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Abstract

This paper uses a survey of 1,826 firms distributed over ten East Asian metropolitan areas – Jakarta, Kuala Lumpur, Manila, Seoul, and five Chinese cities – to investigate the sources of firm-level R&D capabilities. The analysis identifies the impact of 23 survey variables, classified by openness, human capital, R&D network, and institutional quality, on the efficiency of firm R&D operations and on overall firm performance. These firm-level results are used to construct composite measures R&D capabilities for each of the 10 metropolitan economies. Using the firm samples, returns to R&D are also estimated for each of the metropolitan areas. Where cross economy comparisons are possible, as they are for Seoul and the five Chinese cities, we find a strong association between overall R&D productivity in these city economies and the composite measures of citywide R&D capabilities. In particular, high composite measures in Seoul and Shanghai are associated with high returns to R&D in those cities. The large productivity-wage gaps in the Chinese cities appear to be attracting large and visible investment in R&D operations. Whether R&D wages rise to narrow this gap or investment and technology flows continue to sustain the gap will substantially affect the pattern of R&D operations within the Asian region.

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1. Introduction

For developing nations, a necessary precondition for catch up with the world's most advanced economies is the capacity to innovate and sustain technological progress. The premise of this paper is that within market economies, the firm is the key actor upon which successful innovation depends. This premise is reinforced by the observation of Nelson and Rosenberg (1993) that it is firms that "master and get into practice product designs and manufacturing processes that are new to them" (p. 4).

While firms may represent the most fundamental unit of the national innovation system, they are, however, but a piece of the whole.[3] Laws and regulations, government policy and programs, factor and product markets, research institutes, universities, and R&D networks together create the institutional context within which firms struggle to achieve competitive advantage. This study is based on an extraordinary survey of these conditions as reported by a large sample of firms in ten Asian cities. With these survey data, the World Bank has created a rich database that documents firm-level R&D resources and performance as well as the broad institutional context within which firms across Asia conduct their R&D operations.

The 1,826 firms included in this study are distributed across Bangkok, Jakarta, Kuala Lumpur, Manila, Seoul, Singapore Jakarta, Seoul, Kuala Lumpur, Beijing, Chengdu, Guangzhou, Shanghai, and Tianjin.[4] For each of the remaining ten metropolitan economies, the sample of firms spans ten industries, consisting of five manufacturing and five service industries.

This paper identifies 23 attributes that potentially enhance the productivity and profitability of firm-level R&D operations. We group these 23 attributes – each assessed at the level of the firm - across four areas: the firm's exposure to the international economy, the quality of human capital, participation in R&D networks, and the institutional context of the firm.

Having identified the attributes that shape R&D performance at the firm level, we rank the significance of each attribute across the ten city economies. Through this process of aggregating up from the ten sets of firm samples, we develop economy-wide measures of openness, human capital, R&D networks, and institutions for each of the ten metropolitan areas. We then examine whether these composite measures can explain differences in overall returns to R&D and firm performance across the ten participating economies.

2. Key research issues

Our first research issue relates to the robustness of the relationships between R&D effort and measures of firm performance, including productivity and profitability. We are interested not only in the impact of R&D on firm performance, but also in the channels through which R&D operates to affect performance. To explore these channels, we

[3] See Jefferson and Hu's (2000) study of China's industrial innovation system.
[4] We determine that the sample for Singapore is too small and unrepresentative to be useful.

estimate knowledge production functions – the ability of R&D to create new products and processes – as well as the impact of these innovations on firm performance.

Having examined the impact of R&D inputs and productivity and profitability, the next task of the paper is to identify from among the 23 attributes that characterize the firm and market and institutional context within which it operates those that affect firm-level performance. Specifically, we distinguish whether these attributes impact directly on firm performance or if they operate through the R&D channel. We anticipate that some of these attributes, such as R&D networks and investment in information technology, improve performance by enhancing the effectiveness of the firm's R&D operation. Other factors, such as imported equipment and the share of imports in the firms relevant market, may affect overall firm productivity but not the quality of its R&D operation.

Once we have identified the set of attributes that enhance innovation capabilities at the firm level, our next challenge is to aggregate the measures of these attributes into a citywide measure. Among the 23 attributes, we identify 12 that enhance innovation capabilities and five that operate outside the R&D channel. For the 12 R&D enhancing attributes, we create a composite measure for the purpose of comparing the overall R&D environment of the ten participating cities.

Finally, we estimate the composite returns to R&D for each city and test the relationship between our estimates of composite R&D returns and the composite measures of metropolitan R&D environments. This exercise is based on the assumption that, if our city samples are reasonably representative, then the attributes that shape R&D performance at the microeconomic level should also be exhibited at the metropolitan economy-wide level.

Before examining each of these issues, we create a conceptual framework for the analysis.

3. A conceptual framework: the firm's problem

We situate this research within a theoretical perspective, which, like Jefferson and Su (2002), applies a set of economy-wide relationships developed in the growth literature to the analysis of technical change, investment, and growth at the level of the firm. Like Romer (1990), we augment the basic Solow neoclassical growth model with human capital and the possibility for deliberate technical change. However, rather than viewing these dynamics from an economy-wide perspective, we allow the firm's manager to solve an optimizing problem, which determines the amount of human capital to dedicate to the firm's R&D operation. The solution to this problem involves two interrelated decisions – first, how to divide retained earning between physical investment and investment in human capital and, second, the distribution of human capital within the firm. The manager applies the proportion u of total human capital to the routine production of goods and R&D and the balance (1-u) to R&D.

This “reduced form” of the firm’s intensive production function, which is consistent with the optimizing problem described above, is:

$$y(t) = E(t)k(t)^{\alpha}[uh(t)]^{\beta}, \qquad (1)$$

where k and h respectively represent the ratios of the firm’s total stocks of physical and human capital to the labor force, y is value added per worker, and E is a measure of joint factor productivity.

The production of new knowledge, which spurs productivity advance, takes the following form:

$$E(t+1) = a(1-u)h(t)^{\gamma} \qquad (2)$$

Since output in equation (1) produced from physical or human capital deepening results in higher output per worker and available retained earnings per workers, the growth of retained earnings spurs investment in both physical and human capital. Hence the introduction of human capital and R&D create the possibility for continuous productivity growth and for the endogenous growth of output per worker.

The underlying parameter of interest in our model is that concerning the motivation for investing in human capital and R&D. A reasonable starting point for specifying this allocation is Aghion and Howitt (1992), in which the firm is allocating a fixed stock of human capital between competing uses for manufacturing and research. This allocation decision can be characterized as in the patent-race literature, which has been surveyed by Tirole (1988) and Reinganum (1989). The allocation of human capital is determined by an arbitrage condition in which the expected value of an hour in research – the flow probability of an innovation times its value – is set equal to the value of an hour in manufacturing.

For our purposes, as shown in equation (2), we measure the basic, unaugmented elasticity of knowledge with respect to human capital input as γ. To represent the impact of any one of the 23 attributes that potentially enhances the efficiency of the firm’s R&D operation, we add the variable θ_i, i = 1…23, with value ≥ 1. By incorporating θ_i directly into the elasticity, i.e. $H^{\theta\gamma}$, θ_i captures the augmentation effect of attribute i on the firm’s basic measure of human capital, say the number of R&D personnel.

To test the augmentation effect of each of the 23 firm attributes, we interact them one at a time with our measure of R&D personnel to determine if through the firm’s R&D operation they enhance firm-level productivity and profitability. In cases where the interactive term is insignificant, we then incorporate the attribute separately to determine whether, independent of the R&D operation, it exhibits a significant direct impact on firm performance.

4. Categories of analysis and literature review

We classify the list of 23 attributes that are measured in the World Bank survey into four broad categories. The categories, shown in Table 1, also used by Hill (2001) are openness, human capital attributes, R&D networks, and institutions. Depending on their focus of performance, other studies employ similar categories in their attempt to summarize firm capabilities. Kumar and Chadee (2002), for example formulate measures of three internal factors – technology and ICT, human resources, and organizational structure – and two measures of external factors – the role of government and finance and capital.

Openness. The recent growth literature generally agrees that there is no systematic evidence to support the notion of a convergence of living standards among the world's rich and poor economies (e.g. DeLong, 1988).[5] The growing acceptance of the stylized fact of non-convergence has motivated researchers to identify conditions that distinguish metropolitan areas that exhibit convergence from those that do not. One such study of conditional convergence demonstrates the tendency toward convergence among the world's most open developing economies. Creating an index of openness, Sachs and Warner (1995) demonstrate that the 30 countries among those most open to trade between 1965 and 1997 show convergence in income per capita. This results is consistent with the observation of Hill (2001): "More than 90 percent of the world's R&D is undertaken in the OECD economies, and thus openness to the world is critical for borrowers and latecomers, such as those in East Asia" (p. 5).

The World Bank survey collects data on a wide range of measures that relate to economic openness. Among these measures are the firm's domestic market share, the share of the domestic market supplied by imports, exports as a share of sales, the share of FDI in total equity, and the number of competitors identified by each firm. In Section 8, we identify whether these attributes affect firm performance and whether their influence operates through the R&D channel.

Human capital attributes. In their influential paper, Mankiw, Romer and Weil (1992) demonstrate that the "fit" of the Solow model with the convergence hypothesis could be improved by extending the model to include human capital. R&D personnel, the basic measure that we use to capture R&D intensity, simply measures the number of persons assigned to the firm's R&D function; it may not capture the quality of the firm's human capital employed in the R&D process.

Among the measures included in the Bank survey that serve to augment basic R&D personnel are the foreign work experience of the workforce, the proportion of workers using the internet, and the educational level of management. The econometric analysis in

[5] Sali-i-Martin (2002) demonstrates that this condition of non-convergence depends critically on the choice of unit of analysis. While the finding of non-convergence holds for the universe of all nations, it does not hold when the unit of analysis is the individual.

Section 8 examines the extent to which each of these enhances the effectiveness of the firm's R&D operations.

R&D networking. During the decades following the publication of Solow's neoclassical growth model, which underscored the reliance of long-run growth of living standards on technological progress, economists implicitly or explicitly assumed that technology was a public good. As a public good, technology could, at little or no cost, be shared or transferred among agents.

In recent years, researchers have become more interested in the barriers to technology transfer. These include formal, intentional barriers, such as intellectual property rights (IPR) law, and practical impediments. The study by the British Commission on Intellectual Property Rights notes that in certain critical areas the strict enforcement of IPR in the international system has become a burden on technology development and diffusion (CIPR, 2002). Practical impediments, such as the lack of access to computers required to access the internet, effectively limit the public good component of technology (UNDP, Box 2.3, p. 35).

In their examination of the geographic concentration, agglomeration, and co-location of university research and industrial R&D, Agrawal and Cockburn (2002) find strong evidence of co-location of upstream and downstream constituents of "local innovation systems." This idea of neighborhood innovation systems is further reinforced by the notion of inter-firm know-how networks, such as those examined by Von Hippel (1987) and Carter (1987). They find that while these know-how networks serve as channels for the diffusion of technology, they also limit their memberships to users with the capacity to reciprocate.

Finally, market structure may also affect the motivation for R&D networking. Goyal and Moraga (2000) examine the effects of collaboration on individual firm R&D effort. They find that in individual markets, R&D effort is increasing in the level of collaborative activity, whereas, if firms are Cournot competitors individual effort declines in the level of collaborative activity.

Our characterization of R&D networking includes multiple measures. These include commercial transactions, such as the purchase of externally performed R&D services and foreign technology licenses. A second broad category of networking measure is that relating to institutional linkages, such as collaborations with R&D institutions, including universities and research institutes, and the receipt of either external R&D assistance or final R&D products. Section 8 examines the extent to which these network measures augment the effectiveness of basic R&D personnel.

Institutional quality: The lecture delivered by R.H. Coase when he received the Nobel price in economics – "The Institutional Structure of Production" (1992) – summarizes the regard that economists now have for the central role that institutions play in shaping the behavior of individuals and organizations. During the past decade, numerous researchers and organizations have attempted to summarize and rank national economies by the attributes of the institutions that govern their economic activity. These include composite measures prepared by Freedom House (2002) and the Heritage Foundation and Wall Street Journal (Driscoll, et al. 2002).

Measures of the institutional qualities of an economy potentially span a wide field of institutional attributes. The above-cited studies focus on variables such as corruption and transparency. While the World Bank survey does not compile similar measures, it focuses on asset ownership structures, including public ownership and foreign ownership shares. It also measures the proportion of IT assets in total assets. The Bank survey also assesses the quality of government services measured in terms of the firms' use of government services intended to assist with establishing a range of relationships with foreign firms. Also include is a measure of the firm's production setting, i.e. whether it is located in an industrial zone. As with the other categories of attributes, these measures of institutional quality are interacted with R&D personnel to identify the extent to which they augment R&D effectiveness.

5. Distribution of innovation activity across metropolitan economies

The data are drawn from a survey that was administered in 11 metropolitan economies. The distributions of firms across metropolitan areas and by sector are shown in Tables 2a and 2b. The data set spans a total of 1,826 firms of which 1,500 are located in China. The remaining 326 firms are distributed among Seoul (85), Djakarta (76), Manila (65), Kuala Lumpur (56)[6], Bangkok (26), and Singapore (18).

Before examining the link between innovation inputs and outputs at the firm level, we compare the intensity of innovation activity at the level of the city economies included in the Bank survey.

Innovation outputs. Table 3a shows the distribution and intensity of reported innovation outputs. Overall, the new product sales ratio (column 2) is higher in China than elsewhere. Within China, Shanghai exhibits the highest ratio of new product sales. Columns 3 through 7 show the incidence of five distinct forms of innovation. The first two – the introduction of new product(s) in an existing business line and entries into new business line(s) – measure the incidence of new product innovation. Compared with the new product-sales ratios shown in Column 2, these figures indicate only a small advantage for Chinese firms.

Table 4 formally tests the statistical significance of differences in each innovation type across the 11 metropolitan areas. Here and elsewhere, Beijing is used as the reference location in the regression analysis. One difference between Tables 3a and 4 is that the latter controls for differences in industrial composition. The results in Table 4 show that firms in the Shanghai sample stand out as high-incidence new product innovators; other than Shanghai, only Jakarta stands out as a high-incidence new product innovator. By comparison, the Tianjin sample exhibits the lowest rate of innovation, followed by Guangzhou, Kuala Lumpur, and Manila.

[6] Three of the firms that constitute the Kuala Lumpur sample were located in Penang.

In Table 3a, columns 4 through 6 describe three process-related areas of innovation: new production process improvement(s), new management technique(s), and new quality control(s). The incidence of overall process innovation is comparable between the Chinese cities and the other East Asian economies. For two forms of process innovation – management techniques and quality controls – the Chinese sample exhibits approximately a two-to-one advantage.

Table 4, which focuses on differences in the likelihood of process innovation, confirms the results shown in Table 3a. Controlling for industry composition, Table 4 shows that in comparison with the six country economies, the Chinese cities, with the exception of Tianjin, exhibit somewhat higher rates of process innovation. Chengdu emerges as the high-incidence process innovator, followed by Guangzhou and Shanghai. The greater incidence of innovation in management techniques and quality controls across Chinese cities may reflect the likelihood of a higher incidence of ownership and management restructuring in the Chinese sample during the latter half of the 1990s.

The last column of Table 2a shows the incidence of new patent applications, both at home and in the U.S. These inventions may relate either to new products or to new processes; our data do not distinguish. All of the city samples exhibit very low rates of patent applications pending in the U.S. – larger in the six non-Chinese metropolitan areas but still less than one percent of the sampled firms. Among home patent applications, China enjoys a small advantage. Within China, the firms in Tianjin once again exhibit the lowest rate of innovation

Innovation inputs. Table 5 shows the intensity of innovation effort. The first two columns report differences in R&D intensity measured as the R&D expenditure/sales ratio. The means, shown in the first column, show Chengdu, Guangzhou, the Manila and Seoul with similar expenditure intensities. Column 2 shows, however, that among the 11 economies, only Chengdu exhibits a statistically higher expenditure ratio.

Columns 3 and 4 report the intensity of innovation measure in terms of the share of R&D personnel in total employment. By this measure, Seoul exhibits by far the highest ratio, which is shown in Column 4 to be significant greater than that of any other city. At the other end of the distribution, the Manila, Tianjin, and Kuala Lumpur exhibit R&D personnel ratios, which are significantly less than the other Asian economies.

Overall, we see a pattern of innovation effort in terms of intensity of R&D personnel in which Seoul stands out among the 11 cities, Beijing, Chengdu, Guangzhou, and Chengdu follow in the second tier, followed by Tianjin and the remaining Asian cities. This distribution is broadly consistent with the overall national data shown in Table 6. These data, collected and reported by the UNDP, show Singapore an Korea with the highest proportion of their populations engaged in R&D, followed by China, with Indonesia, Malaysia, the Philippines, and Thailand trailing. The R&D/GDP data are also broadly consistent with this ranking. The UNDP data are dramatically at variance with the small sample of Singapore-based firms shown in Table 5. Given this disparity, we conclude that the World Bank sample for Singapore is too small and unrepresentative to be useful for this study. We therefore exclude Singapore from our subsequent analysis.

6. Estimating the knowledge production and innovation-performance functions

Estimating the impact of R&D effort on firm performance can be accomplished through either of two approaches. The first of these is to estimates a structural model. That is, we first examine the impact of R&D, measured here as the ratio of R&D personnel to the total workforce [i.e. 1-u in equation (2)] on the firm's ability to produce innovation outputs. That is, we estimate a set of knowledge production functions, similar to that shown in equation (2). The second step in this structural model approach is to test the impact of the innovation outputs, or knowledge, on the firm's performance. This is accomplished by substituting our measures of knowledge - the innovation outputs shown in Table 3a – into equation (1).

The second approach is to estimate a kind of reduced form, which results from substituting the knowledge production function [i.e. equation (1)] into the innovation-performance function [i.e. equation (2)]. We use the reduced form to estimate the direct and total impact of R&D personnel on the firm's productivity and profitability.

We report the results of the structural model estimates in Tables 7 and 8. The knowledge production function estimates, which control for firm size (lnSALES), industry, and city, are shown in Table 7. These results show that for most of the five measures of innovation output, knowledge production highly associated with R&D intensity. For both the full sample that includes reported levels of zero activity for the relevant innovation measure and for subsamples that drop the zero observations, the role of R&D personnel is highly statistically significant for each of the five innovation measures.

Estimates of the impact of innovation on firm performance are shown in Table 8. The introduction of new products, new management techniques, and quality controls all exhibit statistically significant relationships with productivity and profitability. New process innovation, while not highly statistical significant in its impact on productivity, is significantly associated with profitability. That the introduction of new business lines does not exhibit such a connection with performance may result from the contemporaneous disruption and subsequent break-in time required for radical product innovation to translate into improved firm performance.

Still, this structural model may capture only a portion of the impact of R&D on firm performance. A firm's R&D activity may affect firm performance through channels other than those formally measured. R&D personnel, for example, may expend effort on improvements in the quality of existing products, on the installation and efficient use of new machinery, or on other incremental tasks that substantially improve firm performance but are not captured in counts of innovation outputs.

In their study of R&D in Chinese industry, Jefferson, Bai, Guan, and Yu (2001) demonstrate that conventional measures of innovation activity account for but a fraction of overall measured returns to R&D. Using data on counts of patent applications and the share of sales accounted for by new products, Jefferson and his colleagues find that, among China's large and medium-size firms, these measures account for only 16 percent of the returns to R&D personnel.[7] While patents account for just five percent of total returns, new product sales represent 11 percent of overall returns.

Our objective is to calibrate the impact of firm, market, and institutional attributes on the efficiency of R&D personnel. In principle, we could incorporate interactive terms for each of the 23 attributes into both the knowledge production functions (Table 7) and the innovation-performance impact equations (Table 8). For the knowledge production functions, interactions between R&D personnel and the attributes would measure quality differences across R&D personnel. For the innovation-performance equations, we could interact the same list of attributes with the list of innovation outputs shown in Tables 7 and 8. These interactions would capture quality differences among innovations, such as differences in the productivity of innovation counts originating within an IT- intensive company as compared with a more conventional firm.

While we can in principle carry out these regression exercises, given the stratification of the data across five innovation channels, it is by no means certain that the survey data can support such a detailed analysis. Moreover, our basic research objective is to measure the impact of the 23 attributes on the effectiveness of R&D as it impacts firm productivity and profitability. The findings of Jefferson, Bai, Guan, and Yu suggest that some of this impact may occur outside of measured innovation channels. Finally, given the need to design a manageable research method, we choose here to examine the role of our 23 firm, market, and institutional attributes within the context of the reduced form. That is, we investigate how the interaction of individual firm, market, and institutional attributes with R&D personnel influences the productivity and profitability of R&D.

7. The direct impact of R&D on firm performance: estimating the reduced form

By substituting the knowledge production function, i.e. equation (2), into the innovation production function, i.e. equation (1), we obtain a reduced form equation, which directly identifies the impact of R&D effort on firm performance. By transforming equation (1)

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[7] The share of measured returns to R&D expenditure accounted for by patents and new products is substantially higher – 73 percent. The authors argue that the reason for this disparity is the tendency for R&D in large firms to be substantially more capital intensive than in smaller firms. Within the typical large firm, the model is one of an R&D lab in which R&D expenditures are focused on the production of patentable innovations and measurable new products. By comparison, the typical medium-size enterprise maintains a far more labor-intensive R&D operation in which R&D teams appear to be focused on incremental innovation, such as product quality and small process improvements.

into a restricted profit function, substituting profit for output as the dependent variable, we can similarly derive a reduced for to estimate the impact of R&D on profit.

Table 9 reports the elasticities of productivity and profitability with respect to R&D personnel. Both elasticities are statistically significant. R&D personnel in Seoul, Shanghai, and Guangzhou – in descending order – exhibit the largest impacts on productivity and profitability.

As a three-year average over the period 1998-2000, our R&D variable is a kind of stock measure representing both the cumulative and lagged impact of R&D on firm performance. While at least a portion of the stock measure may be viewed as predetermined, there is still cause to be concerned about the endogeneity of R&D personnel in the performance equations. For example, firms that consistently exhibit above average levels of profitability may be well placed to support larger R&D operations. This is likely, since; as Jefferson, Bai, Guan, and Yu (forthcoming) show, retained earnings are an important source of R&D finance. Nonetheless, they also demonstrate that efforts to correct for possible endogeneity do not alter substantially the robust impact of R&D effort on firm performance. In this paper we do not attempt to correct for possible endogeneity. Our focus is on those attributes, which interact with R&D effort to enhance firm productivity. We anticipate that these interaction terms are at once less susceptible to endogeneity, while at the same time, the construction of effective instrumental variables for these interactive terms is likely to be elusive.

8. Attributes that determine firm-level innovation capabilities

Tables 10a and 10b and Table 11 distinguish between the sets of attributes that operate through R&D channels and those that impact firm performance outside the R&D channel. Tables 10a and 10b identify attributes that operate, in some significant measure, through the formal R&D function. The attributes identified in Table 10 do not exhibit statistically significant interactive terms with R&D personnel. They do, however, exhibit significant direct impacts, which operate through intercept shifts, on productivity and profitability. Annex A identifies these outcomes as well as the variables that exhibit no link to firm performance, either directly or through the R&D channel.

Tables 10a and 10b identify a list of firm, market, and institutional attributes that complement the contribution of R&D personnel to firm-level productivity and profitability. The results in Table 10a demonstrate the impact of ownership structure on firm-level R&D capabilities. While foreign ownership increases the effectiveness of R&D, public ownership appears to limit the returns to a firm's R&D operation.

Each of the factors shown in Tables 10a and 10b is associated with a plausible story that would cause it to influence the effectiveness of a firm's R&D operation. R&D personnel that are internet users tend to operate relatively successful R&D operations. As a source of technical information and channel for the exchange of know-how, the internet provides an invaluable R&D network for R&D personnel. Similarly, the results in Table 10a show that firms that invest heavily in information technology (IT) assets are creating within the firm the physical infrastructure needed to participate effectively in the internet-based R&D network.

The finding that both of these characteristics – the proportion of workers using the internet and investment in IT assets – are important drivers of R&D efficiency probably indicates that, to a substantial degree, these are complementary inputs to an internet-based R&D network. In principle, we should combine these attributes, which may operate as complement, as well as other characteristics that we believe enhance the effectiveness of the R&D process, into a single regression equation. Otherwise, owing to the high correlation of these attributes, estimating the effect of each of these attributes alone is likely to create an upward bias in estimates of their contribution to the efficiency of R&D. On the other hand, multi-collinearity among these attributes is likely frustrating any attempt to distinguish between the separate contributions of highly complementary inputs. In this paper, we examine the impact of each attribute without controlling for complementary factors, other than the usual controls for conventional capital and labor.

We next examine the impact of the number of competitors on returns to R&D. The negative sign most likely reflects the tendency of competition to limit the markup on innovations. Lower markups – and prices – depress measures of both profit and productivity. This result seems to give support for Schumpeter's view (1950) of the advantages of market power in innovation in comparison with those of Arrow (1962). Arrow argued that by spreading an innovation over a larger number of sales in a competitive market, innovators operating in competitive markets net more than monopolists.

Each of the first four attributes shown in Table 10b relates to explicit external R&D-related transactions of the firm. The purchase of outside technology, including the purchase of foreign licenses, enhances the effectiveness of R&D. Likewise, the receipt of R&D assistance from an external source raises R&D efficiency. Finally, firms that provide design or R&D services to a foreign firm exhibit relatively efficient R&D operations. The results suggest a consistent pattern in which R&D networking – external commercial transactions and reciprocal exchanges – enhances the effectiveness of R&D.

Table 11 identifies a number of attributes that are associated with higher firm productivity and profitability, but their effect does not, at least in a statistically significant sense, operate through the firm's formal R&D channel. The attributes each create positive intercept shifts in the measure of firm performance.

One variable that we might expect to operate through the R&D operation, but seemingly does not, is the external R&D variable. For this variable, firms were asked "Did you have a contractual or long-standing relationship with any of the following to perform R&D for your plant?" The possible sources of R&D services are a local university, government research institute, private research institute, or private company. That this attribute significantly affects the firm's performance without enhancing its R&D program indicates that contracting for external services may represent a substitute for internal

R&D capabilities. The services improve firm performance but, unlike other forms of R&D transactions and networking, the avenue of impact does not run though the firm's R&D operation.

The other factors – imported equipment, market share, the market share of imports, and government assistance in locating a foreign client, supplier, or investor relationships – all enhance firm performance. Like externally performed R&D services, each of these attributes impacts firm performance through channels other than the firm's R&D operation.

9. The role of foreign investment

The first result in Table 10a shows the positive interactive effect of foreign investment and R&D personnel. We further investigate the significance of this result within the context of findings reported by Hu and Jefferson (2002). Using a panel of approximately 20,000 of China's large and medium-size enterprises, they find the following:

- In the short-run, FDI gives the FDI receiving firms a substantial productivity advantage over their domestic counterparts. Also, in the short-run, the more FDI-intensive the industry, the more it depresses productivity and sales for domestic firms.

- The depressing effect of industry FDI on measured productivity and sales is more than a market-steeling phenomenon, the single focus of Aitkin and Henderson (1999). Hu and Jefferson find that a substantial portion of the reduction in measured productivity results from a reduction in price markups.

- For firms surviving over a five-year period, in six of eight industries examined by Hu and Jefferson, the market stealing effect of industry FDI intensity disappears; moreover, in all but two (other) industries, the initial advantage of FDI-intensive firms is no longer statistically significant.

This latter result implies the presence of significant spillover effects from foreign invested firms to domestic firms. The ability of some domestic firms to substantially catch-up provides a context for our findings in which we identify specific avenues through which openness and links with foreign resources enhance firm performance. A substantial portion of the attributes that affect firm performance shown in Annex A either result from or are closely associated with openness, both FDI and trade.

10. The distribution of attributes by metropolitan economy

Having at the firm level identified attributes that enhance firm performance, both directly and through enhancement of the firm's R&D function, we now examine how these attributes are distributed over the 10 economies covered in the World Bank project.

To identify the incidence of these attributes in each of the 10 metropolitan economies, we regress each attribute on a set of country/city dummies as well as a set of industry dummies. When the survey data provide us with a continuous measure of the attribute, we use a log-linear estimation equation. When the attribute is an on-off measure, such as imported equipment, we use a logit model.

As shown in Tables 12-15, we have created two composite measures. The first is the number of estimates that are statistically significant at the 95 percent level ($t \sim 1.95$). The incidence of each attribute, relative to Beijing, the reference, may be positive or negative. The second composite measure is the sum of the t-statistics. While summing the t-statistics is a somewhat arbitrary approach, this method has been used as an aggregator in at least one other context (Djankov and Murrell, 2002).[8]

For each of the four broad categories of attributes that affect firm performance, we compute two sets of composite measures. The first is a total measure that is constructed from all the attributes that affect firm performance, whether they operate through the R&D channel or otherwise. The second composite measure is limited to those attributes that operate through the R&D channel. These are highlighted by an asterisk (*).

Openness. Our measure of economy-wide openness incorporates six of the 23 measures include in Tables 10 and 11. These are shown in Table 12. We find that the greater the number of competitors, the lower is the firm's productivity and profitability. Also, the larger the firm's own market share the greater the firm's productivity and profitability. In creating the composite measure of competitiveness as a source of enhanced firm performance, we reverse the sign on the number of competitors. We anticipate that a reduced markup associated with heightened competition erodes measures of productivity and profitability. Where competition is relatively low, measured productivity and profitability should be relatively high.

Viewing Table 12, we find that Manila, Jakarta, and Kuala Lumpur exhibit the highest degree of openness, followed by Shanghai. The second tier consists of Seoul and Bangkok, followed by Guangzhou. The openness measures for Tianjin, Chengdu, and Beijing lag considerable behind those of the other metropolitan areas.

Our composite measure relating to attributes that affect R&D effectiveness suggests four tiers with Manila and Shanghai occupying the top tier, followed by Jakarta, Kuala Lumpur, and Bangkok. Seoul, Beijing, and Guangzhou occupy the third tier, with Chengdu well behind.

[8] According to Djankov and Murrell, "The theory justifying the aggregation of t-statistics is analogous to that used when conducting tests on the mean of a sample" (p. 749). Djankov and Murrell survey a wide range of regression results that employ different functional forms and data sets. Our study employs the same data set and functional form across cities, but for each city (the observation for which we aggregate t-statistics), we use different measures as proxies for each of the four broad categories of attributes – openness, human capital, R&D network, and institutional quality.

Human capital. Table 13 shows the distribution of human capital over the 10 economies. Since all of the eligible attributes operate through the R&D channel, we compute a single composite measure. Seoul stands out as the economy with the highest measured intensity of human capital. Only with respect to foreign work experience does Seoul lag behind any of its peers. This finding is consistent with the relatively closed character of the Seoul economy. While all four of the ASEAN economies lag behind Seoul, their composite human capital measures are notably larger than those of the next tier – the Chinese cities not including Tianjin. At least with respect to our measure of the quality of human capital, Tianjin considerably lags behind all of the other nine metropolitan areas.

R&D networking. In Table 14, we examine the distribution of five measures of R&D institutions and networks across our 10 economies. All but one of these affect the quality of R&D operations. Among the 10 economies, Kuala Lumpur, Shanghai, and Chengdu exhibit the highest total composite measures of R&D networking. Again, Tianjin lags far behind. Closer examination shows that Chengdu's surprisingly high ranking results in part from two measures - the purchase of externally-performed R&D services and the purchase of outside technology.

When we examine the four attributes that affect R&D alone, Chengdu loses its leadership status, while Kuala Lumpur and Shanghai continue to exhibit strength with this measure. Tianjin continues to appear at the bottom.

Institutional quality. Table 15 covers five measures of the institutional setting of the firms included in the Bank survey. One of these – share of foreign-owned assets – is double counted with openness. For the measure of institutional quality, the non-Chinese economies typically outperform the Chinese economies. These differences reflect the relative scarcity of public ownership in the cities outside China. The four ASEAN cities dominate Seoul largely due to the low incidence of FDI in Korean companies and also the relatively low level of government assistance in establishing links with foreign firms. The relatively low incidence of FDI in Seoul is consistent with characterizations of Seoul's industrial development strategy, which emphasize the role of human capital in reverse engineering imported goods and equipment rather than FDI (Westphal, unknown). The Seoul emphasis on human capital is confirmed by the results reported in Table 13.

For the R&D only composite measure, Manila and Kuala Lumpur exhibit the highest measures, while Shanghai, Jakarta, and Seoul follow. Bangkok, Guangzhou, and Tianjin exhibit comparable levels of institutional quality, followed by Beijing and by an even wider margin by Chengdu.

Summary of attributes. In Table 16, we construct a composite measure of the four individual country-city attributes. Extending the approach used to construct the composite measures for each of the four broad categories, we construct single composite measures of competitiveness and R&D capabilities.

The rankings in Table 16 suggest several basic finding. We focus on the composite measure of R&D capability. We broadly identify two clusters that stand out at the tails of the distribution. These are Kuala Lumpur, Manila, and Seoul at the high end of the distribution, while Tianjin and Chengdu occupy the low end of the distribution. A second notable result is the considerable variation among the Chinese cities. The difference between Shanghai and Tianjin is about twice the difference between the highest- and lowest-ranking Asian cities. Finally, we find considerable variation across the four different attributes. Measured by openness, Seoul is among the lowest of the 10 economies, whereas no other economy comes close to Seoul in its composite measure of human capital. Our chosen index, for which we add together the composite t-statistics for each of the four categories, suggests a high degree of substitutability among the four components that shape R&F capability. For example, rather than capture spillovers for foreign investment, Seoul is able to employ a highly trained corps of scientists and engineers to reverse engineer imported equipment.

Recently, China's *Economic Daily* (2001) reported rankings of aggregate competitiveness for 10 Chinese cities prepared by the Management School of China South-East University (CSEU). Whether we use our composite measure of competitiveness or R&D capability, CSEU's list, while omitting Chengdu, does match our ranking for the other four cities. Below, we summarize the conditions, which distinguish each of the country/city economies.

Shanghai. According to the CSEU ranking, Shanghai ranks first in aggregate competitiveness. Shanghai enjoys the most advantageous location and best infrastructure. It is the financial center of China. Shanghai's government is well organized, efficient, flexible and creative. Shanghai ranks first in the competitiveness of capital, technology, location, social order and management; it ranks second in the competitiveness of human capital and culture.

According to our World Bank survey data, Shanghai stands out among the five participating Chinese cities; it dominates the other Chinese cities along all dimensions. Shanghai exhibits by a wide margin the highest incidence of FDI. A high incidence of Shanghai firms also report being located in industrial parks – a substantially higher incidence than any of the other four cities, but less than several of the other city economies.[9]

Guangzhou. Guangzhou is the first city opened to the western world in China's modern history. The CSEU survey emphasizes Guangzhou's mercantile tradition and its active entrepreneurship. Guangzhou is the key city in China's southern economy; it enjoys close proximity to Hong Kong. The CSEU survey ranks Guangzhou's economic structure as the most competitive among Chinese cities, citing its strong manufacturing industry and strong service sector. Guangzhou ranks second in the competitiveness of its enterprise management. According to the CSEU survey, Guangzhou's municipal

[9] We do not know the proportion of firms in each city that reside in industrial or technology parks, but we should acknowledge that the robust performance of Shanghai (and possibly other cities) may result from oversampling of firms situated in such parks.

government is efficient, however, the city needs to improve its physical environment and social order.

Among the five Chinese cities in our survey, Guangzhou trails only Shanghai in openness. Like Shanghai, it registers high import shares and a high incidence of imported equipment. By a substantial margin, Guangzhou registers the lowest incidence of public ownership.

Beijing. According to the CSEU survey, Beijing's aggregate competitiveness has substantially improved in recent years. It ranks first in the competitiveness of human capital and R&D research and second in the competitiveness of capital. Beijing is also a very open city with good infrastructure. It is the political center of China and also the economic center of north China. However, according to the CSEU survey, Beijing needs to improve its urban living conditions and accelerate institutional reform for the purpose of facilitating technology transfer.

The World Bank survey does not rank Beijing highly in its human capital and R&D networking. However, because human capital is the one area in which Beijing is not at a disadvantage relative to Shanghai and Guangzhou, human capital may be viewed as one of Beijing's *comparative* advantages. Our survey shows that Beijing's R&D network is not as robust as that of Shanghai, the leader, or those of Guangzhou and Chengdu. Our finding of Beijing's relatively low ranking with respect to the purchase of foreign technology and external R&D assistance may be consonant with the CSEU report, which calls for institutional reform in support of technology transfer.

Chengdu. Chengdu and Tianjin represent the two cities for which the findings of the CSEU survey and the World Bank survey are at variance. Chengdu is omitted from the CSEU's top 10 most competitive cities. Our data yields a higher ranking for Chengdu than for Tianjin, which ranks seventh in the CSEU survey. Both rank significantly below Beijing.

According to our survey results, among all 10 economies, Chengdu ranks the lowest in openness; it is the only economy in which all three of the openness measures are significantly negative. This relatively low ranking in openness is not surprising; unlike the other nine economies, Chengdu has no coastal area. With respect to the other four Chinese cities, Chengdu not only rates lowest with respect to FDI, it also rates the highest on public ownership. Notwithstanding its clear competitive disadvantage with respect to openness and institutional quality, Chengdu ranks comparatively well in certain aspects of human capital and R&D networking. Chengdu's sample of firms rank highest in R&D intensity; among the 10 economies, it is second only to Seoul. However, measured in terms of internet use, foreign experience, and management's education level, the quality of its human capital is not high. Moreover, firms in Chengdu seem to purchase technology or purchase R&D services, generally from domestic sources, rather than perform R&D internally or provide it to others.

Tianjin. Tianjin enjoys a strong locational advantage in north China. According to the CSEU survey, Tianjin has strong manufacturing industry and good infrastructure. Its investment costs are relatively low and profitability is relatively high. The CSEU survey finds that many multinational firms are switching their production to Tianjin. Tianjin's social order is also very good.

Results based on the World Bank survey do not rank Tianjin so highly. Beijing and Tianjin rank similarly in both openness and in institutional quality. The dimension along which Tianjin suffers relative to the other Chinese cities and the other Asian economies is in its measures of human capital and R&D network. In human capital, next to Manila, Tianjin ranks lowest in R&D intensity. It is the lowest in percent of workers using the internet. In R&D networking, Tianjin tends not to purchase foreign or outside technology or to receive external R&D services.

Because the World Bank survey spans only five Chinese cities, the reader may find of interest the list of all 10 cities included in the CSEU survey. The reported 2001 ranking is Shanghai, Shenyang, Guangzhou, Beijing, Xiamen, Wuchang, Tianjin, Dalien, Hangzhou, and Nanjing.

11. The Role of Industrial Parks

From Table 11a, we see that the quality and productivity of a firms' R&D operation tends to be enhanced by locating in an industrial park or export processing zone. In order to better understand the ways in which a park setting might influence the R&D capabilities of cities, we more closely examine three zones. These are the Haidian Science Park in Beijing, the Pudong New Area, and its four constituent parks, and the Hsinchu Science and Technology Part (HSTP) in Taiwan. While Taiwan is not included in our study, we include a comparison of the parks in Beijing and Shanghai with HSTP, because the success of the latter has emerged as a standard for S&T parks in Asia.

The comparisons in Annex B shows that in terms of current sales, the New Pudong Area (NPA), the youngest of the three parks, already exceeds the scale of its Taiwan and Beijing counterparts. Total sales and R&D spending by firms in the NPA overshadow those of HSTP and the Haidian Science Park (HSP).

With only 272 companies to account for its voluminous sales, HSTP is clearly comprised of large-size companies. The average annual sales of the HSTP firms is approximately $50 million, which is about 15 times the size of the average firm in the Pudong New Area and more than 40 times the scale of its typical counterpart in the Haidian Science Park. The substantially larger average size firm in Taiwan most likely reflects two conditions. One is the relative age of the parks. Hsinchu was established in 1980, acquiring a head start over the respective 1988 and 1992 start up dates for Beijing and Shanghai. A second distinctive feature of HSTP is that a substantial portion of the firms, approximately 40 percent, were founded by returning expatriates that probably had far better access to capital sources than their counterparts in Beijing and Shanghai. Still, both the Beijing and Shanghai parks include substantial FDI – a flow of $123 million in 1998 for the Beijing park and a cumulative investment by 2000 of $34 billion for the Shanghai park.

An overall comparison of the three parks indicates that the Shanghai park is challenging and overtaking the achievements of its Taiwan counterpart and substantially outperforming the park in Beijing. R&D intensity of its member companies is approaching that of HSTP. The fact that the Pudong area has become China's leading center of financial reform and FDI in the financial sector further underscores the vast potential of the Shanghai zone.

12. Firm-level R&D, economy-wide returns to R&D, and R&D salaries

In this section, we develop estimates of firm-level and composite city-level returns to R&D and explore the association of composite returns with the composite measures of R&D capability, shown in Table 16. Our estimates of the city marginal products of R&D personnel are constructed using the estimate of the output elasticity of R&D personnel shown in Table 9, i.e. 0.325. We then construct an average product for R&D personnel as the ratio of the sum of total value added and total R&D personnel for all of the firms included in each city sample. Finally, we convert these estimates of marginal productivities to common U.S. dollar measures using average exchange rates for May 2001, the period that matches or closely approximates the date of the survey work.

This exercise of estimating the marginal products of R&D personnel for each of the 10 cities substantially narrows the field of comparable cities. Apart from Seoul and the five Chinese cities, we find a tendency for a substantial proportion of firms to use different units of account. While this irregularity is generally not a problem for estimation work using logarithmic transformations of the reported values, it does become problematic when we reconvert the data to levels. The problems of small samples, missing observations, and the inconsistent use of units together are severe enough for the samples other than Seoul and the Chinese cities to require eliminating these from the level comparisons. Our estimates of the marginal productivities of R&D labor for the six cities are reported in column (3) of Table 17.

Using these figures, we estimate the relationship between the composite marginal productivities of R&D labor and the composite measure of R&D capabilities. Regressing the observations in column (3) on column (2), we report the results in Table 18. These results show that our composite measure of R&D capability exhibits surprising explanatory power. The adjusted R-square for the regression is 0.910. Figure 1 shows the scatter plot using these data, with the observations for Seoul and Shanghai anchoring the upper end of the regression line. Our conclusion is that that together the 12 attributes shown in Tables 10a and 10b and in Annex A constitute a useful set of indicators of cross firm and cross city differences in the marginal product of R&D personnel.

Finally, also in Table 17, we show the average reported wage for R&D personnel for each of the 6 city firm samples. In the last column, we compute the ratio of the marginal product to the wage of R&D personnel. Before comparing the ratios, we note that all of the ratios are considerably greater than unity, the result that we might expect if firms hired in R&D personnel up to their marginal product. That the ratios significantly exceed unity may result from one or both of two conditions. First, we note that fringe benefits, not reported in the survey, may account for a significant fraction of the base wage, so that in practice the ratio of marginal product to total compensation may be somewhat less than shown. Second, it is also possible that the estimate of the output elasticity of R&D personnel, shown in Table 9, is biased upward. We discussed this problem earlier. If this estimate is biased, while the use of the "correct" estimate would serve to reduce our estimates of marginal products and the ratios shown in Table 17, the changes would be proportionate, so that the relative size of the ratios would remain unchanged.

The striking feature of the ratios shown in the last column of Table 17 is the large disparity between Seoul and the Chinese cities. In the Chinese cities, the ratios of marginal product over the wage are typically larger than that of Seoul by a factor of two or three.

At least two sources have commented on the relative R&D cost advantage that has emerged in China. Writing in the *New York Times*, James Brooke (2002) suggests that Japanese investment in the China's R&D sector is contributing to China's transformation from "the factory of the world" to the "design laboratory of the world." Brooke catalogs the R&D investments of a number of Japanese multinationals in China, virtually all of which were centered on Shanghai. Spurring the investments are, according to Brooke, the low wages of Chinese engineers, followed by the growing Chinese market for computer chips and the expectation that China's entry into the WTO will bring protection for patents. Pursuing the same theme in the Far Eastern Economic Review, David Kruger (2002) reports on the shifting of the headquarters of one large Japanese firm, following the earlier move of its technology operations, to Shanghai. There, according to Kruger, costs are 10 times lower than in Japan. While these articles make no mention of Korea, our finding of greater surplus for spending on R&D in the five Chinese cities than in Seoul offers an explanation for the direct relocation of these R&D operations to China.

Our finding is that Chinese cities, particularly Shanghai, have begun to create the firm, market, and institutional attributes that boost the productivity of R&D. While the compensation for R&D personnel have begun to rise to capture these productivity gains, wages still lag far behind productivity and behind the salaries of R&D personnel in more prosperous Asian economies, notably Seoul and Japan. This gap between productivity and cost appears to be making China, particularly Shanghai, an attractive focus for foreign investment and technology. Our findings in Tables 10a and 10b suggest that these factors, which are flowing to Shanghai from abroad, are precisely the factors, which are raising the productivity of R&D in Shanghai and elsewhere. It may be that the wages of R&D personnel rise to reduce this productivity-wage gap. Alternatively, the gap may create the potential for a "virtuous circle" in which a large productivity-wage spread attracts investment and technology from abroad, which in turn enlarges or sustains the productivity-wage spread that initially attracted overseas investment.

13. Conclusions

Using a set of survey data spanning firms from 11 East Asian metropolitan economies, we investigate the factors that determine the productivity and profitability of R&D operations at the firm level. We build on our findings at the firm level to construct composite quality measures for ten of the 11 city economies. We are particularly interested in investigating the extent to which these composite citywide measures explain differences in citywide R&D productivity across the metropolitan economies within our study.

The following conclusions stand out from our analysis. We identify a substantial number of survey variables that impact R&D capabilities and firm performance. These can be grouped into four categories: openness, human capital, R&D networking, and institutional quality. Among the 23 attributes that we investigate, 12 operate on firm performance through the R&D channel. Five other attributes operate outside the R&D channel to enhance firm performance. Not surprisingly, all of the human capital variables work to enhance the effectiveness of R&D; five of the six R&D network variables also serve to improve R&D effectiveness.

Some of these results suggest the importance of clusters for high-performance R&D. Among these cluster attributes that enhance R&D effectiveness are industrial parks, IT investments, proportions of internet users, R&D network relationships, and concentrations of competitors. We compare the volume of FDI and degree of R&D intensity among the industrial and technology parks of Taiwan, Beijing, and Shanghai and find evidence that suggests that the Shanghai park is emerging as the dominant park in the region.

The 10 participating metropolitan areas exhibit considerable differences in levels of openness, human capital, R&D networks, and institutions. Several findings stand out. One is the strikingly low measure for Seoul along the dimension of openness and, by comparison, its strikingly high measure for human capital. We surmise that the relatively low participation of foreign direct investment in Seoul is compensated for by a rich supply of high-quality domestic scientists and engineers. A second striking finding is, within China, the large variation in composite measures of competitiveness and R&D capabilities. In particular, Shanghai stands out for its achievements, which seem to make it more comparable to Seoul and the ASEAN cities than to Beijing, Tianjin, and Chengdu.

We construct measures of city economic performance, including overall productivity, the value of marginal productivity of R&D, and salaries for R&D personnel. We find that for Seoul and the five Chinese cities, where comparisons can be made, these performance measures are highly associated with our composite city measures of R&D capabilities.

The ratio of R&D productivity to wages is particularly large in the five Chinese cities. This productivity-wage spread appears to be at least partially responsible for the recent acceleration of large and visible flows of overseas investments in R&D operations in China. Whether this spread is narrowed by rapid increases in salaries for R&D personnel or is sustained by continued flows of investment and technology to China will be critical to the evolving pattern of R&D operations throughout Asia.

Table 1
Firm, Market, and Institutional Attributes that Potentially Augment R&D and Enhance Firm Performance

A. **Openness/competition**
Share of foreign ownership
Number of competitors
Imported equipment
Export sales ratio
Engaged in activities with foreign firm located abroad (other than providing design or R&D services).
Firm's market share
Import market share
B. **Human capital**
% of workers using the internet
% of workforce with foreign experience
Level of management's education
C. **R&D network**
IT assets/total fixed assets
Purchase of outside technology
Purchase a foreign license
Receive external R&D assistance
Provide design or R&D services
Purchased externally-performed R&D services
D. **Institutions**
Share of foreign ownership
Share of public ownership
Industrial park/export processing zone
Government assist in identifying a foreign relationship
Member of a business association
Useful functions of a business association
Constraints on growth in the domestic market

Table 2a
Distribution of Firms by City

China/industry	Beijing	Tianjin	Shanghai	Guangzhou	Chengdu	total
apparel	49	42	40	46	45	222
elec. equipment	41	36	40	40	35	192
elec. components	43	41	40	39	40	203
consumer products	21	35	40	33	36	165
vehicles	44	46	40	42	44	216
IT service	25	29	20	30	24	128
communications	11	11	20	12	17	71
accounting	23	23	20	18	20	104
advertising	20	19	20	11	19	89
logistics	23	18	20	29	20	110
total	300	300	300	300	300	1500

Table 2b
Distribution of Firms by City continued

Other East Asia/industry	Jarkata	Seoul	Kuala Lumpur	Manila	Singa-pore	Bangkok	total
apparel	21	9	4	18	0	8	60
elec. equipment	0	15	7	9	1	1	33
elec. components	4	18	9	5	3	4	43
cons. products	0	8	4	0	0	1	13
vehicles	5	5	4	5	2	2	23
IT service	11	8	7	7	2	2	37
communications	6	7	2	4	0	0	19
accounting	10	2	4	4	3	1	24
advertising	4	5	4	4	2	1	20
logistics	15	8	11	9	5	6	54
total	76	85	56	65	18	26	326

Manufacturing industries – code		**Service industries – code**	
Apparel	Apparel and leather goods	IT service	Information technology services
Elec.equip	Electronic equipment	Communications	Communications service
Elec.comp	Electronic components	Accounting	Accounting and related services
Cons. Prod	Consumer products	Advertising	Advertising and related services
Vehicles	Vehicles and vehicle parts	Logistics	Business logistics services

Table 3a
Distribution of Innovation Activity by Country and City

Location	New product/ sales (mean) in 2000 (%)	New products (1)[1]	New business lines (2)[1]	New processes (3)[1]	New mgt techniques (4)[1]	New quality controls (5)[1]	# of firms filing patent applications[2]
		1498	1498	1498	1499	1499	
China total	36.1 (498)[3]	35.5 (533)	20.5 (307)	29.5 (442)	47.5 (713)	45.2 (678)	198(13.2)/7
Beijing	35.8 (109)	35.0 (105)	21.3 (64)	28.0 (84)	46.0 (138)	44.3 (133)	48(16.0)/1
Chengdu	33.20 (117)	40.7 (122)	26.3 (79)	38.0 (114)	53.3 (160)	51.0 (153)	55(18.3)/3
Guangzhou	35.6 (79)	30.0 (90)	20.0 (60)	30.3 (91)	54.7 (164)	52.0 (156)	43(14.3)/1
Shanghai	39.8 (138)	51.0 (153)	23.2 (70)	34.3 (103)	49.3 (148)	47.3 (142)	34(11.3)/1
Tianjin	38.7 (55)	21.0 (63)	11.3 (34)	20.0 ((50)	34.3 (103)	31.3 (94)	18(6.0)/1
Other East Asia total	24.4 (81)	32.5 (106)	19.6 (64)	30.7 (100)	22.7 (74)	23.3 (76)	37(11.4)/10
Jakarta	30.7 (16)	39.5 (30)	19.7 (15)	21.8 (16)	27.6 (21)	26.3 (20)	11(14.5)/3
Kuala Lumpur	22.8 (9)	30.4 (17)	21.4 (12)	42.9 (24)	33.9 (19)	25.0 (14)	5(8.9)/2
Manila	24.5 (13)	21.5 (14)	13.9 (9)	32.3 (21)	23.1 (15)	24.6 (16)	2(3.1)/0
Bangkok	19.2 (8)	34.6 (9)	19.2 (5)	15.4 (4)	11.5 (3)	7.7 (2)	2(7.7)/0
Seoul	23.5 (28)	34.1 (29)	22.4 (19)	32.4 (28)	15.3 (13)	24.7 (21)	14(16.5)/5
Singapore	21.4 (7)	38.9 (7)	22.2 (4)	38.9 (7)	16.7 (3)	16.7 (3)	3(16.7)/0

[1]proportion of firms reporting innovation for the year 2000 in each of the following categories:
1 = introduced new products in an existing business line (B1.1); 2 = entered new business line (B1.2); 3 = new process improvements (B1.3); 4 = new management techniques (B1.4); 5 = new quality controls in production (B1.5)
[2]Number of firms filing patent applications filed at home (proportion shown in parentheses)/in the U.S. during 1998-2000.
[3]The total number of firms reporting the relevant observation (i.e. ≥ 0).

Table 3b
Distribution of Innovation Activity by Industry

Industry	New product/ sales (avg) in 2000	New products (1)	New business lines (2)	New processes (3)	New mgt techniques (4)	New quality control (5)	# of firms filing patent application[2]
Accounting (128)	14.643(14)	20	16	5	35	25	5/0
Advertising (109)	29.636(11)	16	12	13	27	24	3/0
Apparel (282)	35.216(51)	62	20	79	103	115	21/1
Logistics (164)	14.45(20)	29	22	18	60	40	3/1
Commun (90)	27.391(23)	22	22	13	40	26	4/3
Cons. prod. (178)	35.789(71)	72	38	55	75	83	51/4
Elec. comp. (246)	28.827(110)	115	58	115	129	135	29/0
Elec. equip. (225)	43.546(119)	126	79	103	117	117	51/4
IT service (165)	41.745(55)	63	56	37	78	55	29/2
Vehicles (239)	35.4(105)	114	48	104	123	134	39/2
Total (1826)	34.807(579)	639	371	542	787	754	235/17

[1]proportion of firms reporting innovation for the year 2000 in each of the following categories:

1 = introduced new products in an existing business line (B1.1); 2 = entered new business line (B1.2); 3 = new process improvements (B1.3); 4 = new management techniques (B1.4); 5 = new quality controls in production (B1.5)

[2]patent applications filed at home/in the U.S. during 1998-2000.

[3]mean is for number of firms reporting new products > 0 (shown in parentheses).

Table 4
Likelihood of innovation by country/city

	Jakata	Kuala Lump	Manila	Bang-kok	Seoul	Sing-apore	Tian-jin	Shang	Guang	Cheng	R^2/obs.
NPsales/ total sales (1)	-0.662 (0.96)*	-2.421 (3.11)	-1.538 (2.10)	-0.252 (0.23)	-0.854 (1.30)	1.009 (0.78)	-2.327 (5.33)	1.163 (2.66)	-1.352 (3.10)	-0.258 (0.59)	0.153 (1826)
NP in existing business line (2)	0.754 (2.67)	-0.157 (0.47)	-0.529 (1.54)	0.291 (0.64)	-0.143 (0.52)	0.505 (0.93)	-0.809 (0.20)	0.724 (4.04)	-0.293 (1.59)	0.258 (1.59)	0.112 (1824)
Entered new business line (3)	0.187 (0.55)	-0.057 (0.15)	-0.460 (1.15)	0.156 (0.29)	-0.091 (0.30)	0.138 (0.23)	-0.822 (3.48)	0.091 (0.45)	-0.133 (0.64)	0.280 (0.52)	0.071 (1824)
New product innov: (1) + (2) + (3)	**1/0**	**0/1**	**0/1**	**0/0**	**0/0**	**0/0**	**0/2**	**2/0**	**0/1**	**0/0**	
New process improvements (4)	0.166 (0.50)	0.964 (2.92)	0.430 (1.36)	-0.641 (1.11)	0.120 (0.71)	1.123 (1.95)	-0.732 (3.49)	0.337 (1.79)	0.114 (0.60)	0.515 (2.76)	0.119 (1824)
New management techniques (5)	-0.665 (2.31)	-0.526 (1.69)	-1.024 (3.19)	-1.854 (2.95)	-1.671 (5.11)	-1.406 (2.15)	-0.513 (3.00)	0.135 (0.81)	0.327 (1.95)	0.301 (1.80)	0.069 (1825)
New quality controls (6)	-0.494 (1.67)	-0.807 (2.37)	-0.811 (2.54)	-2.252 (2.99)	-0.976 (3.42)	-1.189 (1.79)	-0.611 (3.46)	0.124 (0.72)	0.308 (1.81)	0.278 (1.64)	0.087 (1825)
New process innov: (4) + (5) + (6)	**0/1**	**1/1**	**0/2**	**0/2**	**0/2**	**1/1**	**0/3**	**0/0**	**1/0**	**2/0**	

* The figures in parentheses are t-statistics.

Table 5: Distribution of innovation inputs by city

Location	% R&D expend/sales[1]	% R&D expend/sales[3]	R&D person/ total employ[1]	R&D person/ total employ[3]
Full six-city sample (326)	1.89 (242)[2]	-	3.90(276)	-
Jakarta (76)	1.77 (37)	-0.001 (0.01)	1.99(60)	-0.024 (1.62)
Kuala Lumpur (56)	0.04 (47)	-0.016 (1.47)	1.59(49)	-0.037 (2.25)
Manila (65)	2.86 (55)	0.010 (0.94)	0.58(55)	-0.047 (3.05)
Bangkok (26)	1.31 (19)	-0.001 (0.017)	1.12(20)	-0.022 (-0.92)
Seoul (85)	2.82 (74)	0.008 (0.83)	10.37(79)	0.049 (3.57)
Singapore (18)	0 (10)	-0.020 (0.87)	0.37(13)	-0.052 (1.77)
Full China sample (1500)	2.40 (1217)	-	4.61(1254)	-
Beijing (300)	2.03 (262)	0.001 (0.021)	4.91(272)	0.010 (1.18)
Chengdu (300)	3.19 (268)	0.013 (2.17)	5.22(266)	0.007 (0.79)
Guangzhou (300)	2.91 (217)	0.009 (1.35)	5.91(236)	0.012 (1.25)
Shanghai (300)	1.98 (232)	0.000 (0.05)	4.73(237)	0.002 (0.18)
Tianjin (300)	1.84 (238)	-0.002 (0.32)	2.23(243)	-0.028 (3.01)
Adj. R^2 (obs.)	-	0.075 (1459)	-	0.194 (1530)

[1]Three years' average and for rdsar00 < 1 or rdmr00 < 1.
[2]Numbers in brackets are the numbers of include observations
[3]Controls for differences across industry categories
[4]Here and elsewhere, when a single number is reported it is the t-test associated with the estimate of the relevant variable. In this case, the variables are country dummies.

Table 6
Comparisons of national level innovation intensities and capabilities

Country	R&D/GDP (%)	R&D expenditure in business (as a % of total)	Scientists and engineers in R&D (per 100,000)	Hich-tech Exports (as a % of total in 1999)	UNDP technology achievement index
Korea	2.8	84.0	2,193	33	0.666
Singapore	1.1	62.5	2,318	58	0.585
Malaysia	0.2	8.3	93	52	0.396
Thailand	0.1	12.2	103	30	0.337
Philippines	0.2	1.9	157	26	0.300
China	0.7	-	454	21	0.299
Indonesia	0.1	76,4	182	7	0.211

Source: UNDP (2001), pp. 48-55

Table 7
Knowledge production
$LnX_i = \alpha_0 + \alpha_1 ln(R^* + 0.0001) + \alpha_2 lnSales + \Sigma\alpha_1 lnLOC + \Sigma\alpha_1 lnIND + \varepsilon$
(i = 1,2,…5)**

	New products (1)		New bus. line (2)		Process innov. (3)		New mgt tech. (4)		New quality controls (5)	
	All obs.	obs. > 0 only	All obs.	obs. > 0 only	All obs.	obs. > 0 only	All obs.	obs. > 0 only	All obs.	obs. > 0 only
constant	-1.527 (-3.54)	-0.230 (-0.33)	-2.177 (-4.30)	-1.217 (-1.58)	-.677 (-1.54)	-.631 (-0.91)	-.769 (-1.91)	-.645 (-0.90)	-.735 (-1.80)	-.336 (-0.47)
lnR*	0.159 (7.47)	0.299 (3.46)	0.136 (5.71)	0.359 (3.93)	0.183 (8.16)	0.161 (1.91)	0.113 (5.48)	0.184 (2.15)	0.123 (5.88)	0.189 (2.20)
lnSales	0.156 (4.90)	0.136 (2.60)	0.096 (2.72)	0.106 (0.055)	0.110 (3.38)	0.137 (2.64)	0.127 (4.31)	0.185 (3.45)	0.148 (4.90)	0.192 (3.55)
Jakarta	.378 (0.91)	0.704 (0.84)	.136 (0.28)	1.060 (1.26)	-.306 (-0.58)	-.319 (-0.35)	-1.141 (-2.51)	-1.457 (-1.65)	-.388 (-0.95)	-.708 (-0.86)
Seoul	-1.573 (-4.36)	-1.499 (-3.17)	-1.065 (-2.73)	-1.446 (-2.84)	-.766 (-2.11)	-1.090 (-2.31)	-2.670 (-6.90)	-3.102 (-5.96)	-2.141 (-5.98)	-2.698 (-5.42)
Kuala Lumpur	-0.292 (-0.76)	-0.823 (2.58)	-0.134 (-0.33)	-1.679 (-1.55)	1.051 (2.77)	-0.023 (-0.03)	-0.608 (-1.73)	-1.851 (-2.44)	-1.083 (-2.76)	-2.671 (-3.01)
Manila	-1.087 (-2.55)	-0.686 (-0.85)	-1.139 (-2.10)	-0.485 (-0.51)	-0.091 (-0.22)	-0.123 (-0.15)	-1.574 (-3.87)	-1.709 (-2.04)	-1.355 (-3.40)	-1.175 (-1.48)
Bangkok	0.221 (0.37)	-0.291 (-0.22)	0.478 (0.75)	n.a.	-0.551 (-0.70)	n.a.	-2.637 (-2.50)	n.a.	n.a.	n.a.
Tianjin	-0.324 (-1.45)	0.089 (0.24)	-0.395 (-1.53)	-0.132 (-0.34)	-0.302 (-1.27)	-0.102 (-0.28)	-0.215 (-1.09)	-0.161 (-0.44)	-0.278 (-1.37)	-0.460 (-1.25)
Shanghai	0564 (2.71)	0.817 (2.58)	-0.235 (-1.01)	-0.274 (-0.88)	0.199 (0.92)	0.030 (0.10)	-0.141 (-0.73)	-0.279 (-0.94)	-0.064 (-0.33)	-0.444 (-1.46)
Guangzhou	-0.352 (-1.67)	-0.066 (-0.22)	-0.284 (-1.21)	0.018 (0.06)	0.123 (0.58)	0.161 (0.53)	0.325 (1.71)	0.466 (1.48)	0.264 (1.37)	0.151 (0.48)
Chengdu	0.331 (1.65)	0.548 (1.91)	0.124 (0.57)	0.204 (0.71)	0.504 (2.44)	0.591 (2.06)	0.249 (1.35)	0.303 (1.05)	0.235 (1.25)	0.129 (0.44)
IND	Yes	yes	yes	yes	yes	Yes	yes	yes	yes	yes
Adj R^2 (obs.)	0.168 1458	0.108 (572)	0.102 1458	0.067 569	0.170 1458	0.089 569	0.105 1459	0.109 569	0.118 1442	0.101 569

*R = average R&D personnel (1998-2000); "0" observations have been converted to "1".
**Estimation equation with dummy for "0" observations; all dummy estimates were not statistically significant at the 5% level.

Table 8
Impact of innovation on firm performance

	Productivity ln(VA)					Profitability ln(Profit)				
Constant	1.920 (7.19)	1.887 (6.99)	1.894 (7.02)	1.866 (6.94)	1.846 (6.86)	0.753 (2.14)	0.728 (2.05)	0.734 (2.08)	0.697 (1.98)	0.678 (1.92)
lnK	0.438 (13.66)	0.450 (13.90)	0.447 (13.80)	0.445 (13.76)	0.442 (13.66)	0.547 (13.20)	0.557 (13.40)	0.552 (13.27)	0.548 (13.23)	0.549 (13.20)
lnL	0.464 (9.05)	0.467 (8.98)	0.465 (8.93)	0.463 (8.94)	0.468 (9.06)	0.326 (4.95)	0.328 (4.94)	0.325 (4.90)	0.320 (4.84)	0.328 (4.96)
New product	0.434 (4.20)	-	-	-	-	0.404 (3.02)	-	-	-	-
New business line	-	0.116 (1.02)	-	-	-	-	0.152 (1.05)	-	-	-
New process innovation	-	-	0.157 (1.50)	-	-	-	-	0.291 (2.12)	-	-
New mgt technique	-	-	-	0.235 (2.40)	-	-	-	-	0.392 (3.11)	-
New quality controls	-	-	-	-	0.255 (2.61)	-	-	-	-	0.301 (2.40)
LOC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IND	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$AdjR^2$ (obs.)	0.68 (797)	0.67 (797)	0.67 (797)	0.67 (797)	0.67 (797)	0.60 (730)	0.60 (730)	0.60 (730)	0.60 (730)	0.60 (730)

Table 9
Effect of R&D on firm performance (reduced form)

	Productivity ln(VA)	Profit ln(Profit)
constant	3.094 (7.67)	1.897 (3.51)
lnK	0.373 (8.01)	0.484 (7.91)
lnL	0.270 (3.71)	0.139 (1.48)
lnR*	0.325 (6.05)	0.276 (3.85)
Jakarta	(dropped)	(dropped)
Seoul	5.753 (9.43)	4.742 (5.09)
Kuala Lumpur	-0.614 (-0.68)	-2.112 (-1.88)
Manila	1.372 (1.16)	1.064 (0.73)
Bangkok	(dropped)	(dropped)
Tianjin	-00178 (-0.07)	0.031 (0.09)
Shanghai	0.831 (4.81)	0.804 (3.45)
Guangzhou	0.525 (2.90)	0.456 (1.85)
Chengdu	-0.058 (-0.34)	0.068 (0.29)
Adj R^2 (obs.)	0.688 (408)	0.580 (359)

*R = average R&D personnel (1998-2000); “0” observations have been converted to “1”.

Table 10a
Effect of R&D interacted with firm attributes

$$\ln X = \alpha_0 + \alpha_1 \ln K + \alpha_2 \ln L + \alpha_3 \ln R + \alpha_4(\ln R^*\ln Z) + \Sigma\alpha_1 \ln LOC + \Sigma\alpha_1 \ln IND + \varepsilon$$

Factor	variable	X_1 = Value Added	X_2 = Profit
Share of foreign ownership	ln R	0.189 (5.19)	0.221 (4.79)
	ln R* ln(foreignsh)[1]	0.009 (2.49)	0.013 (2.86)
	R^2 (obs)	0.662 (876)	0.591 (801)
Share of public ownership	ln R	0.073 (2.12)	0.085 (1.92)
	lnR* ln(publicsh)[1]	-0.014 (4.11)	-0.013 (2.97)
	Adj. R^2 (obs)	0.667 (875)	0.593 (800)
% workers using internet	lnR*	0.107 (3.44)	0.108 (2.66)
	lnR* ln(netsh)[1]	0.023 (4.63)	0.031 (4.77)
	Adj. R^2 (obs)	0.678 (866)	0.596 (798)
ITassets/total fixed assets	lnR	0.227 (4.69)	0.318 (4.38)
	lnR* ln(ITsh)[1]	0.047 (4.04)	0.055 (3.61)
	Adj. R^2 (obs)	0.718 (502)	0.636 (482)
Number of competitors	lnR	0.226 (4.58)	0.276 (4.58)
	lnR* ln(compete)	-0.032 (2.43)	-0.045 (2.70)
	Adj. R^2 (obs)	0.668	0.580 (723)
Industrial park/export processing zone	lnR	0.104 (3.01)	0.088 (2.02)
	lnR* zone	0.099 (2.33)	0.184 (3.39)
	Adj. R^2 (obs)	0.674 (881)	0.596 (808)
Manage-ment's level of education	lnR	0.496 (6.15)	0.474 (5.03)
	lnR* educ	0.391 (4.67)	0.360 (3.69)
	Adj. R^2 (obs)	0.678 (742)	0.607 (653)

Table 10b
Effect of R&D interacted with firm attributes
$$\ln X = \alpha_0 + \alpha_1 \ln K + \alpha_2 \ln L + \alpha_3 \ln R + \alpha_4(\ln R*\ln Z) + \Sigma\alpha_1 \ln LOC + \Sigma\alpha_1 \ln IND + \varepsilon$$

Factor	variable	X_1 = Value Added	X_2 = Profit
Purchased a foreign license	LnR	0.131 (4.05)	0.147 (3.54)
	LnR* ln(forlicence)	0.179 (2.88)	0.174 (2.19)
	Adj. R^2 (obs)	0.672 (857)	0.583 (790)
Purchase outside technology	LnR	0.092 (2.60)	0.113 (2.52)
	LnR* ln(purch_tech)	0.135 (3.17)	0.111 (2.05)
	Adj. R^2 (obs)	0.673 (862)	0.593 (793)
Provide design or R&D services	LnR	0.131 (3.66)	0.123 (2.81)
	LnR*D(pro-vide_RD)	0.016 (1.38)	0.032 (2.27)
	Adj. R^2 (obs)	0.659 (642)	0.588 (540)
Received external R&D assistance	LnR	0.095 (2.45)	0.076 (1.54)
	LnR*D(extRD asst)	0.114 (2.70)	0.177 (3.31)
	Adj. R^2 (obs)	0.660 (779)	0.581 (705)
% of work-force with foreign experience	LnR	0.420 (2.42)	0.647 (2.93)
	LnR*(%for_ exper)	0.057 (1.92)	0.111 (2.95)
	Adj. R^2 (obs)	0.889 (65)	0.811 (57)

Table 11
Direct impact of firm attributes on value added and profit
(i.e. no impact through the R&D channel)

$$\ln X = \alpha_0 + \alpha_1 \ln K + \alpha_2 \ln L + \alpha_3 \ln R + \alpha_4 \ln Z + \Sigma\alpha_1 \ln LOC + \Sigma\alpha_1 \ln IND + \varepsilon$$

Factor	Variable	X_1 = Value Added	X_2 = Profit
Imported equipment	Constant	2.448 (9.32)	1.388 (4.07)
	LnR	0.142 (4.60)	0.155 (3.93)
	D(import_ equip)[1]	0.217 (2.01)	0.269 (1.89)
	Adj.R^2 (obs)	0.672 (884)	0.590 (813)
Firm's share of market	constant	2.193 (6.88)	1.392 (3.52)
	LnR	0.123 (3.48)	0.136 (3.12)
	D(firm_ mktsh)	0.156 (4.01)	0.120 (2.45)
	Adj. R^2 (obs)	0.678 (631)	0.602 (570)
Purchased externally-performed R&D services	constant	2.330 (8.94)	1.270 (3.77)
	lnR	0.128 (3.93)	0.110 (2.65)
	D(RDnet)	0.163 (1.34)	0.483 (3.13)
	Adj. R^2 (obs)	0.061 (877)	0.604 (806)
Import market share	constant	2.559 (8.89)	1.358 (3.63)
	lnR	0.135 (4.11)	0.150 (3.49)
	ln(import_ mktshare)	0.026 (2.92)	0.134 (1.21)
	Adj. R^2 (obs)	0.675 (738)	0.582 (692)
Gov't assistance in identifying a foreign relationship	constant	2.183 (7.81)	1.132 (3.06)
	lnR	0.127 (3.86)	0.137 (3.21)
	D(gov't_ assistance)	0.263 (2.11)	0.367 (2.21)
	Adj. R^2 (obs)	0.676 (726)	0.580 (662)

Table 12
Openness

	Jakarta	Kuala Lumpur	Manila	Bang-kok	Seoul	Tianjin	Shang-hai	Guang-zhou	Cheng-du	Adj. R^2/obs.
% of domestic mkt. supplied by imports	1.112 (1.29)	2.888 (3.14)	0.260 (0.32)	0.508 (0.38)	2.822 (3.75)	0.320 (0.61)	1.192 (2.22)	1.099 (2.06)	-1.038 (2.08)	0.122/ 1316
*% FDI/total capital	0.979 (0.76)	1.804 (1.57)	5.382 (5.19)	2.398 (1.33)	-2.356 (2.76)	-0.061 (0.12)	2.656 (5.34)	0.578 (1.16)	-2.001 (4.15)	0.131/ 1399
Imported equipment	0.985 (2.81)	1.201 (3.28)	1.724 (4.73)	0.411 (0.75)	0.562 (1.94)	-0.316 (1.49)	0.632 (3.09)	0.703 (3.49)	-0.445 (2.14)	0.179/ 1530
*Number of competitors[1]	-0.876 (3.11)	-0.632 (2.14)	-0.803 (2.78)	-0.570 (1.20)	-0.827 (3.52)	0.187 (1.13)	-0.184 (1.10)	-0.116 (0.67)	0.096 (0.60)	0.114/ 1345
Firm's market share	2.038 (9.31)	0.697 (3.08)	1.198 (4.50)	1.430 (3.97)	0.764 (4.20)	-0.362 (2.81)	0.323 (2.48)	-0.260 (1.83)	-0.097 (-0.71)	0.161 1269
Total # t > 2/ t < -2 (sum of t-stats)	3/0 (16.28)	4/0 (13.21)	4/0 (17.52)	1/0 (7.63)	4/1 (10.65)	0/1 (-2.68)	4/0 (14.23)	2/0 (5.55)	0/3 (-9.68)	-
***R&D only**	**1/0 3.87**	**1/0 3.71**	**2/0 7.97**	**0/0 2.53**	**1/1 0.76**	**0/0 -1.25**	**1/0 6.44**	**0/0 1.83**	**0/1 -4.75**	-

*Here and in tables 13-15, **R&D only** represents the composite measure for those attributes which are designated in Table 11 to affect firm performance through the R&D channel.
[1]Because a large number of competitors are found to depress measure productivity and profitability (probably through reduced markups), in creating the composite measures in the last row we reverse the sign of the reported t-statistics.

Table 13
Human capital

	Jakarta	Kuala Lumpur	Manila	Bang-kok	Seoul	Tianjin	Shang-hai	Guang-zhou	Cheng-du	Adj. R^2/obs.
*R&D personnel/ total workers	-0.203 (0.51)	-1.141 (2.67)	-1.623 (3.99)	-0.510 (0.80)	1.897 (5.38)	-1.220 (5.02)	0.095 (0.39)	0.046 (0.19)	0.605 (2.55)	0.258/ 1530
*% workers using the internet	2.111 (3.04)	3.142 (4.20)	1.485 (2.09)	3.395 (3.04)	4.422 (7.18)	-0.995 (2.31)	.464 (1.06)	0.673 (1.56)	-1.165 (2.79)	0.185/ 1492
*Foreign work experience/total	0.148 (0.47)	0.227 (0.73)	0.862 (2.67)	0.842 (1.75)	0.495 (1.83)	0.842 (2.39)	0.005 (0.02)	-0.254 (0.94)	-0.139 (0.52)	0.245/ 369
*Management's education level	0.073 (1.78)	0.243 (6.91)	0.307 (6.00)	0.294 (3.37)	0.243 (6.91)	-0.034 (1.36)	-0.002 (0.09)	-0.018 (0.75)	0.028 (1.20)	0.259 (1155)
Total # t > 2/ t < -2 (sum of t-stats)	**1/0 5.34**	**2/1 9.17**	**3/1 6.77**	**2/0 7.36**	**3/0 21.30**	**1/2 -6.30**	**0/0 1.38**	**0/0 1.06**	**1/1 0.44**	-
***R&D only**	**Same as above row**									-

Table 14
R&D networking

	Jakarta	Kuala Lumpur	Manila	Bang-kok	Seoul	Tianjin	Shang-hai	Guang-zhou	Cheng-du	Adj. R^2 (obs.)
Purchased external performed R&D serv.	1.070 (3.07)	0.026 (0.06)	-0.446 (0.94)	n.a.	0.423 (1.32)	-0.788 (2.71)	0.019 (0.08)	-0.124 (0.49)	0.657 (2.96)	0.070 (1502)
*External R&D assistance	-0.245 (0.55)	0.670 (1.75)	0.656 (1.46)	0.850 (1.43)	0.630 (1.97)	-0.380 (1.60)	0.625 (2.88)	0.206 (0.90)	0.327 (1.54)	0.092 (1314)
*Purchase foreign license	1.204 (2.22)	1.308 (2.70)	0.940 (1.80)	n.a.	-0.869 (1.13)	-1.366 (2.39)	0.558 (1.59)	-0.032 (0.08)	-0.152 (0.40)	0.109 (1462)
*Purchase of outside technology	0.242 (0.42)	0.095 (0.18)	0.189 (0.33)	1.010 (1.45)	0.207 (0.51)	-0.811 (2.16)	0.680 (2.45)	0.287 (0.97)	1.189 (4.64)	0.096 (1473)
*Provided R&D for a foreign firm	1.008 (1.44)	2.058 (3.97)	1.430 (2.68)	0.345 (0.32)	0.647 (1.20)	-0.469 (0.94)	0.580 (1.46)	0.756 (1.95)	-0.321 (0.67)	0.080 (1170)
# for which t > 2/ t < -2 (sum of t-stats)	2/0 6.60	2/0 8.66	1/0 5.33	0/0 3.20	1/0 3.87	0/3 -7.64	2/0 8.46	1/0 3.25	2/0 8.07	-
***R&D only**	**1/0 3.53**	**2/0 8.60**	**1/0 6.27**	**0/0 3.20**	**1/0 2.55**	**0/2 -7.09**	**2/0 8.38**	**1/0 3.74**	**1/0 5.11**	-

Table 15
Institutional quality

	Jakarta	Kuala Lumpur	Manila	Bang-kok	Seoul	Tianjin	Shang-hai	Guang-zhou	Cheng-du	Adj. R^2/obs
*Share public ownership[1]	-4.483 (3.51)	-3.916 (3.35)	-4.179 (3.91)	-4.431 (2.30)	-3.930 (4.53)	-0.598 (1.19)	-0.465 (-0.92)	-1.336 (2.64)	1.472 (3.00)	0.085/ 1397
*Share foreign ownership	0.979 (0.76)	1.804 (1.57)	5.382 (5.19)	2.398 (1.33)	-2.356 (-2.76)	-0.061 (0.12)	2.656 (5.34)	0.578 (1.16)	-2.001 (4.15)	0.131/ 1399
*Industrial zone	0.759 (2.02)	2.170 (5.84)	1.339 (3.89)	-0.457 (0.58)	1.509 (4.98)	0.219 (0.95)	0.702 (3.11)	0.141 (0.61)	0.196 (0.86)	0.135/ 1456
Gov't assistance	0.245 (0.59)	0.721 (1.80)	0.589 (1.38)	2.476 (4.11)	-.910 (-1.65)	-0.384 (1.29)	0.101 (0.37)	-0.062 (-0.22)	0.686 (2.93)	0.065/ 1253
*IT assets/total fixed capital	3.711 (2.32)	-0.047 (-0.08)	-0.117 (-0.27)	0.810 (1.01)	0.300 (0.52)	0.536 (1.86)	-0.088 (-0.42)	0.073 (0.33)	0.118 (0.57)	0.430/ 523
# for which t > 2/ t < -2 (sum of t-stats)	3/0 9.20	2/0 12.48	3/0 14.10	2/0 11.37	2/1 5.62	0/0 2.59	2/0 9.32	1/0 4.52	1/2 -2.79	-
***R&D only**	**2/0** **8.61**	**2/0** **10.68**	**3/0** **12.72**	**1/0** **5.22**	**2/1** **7.27**	**0/0** **3.88**	**2/0** **8.95**	**1/0** **4.74**	**0/2** **-5.72**	-

[1]The sign of public ownership share is reversed in the tallies shown in the last row.

Table 16
Composite measure of country and city attributes

	Openness	Human capital	R&D network	Institutional quality	**Composite measure of competitiveness**	**Composite measure of R&D capability**
Jakarta	4.86 (1/0)	5.34 (1/0)	6.60 (2/0)	9.20 (3/0)	**26.00 (7/0)**	**20.72 (5/0)**
Kuala Lumpur	7.99 (2/0)	9.17 (2/1)	6.66 (2/0)	12.48 (2/0)	**36.30 (8/1)**	**32.16 (7/1)**
Manila	10.24 (2/0)	6.77 (3/1)	5.33 (1/0)	14.10 (3/0)	**36.44 (9/1)**	**33.04 (9/1)**
Bangkok	2.46 (0/0)	7.36 (2/0)	3.20 (0/0)	11.37 (2/0)	**24.39 (4/0)**	**18.31 (3/0)**
Seoul	2.93 (2/1)	21.30 (3/0)	1.48 (1/0)	5.62 (2/1)	**31.33 (8/2)**	**31.18 (7/2)**
Beijing	0.00	0.00	0.00	0.00	**0.00 (0/0)**	**0.00 (0/0)**
Chengdu	-8.37 (0/3)	0.44 (1/1)	8.07 (2.0)	-2.79 (1/2)	**-2.65 (4/6)**	**-7.92 (2/4)**
Guangzhou	6.71 (2/0)	1.06 (0/0)	3.25 (1/0)	4.52 (1/0)	**15.54 (4/0)**	**6.63 (2/0)**
Shanghai	10.65 (3/0)	1.38 (0/0)	8.46 (2/0)	7.48 (2/0)	**27.97 (7/0)**	**25.15 (5/0)**
Tianjin	-0.93 (0/0)	-6.30 (0/0)	-7.64 (0/3)	2.59 (0/0)	**-12.28 (0/3)**	**-10.76 (1/5)**

Table 17
Comparison of Seoul and the 5 Chinese cities

City	Composite measures R&D capabilities		Performance measures[1]		
	# of t's (1)	Sum of t's (2)	MP of R&D personnel ($) (3)	R&D personnel wage ($) (4)	ratio (5)
Seoul	7/2	31.88	37,639	20,847	1.81
Shanghai	5/0	25.15	24,086	5,655	4.26
Guangzhou	2/0	6.63	14,984	3,249	4.62
Beijing	0/0	0.00	13,479	3,494	3.86
Chengdu	2/4	-7.92	9,676	3,102	3.12
Tianjin	1/5	-10.26	8,818	1,569	5.62

[1]The estimates are from Table 9; The Seoul won is converted using the average exchange rate May 2001 (i.e. 1130); the Chinese yuan figures are converted using 8.28, the average for that period.

Table 18
Impact of firm, market, and institutional factors (summarized by the composite R&D t-statistic) on the composite marginal productivity of R&D personnel

variable	estimate
constant	13,543 (8.10)
β	602.96 (6.35)
R-sq.	0.910
Obs.	6

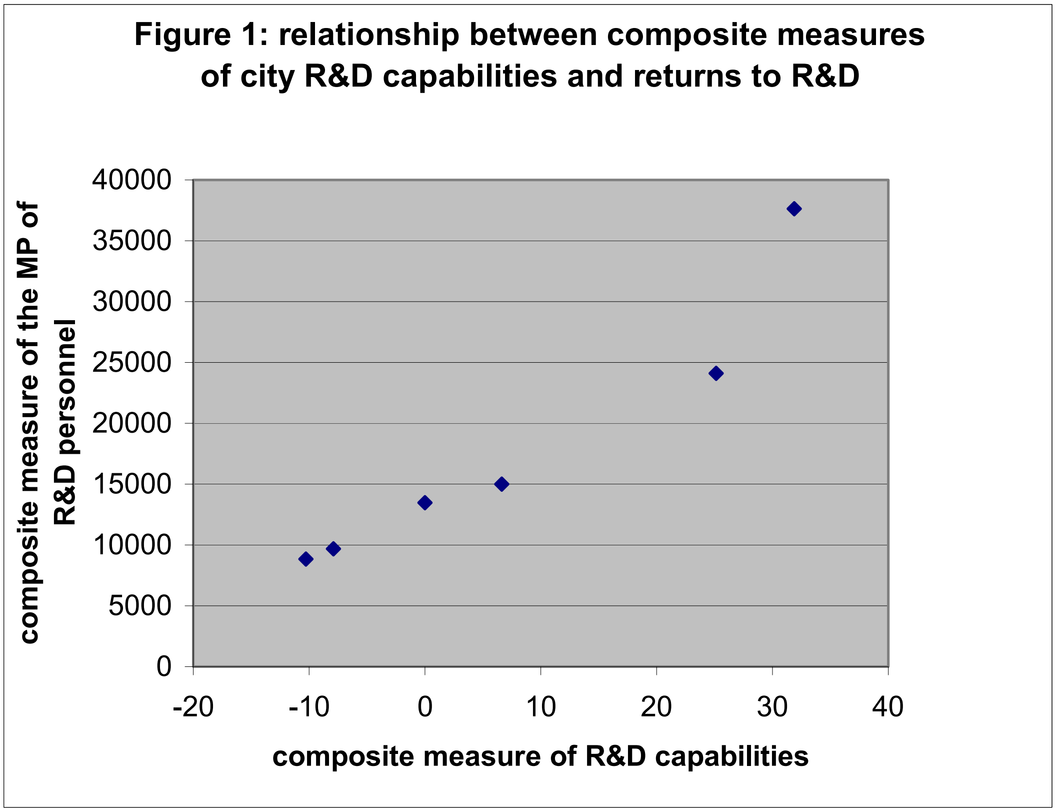
Figure 1: relationship between composite measures
of city R&D capabilities and returns to R&D
composite measure of the MP of
R&D personnel
40000
35000
30000
25000
20000
15000
10000
5000
0
-20
-10
0
10
20
30
40
composite measure of R&D capabilities

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Annex A
Effect of Firm, Market, and Institutional Factors on Firm Performance

	productivity	profit
A. **Operates through the R&D channel**		
Share of foreign ownership	+	+
Share of public ownership	-	-
Number of competitors	-	-
Industrial park/export processing zone	+	+
% of workers using the internet	+	+
IT assets/total fixed assets	+	+
% of workforce with foreign experience	+	+
Level of management's education	+	+
Purchase of outside technology	+	+
Purchase a foreign license	+	+
Receive external R&D assistance	+	+
Provide design or R&D services	+	+
B. **Impacts directly; not through R&D**	+	+
Firm's market share	+	+
Import market share	+	+
Imported equipment	+	+
Purchased externally-performed R&D services	+	+
Government assist in identifying a foreign relationship	+	+
C. **Exhibits no impact**		
Purchase a domestic license	0	0
Export sales ratio	0	0
Engaged in activities with foreign firm located abroad (other than providing design or R&D services).	0	0
Member of a business association	0	0
Useful functions of a business association	0	0
Constraints on growth in the domestic market	0	0

Annex B
Comparison of technology parks

	Taiwan	Beijing	Shanghai
Name of park and year founded	Hsinchu Science & Technology Park (HSTP) (1980)	Haidian Science Park (HSP) (1988)	Pudong New Area (PNA) (1990)
Total number of technology parks	One	The largest of 3 parks in the Zhongguancun Science Park.	(1) Zhangjiang High-Tech Park, (2) Waigaoqiao Free Trade Zone, (3) Lujiazui Finance and Trade Zone, (4) Jinqiao Export Processing Zone
Purpose	To promote the development of high tech industries in Taiwan	Also known as China's "Silicon Valley", HSP is the country's leading incubator of high-tech businesses and a major cradle of the knowledge-based economy in China.	Part of the nation's strategy for economic development, PNA is intended to build Shanghai into an international center of trade and finance to regenerate the economy of the entire Yangtze River Valley.
Scale	1998: 272 companies with combined annual sales of $13.7 billion and total employment of 72,623, including over 3,000 returned expatriates.	1998: 4,546 companies and annual sale was 45.16 billion Rmb. HSP included 147,286 employees, including 748 returned expatriates.	1998: 3,967 companies and annual sales of 135 billion Rmb ($16.3 billion). Employment in 1998 was 606,100.
University linkages	National Tsinghua Univ and National Chiaotong Univ.	Peking Univ, Tsinghua Univ. and China Science and Technology institute	37 regular institutions of higher learning and four advanced vocational and technical colleges in Shanghai.
Foreign participation	109 firms, i.e. about 40%, were founded by returning expatriates.	Among the 4,506 forms located in HSP, 19.67% were WFOE & JV entities. In 1998, FDI totaled $123 million.	By 2000, Pudong had attracted 6,635 foreign-invested companies. Cumulative investment is US$34.430 billion; contracted investment = US$14.451 billion.
R&D intensity	1997 – park companies spent 6.2% of their sales revenue on R&D (i.e. $0.85 billion) compared with only about 1% for mfg industry in all Taiwan. R&D personnel numbered 11% of the workforce.	1.07 billion Rmb R&D expenditure. The implied R&D/sales ratio is 2.4%.	Total R&D spending in 2000 was 7.553 billion Rmb (i.e. $0.91 billion). The implied R&D/sales ratio is 5.6%.
Patents	More than one half of the top 10 patents granted patent rights in Taiwan are from HSTP.	218 new patent in 1998	n.a.

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