of Chinese firms

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This paper investigates the influence of ownership on the research and development (R&D) efficiency of Chinese firms. In a sample of 8341 Chinese industrial firms, ownership is found to be a contributing factor in the cross-sectional variance of both R&D and productive efficiencies. The state sector has significantly lower R&D and productive efficiency than the non-state sector. Within the non-state sector, foreign firms have higher R&D and productive efficiency than domestic collective-owned enterprises and joint stock companies. The higher R&D efficiency of foreign firms appears to be due to a higher R&D intensity, which in turn leads to higher productivity. *Journal of Comparative Economics* **31** (3) (2003) 444–464. Sauder School of Business, University of British Columbia, Vancouver, BC, Canada V6T 1Z2; Department of Economics and Finance, City University of Hong Kong, Kowloon, Hong Kong; Department of Accounting and Business Law, Monmouth University, West Long Branch, NJ 07764-1898, USA.


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## 1. Introduction

The research and development (R&D) efficiency of Chinese industrial firms is investigated by dividing firms into different ownership groups. Existing studies indicate that state ownership in centralized economies can stifle innovation and R&D in firms. For the Soviet Union, Berliner (1976) argues that, even though the planning bureaucracy created many difficulties for innovators, many of its engineers and managers would have overcome these obstacles, if they were offered the prospect of capital gains equivalent to those in capitalist economies. Hence, private ownership has the advantage of offering larger material rewards for innovation, in the form of capital gains, than is possible in a society committed to state ownership. Recent theoretical work by Qian and Xu (1998) and Huang and Xu (1998) show that R&D activities in centralized economies are less efficient than those in decentralized market economies, due to project screening mechanisms and project financing methods with their associated soft or hard budget constraints. However, casual empiricism fails to establish compelling evidence to support a significantly negative relationship between state ownership and R&D performance so that state ownership need not stifle innovation and firm R&D performance. Based on a large firm-level data set, we examine the difference in performance between state-owned enterprises (SOEs) and non-state firms in China.

Several studies examine the determinants of inter-firm differences in productive efficiency, including ownership and other institutional factors. For example, based on a study of US manufacturing industries, Goel (1999) reports that the input-output coefficients used to define production processes typically respond to changes in the institutional environment under which those processes operate. For transition economies, Frydman et al. (1999) and Zhang et al. (2001) find that a high degree of state ownership tends to reduce firm productivity. Empirical analysis of institutional impacts on firm R&D efficiency is relatively rare. On the other hand, Griliches (1979) points out that all productivity growth, when measured correctly, is related to expenditure on R&D. In the literature investigating the relationship between R&D expenditure and productivity, e.g., Griliches and Mairesse (1984) and Griliches (1986, 1998), a positive and significant relationship is found between a firm's R&D investment and its productivity, although the relationship is weaker at the industrial level than at the firm level. More generally, studies show that firm-level R&D is a driving force for technological innovation and economic growth, e.g., Romer (1986, 1990) and Lucas (1988). Taken together, these two observations suggest that determining the ownership effect on R&D efficiency is important for a better understanding of the institutional dimension of firm R&D activities in general, and for China's SOE reform and economic growth in particular.

In this paper, we find ownership to be a contributing factor to the cross-sectional variance of R&D efficiency in Chinese industrial firms. The state sector has lower R&D efficiency than does the non-state sector. Within the non-state sector, foreign-invested firms and firms with investors from Hong Kong, Macau, and Taiwan have higher R&D efficiencies than do domestic collective-owned enterprises and joint stock companies. Furthermore, good R&D infrastructure is found to exert a positive influence on firm R&D efficiency.

Our second objective is to consider R&D efficiency and R&D intensity or expenditure as potential channels through which the ownership effect on productivity is transmitted. First we show that a high degree of state ownership tends to reduce firm productivity, which is consistent with earlier studies on transition economies. In particular, we find that the state sector exhibits significantly lower efficiencies in both R&D and overall production than the non-state sector. Within the non-state sector, foreign firms have higher R&D and productive efficiencies than do domestic collective-owned enterprises and joint stock companies. Higher R&D efficiency of foreign firms leads to a higher R&D intensity, which in turn leads to higher productivity. If the state and non-state sectors are combined, we find no systematic differences in R&D investment between SOEs and non-state firms after adjusting for firm size. One implication of the analysis is that, contrary to the existing literature, R&D expenditure is not a good explanatory variable for the ownership-productivity link. Instead, R&D efficiency might serve as a possible channel through which the ownership effect on productivity is transmitted. Since we find a significantly positive correlation between the R&D efficiency and productivity of firms, this suggests that state ownership might be associated with low productivity because of poor R&D performance, given the negative relationship between the degree of state ownership and R&D efficiency.

Although many papers have investigated the positive relationship between R&D investment and productivity, few studies have distinguished the different effects of private and government R&D expenditure on firm productivity. To account for the differences in technical performance across the ownership spectrum in China, Hu (2001) investigates how much of the cross-sectional variation of productivity can be attributed to differences in R&D expenditure. Using survey data gathered from high-tech firms in the Haidian District of Beijing, he finds a strong link between private R&D expenditure and firm productivity, but an insignificant effect of government R&D expenditure on productivity. Government R&D expenditure contributes indirectly to productivity by promoting private R&D expenditure. Therefore, his analysis suggests that providing incentives for enterprises to invest in R&D may be a better alternative than providing R&D grants directly. However, the factors determining a Chinese firm's R&D expenditure remain unclear.

Many studies consider the forces driving innovation activities in Chinese firms. Jefferson et al. (1999) analyze the relationship between innovation and ownership in the Chinese economy. Using the innovation ladder paradigm for Chinese enterprises developed by Jefferson and Rawski (1995), they find evidence supporting the hypotheses that competition between state-owned firms at the core and collective-owned firms at the periphery drives innovation activity in China. In related theoretical studies, Qian and Xu (1998) show that the bureaucracy in a centralized economy might hinder innovation under a soft budget constraint. Huang and Xu (1998) analyze the different optimal choices of R&D projects in centralized and decentralized economies. In one of the first studies to investigate the determinants of R&D expenditure in China, Lin (1992) analyzes the driving force of China's agricultural R&D using hybrid rice as an example. Our paper investigates

whether the type of ownership has any influence on R&D efficiency in Chinese firms and how ownership might affect productivity through a firm's R&D performance.[1]

This paper sheds light on the empirical assessment of China's SOE reforms. Economists outside of China focus on the effects of reform on technical efficiency, measured by total factor productivity (TFP) growth, with mixed results. Woo et al. (1994) find that TFP growth in SOEs was zero at best in the 1984 to 1988 period. In contrast, Chen et al. (1988), Dollar (1990), Jefferson and Xu (1991), Jefferson et al. (1992), World Bank (1992), Groves et al. (1994), Gorden and Li (1995), Li (1997) and Kalirajan and Zhao (1997), find significant improvements in the productivity of SOEs. The estimates of annual TFP growth in the late 1970s and 1980s in these studies range from 2 to 5%, compared with almost no growth prior to reforms. Hence, western researchers conclude that China's SOE reforms were largely successful. In contrast, Chinese economists focus on the profitability of SOEs. The prevalent view is that SOE reforms have not been very successful, at least in terms of accounting profitability measures, e.g., Zhang (1997). Bai et al. (1997) provide an analysis of the validity of using productivity growth as an index of efficiency improvement in SOEs. In a simple model, these authors show that the measured growth of TFP may be a misleading indicator of performance due to significant non-profit objectives of SOEs. Our paper contributes to this research by examining the role of R&D efficiency and its link to the overall productive efficiency of firms under various forms of ownership, including SOEs.

The paper is organized as follows. Section 2 describes industrial R&D in China and the evolution of ownership structures in the industrial sector. Section 3 describes the theoretical structure and presents a simple theoretical examination of R&D efficiency. Section 4 discusses the empirical methodology and the data. Section 5 presents and interprets the empirical results; Section 6 presents concluding remarks.

## 2. Industrial R&D in China

Before presenting some background statistics on industrial R&D distribution in China, we provide an overview of the evolution of the ownership structures of Chinese industrial firms. Under the previous central planning system, the Chinese industrial sector was dominated by SOEs, which acted as cost centers to fulfill production quotas and provide life-long employment. The restructuring of SOEs evolved from implementing a contract system in the 1980s, which improved internal managerial and incentive systems but left state ownership unaltered, to the separation of business management from state ownership through the creation of domestic joint stock companies in the 1990s.

Many SOEs were reorganized into limited-liability joint stock companies (STOCKs) and a select group of joint stock companies were listed on domestic stock exchanges. This process, which is termed corporatization or partial privatization (Zhu, 1999), is intended to attract more capital and improve firm performance through monitoring by shareholders.

[1] Several studies consider issues of R&D management in transition economies using mainly case studies, e.g., Bernstein (1994), Tan and Litschert (1994), Sedaities (1997), IDRC (1997), and Zhao (2003).

When a joint stock company is listed, it issues three classes of common shares, namely, state, institutional, and individual or tradable domestic A shares. The three groups of shareholders exert significantly different influences on corporate governance and firm performance is determined largely by which group has the controlling interest. Typically, the state and institutional blockholders control both the board and the management so that individual shareholders play a very limited role in corporate governance. Under state dominance, the control rights rest with bureaucrats who have only an indirect interest in profit, which leads to inefficiencies (World Bank, 1992; Shleifer and Vishny, 1994). In contrast, the institutional blockholders have greater ability, expertise, and incentives to monitor managers and increase profitability. Previous studies find a significantly positive effect of dominance by institutional shareholders on firm performance, e.g., Xu and Wang (1999).

In tandem with the restructuring of SOEs, China's gradual economic reforms fostered a variety of firm ownership types. The establishment of a private ownership system was not contemplated initially; rather, the dramatic development of a vital non-state sector is an unintended consequence of the reform process.[2] The emergence of the non-state sector over the last two decades is due partially to the restructuring of SOEs and partially to industrial deregulations that allow the entry of millions of new enterprises. Collective-owned enterprises (COEs) are owned and organized by local authorities. Before the economic reform, they constituted cost centers responsible for fulfilling government quotas at different levels. As a result of the economic reform, COEs must also meet a profit quota even though they are still subject to administrative orders from the government. Hence, the government can order them to put political objectives above economic consideration. For example, if the government were to implement an austerity policy, all SOEs and COEs would refrain from capital investments, even those that are economically justified. Basically, SOEs and COEs retain much of the traditional organization structure and governance system so that management suffers from the agency problems found in a command economy. COEs include many township-village enterprises (TVEs). Beginning typically from small bases, TVEs have been allowed to grow with relatively few restrictions and have expanded rapidly, especially during the 1980s. They have greater managerial autonomy and harder budget constraints than SOEs or COEs. Since the economic reforms began, the managers of TVEs have been under increasing pressure to become efficient; consequently, TVEs have reduced the number of employees. Meanwhile, private-owned enterprises (POEs) have emerged to serve deregulated domestic markets and experienced rapid growth for the past two decades. Almost non-existent before 1980, over 6 million POEs were operating by 1995.

Whilst SOEs, STOCKs, COEs, and POEs are mainly domestic firms, the government encouraged the establishment of foreign firms beginning in the mid-1980s to attract international capital, advanced technology, and management expertise and also to boost exports. Two groups of foreign firms have emerged, namely, foreign-invested enterprises (FIEs) and enterprises owned by overseas Chinese from Hong Kong, Macau, and Taiwan

[2] Li et al. (2000) provide an interesting analysis of some of the driving forces behind the unintended rise of a private ownership system in China.

(HMTs). The Law on Sino-foreign Joint Venture, which was passed by the National People's Congress in 1990, applies to both types and stipulates that foreign investors' share cannot be less than 25% of the total equity. The Chinese and foreign parties share profits or losses according to their equity ownership and transfer of ownership needs the approval of all parties. All joint ventures (JVs) have a board of directors. If the Chinese party appoints the chairman of the board, the foreign party appoints a deputy chairman and vice versa. Many FIEs and HMTs are located in special economic zones and are restricted by regulations from participating in domestic markets. Thus, FIEs and HMTs are engaged mainly in export business; in 1994, these firms accounted for 37% of China's total exports.[3]

In the centralized economy, an enterprise was either a SOE or a COE. The principal difference is that SOEs are controlled by the central government through different ministries of industries and COEs are controlled by various levels of local governments. In this paper, the five ownership types are defined as follows.[4] SOEs include state-owned enterprises, JVs between state-owned enterprises, and limited liability companies owned solely by the state. COEs consist of collective-owned enterprises and JVs between collective-owned enterprises. STOCKs are domestic limited liability companies and joint-stock companies. FIEs include Sino-foreign cooperative JVs, Sino-foreign equity JVs, Sino-foreign joint-stock companies, and solely foreign-owned enterprises. Finally, HMTs consist of the same arrangements as FIEs, except the investors are from Hong Kong, Macau, or Taiwan.

By these definitions, limited liability companies, but not joint stock companies, can be owned solely by the state; in which case, they are classified as SOEs. In general, there is no limit on the state ownership in limited liability and joint stock companies, but we do not have data to quantify the state share in STOCKs. The categories of FIEs and HMTs, which have offshore investment, include many firms partially owned by Chinese government agencies. Despite mixed ownership, the above classifications capture the degree of state ownership in Chinese enterprises, with SOEs on one side of the spectrum and both FIEs and HMTs on the other. Hence, we expect to see significantly different performances in R&D by these firms, which can be attributed to their differences in ownership structure and associated governance system.

In 1995, the contributions of SOEs, COEs, and other firms, i.e., STOCKs, FIEs, HMTs, and POEs to the total industrial output were 35%, 36%, and 29%, respectively. Given the fairly significant output contribution of SOEs, which was 78% at the beginning of the reform period in 1978, their productive and R&D efficiencies are critical to China's transition from a centralized economy to a market economy. Approximately 81% of China's economic growth since the 1950s has been attributed to increases in capital and labor inputs, while only 19% has been estimated to be due to technological progress (Dai et al., 1993). The relatively low contribution of technological progress to economic growth

[3] By 1994, foreign investors and investors from Hong Kong, Macau, and Taiwan had injected a total of $100 billion in investment into 198,000 joint ventures.

[4] Given the negligible R&D input of POEs, we focus only on five ownership types in this study, namely, SOE, COE, STOCK, FIE, and HMT.

may be related to China's low R&D expenditure.[5] However, it could also be caused by the lower efficiency of SOEs in R&D activities compared with firms in decentralized market economies.

In 1995, 23,026 industrial enterprises in China were classified as large and medium-sized enterprises (LMEs); their R&D statistics by ownership is reported in Table 1. Industrial R&D is classified officially into two categories. Basic research and development (BRD) includes basic research, applied research, and development. Technological and industrial development (TID) includes technological upgrading or the assimilation of new technology. As Table 1 indicates, almost 80% of the national expenditure on industrial R&D was on TID in 1995. Firms may apply for BRD funding from the government, but they are responsible for their own TID funding. In 1995, LMEs received a total BRD budget of 9.1 billion yuan from the government. 64 million yuan or less than 1% was for basic research, 1.2 billion yuan or about 14% was for applied research, and 7.8 billion yuan or almost 86% was for development.[6] The total expenditure of LMEs on TID amounted

Table 1
R&D of large and medium industrial firms, 1995 (thousand yuan)

| | SOEs | COEs | STOCKs | FIEs | HMTs | Total |
|---|---|---|---|---|---|---|
| Total BRD expenditure | 6,992,894 | 0 | 30,914 | 1,260,850 | 203,243 | 8,487,901 |
| Basic research | 54,024 | 0 | 50 | 4649 | 50 | 58,773 |
| Applied research | 1,010,632 | 0 | 800 | 163,476 | 27,191 | 1,202,099 |
| Development cost | 5,928,238 | 0 | 30,064 | 1,092,725 | 176,002 | 7,227,029 |
| Total TID expenditure | 25,858,333 | 3,052,607 | 3,410,181 | 2,835,476 | 1,261,081 | 36,417,678 |
| New product development | 11,468,530 | 1,327,920 | 1,558,361 | 1,576,946 | 527,596 | 16,459,353 |
| Labor cost | 5,029,672 | 403,093 | 607,552 | 257,613 | 157,958 | 6,455,888 |
| Material cost | 8,750,945 | 868,922 | 999,065 | 1,015,704 | 356,543 | 11,991,179 |
| Capital investment | 8,319,450 | 1,567,653 | 1,491,564 | 1,175,565 | 534,584 | 13,088,816 |
| Total R&D expenditure (BRD + TID) | 32,851,227 | 3,052,607 | 3,441,095 | 4,096,326 | 1,464,324 | 44,905,579 |
| Total TID budget | 29,528,929 | 3,408,906 | 3,773,256 | 4,548,684 | 1,311,552 | 42,571,327 |
| Government funding | 2,592,556 | 31,670 | 66,430 | 12,873 | 6259 | 2,709,788 |
| Special loans | 5,179,377 | 822,936 | 766,709 | 278,249 | 194,659 | 7,241,930 |
| Internal fund | 19,838,358 | 2,474,865 | 2,772,770 | 4,226,800 | 1,073,549 | 30,386,342 |
| Contract revenue | 515,671 | 27,726 | 148,944 | 14,072 | 275 | 706,688 |
| Other sources | 1,402,967 | 51,764 | 18,500 | 16,690 | 36,780 | 1,526,701 |
| Sales revenue (mil. yuan) | 2,152,000 | 287,000 | 253,000 | 226,000 | 160,000 | 3,078,000 |
| Sales from new outputs (mil. yuan) | 158,000 | 22,000 | 28,000 | 36,000 | 17,000 | 261,000 |
| R&D intensity | 1.53% | 1.06% | 1.36% | 1.81% | 0.92% | |
| R&D expenditure per scientist/engineer (yuan) | 87,408 | 148,466 | 92,930 | 404,216 | 185,852 | |

*Note*. R&D intensity is measured by the ratio of expenditure to sales revenue.
*Data source*. NBSMST (1996).

[5] China's R&D expenditure has been much lower than R&D expenditures of developed, market-oriented economies. In 1995, the national R&D expenditure for China was 34.87 billion yuan (RMB), or 0.6% of GDP. In the same year, this ratio was 2.61% for the USA, 2.98% for Japan, 2.02% for the UK, 2.34% for France, and 2.31% for Germany (EIU, 1997).

[6] Part of this BRD budget was a carryover from the previous years' budgets.

to 36.6 billion yuan, which included 6.5 billion yuan or about 18% for labor costs, 12.1 billion yuan or about 33% for material costs, and 13.1 billion yuan or about 36% for capital investment.[7] About 45% of the TID expenditure was channeled into new product development. Finally, Table 1 shows that the total BRD and TID expenditure by SOEs, equal to 32.8 billion yuan, was three times more than the total BRD and TID expenditure of all other ownership categories. The total sales revenue of the five groups was 3.08 billion yuan, including 261 million yuan from the sale of new products.

The R&D personnel of an enterprise include those directly participating in R&D activities, such as scientists, engineers, technicians, and other research personnel working in enterprise research centers and pilot work shops, but also R&D management and support personnel, such as R&D administrators, clerks, archivists, and maintenance workers. In 1995, LMEs employed a total of 1,234,144 R&D personnel, including 451,911 scientists and engineers, which is about 37% of all personnel.[8] Using the above statistics, we calculate the industrial R&D expenditure per scientist or engineer and the standard R&D intensity measure, which is defined as the ratio of industrial R&D expenditure divided by sales revenue. These two measures are given by ownership types in the last two rows of Table 1.

Significant differences in industrial R&D exist among the 30 provinces in Mainland China, including the five province-level autonomous regions and the three province-level municipalities of Beijing, Shanghai, and Tianjin.[9] Following Gu and Zhao (1998), we categorize the 30 provinces into three tiers according to their R&D infrastructure development ranking.[10] Eight provinces, which include Beijing, Shanghai and Guangdong, are considered to have the most developed R&D infrastructure. These provinces will be referred as first-tier provinces or the Tier-1 region. Nine provinces, including Tianjin, Zhejiang and Jiling, are classified as provinces with medium-developed R&D infrastructure and will be referred to as the Tier-2 region. The remaining 13 provinces, which are located mainly in China's western region, have underdeveloped R&D infrastructure and will be referred to as the Tier-3 region. Table 2 lists the name of the provinces and shows the industrial R&D statistics for these three regions. In our empirical work, we use infrastructure dummies to capture the different levels of R&D infrastructure development in the three regions. In our next section, we develop the analytical framework for the empirical work.

[7] These figures are slightly larger than those reported in the last column of Table 1 due to the omission of POEs.

[8] The number is calculated on a full time equivalent basis.

[9] Chongqing of Sichuan province became the fourth independent province-level municipality in the mid-1990s.

[10] The ranking is based on several factors, namely, the number of R&D institutions, scientists and engineers, the number of R&D projects and R&D contracts, the number of publications, awards and patents, as well as the R&D budget and the level of R&D revenue.

Table 2
Industrial R&D of different Chinese regions, 1995

| | Tier-1 region | Tier-2 region | Tier-3 region |
|---|---|---|---|
| Total R&D expenditure (billion yuan) | 27 | 12 | 6 |
| R&D intensity (%) | 1.57 | 1.38 | 1.36 |
| No. of scientists/engineers | 244, 328 | 139, 922 | 67, 661 |
| R&D expenditure per scientist/engineer (thousand yuan) | 111 | 86 | 88 |

*Note*. The Tier-1 region consists of Beijing, Shanghai, Jiangsu, Liaoning, Sichuan, Shandong, Guangdong, and Hubei. The Tier-2 region includes Tianjin, Hunan, Heilongjiang, Henan, Zhejiang, Jiling, Shaanxi, Hebei, and Shanxi. The Tier-3 region is made up of Gansu, Qinghai, Ningxia, Xinjiang, Guizhou, Yunnan, Tibet, Hainan, Guangxi, Anhui, Fujian, Jiangxi, and Inner Mongolia.
Data *source*. NBSMST (1996).

## 3. A theoretical examination of R&D efficiency

Let $V$ denote the value of the output that is created by a firm's R&D activities and consider the following Cobb–Douglas production function

$$V = \theta K^{\alpha_K} L^{\alpha_L}, \tag{1}$$

where $K$ and $L$ are the capital input and labor input, respectively, and $\theta$ is a factor reflecting the firm's R&D efficiency. Our cross-sectional data do not allow us to construct a stock variable so that capital input is measured by contemporaneous non-personnel R&D expenditure following Hu (2001). Using a sample of SOEs in Beijing from 1991 to 1995, Hu finds that the correlation between contemporary R&D and stock measures was consistently greater than 0.85. The optimal allocation of R&D capital and labor inputs is determined by

$$\max_{K,L} \pi = \max_{K,L} V - K - wL, \tag{2}$$

where $w$ is the labor cost of R&D scientists and engineers.

In the above formulation, $V$ may be interpreted as the present discounted value of the cumulative effects of current R&D choices. To illustrate this, let $V_0(K_0, L_0)$ be the initial value of the output generated by current R&D inputs $K_0$ and $L_0$. Because current inputs will contribute to the cumulative stocks of R&D knowledge, they have long-lasting effects. Let $V_t(K_0, L_0)$ be their effect at time $t$ and assume that the stock of knowledge capital depreciates over time at a constant rate of $g$ so that

$$V_t(K_0, L_0) = V_0(K_0, L_0)\mathrm{e}^{-gt}.$$

Hence, the cumulative effects of current R&D inputs are equal to

$$V(K, L) = \int V_t(K, L)\mathrm{e}^{-rt}\,\mathrm{d}t = \int V_0(K, L)\mathrm{e}^{-gt}\mathrm{e}^{-rt}\,\mathrm{d}t = \frac{1}{g+r} V_0(K, L), \tag{3}$$

where $r$ is the discount factor.[11] Thus, the present discounted value of the cumulative effects of contemporary R&D inputs is simply a multiplier of the contemporary value of output.

The first-order conditions for the optimization problem in (2) can be characterized as

$$K = V\alpha_K \quad \text{and} \quad L = V\alpha_L/w. \tag{4}$$

Second-order conditions require

$$\frac{\partial^2\pi}{\partial K^2} < 0, \qquad \frac{\partial^2\pi}{\partial L^2} < 0, \quad \text{and} \quad \frac{\partial^2\pi}{\partial K^2}\frac{\partial^2\pi}{\partial L^2} - \frac{\partial^2\pi}{\partial K\,\partial L}\frac{\partial^2\pi}{\partial K\,\partial L} > 0.$$

From (4), the $K/L$ ratio, which is the non-personnel R&D expenditure per scientist or engineer, is given by

$$K/L = w\alpha_K/\alpha_L. \tag{5}$$

From (5), the $K/L$ ratio is related positively to the labor cost of scientists and engineers. In China, the scientists and engineers who work for FIEs and HMTs receive much higher labor compensation than do their counterparts working for domestically owned enterprises, namely, SOEs, COEs, and joint-stock companies (Lu and Tang, 1997). Given a higher wage for FIEs and HMTs, $K/L$ ratios should be higher, on average, than those of SOEs, COEs, and STOCKs. Table 1 confirms this in that FIEs have the highest R&D expenditure per scientist or engineer, followed by HMTs, COEs, STOCKs, and SOEs. From this ranking, one could infer that SOEs might pay the least amount to their scientists and engineers of the five enterprise types. Similarly, Lu and Tang (1997) and Gu and Zhao (1998) report that the average compensation for R&D personnel in the first-tier provinces, which are generally the more developed areas in China, is higher than that in the two other tiers. Consequently, the $K/L$ ratio should be higher, on average, in the first-tier region as Table 2 confirms.

To consider an enterprise's R&D intensity and its contributing factors, we let $Y$ denote the total output of the firm and $R$ the share of the output that is not related to R&D, so that $Y = V_0 + R$. Dividing (4) by $Y$ and differentiating the resulting expression with respect to $w$, we determine the following inequalities by using the second-order conditions:

$$\frac{\partial(K/Y)}{\partial w} < 0 \quad \text{and} \quad \frac{\partial(L/Y)}{\partial w} < 0. \tag{6}$$

Hence, R&D intensity is related negatively to the labor cost of R&D scientists or engineers. The efficiency of R&D activities, which is represented by parameter $\theta$, may also influence a firm's R&D intensity. Using the same comparative statics technique and differentiating (4) with respect to $\theta$, we obtain:

$$\frac{\partial(K/Y)}{\partial\theta} > 0 \quad \text{and} \quad \frac{\partial(L/Y)}{\partial\theta} > 0. \tag{7}$$

Hence, firms with higher R&D efficiency tend to have higher R&D intensity.

As Table 1 shows, FIEs have higher R&D intensity and higher $K/L$ ratios, on average, than firms in the other categories. The high $K/L$ ratio is explained by the high labor cost

[11] For brevity we drop the subscripts to current R&D inputs in (3).

of R&D personnel in FIEs. However, a high R&D intensity can be due either to a low labor cost or to a high R&D efficiency according to (6) and (7). Given the high labor cost of R&D personnel in FIEs, the logical explanation for FIEs having the highest R&D intensity is that FIEs should have the highest R&D efficiency when compared to firms of other categories. Table 1 also indicates that SOEs have the second largest R&D intensity. The above analysis suggests that, if SOEs were profit maximizers, the high R&D intensity could result either from a low labor cost of R&D personnel, which is consistent with the above analysis on the $K/L$ ratio, or from a high R&D efficiency, or from both. These issues will be examined in a later section.

Regarding HMTs, Table 1 indicates that they have a higher $K/L$ ratio than SOEs, COEs, and joint-stock companies. However, the R&D intensity of HMTs is the lowest of all five ownership types. Based on our analysis in (5)–(7), the labor costs of R&D personnel should be higher for HMTs than for SOEs, COEs and STOCKs, but the R&D efficiency of HMTs should be lower than that of FIEs. This prediction that HMTs have a lower R&D efficiency than FIEs is consistent with the above prediction made. With respect to the inter-regional comparison, Table 2 indicates that the R&D intensity of the firms located in the first-tier region is higher than that of the firms in the second- and third-tier regions. Since firms in Tier 1 also have the highest $K/L$ ratio, their labor costs for R&D personnel and their R&D efficiency are likely to be higher than those of the firms located in other two regions.

These observations indicate that R&D efficiency plays a crucial role in the determination of R&D inputs by firms of different ownership types. Under normal competitive conditions, favorable R&D infrastructure results in greater R&D efficiency by firms, whereas higher R&D intensity is expected to lead to higher overall productive efficiency (Jacobs, 1984; Bairoch, 1988; Lucas, 1988). Firms in Tier 1 are mainly from coastal areas with a concentration of major cities that bring economic agents into close proximity with each other. The highly developed R&D infrastructure of these areas, including human capital (Fleisher and Chen, 1997), provides information externalities, including knowledge spillover, thereby allowing firms to enjoy higher R&D efficiency than Tier-2 and Tier-3 firms. In addition, good R&D infrastructure corresponds to economic conditions and policies that encourage market competition that further improves R&D efficiency and knowledge acquisition.

Furthermore, ownership type should affect the R&D efficiency of firms because managerial incentives, project screening mechanisms, project financing methods, and the hardness of the budget constraint may be different across ownership types (World Bank, 1992; Shleifer and Vishny, 1994; Qian and Xu, 1998; Huang and Xu, 1998). For example, Huang and Xu (1998) show that centralized economies make R&D inefficient due to a lack of competitive financing sources with effective monitoring mechanisms. As a result of soft budget constraints, state enterprises lack the commitment to stop bad R&D projects through effective *ex-post* screening mechanisms. In contrast, as Table 1 shows, FIEs spend only 62% of their TID budgets indicating that they terminate 38% of their TID projects. This termination rate is much higher than the termination rates of 12%, 10%, 10% and 4% for SOEs, COEs, STOCKs and HMTs, respectively. Since FIEs exercise the tightest financial control over their R&D budgets, FIEs should have the highest R&D efficiency when compared to firms of other ownership categories. In the next two sections, we investigate empirically the R&D efficiency of Chinese enterprises of different ownership

types and in different regions. We also test whether the above predictions are consistent with the empirical evidence.

## 4. The empirical methodology and the data

Our test data is derived from the 1995 General National Survey. China conducts a general national survey every five years to review the implementation of its five-year economic development plans. The survey provides comprehensive firm-level economic data, including R&D data, on a national basis. In 1995, the National Bureau of Statistics computerized the survey results.[12] We delete industries that have fewer than 20 firms and firms that have missing values. Since we use a Cobb–Douglas type production function that requires log transformations, we delete any observation with a zero R&D input. Our sample is a cross-section database of 8341 large and medium-sized enterprises operating in 33 industries.

Although Marton (2000) and Chow (1993) consider China's economic statistics to be fairly reliable by developing country standards, Rawski and Xiao (2001) take issue with this opinion. Numerous reports indicate that false accounts were commonplace in Chinese industry during 1995 for large and medium firms and for firms of all ownership types.[13] Although no published studies have examined the quality of China's firm-level R&D data, we note that our data may be subject to large margins of error. This problem has implications for the choice of methods for measuring efficiency. Using a frontier model, Farrell (1957) defines economic efficiency in terms of technical efficiency and allocative efficiency. The technical efficiency of any firm is determined by the distance between the realized output of the firm and the maximum possible output on the production frontier, given the set of the firm's inputs. Allocative efficiency is determined by the difference between the actual input bundle and the optimal input bundle along the production frontier, given input prices. The production frontier is taken to be the production function of the most efficient firms.

In practice, production functions are not known and actual observations of firms are not on the frontier. Furthermore, the observed performance of a firm is affected by exogenous shocks over which the firm has no control in addition to endogenous factors relating to inefficiencies. Therefore, the estimation of production functions by ordinary regressions in which both exogenous and endogenous factors are allocated to the same error term may be biased. As an alternative, the stochastic frontier method takes into consideration that deviations from the production frontier may not be entirely under the control of the firm by using a more reasonable error structure.[14] Specifically, Aigner et al. (1977) and Meeusen

[12] Our data are taken from the following website address: http://www.stats.gov.cn/

[13] For example, the 1995 census found large gaps between reality and previously reported data in the TVE sector. However, this problem was largely limited to small enterprises rather than the large firms under consideration here.

[14] In contrast to the parametric approach employed by the stochastic frontier method, the non-parametric approach revolves around mathematical programming techniques that are generally referred to as data envelopment analysis (DEA). DEA takes extreme observations as its standard of efficiency, and measures

and Van den Broeck (1977) propose the following stochastic specification of the production frontier:

$$Y = X\beta + (v - u),$$

where $Y$ is output, $X$ is a vector of inputs, and $\beta$ is the vector of unknown parameters defining the production function. In this specification, the random variable $v$ has a standard normal distribution that captures the effects of omitted variables and measurement errors. The random variable $u$ characterizes the difference between the maximum output on the frontier and the realized output; therefore, $u$ should be non-negative.

In the stochastic frontier approach, the frontier production function is estimated statistically. For this purpose the R&D production function in (1) is converted to the following stochastic specification:

$$\ln V_i = \alpha_0 + \left(\alpha_K + \sum_j \alpha_j I_{ij}\right) \ln K_i + \left(\alpha_L + \sum_j \alpha_j I_{ij}\right) \ln L_i - u_i + \varepsilon_i, \tag{8}$$

where $I_{ij}$ is an industry dummy so that $I_{ij} = 1$ if firm $i$ is in industry $j$. In Eq. (8), the error term $u$ captures technical inefficiency and $\varepsilon$ captures other random effects in R&D production and in data reporting or collection. Following the standard assumptions, the random variables $\varepsilon_i$ are independent, identically distributed according to a normal distribution; in addition, $\varepsilon_i$ and $u_i$ are distributed independently for all $i$. The efficiency measure $\theta$ is between 0 and 1; $\theta$ equal to unity indicates the most efficient R&D production and defines the R&D production frontier. Therefore, $u = -\ln\theta$ is non-negative. We assume that $u$ has a normal distribution truncated at zero so that

$$u \sim N\left(\mu_i, \sigma_u^2\right).$$

Following Battese and Coelli (1995), $\mu_i$ is defined as

$$\mu_i = Z_i\delta, \tag{9}$$

where $Z_i$ is a vector of factors that influence the firms' efficiency.

Ownership types and the level of R&D infrastructure development are included in the $Z$ vector so that Eq. (9) takes the form[15]

$$\mu_i = \delta_0 + \sum \delta_j \mathit{Ownership}_{ij} + \sum \delta_k \mathit{Infrastructure}_{ik}. \tag{10}$$

inefficiency in terms of deviations from extreme data points. When the magnitude of exogenous variables is high, the stochastic frontier approach generally produces better estimates of efficiency than does DEA (Yu, 1998). Given potentially large error margins in this data set, we choose the stochastic frontier method over the DEA method.

[15] Outcomes that we attribute to ownership may be affected by unidentified factors that are correlated with ownership, such as the age of enterprises. Casual observation suggests that SOEs and COEs, except perhaps some TVEs are likely to have been in business longer than FIEs and HMTs, while restructured firms such as shareholding entities carved out of former state enterprises or STOCKs may be in the middle with respect to age. Furthermore, old enterprises typically have surplus workers, many retirees, entrenched managements, who behave like bureaucrats rather than entrepreneurs, and long histories of subordination to government agencies. As a consequence, new firms having none of these characteristics may have an advantage over the old firms with respect to R&D activities and overall production. Thus, adding an age variable to the estimation Eq. (10) can be desirable. Unfortunately, the 1995 General National Survey does not report enterprise age, nor does it have

Ownership refers to dummy variables for SOE, COE, STOCK, FIE, and HMT, and infrastructure represents dummy variables for firms located in the first, second, and third tiers. The value of a firm's R&D output, $V$, is measured by sales revenue from new outputs, which include new products, high-tech products, and technology transfers and services.[16] The government issues an industry-specific list of suggested high technologies to encourage firms to adopt or develop them. Any products meeting the criteria are classified as high-tech products. New products are products involving any new design, new production process, or new packaging that have not been used before by the industry. Firms must apply for official approval before their products can be classified as either new or high-tech products. A firm's R&D inputs, $L$ and $K$, are measured, respectively, by the total number of the firm's R&D personnel and by its total expenditure on non-personnel BRD and TID. The latter includes both internal and external BRD and TID expenditures but excludes production cost and loan payment. The model is estimated using the computer program FRONTIER, version 4.1 (Coelli et al., 1998). To avoid perfect collinearity, the ownership dummy for SOEs, the infrastructure dummy for Tier 1 are the omitted categories in (10), and the industry dummy for the general machine building industry is omitted from the regressions using (8).

## 5. The empirical results

Results from the stochastic frontier estimation of the R&D production function are reported in panel A of Table 3. The sum of coefficients of the R&D labor and capital inputs for the base industry, i.e., general machine building, is 0.691, which indicates that diseconomies of scale might be present for R&D. Furthermore, all the dummies for infrastructure and ownership variables are statistically significant indicating that the ownership type and infrastructure development are important determinants of a firm's R&D efficiency. In particular, the coefficients for the infrastructure dummies reveal that the means of the truncated normal distributions for the log-inefficiency of the firms located in the second and third tiers are 0.710 and 0.926, respectively, suggesting that the firms in these regions are less efficient, on average, than Tier-1 firms as expected.

Regarding the effect of ownership on R&D efficiency, the mean of the truncated normal distribution ($\mu$) for the log-inefficiency of SOEs located in the first tier is 1.38. The

any other items that could be used as proxies. If the ownership variable is not defined precisely enough, or if ownership is correlated with some unidentified factors, it is not clear which method, the stochastic frontier or DEA approaches, is superior (Yu, 1998). Hence, we conducted a two-step DEA analysis in which the relative gross efficiencies are first estimated using inputs and outputs and then the effects of the exogenous variables on the gross efficiency are analyzed using regressions. The DEA analysis confirms the results of stochastic frontier estimation that the non-state sector has significantly higher levels of R&D and productive efficiencies than SOEs and that, within the non-state sector, foreign firms have higher R&D and productive efficiencies than domestic collective-owned enterprises and joint stock companies.

[16] In our measurement of R&D output, we have data on new outputs only. Thus, we are unable to measure the effects of R&D efforts focused on process innovation and cost reduction. Therefore, the level of R&D output may be underestimated systematically. This data limitation does not produce unbiased results as long as the share of $V$ due to process innovation plus cost reduction is invariant across firms and ownership types.

Table 3
Results of stochastic frontier estimation

| | Variable | Coefficient | Std. error |
|---|---|---|---|
| | A: R&D production function[a] | | |
| $\alpha_0$ | Intercept | 7.2293 | 0.1674 |
| $\alpha_L$ | R&D labor input | 0.3942 | 0.0523 |
| $\alpha_K$ | R&D capital input | 0.2966 | 0.0325 |
| $\delta_0$ | Mean efficiency | 1.3784 | 0.3529 |
| $\delta_{\text{COE}}$ | COE dummy | −0.3961 | 0.1401 |
| $\delta_{\text{STOCK}}$ | STOCK dummy | −1.1196 | 0.2469 |
| $\delta_{\text{FIE}}$ | FIE dummy | −2.7673 | 0.4631 |
| $\delta_{\text{HMT}}$ | HMT dummy | −1.6818 | 0.3765 |
| $\delta_{\text{Tier 2}}$ | Tier-2 dummy | 0.7099 | 0.1101 |
| $\delta_{\text{Tier 3}}$ | Tier-3 dummy | 0.9259 | 0.1507 |
| $\sigma^2$ | $(\sigma_u^2 + \sigma_\varepsilon^2)$ | 5.4706 | |
| $\gamma$ | $\sigma_u^2/(\sigma_u^2 + \sigma_\varepsilon^2)$ | 0.7597 | |
| | B: overall production function[b] | | |
| $\beta_0$ | Intercept | 2.4447 | 0.2790 |
| $\beta_L$ | Labor input | 0.5431 | 0.1684 |
| $\beta_K$ | Capital input | 0.4793 | 0.1206 |
| $\delta_0$ | Mean efficiency | 0.2169 | 0.0849 |
| $\delta_{\text{COE}}$ | COE dummy | −0.6669 | 0.2167 |
| $\delta_{\text{STOCK}}$ | STOCK dummy | −0.9030 | 0.2119 |
| $\delta_{\text{FIE}}$ | FIE dummy | −2.4452 | 0.4067 |
| $\delta_{\text{HMT}}$ | HMT dummy | −0.5729 | 0.3941 |
| $\delta_{\text{Tier 2}}$ | Tier-2 dummy | 0.4011 | 0.0657 |
| $\delta_{\text{Tier 3}}$ | Tier-3 dummy | 0.2475 | 0.0648 |
| $\sigma^2$ | $(\sigma_u^2 + \sigma_\varepsilon^2)$ | 0.5149 | |
| $\gamma$ | $\sigma_u^2/(\sigma_u^2 + \sigma_\varepsilon^2)$ | 0.1426 | |

*Notes.* 1. To save space, industry dummies are not reported in the table. 2. $\delta_0$ is the mean log-inefficiency of SOEs in the Tier-1 region.

[a] $\ln V_i = \alpha_0 + (\alpha_K + \sum_j \alpha_j I_{ij}) \ln K_i + (\alpha_L + \sum_j \alpha_j I_{ij}) \ln L_i - u_i + \varepsilon_i$, where $u_i$ has a truncated normal distribution with mean $\mu_i = \delta_0 + \sum \delta_j \mathit{Ownership}_{ij} + \sum \delta_k \mathit{Infrastructure}_{ik}$.

[b] $\ln Y_i = \beta_0 + (\beta_K + \sum_j \beta_j I_{ij}) \ln K_i + (\beta_L + \sum_j \beta_j I_{ij}) \ln L_i - u_i + \varepsilon_i$, where $u_i$ has a truncated normal distribution with mean $\mu_i = \delta_0 + \sum \delta_j \mathit{Ownership}_{ij} + \sum \delta_k \mathit{Infrastructure}_{ik}$.

coefficient on the dummy for COEs is −0.396, indicating that COEs are more efficient than SOEs, which is the omitted category. Similarly, the coefficients for STOCKs, FIEs, and HMTs are all negative indicating that SOEs are least efficient in R&D activities of the five ownership categories. Since the coefficient for FIEs is the highest in magnitude, FIEs are the most efficient ownership firms as expected. Although HMTs appear to be more efficient in R&D activities than SOEs, they are significantly less efficient than FIEs confirming our earlier conjecture.

In transition economies, a high degree of state ownership has been found to reduce the overall productivity of a firm. We consider this ownership-productivity link in China and investigate the role of R&D efficiency. We use the same methodology as before to estimate

a firm's overall production function given by

$$\ln Y_i = \beta_0 + \left(\beta_K + \sum_j \beta_j I_{ij}\right) \ln K_i + \left(\beta_L + \sum_j \beta_j I_{ij}\right) \ln L_i - u_i + \varepsilon_i. \qquad (11)$$

In (11), output $Y$ is measured by the firm's total sales revenue, whereas labor and capital inputs, $L$ and $K$, are measured by the total number of employees and by net productive assets, respectively. The technical efficiency term $u_i$ and the error term $\varepsilon_i$ have the same specifications as those in the R&D model in (8) and (10).[17]

For overall productive efficiency, the results from the estimation of (11) are presented in panel B of Table 3. The sum of the coefficients for the labor and capital inputs is 1.022 for the base industry, which is consistent with constant returns in production. Similar to the case of R&D efficiency, the coefficients for the regional dummies indicate that firms located in Tier 2 and Tier 3 are less efficient than firms in Tier 1. Furthermore, the mean of the truncated normal distribution for log-inefficiency of SOEs in Tier 1 is 0.217, while the means for the firms of other ownership types are significantly smaller, with FIEs being the smallest. Hence, FIEs are most efficient and SOEs are least efficient in overall productivity among the five ownership types. This result is consistent with the existing literature on the ownership-productivity link.

To investigate the role of R&D efficiency in this ownership-productivity link, we start by estimating the technical efficiencies for both R&D and overall production. In addition to the coefficients of the stochastic frontier, the FRONTIER program estimates the value of technical efficiency $\theta = \exp(-u)$ for each firm, conditional on the estimated frontier (Coelli et al., 1998). The descriptive statistics are reported in Table 4. Although the sample size of the groups varies widely, from 4525 firms in Tier 1 to 1272 firms in Tier 3 and from 6097 SOEs to 252 HMTs, the standard deviations of the efficiency measures are similar. Thus, a comparison of means of technical efficiency across groups is valid. Furthermore, the means and medians of R&D efficiency are substantially lower than the means and medians of productive efficiency. In addition, the dispersion for inter-firm R&D efficiencies is wider than for inter-firm productive efficiencies, as indicated by larger standard deviations.

Consistent with the results of stochastic frontier estimation, SOEs have both the lowest productive efficiency at 66.32% and the lowest R&D efficiency at 20.08% among all ownership categories. At the same time, FIEs have the highest efficiency values for both productivity and R&D at 97.47% and 43.42%, respectively. The technical efficiencies of COEs, STOCKs, and HMTs are somewhere in the middle. Interestingly, although FIEs and HMTs have similar managerial structures, noticeable differences are observable in both productive and R&D efficiencies confirming our conjecture that HMTs should have a lower R&D efficiency than FIEs.[18]

[17] Fleisher and Chen (1997), Kalirajan and Zhao (1997) and Demurger (2001) find that firm productivity may vary with geographical location. For example, Fleisher and Chen show that TFP is roughly twice as high in the coastal provinces; they demonstrate that investment in higher education and foreign direct investment help explain this productivity gap.

[18] In terms of the infrastructure factor, Tier 1 has a higher mean productive efficiency of 79.81% than Tiers 2 and 3 at 62.75% and 66.14%, respectively, although the difference between Tiers 2 and 3 is not statistically

Table 4
Summary statistics of technical efficiency $\theta$ (%)

| Group | Mean | Std. dev. | Q1 | Median | Q3 | No. of firms |
|---|---|---|---|---|---|---|
| | | | A: R&D efficiency | | | |
| SOEs | 20.08 | 15.87 | 6.45 | 16.17 | 31.35 | 6097 |
| COEs | 24.58 | 17.47 | 8.52 | 22.59 | 38.32 | 1188 |
| STOCKs | 29.29 | 17.74 | 13.15 | 29.23 | 43.69 | 547 |
| FIEs | 43.42 | 20.87 | 28.62 | 47.80 | 60.16 | 257 |
| HMTs | 34.53 | 18.82 | 18.73 | 34.98 | 49.40 | 252 |
| Tier 1 | 25.59 | 17.59 | 9.80 | 23.88 | 38.94 | 4525 |
| Tier 2 | 19.75 | 16.70 | 5.68 | 14.52 | 31.33 | 2544 |
| Tier 3 | 16.88 | 14.64 | 4.90 | 12.30 | 25.54 | 1272 |
| | | | B: productive efficiency | | | |
| SOEs | 66.32 | 9.47 | 58.14 | 67.43 | 74.73 | 6097 |
| COEs | 87.58 | 3.76 | 85.39 | 89.07 | 90.23 | 1188 |
| STOCKs | 90.54 | 2.29 | 88.51 | 91.52 | 92.27 | 547 |
| FIEs | 97.47 | 1.46 | 96.56 | 96.88 | 97.03 | 257 |
| HMTs | 87.07 | 4.41 | 85.29 | 88.69 | 89.96 | 252 |
| Tier 1 | 79.81 | 8.79 | 73.53 | 76.84 | 89.39 | 4525 |
| Tier 2 | 62.75 | 13.59 | 53.81 | 57.45 | 66.21 | 2544 |
| Tier 3 | 66.14 | 9.42 | 60.66 | 63.89 | 67.48 | 1272 |

*Note*. Q1 and Q3 refer to the 1st and 3rd quartiles.

Table 4 indicates that the productive and R&D efficiencies are consistent for the five ownership categories. Hence, we regress productive efficiency on R&D efficiency, controlling for the other variables, using

$$\theta_{\mathrm{P}} = \eta_0 + \sum \eta_{1i} \mathit{Ownership}_i + \sum \eta_{2j} \mathit{Infrastructure}_j + \eta_3 \theta_{\mathrm{R\&D}} + \varepsilon, \tag{12}$$

where $\theta_{\mathrm{P}}$ and $\theta_{\mathrm{R\&D}}$ denote productive efficiency and R&D efficiency, respectively. R&D efficiency should have a significantly positive impact on productivity. The results of this regression are displayed in Table 5. As expected, R&D efficiency has a highly significantly positive coefficient. Hence, firms that are more efficient in R&D activities tend to be more efficient in production. Combining this result with our earlier result that a higher degree of non-state ownership leads to higher R&D efficiency yields the conclusion that a higher degree of non-state ownership leads to higher productivity. Thus, R&D efficiency provides the link between the degree of state ownership and the level of productivity.

## 6. Concluding remarks

This paper investigates the microeconomics of innovation in transition economies based on a national data set. We find that ownership type is an important determinant of the cross-sectional variance in firm R&D and productive efficiencies. The state sector has

significant. However, the three regions have more distinct differences in their mean R&D efficiencies at 25.59% for Tier 1, 19.75% for Tier 2, and 16.88% for Tier 3.

Table 5
Regression results of productive efficiency on R&D efficiency

| Variable | Coefficient | Std. error |
|---|---|---|
| Intercept | 0.7141 | 0.0010 |
| R&D efficiency | 0.0627 | 0.0031 |
| COEs | 0.1934 | 0.0015 |
| STOCKs | 0.2229 | 0.0021 |
| FIEs | 0.2776 | 0.0030 |
| HMTs | 0.1734 | 0.0030 |
| Tier 2 | −0.1488 | 0.0012 |
| Tier 3 | −0.0889 | 0.0015 |
| R-square | 0.88 | |

significantly lower efficiencies in both R&D and productive activities than does the non-state sector. Within the non-state sector, foreign-invested firms (FIEs) and firms with investors from Hong Kong, Macau, and Taiwan (HMTs) have higher R&D and productive efficiencies than do domestic collective-owned enterprises and joint stock companies. The explanation of why R&D efficiency leads to higher productivity depends on R&D intensity. First, we demonstrate that a profit-maximizing firm with a higher R&D efficiency tends to spend more on R&D. Second, existing literature, e.g., Griliches (1979) and Tassey (1997) establishes that higher R&D expenditure will result in higher productivity. Taken together, these points suggest that R&D efficiency leads to higher productivity through a firm's endogenous choice of its R&D intensity. Our results indicate that, within the non-state sector, higher R&D efficiency in foreign firms leads to a higher R&D intensity, which in turn leads to higher productivity.

However, the case of SOEs requires special attention because SOEs are the least likely of firms in the five ownership types to be profit maximizers. Bai et al. (2000) argue that, because SOEs play an important role both in providing a wide range of social services to employees and their families and in maintaining social stability, the managers of SOEs may be biased toward increasing output rather than maximizing profit.[19] For SOEs, the positive linkage between R&D intensity and firm productivity cannot be established empirically because SOEs have the lowest R&D efficiency but the second highest R&D intensity. Consequently, the conclusion that the low R&D efficiency of SOEs leads to low R&D intensity, which in turn leads to low productive efficiency cannot be established empirically. Hence, R&D intensity is not a good explanatory variable for firm productivity for SOEs. These results are consistent with Hu (2001) who finds a strong, positive link between private R&D and firm productivity, although the direct contribution of government R&D to firm productivity is insignificant.

We find that FIEs have the highest R&D efficiency and the highest productive efficiency when compared to firms of other ownership types. In contrast to FIEs, HMTs show a much

[19] The empirical evidence presented in Zhang et al. (2002) is consistent with non-profit maximizing behavior by SOEs. Since the research activities of SOEs are funded and monitored by the state, non-profit maximizing behavior create incentives for SOEs to obtain more research grants than they need and spend less efforts in exploiting the commercial value of their research.

weaker association between R&D and productive efficiencies. Although their productive efficiency is close to that of FIEs, HMTs have a much lower R&D efficiency, which may reflect the lack of effective coordination of productive and R&D activities in HMTs. In previous work, Zhang et al. (2001) find that HMTs have a higher level but a lower rate of growth in productive efficiency than SOEs. This result can be explained by the disconnect between productive and R&D activities of HMTs. The difference between the R&D practices in FIEs and HMTs may be traceable to the competitive strategies and R&D cultures of their respective parent companies, which is an interesting area for future research.

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