R&D Returns, Spillovers, and Firm Incentives

Evidence from China

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February 2015

Abstract

This paper uses a new data set of 12,000 firms in China to estimate the returns to research and development investment and its spillover effects, and investigates how the returns to research and development depend on firm incentives. For the firms in the sample, the results show that on average firm output increases around 0.4 yuan for each additional 1 yuan spent on research and development in the previous year, and there is high research and development return regardless of whether the analysis deals with the endogeneity of research

and development intensity. Interestingly, the marginal return to research and development is significantly higher in firms whose chief executive officers were not appointed by the government and lower when the chief executive officer's pay is directly related to annual performance. The return to research and development is higher in relatively poor regions and for firms with worse access to finance. There are also non-trivial research and development spillover effects.

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Key words: R&D, returns, incentives, spillover.

JEL codes: D22, D24, O31, O40.

¹ We are grateful for comments to Zhiqi Chen, Justin Lin, and Sole Martinez Peria.

1. Introduction

Even though China has witnessed spectacular growth for three decades, some recent research suggests that China may have relied too much on capital accumulation and (increasingly) too little on technological progress in the past few years. Table 1 reports the contributions by factors to China's economic growth after 1978 (Zheng, Bigsten and Hu, 2006). The evidence suggests that China has relied on capital growth rather than TFP growth since the mid-1990s, and TFP growth has played an increasingly smaller role (see also Zheng and Hu 2006; OECD 2005). From the 1979-1993 period to the 1993-2005 period, the contribution of TFP to total growth declined from 43% to 32%, while that of capital increased from 44% to 62%.² Similarly, Lin and Wang (2008) show that the share of TFP contribution to GDP growth dropped from 31% in 1978-1999 to 20% in 2000-2005.

Some may respond by observing that institutional reforms may continue to provide the necessary productivity boost for productivity to grow in a sustainable manner. Yet the room for institutional reforms likely has decreased substantially over time, and the changes in productivity have to come increasingly from technological changes. China has experienced three major waves of reforms (Zheng, Bigsten and Hu, 2006). The first was the rural reforms and the adoption of the Household Responsibility System³, which resulted in substantial increases in agricultural productivity and output during the period (Lin, 1992; Wen, 1993). The second wave started in the

² The investment boom in the late 1990s and early 2000s were due to several factors (Zheng, Bigsten, Hu, 2006): higher saving rate (due to the liberalization of housing, healthcare, old age support, which causes more precautionary saving rate); massive government infrastructure spending, FDI and domestic investment in manufacturing, preparation for the 2008 Olympic Games. China's 2002 accession to the WTO further attracted new FDI and domestic investment in anticipation of greater market opportunities. In addition, policy distortion may have further increased the investment boom: subsidized factors costs on land, electricity, water; cheap financing for state-owned enterprises and large firms; regional competition due to fiscal decentralization.

³ The Household Responsibility System was essentially allowing farmers to have a long-term lease of public land for agricultural production with a fixed rent so that they had strong incentives. Before this system, farmers acted more like waged employees for collective farms.

mid-1980s and continued into the early 1990s, featuring greater autonomy and incentives for state-owned enterprises (SOEs) and the flourishing of township and village enterprises (TVEs) (Li, 1997; Xu, 2000; Shirley and Xu, 2001; Zheng, Liu and Bigsten, 1998). The third wave started with the southern tour of Deng Xiaoping in 1992, which led to greater corporate restructuring, privatization of small and medium SOEs, and increasing openness, as shown by the take-off of FDI and the increasing role of foreign-owned firms in the Chinese economy (Xu, Zhu and Lin, 2005; Fan et al. 2007, World Bank, 2006). Accompanying all these reforms has been the shifting of the labor force from agriculture to non-agriculture, which induced productivity gains (Zheng, Bigsten and Hu, 2006). While the gains from labor migration from agriculture to non-agriculture are not done yet, the gains from privatization and corporate reforms are likely much more limited than they used to be. Moreover, currency appreciation over time would reduce Chinese firms' price advantage over their competitors, and so would the acceleration of wage growth in China.

One natural conclusion following the above arguments is that China has to increasingly rely on innovation and technological progress to further China's productivity growth in the future, much like what happened in the U.S. when it experienced a sharp productivity decline after the oil shock in the 1970s (Griliches 2000). For sustainable growth, Japan and the Republic of Korea also significantly increased their R&D share in GDP over time (see Figure 1). Indeed, technological innovation is likely the ultimate and inexhaustible source of growth (Romer 1990, Lucas 1988, Helpman 2004).

In this paper, we use a unique large data set of Chinese firms to investigate the returns to R&D investment in Chinese firms. While there is a large literature on the effects of R&D (for a summary, see Griliches 1998, Mairesse and Mohnen 1994), relatively few papers study the effects of R&D in developing countries. This is not surprising. After all, the vast majority of R&D is

conducted in industrial countries (Coe et al. 1997). Yet, it is vitally important to understand the effects of R&D in developing countries. To catch up with industrial economies, own R&D is one avenue to pursue—besides relying on spillover effects of R&D via trade or imported goods (Coe et al. 1997; Coe and Helpman, 1995). Since the nature of R&D differs between developing and developed countries—for instance, it is believed that R&D in developing countries is more likely to be adapting existing technologies to local conditions—the returns to R&D would naturally differ. Moreover, there are also many unsettled questions in research on R&D in the developing world. How large are R&D effects in developing countries relative to those of developed countries? How do R&D effects depend on other factors such as the level of economic development, corporate ownership, and CEO incentives? Are there spillover effects of R&D?

China is an ideal setting to study the effects of R&D in developing countries. China has significantly increased the R&D over GDP ratio over time, from less than 1 percent, typical of developing countries, to around 1.5 percent in 2004 (see Figure 1). China features one of the largest spatial variations across regions in the world. The ratio of the highest to the lowest provincial GDP per capita ranges between 10 and 15. The developed regions such as Shanghai, Guangzhou, Shenzhen, and Beijing are similar to rich middle-income countries, while lagging regions such as Guizhou are still very much poor. This spatial contrast thus allows us to examine how R&D returns differ by income level. The vastness of the country also makes it ideal to study a key issue regarding R&D, namely, the spillover effects of R&D. Firms differ greatly in their ownership and in CEO incentives, which allow us to see how firms differ in their research effectiveness in conducting R&D and whether incentives matter. Finally, the data we use are ideal for our purpose. We have one of the best data sets available in terms of studying R&D. The data set is a random sample of all mainland Chinese provinces (except Tibet), including both large and

small firms. This feature overcomes one limitation of previous data, which tend to include primarily large firms. The data set has details about firm characteristics and incentives. The data set is also very large, with 12,000 firms.

The main difficulty in identifying R&D returns is that firm level R&D intensity could be endogenous due to omitted variables and/or reverse causality. We use the panel structure of our data to purge out the omitted fixed effects. Furthermore, we use the technological modality, captured here by the R&D intensity for the same industry in the U.S. in the 1970s, to instrument for the R&D intensity in our data. The Hausman Test shows that there are no more endogeneity problems other than those that could potentially be caused by firm level fixed effects. Overall, our results are very encouraging. On average in the manufacturing industries, one Chinese yuan spent on R&D in 2003, *ceteris paribus*, increases the output in 2004 by around 0.4 yuan. The magnitude of the marginal return in China is similar to what is found in Japan and the U.S. in the 1970s. The return on R&D varies by region. The less developed regions on average see higher R&D returns. Additionally, we found that there are nontrivial spillover effects. In summary, our estimates above reveal that R&D expenditure has been very effective in boosting productivity. It suggests that investment in R&D can serve as a powerful growth engine for the Chinese economy when the effect of other sources of growth declines.

Our paper is related to two strands of literature. The first is to the literature on R&D effects in China. The previous studies find substantial R&D returns at the firm level in China (Jefferson et al. 2002). R&D inputs are found to increase the share of new products so that R&D in China does not only refer to adapting foreign technology in China (Jefferson et al 2002). Returns to private R&D tend to be higher than those to public R&D (Hu 2001). There are some indications that the returns to R&D have dropped over time, though they are still substantial (Hu and Jefferson

2004). There is significant complementarity between own R&D and foreign technology transfer (Hu, Jefferson and Qian 2005). We differ from them in that we have a random sample,⁴ we have more firm characteristics, we examine how R&D effects depend on CEO incentives and development level, we allow for the spillover effects, and we examine a later period when R&D dramatically increased. The second literature encompasses papers on R&D expenditures and their spillover effects (see Griliches 1998; Mairesse and Mohnen 1994). We differ from this strand in that we focus on the largest developing economy (instead of largely developed countries studied by the previous literature), we allow return heterogeneity across region, development level, and firm incentives.

The rest of the paper is organized as follows. We first examine the basic patterns of R&D and introduce our data in section 2. In section 3, we set up our empirical model. The results and analysis are presented in section 4. Section 5 concludes with findings and policy implications.

2. Basic R&D Patterns and Data

Before we present figures based on the recent investment climate survey, it is useful to compare China's R&D expenditure with some historical data on some of the developed countries (see Table 2). In 1963, the R&D intensity was 1.2 percent for Sweden, 1.4 percent for Japan, 1.5 percent for Germany, 2.2 percent for U.K., and 3.1 percent for U.S. In 1985, the R&D intensities for all these countries, along with Canada and France, hovered around 2 to 3 percent, while that of Italy was only 1.1 percent. In 1991, the R&D intensity was 2.9 percent for Japan, 2.7 for U.S., 1.9 for Korea, and 0.5 for Brazil. 1995 witnessed the takeoff of R&D intensity from 1.9 to 2.5 for Korea. Taiwan, China's number in 1995 is 1.8. In 2000, most countries again invested between 2

⁴ Their samples tend to be the sample of above-scale large and medium enterprises.

to 3 percent, with Brazil at 1.1 percent, Italy at 1 percent, and India at 0.9 percent. China's R&D intensity was comparable to Italy, India and Brazil at 1 percent. In 2004, China's figure rose to 1.35 percent. So there had been a significant increase in R&D intensity in the last half a dozen of years or so. Before the turn of the century, there was a significant increase in R&D level and patent application between 1994 and 1999 amongst large and medium-sized enterprises (Jefferson et al. 2003).

Table 3 shows the distribution of R&D intensity (i.e., R&D expenditure over sales) across provinces.⁵ The top performer of R&D is Beijing, whose firms spend 2.8 percent of their sales on R&D. Beijing is followed by Guizhou (2.1), Hainan (1.9), Shanghai (1.6), Shaanxi and Chongqing (1.5), and Zhejiang (1.4). The bottom performers in R&D intensity are Hebei and Xinjiang (0.6), Yunnan, Henan, Shandong, Anhui (0.7), Jiangxi, Fujian, and Ningxia (0.8).

Table 3 suggests that the southwest provinces on average conduct the most R&D (1.2 percent of their sales), followed by the two coast areas (1.1 percent). Both the northwest and the northeast regions are similar at 1.0 percent. The region that conducts the least amount of R&D is the central region, 0.8 percent.

Table 4 shows that R&D intensity differs greatly by industries. The industries that invest the most on R&D are rubber (2.8 percent), drugs and pharmaceuticals (2.7), instruments (2.4), and communication equipment (2.2). In contrast, some conventional low-tech industries such as agricultural and food processing industries, tobacco, apparel, paper and textile have R&D intensities between 0.3 to 0.5 percent.

The Data Set

⁵ The numbers for the rest of this section all come from our own firm-level survey. The survey will be introduced in the next section.

The data set we use is the World-Bank-NBS Survey on 120 cities of 12,000 firms between 2002 and 2004. In the data all provinces are covered except Tibet.⁶ For each province, the capital city (invariably the largest city of the province) is selected, and if the province is not too small, other cities are also selected. Typically, provinces with high total GDP are allowed to have more cities surveyed. In each province, top cities (as measured by either total GDP or total industrial output) are selected. For all but the four directly-governed cities, we sample 100 firms; for the four mega cities (Beijing, Tianjin, Shanghai, and Chongqing), we sample 200 firms. Thus we have 12,400 firms in total in our sample, all from manufacturing. For each city, the top 10 manufacturing industries in terms of sales revenue are drawn. For each industry, all firms in the sample universe are divided into large, middle and small firms, each accounting for one-third of total industry revenue. Then from each of three types of firms, an equal number of firms are drawn.⁷ Firms are required to have a minimum of 10 employees. Table 5 reports the summary statistics of our data set. The list of our sample provinces and cities are displayed in Table A.1. The distribution of our sample industries is displayed in Table A.2.

The survey has three main parts. The first part was sent to the senior managers of a firm, covering topics such as basic firm characteristics, bottlenecks to firms' growth, relationship with clients and suppliers, labor, infrastructure, trade, finance, corporate governance and relationship with the government. The second part was sent to the accountants and personnel officers, concerning topics on ownership composition, financial statements and labor statistics. The last part is answered at the city level, covering basic characteristics of the city in which a firm is located.

⁶ One of the authors was directly involved in the design and implementation of the survey. Tibet is not selected because there are insufficient number of firms, and that the survey costs would be much higher. In conventional firm surveys conducted by ESO, Tibet is often not selected due to similar reasons.

⁷ In case the segment of large firms do not have sufficient number of firms, local survey organizations deal with the issue consistently in the following way: re-divide the remaining sample into large, medium and small firms, and draw from the new segment of large firms; continue to do so until the required number of large firms are drawn.

3. Empirical Models

To estimate the return to R&D, we use the standard approach that links R&D capital to productivity (see, for instance, Griliches 1998). Since we only have a short panel of three years, we could not reliably construct a R&D knowledge capital stock. We thus opt for the other standard approach in which the change in TFP is linked to R&D intensity (i.e., R&D/sales) (Griliches, 1998). The coefficient on R&D intensity has the interpretation of marginal returns of R&D investment, that is, dQ/dK , where Q is output, and K is the stock of knowledge capital.

To see this, assume a Cobb-Douglas production function, standard in the R&D literature, $Q_{it} = A_i L_{it}^\alpha C_{it}^\beta K_{it}^\gamma$. Q is value added, L is labor as measured by the number of employees, C is physical capital, and K is knowledge capital or R&D capital stock. We assume firm-specific efficiency term A_i . Taking logarithm and first-differencing, we wash out the firm fixed effects and obtain the following:

$$\Delta \ln Q_{it} = \alpha \Delta \ln L_{it} + \beta \Delta \ln C_{it} + \gamma \Delta \ln K_{it} \quad (1)$$

$$\text{Since } \gamma \Delta \ln K_{it} = \frac{\partial \ln Q_{it}}{\partial \ln K_{it}} \frac{\Delta K_{it}}{K_{it}} = \frac{\partial Q_{it}}{\partial K_{it}} \frac{K_{it}}{Q_{it}} \frac{\Delta K_{it}}{K_{it}} = \frac{\partial Q_{it}}{\partial K_{it}} \frac{\Delta K_{it}}{Q_{it}} = \rho \frac{\Delta K_{it}}{Q_{it}}, \quad (2)$$

after re-arranging terms we have:

$$\Delta f_{it} \equiv \Delta \ln Q_{it} - \alpha \Delta \ln L_{it} - \beta \Delta \ln C_{it} = \rho \frac{\Delta K_{it}}{Q_{it}} \quad (3)$$

Note that the term for marginal returns to R&D capital, ρ , is $\frac{\partial Q_{it}}{\partial K_{it}}$. In other words, if the number

is 0.50, it means that a one-dollar increase in R&D capital (or R&D investment) would, holding capital and labor constant, yield an increase in total output by 0.50 dollar, or an increase in total factor productivity by 0.50 (since we have already controlled for physical capital and labor, see equation (1)).

To allow other factors affecting productivity, we add a control vector X . In addition, since contemporary R&D intensity is more likely to exhibit simultaneous bias, and there is usually a lag in R&D effects, we use the one-year-lagged R&D intensity instead of the contemporary R&D intensity. Moreover, the recent literature on endogenous growth and the old literature on R&D spillover all suggest that knowledge is a non-rivalrous but potentially excludable goods (Romer 1990; Lucas 1988)--that is, one's use of the knowledge does not preclude others from using the same knowledge--we also control for the aggregate industry level R&D (i.e., total industry R&D divided by the firm's sales, again once-lagged).⁸

$$\Delta f_{it} = \alpha_0 + \alpha_x X_{it} + \gamma(R_{i,t-1} / Y_{i,t-1}) + \gamma_a \left(\sum_{j=1}^{N_k} R_{j,t-1} / Y_{i,t-1} \right) + \varepsilon_{it} \quad (4)$$

In equation (4) we have already filtered out the firm fixed effects. Our least square estimation based on (4) therefore amounts to the fixed effects estimation. The identification of the R&D return comes from associating changes in TFP with changes in knowledge capital. This would partially overcome the endogeneity of R&D capital that stems from its correlation with the time-invariant firm heterogeneity. Moreover, we have lagged R&D intensity to take into account the fact that the R&D effects need time to materialize, and to avoid arbitrary simultaneous correlation. We have also added a productivity growth shifter to allow other firm and city characteristics to affect productivity growth. We experiment with various control vectors to examine the robustness of our results, and to reduce the likelihood that the effects of R&D intensity are due to an omitted variable bias.

4. Returns to R&D Investment: Evidence from the New Investment Climate Survey

⁸ If we let $Q_{it} = A_i L_{it}^\alpha C_{it}^\beta K_{it}^{\gamma_1} K^{\gamma_2}$, with K being a measure of industry level knowledge capital, we explicitly models the externality effect of R&D expenditure. See Griliches (1998, chapter 11) for justification of similar specifications.

We first discuss how we estimate TFP. For the baseline regressions, we rely on a TFP measure that is constructed based on the sale-capital-labor-material framework. In particular, for each industry, we estimate a Cobb-Douglas production function separately, with a fixed effects model to capture firm quality and managerial ability. The (output) TFP is then the residual including both the fixed effects and the time-varying stochastic factor. From estimated TFP, we then compute the differences in TFP for consecutive years. Since TFP growth has some significant outliers, to ensure that our results are not driven by a few significant outliers, we trim the top and bottom one percent in TFP. We do, however, present evidence in sensitivity checks that our qualitative results are robust with respect to our way of dealing with outliers. We have also tried the Levinsohn-Petrin estimator of productivity (TFPLP), which deals with the potential correlation of input choices with firm productivity. However, although TFPLP and our fixed-effects TFP are closely correlated, the estimate of marginal returns based on TFPLP is implausibly large. We thus stick to the simpler fixed-effects TFP measure.

Base Results and Some Sensitivity Checks

Table 6 presents various specifications in the spirit of (4). In column (1) we include basic firm characteristics (firm size, age, and the city GDP per capita). In column (2) we further include ownership dummies (collective, public corporation, private, foreign, and other) and CEO education. Column (3) adds the spillover term. Column (4) allows the R&D effect to differ by ownership type.

The marginal return for firm-level R&D investment in the last period is substantial, ranging from 0.419 to 0.439. That is, investing in a dollar of R&D in a year would yield a return of a little more than 0.4 dollar. This is in line with what is found at the firm level between 1973 and 1980

for the United States (0.27 to 0.41), and for Japan in the same period (0.30 to 0.56) with similar specifications (Griliches, 1998, p203). Thus, it seems that investing in R&D in a large fast-growing developing country has the same level of return to that in developed countries. The results are fairly robust to controlling for ownership dummies and CEO characteristics. We have also tried including industry dummies, and found that they were jointly insignificant. We therefore do not control for them in any of our specifications.

There is also a strong spillover effect. The lagged aggregate R&D intensity (i.e., lagged aggregate industry-year R&D / lagged sales for the firm) is statistically significant. The coefficient seems trivial: increasing the lagged industry aggregate R&D by 1,000 dollars would increase firm productivity on average by only 0.008. But the appearance is misleading: the implied magnitude is quite large. Increasing this variable from its 10th percentile to its 90th percentile would lead to a productivity growth by 0.68×0.008 , or 0.54 percentage points.⁹ Keep in mind that the average productivity growth (for this particular productivity measure) is only 0.9 percentage points. It amounts to 1.6 percent of one standard deviation of our measured output TFP growth (which is 34%). The magnitude is modest but certainly non-trivial.

The marginal returns to R&D differ greatly among firms of various ownership forms. In general, firms closer to state ownership receive lower payoff from its R&D efforts. The marginal returns of R&D are the highest for domestic private firms, 0.964, followed by public corporations (0.455), collective (0.385, statistically insignificant), state-owned enterprises (0.264), and foreign firms (0.229, statistically insignificant). The stronger effects of R&D for private firms and public corporations reflect their stronger market focuses and incentives to use well their scarce resources. Interestingly, the order of the magnitudes of marginal returns seems to be consistent with the cost

⁹ The 10th and 90th percentile of lagged aggregate R&D/(1000*sale) is 0.002 and 0.684, respectively.

of capital: private firms have the worst, while the SOEs and foreign firms have the best access to external finance.

To check how sensitive our results are to the trimming of the tail one-percent observations in TFP, we re-estimate the base specification without trimming the outliers. The results are in column (1) in Table 7. The average marginal returns to R&D are now 0.71, significantly higher than the 0.42 in Table 6.

Endogeneity of R&D Intensity?

Some might worry that the lagged R&D intensity may be endogenous. For example, some common (presumably time-varying) factors might drive both the lagged R&D intensity and the current productivity growth. For example, regional differences in consumer taste can give rise to both higher R&D intensity and productivity growth. One way to deal with the potential endogeneity is to find variables that determine the firm-level R&D intensity but are not related to the firm productivity growth. To this end, we use the average and the maximum R&D intensities (i.e., R&D/sales) at the two-digit industry level that correspond to their U.S. industry counterparts for the 1974 to 1977 period. Since the R&D intensity variables for the U.S. industry represent technological sophistication and potentials for R&D effectiveness, they should have a significant relationship with our firm-level R&D intensity. Yet the R&D intensity of the U.S. industry should not affect firm-level productivity growth in a specific Chinese firm.

The data on U.S. R&D are from Cohen and Klepper (1992). Since the instruments have limited variations--each of the two variables have 20 distinct values--and they are highly correlated with the aggregate R&D intensity (i.e., the spillover term), we only attempt instrumental estimations for the specifications that assume identical R&D effects for the pooled sample, and we

do not include the spillover effects term. We also refrain from trying the instrumental approach when we interact R&D intensity with ownership variables due to the limited variations of the instruments.

Table 8 reports the results. The marginal returns to R&D are still statistically significant at the 5 percent level. The magnitude (1.25) is larger than what we previously found. It implies that the firm can fully recoup its R&D expenditures in just one year. It is important to note, however, that there may be disruptive effects of R&D in the year when R&D was committed, and the net effect of R&D may be smaller than what the number of 1.25 implies. The Hausman test shows that treating the R&D intensity as exogenous in the productivity growth equation is reasonable. This is not surprising as the firm level fixed effects have been purged out when we get the productivity growth equation by first differencing. In light of this result, we feel comfortable in the rest of this paper to treat R&D intensity as exogeneous in further specifications of the productivity growth equation.

Regional and Sectoral Heterogeneity in R&D Returns

So far we have assumed identical R&D effects across regions and industries. However, it is possible that the effects differ in these two dimensions due to differences in technological opportunities and the presence of complementary factors. To this end, Table 9 allows for the effects of R&D to differ by regions. We classify the Chinese provinces into 6 regions. The north coast region includes Beijing, Tianjin and Shandong; the south coast region, Shanghai, Jiangsu, Zhejiang, Guangdong, Fujian and Hainan; the central region, Anhui, Jiangxi, Hubei, Hunan, Hebei and Henan; the northwest region, Shanxi, Inner Mongolia, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang; the southwest region, Guangxi, Sichuan, Guizhou, Yunnan and Chongqing; finally, the

northeast region, Liaoning, Jilin and Heilongjiang. This regional classification is standard in China, and the regions differ in their basic characteristics. The two coast regions are the richest. The northeast region features a higher concentration of heavy industries. The other regions are poorer.

In the two rich coast regions, the marginal returns are relatively low, at 0.21 (and statistically insignificant) for the north coastal region, and 0.30 for the south coast region. The return is also relatively low in the northwestern region (0.41, and statistically insignificant). The highest returns are observed for the northeastern region (0.75), the central region (0.57), and the southwestern region (0.45). There are thus significant regional differences in the returns to R&D. The overall pattern is suggestive of higher returns in low-income regions.

CEO Incentives and R&D Effects

China is an economy featuring tremendous variations in corporate governance and managerial incentives (Tenev, Zhang and Brefort, 2002; Bai et al., 2004). It is natural to think that the effectiveness of R&D investment would hinge on incentives faced by managers. To this end, we allow TFP growth to depend on managerial incentives and their interactions with the lagged R&D intensity. To measure CEO incentives, we use two variables: whether the CEO is appointed by the government, and whether CEO pay is *ex ante* directly linked to current operating performance. CEOs appointed by the government would be more interested in satisfying the needs of the government such as the maintenance of employment, and they would emphasize less firm performance (Shleifer and Vishney, 1994). As a result, the effectiveness of R&D would be compromised.

Ex ante it is hard to pin down how a CEO-pay-firm-performance link would affect the effectiveness of R&D investment. On the one hand, stronger incentives lead the managers to use

R&D resources more effectively, which would imply a positive relationship. On the other hand, as we find very high returns to R&D investment here and by Jefferson et al. (2006), firms with stronger incentives would invest more on R&D, which would naturally reduce the return to R&D investment given its decreasing returns. Moreover, since an emphasis on current operating performance would induce CEOs to focus on short-term at the expense of long-term performance (Bai and Xu, 2005), the CEOs in these firms would face weaker incentives to improve the efficiency of the R&D expenditure. In light of the counteracting effects we have just discussed, we would let the empirical results decide which hypothesis has more validity.

Table 10 presents the results. Relative to other types of firms, the firms with government-appointed CEOs have a marginal return of R&D of 0.37, slightly less than half of the return for the other firms (0.81). Furthermore, the effects of R&D are significantly reduced when CEO pay is related to current operating performance. This result, coupled with the findings in the literature that such strong incentives induce a higher R&D intensity (Jefferson et al. 2006), indicates that strong incentives for CEOs lead to more R&D investment, which in turn reduces the marginal return to R&D investment. This finding is also consistent with the scenario of the CEO shifting some attention and energy to current performance such that the returns to current R&D investment are reduced.

5. Conclusions

We used a large data set covering a random sample of firms in China to investigate the marginal returns to R&D investments. We found evidence that R&D has large marginal returns. This finding is robust to alternative controls of firm, industry and city characteristics. It is also robust to the endogeneity of R&D intensity. Private and corporatized firms have higher R&D

payoffs than state-owned and foreign firms, and firms whose CEOs are appointed by the government have lower R&D returns. We also found that firms whose CEO pay is tied to current performance tend to have lower marginal returns to R&D. Interestingly, less developed areas tend to have higher R&D payoffs than the more advanced regions, implying a convergence tendency across Chinese regions. Finally, we found significant within-industry R&D spillover effects.

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Source: Hall (2002), Table 1. Hu and Jefferson (2006); Table 1, Hu and Jefferson (2004).

Table 1. China: Growth accounting 1978-93 and 1993-2005

		1978-93	1993-2005
		Average growth (percent per year)	Average growth (per cent per year)
Average growth	GDP	9.9	9.91
	Factors		
	capital	8.76	12.34
	labor	2.51	1.06
	TFP _{0.6}	3.64	2.08
	TFP _{0.5}	4.27	3.21
	TFP _{0.4}	4.89	4.34
	Total		
	GDP	9.9	9.91
<i>Contribution to GDP growth</i>		<i>Share contributed by the sources:</i>	
	Factors	57%	67%
	Capital	44%	62%
	labor	13%	5%
	TFP _{0.5}	43%	32%

Note: TFP_{0.6} refers to the estimates using 0.6 as capital share, and so on so forth.

Sources: Zheng, Bigsten, Hu (2006). (Some rounding errors are corrected from their table)

Table 2. R&D as a Percentage of GDP for Various Countries

Country	1963	1985	1991	1995	2000	2004
Canada		2.5			1.9	
France		2.3			2.2	
Germany	1.5	2.7			2.5	
Italy		1.1			1	
Japan	1.4	2.6	2.93	2.89	2.9	
Sweden	1.2	2.8			3.8	
UK	2.2	2.3			1.9	
USA	3.1	2.8	2.72	2.51	2.76	
Brazil			0.46	0.69	1.05	
Korea, Rep.			1.92	2.50	2.96 ^a	
Taiwan, China				1.78	2.16 ^a	
India					0.86	
China			0.74	0.60	1	1.35

Source: Hall (2002), Table 1. Hu and Jefferson (2006); Table 1, Hu and Jefferson (2004).

^a For year 2001

Table 3. Distribution of R&D across province

<u>by province</u>	<u>mean</u>	<u>s.e.</u>
beijing	0.028	(0.001)***
guizhou	0.021	(0.001)***
hainan	0.018	(0.002)***
shanghai	0.016	(0.001)***
shaanxi	0.015	(0.001)***
chongqing	0.015	(0.001)***
zhejiang	0.014	(0.001)***
qinghai	0.013	(0.002)***
tianjin	0.013	(0.001)***
hubei	0.012	(0.001)***
sichuan	0.012	(0.001)***
hunan	0.011	(0.001)***
liaoning	0.011	(0.001)***
jilin	0.011	(0.001)***
jiangsu	0.011	(0.001)***
guangxi	0.011	(0.001)***
shanxi	0.009	(0.001)***
imongolia	0.009	(0.001)***
longjiang	0.009	(0.001)***
guangdong	0.009	(0.001)***
gansu	0.009	(0.001)***
ningxia	0.008	(0.001)***
fujian	0.008	(0.001)***
jiangxi	0.008	(0.001)***
anhui	0.007	(0.001)***
shandong	0.007	(0.001)***
henan	0.007	(0.001)***
hebei	0.006	(0.001)***
xinjiang	0.006	(0.002)***
yunnan	0.007	(0.001)***
<u>by region</u>	<u>mean</u>	<u>s.e.</u>
South West	0.012	(0.000)***
North Coast	0.011	(0.000)***
South Coast	0.011	(0.000)***
Northwest	0.010	(0.001)***
Northeast	0.010	(0.001)***
Central	0.008	(0.000)***

Table 4. Distribution of R&D by Industries

	(1)	(2)		
rubber	0.028	(0.004)***	0.019	(0.004)***
drugs and pharmaceuticals	0.027	(0.001)***	0.018	(0.002)***
instruments	0.024	(0.002)***	0.015	(0.003)***
communication equipment	0.022	(0.001)***	0.013	(0.003)***
specific equipment	0.018	(0.001)***	0.009	(0.002)***
Craft	0.017	(0.002)***	0.008	(0.003)***
chemical fiber manufacturing	0.016	(0.003)***	0.006	(0.003)*
transportation equipment	0.015	(0.001)***	0.006	(0.002)**
general equipment	0.014	(0.001)***	0.005	(0.002)**
electronics	0.013	(0.001)***	0.004	(0.002)
chemical material and goods	0.010	(0.000)***	0.001	(0.002)
drink	0.009	(0.001)***	0.000	(0.003)
Smelting and pressing of non-ferrous metals	0.008	(0.001)***	-0.001	(0.002)
metal products	0.008	(0.001)***	-0.001	(0.003)
leather goods	0.007	(0.001)***	-0.002	(0.003)
lumber processing and related goods	0.007	(0.001)***	-0.001	(0.003)
furniture	0.006	(0.002)***	-0.003	(0.003)
food	0.006	(0.001)***	-0.002	(0.002)
nonmetal mineral products	0.006	(0.000)***	-0.003	(0.002)
Smelting and pressing of ferrous metals	0.006	(0.001)***	-0.003	(0.002)
educational and sports goods	0.005	(0.003)*	-0.004	(0.004)
plastic	0.005	(0.001)***	-0.004	(0.003)
textile	0.005	(0.001)***	-0.004	(0.002)*
paper	0.004	(0.001)***	-0.004	(0.002)*
printing	0.004	(0.002)*	-0.004	(0.003)
apparel	0.004	(0.001)***	-0.005	(0.003)**
petroleum	0.003	(0.001)**	-0.006	(0.003)**
tobacco	0.003	(0.003)	-0.005	(0.003)
agricultural and food processing	0.003	(0.001)***	-0.005	(0.002)**
ln (GDP PC)			0.001	(0.000)***

Table 5. Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
R&D/sales	36948	0.010	0.031	0.000	0.826
ln(L)	37163	5.544	1.500	0.000	13.502
ln(firm age)	37191	2.115	0.923	0.000	7.602
State ownership dummy	37191	0.091	0.287	0.000	1.000
Collective ownership dummy	37191	0.070	0.255	0.000	1.000
Public corporation dummy	37191	0.499	0.500	0.000	1.000
Foreign ownership dummy	37191	0.125	0.331	0.000	1.000
Other ownership dummy	37191	0.012	0.110	0.000	1.000
dist.avg: PR protection	37191	0.634	-0.192	0.000	1.000
CEO schooling (in years)	37149	15.394	2.023	0.000	18.000
Mean R&D/sales for corresponding U.S. two-digit industries	37191	0.016	0.010	0.002	0.039
Maximum R&D/sales for corresponding U.S. two-digit industries	37191	0.105	0.060	0.004	0.199
ln(city population)	37191	6.224	0.565	4.664	7.936
ln(city level education exp. per capita)	36891	5.974	0.803	3.622	8.348
share of sales to other provinces	37191	0.395	0.358	0.000	9.990
share of sales to foreign	37191	0.165	0.327	0.000	9.990
Dummy: CEO appointed by government	37095	0.118	0.323	0.000	1.000
Years of schooling for city party secretary	37191	16.651	2.223	12.000	21.000
share of employees with college education	37180	0.172	0.174	0.000	1.000
dummy: access to loan	37185	0.600	0.490	0.000	1.000
CEO pay is ex ante linked to performance	37191	0.668	0.468	0.000	1.000

Table 6. TFP growth rate and R&D intensity

	(1)	(2)	(3)	(4)
	OLS	OLS	OLS	OLS
R&D[t-1]	0.427 (0.085)***	0.439 (0.087)***	0.419 (0.087)***	
ln L[t-1]	0.004 (0.001)***	0.002 (0.002)	0.004 (0.002)***	0.002 (0.002)
ln(firm age)	-0.030 (0.003)***	-0.031 (0.003)***	-0.031 (0.003)***	-0.031 (0.003)***
ln (GDP PC)	-0.013 (0.003)***	-0.019 (0.005)***	-0.020 (0.005)***	-0.019 (0.005)***
Collective		-0.011 (0.009)	-0.010 (0.009)	-0.013 (0.010)
Corp		-0.009 (0.006)	-0.008 (0.006)	-0.012 (0.006)**
Private		-0.014 (0.008)*	-0.015 (0.008)*	-0.021 (0.008)***
Foreign		-0.009 (0.007)	-0.007 (0.007)	-0.010 (0.008)
otherOwn		0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
R&D[t-1]_State				0.264 (0.133)**
R&D[t-1]_Collective				0.385 (0.429)
R&D[t-1]_Corp				0.455 (0.123)***
R&D[t-1]_Private				0.964 (0.286)***
R&D[t-1]_Foreign				0.229 (0.290)
CEO Edu		0.003 (0.001)**	0.003 (0.001)**	0.003 (0.001)**
(lagged agg. RD/sale)/ 1000			0.008 (0.002)***	0.174 (0.053)***
Constant	0.158 (0.027)***	0.173 (0.053)***	0.163 (0.052)***	
Province Dummies				
Observations	22524	22498	22498	22498
R-squared	0.01	0.01	0.01	0.01

Note: all the results above are based the sample with the top and bottom 1% observations of TFP trimmed off.

*, **, *** represent statistical significance at the 10, 5 and 1 percent levels. White-corrected standard errors.

Table 7. The Results under Different Choices of Sample

	(1) Original sample, OLS	(2) 1% Trimming, OLS
R&D[t-1]	0.711 (0.101)***	0.419 (0.087)***
Ln L[t-1]	0.003 (0.002)	0.004 (0.002)***
ln(firm age)	-0.040 (0.003)***	-0.031 (0.003)***
ln GDP PC	-0.024 (0.005)***	-0.020 (0.005)***
(lagged agg.RD/sale)/1000	0.011 (0.002)***	0.008 (0.002)***
Collective	-0.013 (0.010)	-0.010 (0.009)
Corp	-0.012 (0.006)*	-0.008 (0.006)
Private	-0.022 (0.009)**	-0.015 (0.008)*
Foreign	-0.012 (0.009)	-0.007 (0.007)
otherOwn	0.000 (0.000)	0.000 (0.000)
CEO Edu	0.003 (0.001)**	0.003 (0.001)**
Constant	0.210 (0.059)***	0.163 (0.052)***
Province Dummies	Yes	Yes
Observations	22958	22498
R-squared	0.03	0.01

Robust standard error in parentheses, *, **, *** represent statistical significance at the 10, 5 and 1 percent levels.

**Table 8. TFP growth rate and R&D intensity:
Endogenous R&D intensity**

	(1)
	GMM
R&D[t-1]	1.253 (0.499)**
ln L[t-1]	0.003 (0.002)*
ln(firm age)	-0.030 (0.003)***
ln (GDP PC)	-0.014 (0.003)***
Constant	0.172 (0.029)***
Province Dummies	No
Observations	22524
R-squared	0.001

Note: all the results above are based the sample with the top and bottom 1% observations of TFP trimmed off.
*, **, *** represent statistical significance at the 10, 5 and 1 percent levels. White-corrected standard errors.

Table 9. R&D effects on TFP growth: by region

ln GDP PC	-0.013 (3.90)**
ln L[t-1]	0.006 (3.69)**
ln (firm age)	-0.030 (10.67)**
Collective	-0.004 (0.49)
Corp	-0.003 (0.54)
Private	-0.008 (1.02)
Foreign	-0.003 (0.34)
CEO edu	0.002 (2.06)*
R&D[t-1] * North East	0.753 (2.13)*
R&D[t-1] * North Coast	0.212 (1.07)
R&D[t-1] * North West	0.406 (1.92)
R&D[t-1] * South Coast	0.303 (2.09)*
R&D[t-1] * South West	0.447 (2.70)**
R&D[t-1] * Central	0.567 (3.05)**
(lagged agg.RD/sale)/1000	0.009 (6.33)**
Constant	0.114 (3.41)**
Observations	22139
R-squared	0.01
Number of group(id)	

*, **, *** represent statistical significance at the 10, 5 and 1 percent levels.
White-corrected standard errors. The intercept is not reported.

Table 10. R&D Effects and CEO Incentives

<u>R&D effects by CEO incentives</u>	
ln L[t-1]	0.001 (0.73)
ln (firm age)	-0.032 (10.90)**
Collective	-0.010 (1.03)
Corp	-0.006 (1.04)
Private	-0.009 (1.12)
Foreign	-0.008 (1.11)
CEO edu	0.002 (2.02)*
R&D[t-1]	0.807 (3.68)**
R&D[t-1] * CEO pay related to performance	-0.380 (1.64)
R&D[t-1] * CEO appointed by the government	-0.442 (2.46)*
CEO pay related to performance	0.005 (1.05)
CEO by govt	0.016 (2.34)*
province dummies	yes
Observations	22227
R-squared	0.01
Number of firms	

*, **, *** represent statistical significance at the 10, 5 and 1 percent levels.
White-corrected standard errors.

Table A.1. The provinces and cities of our sample

Province	City	Province	City	Province	City
Anhui	Anqing	Henan	Luoyang	Neimenggu	Baotou
	Chuzhou		Nanyang		Huhehaote
	Hefei		Shangqiu	Ningxia	Wuzhong
	Wuhu		Xinxiang		Yinchuan
Beijing	Beijing		Xuchang	Qinghai	Xining
Chongqing	Chongqing		Zhengzhou	Shaanxi	Baoji
Fujian	Fuzhou	Hubei	Zhoukou		Xian
	Quanzhou		Huanggang	Shandong	Xianyang
	Sanming		Jingmen		Jinan
	Xiamen		Jingzhou		Jining
	Zhangzhou		Wuhan		Linyi
Gansu	Lanzhou		Xiangfan		Qingdao
	Tianshui		Xiaogan		Taian
Guangdong	Dongguan	Hunan	Yichang		Weifang
	Foshan		Changde		Weihai
	Guangzhou		Changsha		Yantai
	Huizhou		Chenzhou		Zibo
	Jiangmen		Hengyang	Shanghai	Shanghai
	Maoming		Yueyang	Shanxi	Datong
	Shantou		Zhuzhou		Taiyuan
	Shenzhen	Jiangsu	Changzhou		Yuncheng
	Zhuhai		Lianyungang	Sichuan	Chengdu
Guangxi	Guilin		Nanjing		Deyang
	Liuzhou		Nantong		Leshan
	Nanning		Suzhou		Mianyang
Guizhou	Guiyang		Wuxi		Yibin
	Zunyi		Xuzhou	Tianjin	Tianjin
Hainan	Haikou		Yancheng	Xinjiang	Wulumuqi
Hebei	Baoding		Yangzhou	Yunnan	Kunming
	Cangzhou	Jiangxi	Ganzhou		Qujing
	Handan		Jiujiang		Yuxi
	Langfang		Nanchang	Zhejiang	Hangzhou
	Qinhuangdao		Shangrao		Huzhou
	Shijiazhuang		Yichun		Jiaxing
	Tangshan	Jilin	Changchun		Jinhua
	Zhangjiakou		Jilin		Ningbo
Heilongjiang	Daqing	Liaoning	Anshan		Shaoxing
	Haerbing		Benxi		Taizhou
	Qiqihaer		Dalian		Wenzhou
			Fushun		
			Jinzhou		
			Shenyang		

Table A.2 Industrial Distribution of Firms Surveyed in China: 2004

Code	name	freq	%.
13	agricultural and side-line food processing	969	7.81
14	food production	243	1.96
15	beverages production	178	1.44
16	tobacco production	46	0.37
17	textiles manufacturing	952	7.68
18	garment, shoes, and caps manufacturing	206	1.66
19	leather, furs, down, and related products	139	1.12
20	timber processing, bamboo, cane, palm fiber and straw products	141	1.14
21	furniture manufacturing	55	0.44
22	papermaking and paper products	235	1.90
23	printing and record medium reproduction	62	0.50
24	cultural, educational and sports goods	41	0.33
25	petroleum processing and coking	182	1.47
26	raw chemical materials and chemical products	1441	11.62
27	medical and pharmaceutical products	426	3.44
28	chemical fiber products	47	0.38
29	rubber products	21	0.17
30	plastic products	329	2.65
31	nonmetal mineral products	1299	10.48
32	smelting and pressing of ferrous metals	491	3.96
33	smelting and pressing of non-ferrous metals	345	2.78
34	metal products	366	2.95
35	general machinery	1077	8.69
36	equipment for special purposes	486	3.92
37	transportation equipment	989	7.98
39	electrical equipment and machinery	864	6.97
40	electronic and telecommunications equipments	598	4.82
41	instruments, meters, cultural and office machinery	60	0.48
42	handicraft products and other machinery	109	0.88
43	renewable materials processing	3	0.02
Total		12400	100