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Return to R&D Investment and Spillovers in the Chinese Semiconductor Industry: A Tale of Two Segments

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1. Introduction

As manufacturing networks are expanding globally, R&D functions are increasingly moving offshore as well. While this trend remains at an early stage in comparison with manufacturing, its implications for firms and countries may be even more far-reaching. In this study we examine how firms respond to technology opportunities when they have different market orientations and confront different competitive challenges.

We choose China's semiconductor industry as the context of the study because the industry has been active in technology advancement and in recent years has witnessed a surge in the number of companies starting up operations within China and supplying the global market. Some of these operations are local subsidiaries of Western firms. Others have been formed by overseas Chinese entrepreneurs bringing with them a wealth of experience, know-how and contacts. Many others are indigenous and employee turnover in the industry has historically been quite high (Chesbrough 2005).

As a result, not all firms in the Chinese semiconductor industry are alike. The entrants have formed a new segment of the industry very different from the existing firms, most of them state-owned operating on obsolete equipment and supplying domestic market. We take advantage of this firm-level heterogeneity to investigate whether differences in market orientations and firm capabilities lead to different returns to R&D investment and spillover effects from external R&D resources.

Existing research have found evidence that in-house R&D effort facilitates the absorption of external knowledge (Cohen & Levinthal 1990), both in developed countries and in developing countries (Blalock & Gertler 2005b). While the existing literature suggests that exporting is associated with productivity improvement (Blalock & Gertler 2004), it is not clear through what channels the exporting firms improve efficiency. As for the impact of multinational or foreign direct investment on host country firms, previous studies have found mixed results (Tybout 2000). While multinationals investing overseas are believed to carry superior technology and management know-how (Markusen & Venables 1999), whether host country firms benefit from such external resources depends on many factors including the extent of the technology gap, the pattern of industrial linkages (Javorcik 2004), the geographic distance from knowledge sources (Keller 2002, Liang 2007), and the intensity of market competition (Aitken & Harrison 1999, Hu & Jefferson 2002).

We contribute to the existing literature by exploring the heterogeneity of firms within a single industry, namely, the difference between the global-oriented segment and the domestic-oriented segment. We use this heterogeneity to investigate whether the two segments respond differently to the competition and opportunities brought about by the foreign firms. We examine these questions empirically using detailed firm level data on operation, finances, personnel, and R&D activities. The data mainly come from national enterprise surveys that cover all the large and medium sized firms, conducted by the National Bureau of Statistics of China. These are the most comprehensive data sets of the country on the topics we are interested in and have been used in previous researches on China's firms. For example, Hu and Jefferson (2002) study the impact of foreign investment on domestic firms' productivity in textile and electronic industry. Hu, Jefferson, and Qian (2005) examine the technology transfer and R&D activities of Chinese firms and how foreign investment influence the technology activities and domestic firms' productivity.

We find firms in the globally-oriented segment have larger returns to R&D investment than those in the domestically-oriented segment. We also find that the former firms receive larger positive spillovers from R&D investment made by multinational firms, although the effect is only marginally significant. As a firm's export ratio increases, the spillover effect from external R&D investment is reduced, indicating a dominating competition effect. We find little evidence that in-house R&D effort facilitate absorption of external R&D resources in the semiconductor industry, although this is the case in manufacturing sectors overall.

In section 2 we discuss existing literature and develop hypotheses. Section 3 describes the data, measurement, and empirical model. Section 4 presents results. Section 5 concludes and discusses future research.

2. Literature review and hypotheses

Policy makers hold the belief that globalization brings about technology opportunities and management know-how to the host countries. This happens when domestic firms are exposed to internationally competitive market when they engage in exporting, or when multinational corporations invest in the country and bring with them advanced technology. However, whether domestic firms benefit from these exposures remains an open question in empirical research. The mixed empirical result is attributed to firm heterogeneity that influences the ability to absorb and utilize knowledge resources (Tybout 2000). Among these heterogeneities are firms' absorptive capacity, market orientation, technology gap from knowledge source, etc. In this study we focus on the effect of market orientation and a firm's absorptive capacity.

Technology and know-how can be transferred between firms directly via licensing and alliances, or indirectly via personnel turnover or imitation as firms are exposed to new products, production and marketing techniques. To benefit from this exposure, however, the recipient must share similar market and product requirements, in order to utilize the "spillovers" from the knowledge source. Meanwhile, when sharing the same market sector, domestic firms that lag behind multinationals might receive negative spillovers instead of benefits from the technology leaders, as their market share and production are reduced through crowding out effects, especially in the short run (Aitken & Harrison 1999).

Previous studies have found evidence of positive spillovers from foreign invested firms in the same industry in developed countries such as the United States (Keller and Yeaple 2003) and United Kingdom (Haskel 2002, Liu et al. 2000), but there is little evidence of horizontal spillovers from foreign invested firms to domestic firms in developing countries (Aitken & Harrison 1997, Blalock & Gertler 2005a, Javorcik 2004). One of the major reasons, as suggested by Chesbrough (2005) in the study on China's semiconductor industry, is that domestic firms and foreign firms might produce for different markets: most domestic firms supply local market with low demand on quality and product specifications, while multinationals produce for the international market with higher demand on product performance and quality. The difference in market orientation and requirement on product and technology offers less incentive and fewer channels of technology spillovers for the domestic firms to catch up.

On the other hand, when domestic firms produce for the exporting market, they are exposed to demanding customers and competition in the international production network, thus the incentive and channels to absorb external technology knowledge. This argument is especially salient for exporting firms in the developing countries, where the demand and product specification of domestic market are often different from those of international market. The challenge in empirical work is to identify the direction of causality. It could be that more efficient firms self-select into exporting market, which is the contention of Chesbrough's (2005) earlier qualitative study. Indeed, most empirical works have found evidence of prior firm selection rather than technology improvement as a result of exporting. For example, Bernard and Jensen (1999) find US firms' productivity increases prior to exporting. Clerides, Lach, and Tybout (1998) find similar evidence in Columbia and Morocco manufacturing firms. As an exception, Blalock and Gertler (2004) find exporting leads to productivity growth in Indonesia firms.

Based on the existing theory, we hypothesize that:

Hypothesis 1. Firms producing for the export market are more likely to receive positive spillovers from external R&D capital, especially from the R&D capital of multinational firms.

Firms' absorptive capacity, the capability to recognize and adopt the new technology or management skills from others, might also impact whether they benefit from spillovers (Cohen & Levinthal 1990). Absorptive capacity is generally measured with firm's previous experience and investment in research and development and human capital (Blalock & Gertler 2005b). Higher absorptive capacity is believed to lead to better adaptation to changing technology environment and exploitation of the opportunities (Zahra & George 2002, Todorova & Durisin, 2007). China's semiconductor industry is characterized by a rapidly changing landscape as multinationals enter the market with cutting-edge technology. We expect firms with higher existing knowledge capital to benefit more from the external knowledge.

Hypothesis 2. Firms with higher in-house R&D capital are more likely to receive positive spillovers from external knowledge.

Because the semiconductor export market demands higher performance, greater density of circuit designs (as measured by the line width of circuits), and higher quality, we expect export-oriented firms to utilize their knowledge assets more efficiently relative to domestically focused firms. Thus, export oriented firms will enjoy higher returns to their R&D capital.

Hypothesis 3. Globally-oriented firms have higher returns to in-house R&D capital than domestic-focused firms.

3. Data, measurement, and empirical strategy

3.1 Background: semiconductor industry in China

It is widely acknowledged that the market for China's semiconductor industry is growing very rapidly in recent years. The Chinese government was offering substantial incentives to lure foreign investment into the country, particularly in the foundries building products. Meanwhile many Chinese engineers and technicians returning from overseas were providing substantial human capital to enterprises in China.

In an in-depth study, however, Chesbrough (2005) finds that the Chinese semiconductor industry is far from a uniform sector. Instead it is made of two distinct industry segments sharing a common SIC code. The first segment is strong, vibrant, and globally competitive. The Chinese government has been aggressive in providing attractive incentives for foreign investment and thus encouraged a surge of entrants. This new competitive sector possesses substantial industry experience, largely provided by experienced personnel returning from the US, and experienced executives and engineering from Taiwan. It possesses some highly advanced technology, with three 12" fabs already built by 2006, and attracting capital from Taiwan, the US, and Europe to finance the construction of these highly expensive facilities.

Meanwhile there is a second industry segment that is far different in every respect from the first. This second segment is comprised of formerly state owned enterprises (SOEs) that lack the money, the talent, and the basic management processes to compete on the global stage. These companies are employing rather obsolete equipment and inferior technology, and they are serving a largely domestic market whose requirements are far different from those of the global market. They are starved for investment funds, they lack significant management experience in a market economy, and they are constrained in their employment relations with the people they have. The government remains the largest shareholder of these companies.

Since China’s domestic market is distinctly different from the world market, not only in the costs and price of products, but also in the formats and standards that the world market requires, firms supplying the two markets face different challenges and opportunities. Multinationals (MNCs) investing in China to date have utilized their China operations to gain access to the China market, and to establish an export platform to the rest of the world. These twin activities have been quite distinct owing to the market differences noted above, thus reduce the synergies between the activities for the MNCs.

In this study we investigate the technology spillover effects from external industry R&D capital, and the return to firms’ own R&D capital in the two segments of the industry. We partition the industry into a “domestic segment” made of firms with export ratio lower than 50%, and a “global segment” with export ratio of 50% or higher[1]. The means of export ratio for the two segments are 11% and 88%, respectively (Table 2). The distribution of export ratio shows a dividing pattern clearly (Figure 2): there are two concentrations of export ratio, one near 10% and the other near 90%. Thus, the qualitative findings in the earlier study are borne out in the summary statistics of the population of semiconductor firms in China.

3.2 Data

The data used in this study is based on the 1998-2005 Enterprise Survey conducted by the China National Bureau of Statistics (NBS). There are not comparable data available before 1998, owing to changes made in the survey instrument in 1998. The survey is a census, covering all the state-owned enterprises and non-state-owned enterprises with sales above 5 million Yuan (about US$ 600,000 according to the exchange rate in 2007). These enterprises account for 25% of all the registered enterprises and 90% of sales, so the smallest firms are not captured in the census, a limitation of the data we use.

The original census includes roughly 20,000 firms each year, distributed across 36 2-digit SIC manufacturing industry sectors. Our study of the semiconductor industry is based on a subset of the data of 3-digit industry code 405. There were roughly 130 firms in this three digit code in 1998, rising to more than 340 firms by 2005 (Figure 5 and Table A3). This gives us an unbalanced panel of 1,600 firm year observations over the eight years of

[1] The median export ratio for semiconductor industry firms from 1998 to 2005, defined as export divided by output, is 43%. The estimation result is qualitatively similar when the two segments are divided at an export ratio of 43%.

our study, from 1998 to 2005. As a robustness check and a test of external validity, we also compare our results in semiconductor industry with that in all manufacturing enterprises.

The Chinese government's National Bureau of Statistics collects the data through a self-report system, and monitor data quality by conducting random checks on reporting enterprises[2]. The data set include variables on firms' production, output, value-added, capital, labor, investment, and expenditure and personnel in R&D activities. The data has been used in previous studies on China's industrial enterprises. For example, Hu and Jefferson (2002) find that foreign investment have both technology spillover effects and market squeezing effects on domestic firms in textile and electronic industry. Hu, Jefferson, and Qian (2005) find a complementary relationship between in-house R&D activities and external expenditure on purchasing technology.

3.3 Productivity Estimation

To examine the return to R&D capital and spillovers, we use an approach similar to previous literature and estimate the following Cobb-Douglas production function:

$$(1) \qquad \ln Y_{it} = \alpha + \beta_1 \ln C_{it} + \beta_2 \ln L_{it} + \beta_3 \ln M_{it}$$

[2] Jefferson et. al. 2003 provides a comprehensive review of the enterprise survey data collected by National Bureau of Statistics. Since the government is the dominant shareholder in the state owned enterprises, we expect these data to be highly reliable. Privately owned firms may under-report their financial results, but there are other checks discussed by Jefferson that limit this behavior as well. Our spot checking of individual cases did not find any evidence of under-reporting, so we regard the data as reasonably reliable (as did Jefferson). Further, any downward bias in financial reporting by privately held firms would mean that we would be under-estimating the productivity effects. Thus, any findings of significantly better returns to R&D for export-oriented firms – which tend to be privately owned - would be conservatively biased, and understate the reality.

$+ \beta 4 \ln K\_own_{it} + \beta 5 \ln K\_ext_{it} + \beta 6 \, Export\ Ratio * \ln K\_ext_{it} + \beta 7 \ln K\_own_{it} * \ln K\_ext_{it}$

$+ \gamma Z_{it} + \alpha_i + \alpha_t + \xi_{it}$

Y_{it} stands for real output in 1998 price of firm i in year t, as reported as industrial output, or revenue, in the original data set, deflated by output price index at 2-digit industry level. C_{it} is capital defined as the net fixed asset average balance, deflated by fixed asset investment price index at province level. L_{it} is labor input measured by total employment[3]. M_{it} is intermediate input deflated by intermediate input price index at national level. K_own_{it} is the firm's own R&D capital, constructed using a perpetual inventory method (Hall & Mairesse 1995), assuming a depreciation rate of 15% and an annual growth rate of 3% of R&D expenditure[4]. K_ext_{it} is external R&D capital, defined as the sum of other firms' R&D capital in the same 3-digit SIC industry sector at the national level. In a variety of estimations, we use external R&D capital of all the firms, of foreign invested firms, and of firms in the global segment and in the domestic segment. R&D capital is deflated with an industry output index[5]. The interactive term of own R&D capital and external R&D capital is included to capture the effect of firm absorptive capacity on spillovers. The interactive term of export ratio and external R&D capital is to

[3] Both labor and capital are adjusted for double counting of R&D capital by subtracting R&D employment from employment, subtracting an "R&D capital stock" constructed from the equipment investment component of R&D expenditure from the capital stock, following Hall and Mairesse (1995) and Schankerman (1981). The estimation result is qualitatively similar before and after the adjustment. The coefficients of returns to R&D are slightly larger after adjustment, but not statistically more significant.
[4] The annual growth rate of 3% is based on the sample mean of the data set we use for this study. The growth rate is often assumed to be 5% in previous research, including Hall and Mairesse (1995), Jefferson 2004.
[5] Ideally we should use an R&D deflator based on R&D personnel wage index and expenditure index (Mansfield 1987), but such information is not yet available to us for the NBS data set. Hall and Mairesse (1995) suggest that using industry output index does not bias the coefficient on return to R&D severely.

capture the effect of market orientation on spillover effect. A Cobb-Douglas production function is used in the estimation.

A set of control variables α_i, α_t, and Z_{it} are included in the regression. The analysis needs to address the omission of unobserved variables, such as firm-specific factors unknown to the researcher but known to the firm that may affect the relation between firm productivity and R&D investment. Examples of these unobserved variables include a pre-existing efficient R&D department, newer equipment, macroeconomic shocks such as exchange rate fluctuation, etc. Firm fixed effects α_i and year fixed effects α_t are included in the regression to remove these unobserved effects.

A vector of control variables Z_{it} includes the export ratio of the firm that year and a dummy variable for whether there were any exports in that year. The firm's export ratio is defined as the firm's exports divided by its overall sales in that year. Previous studies suggest a positive correlation between firm productivity and export activities (Blalock & Gertler 2004; Hallak & Sivadasan 2006) in the developing country context because overseas customers may have higher demand on product quality and on-time delivery, and prompt exporting firms to improve productivity. Such effects are firm-time specific and cannot be removed by fixed effects, and a large number of firms report zero export in the sample. So we include in our regressions a dummy variable indicating whether a firm is involved in export activities in a certain year. It is defined as one if a firm reports positive value of export in a certain year. We also include interaction terms of the firm's export ratio with its own R&D capital.

Table 1 shows summary statistics of all the firms in semiconductor industry. Table 2 shows the statistics of the two segments. It can be seen that firms in the global segment have grown from 1998 to 2005 (Figure 3 and 4, and Table A3), such that they product larger outputs, are more capital intensive, and have larger share of foreign ownership. But the domestic segment firms have a larger R&D capital stock, higher R&D expenditure intensity, and higher profit.

4. Results

According to Hypothesis 1, a positive coefficient of the interaction term of export ratio and external R&D capital would indicate positive relationship between a firm's global market orientation and its spillover effects from external R&D resources. According to Hypothesis 2, a positive coefficient of the interactive term of firms' own R&D capital and external R&D capital indicates that a firm's absorptive capacity facilitates reaping benefit from outside technology opportunities. Hypothesis 3 predicts that firms in the global segment should have higher returns to R&D investment than firms in the domestic segment.

The estimation results for semiconductor industry are in Table 4-9. For comparison, the results for all manufacturing firms are in Table 10 and Table 11. In all these tables, we compare the estimation result on all the firms in the census and on those firms that reported conducting R&D activity in that year. Internal R&D capital is highly correlated with external R&D capital, creating collinearity problems in the estimation. Adding an interaction term for the two variables causes large changes of the estimated coefficients of the returns. We therefore present the results both with and without the interaction term. Table 4-7 present results without the interactive term, while Table 8 and Table 9 include the term. In these tables external R&D capital are defined as total R&D capital, foreign R&D capital, R&D capital in the global segment, and in the domestic segment, respectively. All these R&D measures are the sum of R&D capital of individual firms in the 3-digit industry sector. Table 10 and Table 11 present result for all manufacturing firms with and without the interactive term respectively.

In semiconductor industry, Hypothesis 3 is partially supported by the result, but Hypotheses 1 and 2 are not supported. In Table 4-9, we find the return to in-house R&D capital is near zero for firms in both segments, but much larger for firms with positive R&D capital stock, although the coefficient is not significant or only marginally significant. In most of these specifications, R&D performers in the semiconductor industry, i.e. those firms with non-zero R&D capital, have a 5% return on R&D capital; for R&D performers in the global segment, the return is 15%; in the domestic segment, the return is 3%. The scale of the return is consistent with findings in previous studies. For example, Hall and Mairesse (1995) find a return rate of 5% on R&D capital in the within estimation using data of French manufacturing firms in 1980s; Hu and coauthors (2005) find the return to in-house R&D capital to be 3-5% in a cross-sectional estimation using data on manufacturing firms in China from 1995 to 1999.

We find little evidence of spillovers from the measures for external R&D stock. The coefficient of the return to external R&D capital is near zero and not significant or negative in most of the model specifications, except that we find positive spillover effects between the two segments, as in Table 6, Column 5-6, and Table 7, Column 3-4. This might indicate the firms in the two segments are actually learning from each other as they encroach into each other's market turf. Employee turnover rates are high in this industry, and IP protection is acknowledged to be incomplete at this time, two factors that might explain these effects.

The coefficient of the interactive term of export ratio and external R&D capital is near zero or negative in most models, contrary to the prediction of Hypothesis 1. This might result from the competition effect suggested by Aitken and Harrison (1999). As firms are more involved in the global market, the short term market stealing effect might dominate the positive spillover effect from the competing firms. We also note that the global firms are younger, and likely have less depreciated capital equipment, while domestic firms are older and likely utilize fixed capital that has already been substantially depreciated.

The coefficient of the interactive term of in-house and external R&D capital is near zero in most of the specifications. This might indicate that firms' own R&D capability has little impact on the absorption of external technology resources in the semiconductor industry.

From the estimation results of all manufacturing firms, we find a positive return to in-house R&D capital and positive spillovers from external R&D capital (Table 10). The return to in-house R&D is 0.1% for all firms, and 2% for R&D performers (Table 10, Column 2 and 4). The return to external R&D is 1.3% and the return to external R&D from foreign invested firms is 0.6%. We also find a positive coefficient for the interactive term of in-house R&D and external R&D (Table 11). This suggests firms own R&D investment might facilitate spillovers in general, although the evidence is thin in semiconductor industry. Similar to the result in semiconductor industry, the interactive term of export ratio and external R&D is negative, indicating a market stealing effect dominating positive spillovers.

5. Conclusion and discussion

This study utilizes detailed industry and firm information in the semiconductor industry of China to investigate how firms respond to technology opportunities when they have different market orientations and resources. We find that firms in the globally-focused segment enjoy a higher return to R&D investment than those in the domestic segment. Despite the rapid change of industry environment and technology landscape, however, we find little evidence of technology spillovers within the industry. In the overall manufacturing sector in China, by contrast, there is evidence that overall China's manufacturing firms benefit from external R&D resources and the positive spillover effect is enhanced by in-house R&D investment.

This finding is not very surprising given previous research on the topic in general and on the semiconductor industry in particular. Firms with advanced technology and management skills might implement measures to prevent knowledge leakage to local competitors, such as paying higher wages to employees to prevent turnover. In addition, domestic firms may have limited absorptive capacity to recognize and adopt the new technology or management skills from the multinationals. These factors prevent domestic firms from reaping the benefit of technology spillovers through the channels of personnel turnover and imitation.

Multinational corporations might have also been careful to partition their technology deployment so that individual portions of a system are built in the host country, but the overall systems integration resides elsewhere, in a region with much stronger intellectual property (IP) protection. This enables the multinationals to manage the risk of IP misappropriation, but deprives the domestic industry of a vital source for developing more overall systems knowledge. If the host country government's goal of attracting foreign investment is to facilitate technology advancement of domestic industry, a stronger IP regime and a more open domestic market might work toward this goal instead of against it.

Several issues remain to be solved in this study. We did not address selection bias in R&D investment – R&D performing firms are expected to have higher capability to improve efficiency through conducting R&D activities. We will deal with this issue using a simultaneous equation system in the next step. We will also examine the spillover effects from linked industry sectors.

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Tables and graphs:

Table 1. Summary statistics of semiconductor manufacturing firms in China 1998-2005

Variable	Number of Observations	Mean	Standard Deviation	Min	Max
Output (1,000 Yuan*)	1,640	575,464.70	1199335.00	0	11,500,000
Value-added (1,000 Yuan)	1,640	151,486.40	393470.90	-583,841	6,428,407
Employment (persons)	1,640	1,198.82	1464.66	0	15,175
Fixed Asset (1,000 Yuan)	1,640	328,739.50	847063.10	0	14,600,000
Material (1,000 Yuan)	1,640	436,205.10	940287.00	0	7,817,062
Long-term Investment (1,000 Yuan)	1,640	47,448.69	276263.10	-3,493	6,308,840
Profit (1,000 Yuan)	1,640	21,990.39	134586.60	-1,563,182	2,068,840
Return on Asset	1,639	0.03	0.10	-0.67	0.92
Export Ratio	1,633	0.43	0.40	0	1
R&D Expenditure/Sales	1,371	0.02	0.07	0	1
R&D Staff/Employment	1,639	0.04	0.09	0	1
Firm Age	1,640	13.59	12.28	0	57
Science & Technology Expenditure (1,000 Yuan)	1,640	15,436.18	53964.67	0	1,033,187
Science & Technology Stock (1,000 Yuan)	1,640	58,158.94	182483.40	0	2,100,063

* The official exchange rate between Yuan and US$ is 8.27 Yuan/US$ 1998-2005.

Table 2. Summary statistics of the two segments in the semiconductor industry 1998-2005

Variable	Domestic-oriented segment		Global-oriented segment	
	Number of Observations	Mean	Number of Observations	Mean
Output (1,000 Yuan*)	950	500,828.30	683	685,013.90
Value-added (1,000 Yuan)	950	131,575.30	683	180,554.00
Employment (persons)	950	1,215.33	683	1,185.54
Fixed Asset (1,000 Yuan)	950	297,699.50	683	375,206.70
Profit (1,000 Yuan)	950	27,544.54	683	14,484.39
Return on Asset	950	0.03	683	0.03
Export Ratio	950	0.11	683	0.88
R&D Expenditure/Sales	742	0.03	629	0.01
R&D Staff/Employment	950	0.05	683	0.02
Firm Age	948	18	683	8
Science & Technology Stock (1,000 Yuan)	948	63,476	683	50,742
State-owned share	950	0.36	681	0.06
Foreign-owned share	950	0	681	0.53
Foreign-owned firm-year observations	217		389	
Overseas Chinese firm-year observations	116		248	
Domestic firm-year observations	615		46	

* The official exchange rate between Yuan and US$ is 8.27 Yuan/US$ 1998-2005.

Table 3. Pair-wise correlation matrix of semiconductor industry

	1	2	3	4	5	6	7	8
1. Log Output	1							
2. Log C	0.64	1						
3. Log L	0.56	0.52	1					
4. Log M	0.95	0.61	0.54	1				
5. Log knowledge stock	0.18	0.22	0.14	0.17	1			
6. Log external knowledge stock	0.34	0.08	0.14	0.30	-0.13	1		
7. Log external foreign knowledge stock	0.33	0.07	0.12	0.30	-0.12	0.99	1	
8. Export ratio	0.30	0.13	0.15	0.28	-0.36	0.30	0.29	1

Note: All the correlations are significant at 1% level.

Table 4. Return to R&D stock and spillovers from R&D stock in semiconductor industry 1998-2005

Dependent Variable: Log industrial output (in 1,000 Yuan)

	(1) All semiconductor manufacturers	(2) All semiconductor manufacturers: R&D performers	(3) Global segment	(4) Global segment: R&D performers	(5) Domestic segment	(6) Domestic segment: R&D performers
Log Capital	0.0943	0.0752	0.1569	0.1370	0.0819	0.0815
	(0.0316)***	(0.0362)**	(0.0526)***	(0.0969)	(0.0397)**	(0.0423)*
Log Labor	0.1827	0.1597	0.2630	0.2591	0.1579	0.1547
	(0.0581)***	(0.0758)**	(0.0792)***	(0.1294)**	(0.0718)**	(0.0798)*
Log Material	0.5413	0.5827	0.4140	0.5057	0.5973	0.5806
	(0.0623)***	(0.0668)***	(0.1295)***	(0.1662)***	(0.0570)***	(0.0787)***
Log K_own	-0.0016	0.0446	-0.0089	0.1664	0.0080	0.0349
	(0.0090)	(0.0327)	(0.0265)	(0.1284)	(0.0116)	(0.0371)
Log K_ext	-2.9966	-1.5556	-7.5956	0.3214	-1.8992	-0.8971
	(1.1177)***	(1.2674)	(11.2128)	(7.6999)	(1.1120)*	(1.1810)
Export ratio * Log K_own	-0.0062	0.0737	-0.0033	0.0163	0.0018	-0.0425
	(0.0123)	(0.0581)	(0.0292)	(0.1255)	(0.0314)	(0.0737)
Export ratio * Log K_ext	0.0009	0.0107	-0.3316	-0.0538	-0.0914	-0.0563
	(0.0631)	(0.0840)	(0.1795)*	(0.2193)	(0.1724)	(0.1959)
Number of observations	1551	936	639	233	910	701
Number of firms	589	308	312	109	332	223
R-squared	0.68	0.70	0.72	0.82	0.66	0.62

Notes: Robust clustered standard errors in parentheses. The error terms are corrected for clustering for each firm. All the regressions include firm fixed effects and year dummies. The dependent variable is log output in 1998 price. The right-hand side variables include capital stock, labor, and materials in log terms deflated to 1998 price, adjusted for double-counting of R&D stock by subtracting R&D capital stock from capital, and R&D staff from labor. All the regressions exclude upper 1% outliers of capital, labor and material.
R&D performers are those firm-year observations with positive R&D stock.
*, **, *** significant at 10%, 5%, and 1% level.

Table 5. Return to R&D stock and spillovers from foreign R&D stock in semiconductor industry 1998-2005

Dependent Variable: Log industrial output (in 1,000 Yuan)

	(1) All semiconductor manufacturers	(2) All semiconductor manufacturers: R&D performers	(3) Global segment	(4) Global segment: R&D performers	(5) Domestic segment	(6) Domestic segment: R&D performers
Log Capital	0.0943	0.0741	0.1583	0.1385	0.0814	0.0799
	(0.0319)***	(0.0366)**	(0.0534)***	(0.0977)	(0.0402)**	(0.0429)*
Log Labor	0.1867	0.1614	0.2635	0.2579	0.1596	0.1560
	(0.0582)***	(0.0762)**	(0.0791)***	(0.1300)**	(0.0720)**	(0.0800)*
Log Material	0.5422	0.5840	0.4134	0.5050	0.5972	0.5802
	(0.0623)***	(0.0666)***	(0.1294)***	(0.1665)***	(0.0570)***	(0.0787)***
Log K_own	0.0011	0.0544	-0.0139	0.1634	0.0103	0.0400
	(0.0089)	(0.0320)*	(0.0278)	(0.1213)	(0.0115)	(0.0350)
Log K_ext_foreign	-0.8541	-0.5837	0.2005	0.2819	-0.7253	-0.5323
	(0.3893)**	(0.3544)	(1.8676)	(1.2147)	(0.3816)*	(0.3869)
Export ratio*Log K_own	-0.0081	0.0662	0.0044	0.0214	-0.0016	-0.0503
	(0.0123)	(0.0580)	(0.0316)	(0.1262)	(0.0313)	(0.0719)
Export ratio*LogK_ext_foreign	-0.0073	0.0113	-0.2782	-0.0503	-0.0726	-0.0349
	(0.0449)	(0.0580)	(0.1320)**	(0.1450)	(0.1228)	(0.1335)
Number of observations	1551	936	639	233	910	701
Number of firms	589	308	312	109	332	223
R-squared	0.68	0.70	0.72	0.82	0.66	0.62

Notes: Robust clustered standard errors in parentheses. The error terms are corrected for clustering for each firm. All the regressions include firm fixed effects and year dummies. The dependent variable is log output in 1998 price. The right-hand side variables include capital stock, labor, and materials in log terms deflated to 1998 price, adjusted for double-counting of R&D stock by subtracting R&D capital stock from capital, and R&D staff from labor. All the regressions exclude upper 1% outliers of capital, labor and material.
R&D performers are those firm-year observations with positive R&D stock.
*, **, *** significant at 10%, 5%, and 1% level.

Table 6. Return to R&D stock and spillovers from R&D stock in the global segment in semiconductor industry 1998-2005

Dependent Variable: Log industrial output (in 1,000 Yuan)

	(1) All semiconductor manufacturers	(2) All semiconductor manufacturers: R&D performers	(3) Global segment	(4) Global segment: R&D performers	(5) Domestic segment	(6) Domestic segment: R&D performers
Log Capital	0.0944	0.0740	0.1584	0.1386	0.0843	0.0822
	(0.0317)***	(0.0363)**	(0.0534)***	(0.0968)	(0.0397)**	(0.0422)*
Log Labor	0.1829	0.1598	0.2642	0.2539	0.1575	0.1545
	(0.0584)***	(0.0759)**	(0.0799)***	(0.1303)*	(0.0716)**	(0.0797)*
Log Material	0.5429	0.5845	0.4138	0.5057	0.5985	0.5813
	(0.0624)***	(0.0665)***	(0.1299)***	(0.1659)***	(0.0570)***	(0.0787)***
Log K_own	0.0022	0.0595	-0.0110	0.1556	0.0121	0.0442
	(0.0088)	(0.0315)*	(0.0278)	(0.1181)	(0.0115)	(0.0341)
Log K_ext_global	-0.5762	-0.4357	0.1596	0.2036	0.0928	0.0744
	(0.7280)	(0.7192)	(0.7243)	(0.5844)	(0.0272)***	(0.0303)**
Export ratio * Log K_own	-0.0109	0.0510	0.0020	0.0302	-0.0043	-0.0567
	(0.0123)	(0.0559)	(0.0317)	(0.1228)	(0.0312)	(0.0721)
Export ratio * Log K_ext_global	0.0175	0.0285	-0.1809	-0.0641	-0.0647	-0.0330
	(0.0352)	(0.0497)	(0.0978)*	(0.1166)	(0.0966)	(0.1114)
Number of observations	1551	936	639	233	910	701
Number of firms	589	308	312	109	332	223
R-squared	0.68	0.70	0.72	0.83	0.66	0.62

Notes: Robust clustered standard errors in parentheses. The error terms are corrected for clustering for each firm. All the regressions include firm fixed effects and year dummies. The dependent variable is log output in 1998 price. The right-hand side variables include capital stock, labor, and materials in log terms deflated to 1998 price, adjusted for double-counting of R&D stock by subtracting R&D capital stock from capital, and R&D staff from labor. All the regressions exclude upper 1% outliers of capital, labor and material. R&D performers are those firm-year observations with positive R&D stock.

*, **, *** significant at 10%, 5%, and 1% level.

Table 7. Return to R&D stock and spillovers from R&D stock in the domestic segment in semiconductor industry 1998-2005

Dependent Variable: Log industrial output (in 1,000 Yuan)

	(1) All semiconductor manufacturers	(2) All semiconductor manufacturers: R&D performers	(3) Global segment	(4) Global segment: R&D performers	(5) Domestic segment	(6) Domestic segment: R&D performers
Log Capital	0.0953	0.0759	0.1587	0.1369	0.0832	0.0822
	(0.0317)***	(0.0363)**	(0.0524)***	(0.0957)	(0.0397)**	(0.0424)*
Log Labor	0.1853	0.1616	0.2634	0.2575	0.1578	0.1546
	(0.0578)***	(0.0756)**	(0.0793)***	(0.1276)**	(0.0717)**	(0.0798)*
Log Material	0.5426	0.5846	0.4137	0.5062	0.5981	0.5811
	(0.0623)***	(0.0666)***	(0.1289)***	(0.1654)***	(0.0570)***	(0.0787)***
Log K_own	0.0001	0.0532	-0.0139	0.1641	0.0094	0.0423
	(0.0091)	(0.0336)	(0.0290)	(0.1292)	(0.0117)	(0.0366)
Log K_ext_domestic	-1.5675	-0.3124	0.8843	0.2734	-1.2307	-0.1707
	(1.3404)	(1.5415)	(0.2916)***	(0.2557)	(1.2822)	(1.2589)
Export ratio * Log K_own	-0.0060	0.0792	0.0045	0.0167	-0.0012	-0.0550
	(0.0126)	(0.0583)	(0.0333)	(0.1431)	(0.0313)	(0.0712)
Export ratio * Log K_ext_domestic	-0.0389	-0.0395	-0.5460	-0.1230	-0.1464	-0.0850
	(0.0931)	(0.1229)	(0.2710)**	(0.3158)	(0.2535)	(0.2745)
Number of observations	1551	936	639	233	910	701
Number of firms	589	308	312	109	332	223
R-squared	0.68	0.70	0.72	0.82	0.66	0.62

Notes: Robust clustered standard errors in parentheses. The error terms are corrected for clustering for each firm. All the regressions include firm fixed effects and year dummies. The dependent variable is log output in 1998 price. The right-hand side variables include capital stock, labor, and materials in log terms deflated to 1998 price, adjusted for double-counting of R&D stock by subtracting R&D capital stock from capital, and R&D staff from labor. All the regressions exclude upper 1% outliers of capital, labor and material.
R&D performers are those firm-year observations with positive R&D stock.
*, **, *** significant at 10%, 5%, and 1% level.

Table 8. Return to R&D stock and spillovers from R&D stock, with interactive terms, in semiconductor industry 1998-2005

Dependent Variable: Log industrial output (in 1,000 Yuan)

	(1) All semiconductor manufacturers	(2) All semiconductor manufacturers: R&D performers	(3) Global segment	(4) Global segment: R&D performers	(5) Domestic segment	(6) Domestic segment: R&D performers
Log Capital	0.0915	0.0751	0.1581	0.1402	0.0796	0.0808
	(0.0317)***	(0.0362)**	(0.0526)***	(0.0954)	(0.0396)**	(0.0424)*
Log Labor	0.1818	0.1587	0.2607	0.2901	0.1540	0.1541
	(0.0583)***	(0.0763)**	(0.0761)***	(0.1295)**	(0.0724)**	(0.0800)*
Log Material	0.5402	0.5832	0.4141	0.4992	0.5946	0.5812
	(0.0623)***	(0.0669)***	(0.1295)***	(0.1666)***	(0.0564)***	(0.0788)***
Log K_own	0.1223	-0.0719	-0.0379	0.6380	0.1823	-0.1107
	(0.0956)	(0.3055)	(0.1705)	(0.6854)	(0.1573)	(0.3598)
Log K_ext	-1.9440	-2.1430	-8.8548	6.3575	-0.9035	-1.5951
	(1.3267)	(1.9731)	(14.4424)	(13.0770)	(1.4245)	(2.0302)
Log K_own*log K_ext	-0.0077	0.0072	0.0018	-0.0273	-0.0111	0.0090
	(0.0058)	(0.0191)	(0.0101)	(0.0410)	(0.0098)	(0.0226)
Export ratio * Log K_own	-0.0065	0.0753	-0.0043	0.0154	0.0086	-0.0357
	(0.0123)	(0.0585)	(0.0284)	(0.1245)	(0.0317)	(0.0771)
Export ratio * Log K_ext	-0.0280	0.0078	-0.3185	-0.0127	-0.0767	-0.0672
	(0.0698)	(0.0844)	(0.1529)**	(0.2074)	(0.1755)	(0.2020)
Number of observations	1551	936	639	233	910	701
Number of firms	589	308	312	109	332	223
R-squared	0.69	0.70	0.72	0.83	0.67	0.62

Notes: Robust clustered standard errors in parentheses. The error terms are corrected for clustering for each firm. All the regressions include firm fixed effects and year dummies. The dependent variable is log output in 1998 price. The right-hand side variables include capital stock, labor, and materials in log terms deflated to 1998 price, adjusted for double-counting of R&D stock by subtracting R&D capital stock from capital, and R&D staff from labor. All the regressions exclude upper 1% outliers of capital, labor and material.
R&D performers are those firm-year observations with positive R&D stock.
*, **, *** significant at 10%, 5%, and 1% level.

Table 9. Return to R&D stock and spillovers from foreign R&D stock, with interactive terms, in semiconductor industry 1998-2005

Dependent Variable: Log industrial output (in 1,000 Yuan)

	(1) All semiconductor manufacturers	(2) All semiconductor manufacturers: R&D performers	(3) Global segment	(4) Global segment: R&D performers	(5) Domestic segment	(6) Domestic segment: R&D performers
Log Capital	0.0919	0.0739	0.1577	0.1425	0.0794	0.0795
	(0.0319)***	(0.0366)**	(0.0532)***	(0.0963)	(0.0401)**	(0.0431)*
Log Labor	0.1860	0.1607	0.2650	0.2877	0.1565	0.1556
	(0.0583)***	(0.0765)**	(0.0773)***	(0.1322)**	(0.0724)**	(0.0800)*
Log Material	0.5406	0.5847	0.4131	0.4965	0.5942	0.5809
	(0.0622)***	(0.0668)***	(0.1295)***	(0.1680)***	(0.0563)***	(0.0788)***
Log K_own	0.0889	-0.0130	0.0006	0.5407	0.1243	-0.0675
	(0.0646)	(0.1628)	(0.1101)	(0.4903)	(0.0996)	(0.1637)
Log K_ext_foreign	-0.5029	-0.7304	0.4037	1.5882	-0.4480	-0.7430
	(0.4295)	(0.5130)	(2.2983)	(2.0850)	(0.4156)	(0.5258)
Log K_own*log K_ext_foreign	-0.0058	0.0046	-0.0010	-0.0233	-0.0079	0.0074
	(0.0042)	(0.0109)	(0.0067)	(0.0314)	(0.0066)	(0.0114)
Export ratio * Log K_own	-0.0079	0.0660	0.0052	0.0134	0.0072	-0.0503
	(0.0122)	(0.0580)	(0.0307)	(0.1283)	(0.0318)	(0.0737)
Export ratio * Log K_ext_foreign	-0.0321	0.0101	-0.2873	-0.0353	-0.0581	-0.0475
	(0.0513)	(0.0582)	(0.1156)**	(0.1403)	(0.1253)	(0.1354)
Number of observations	1551	936	639	233	910	701
Number of firms	589	308	312	109	332	223
R-squared	0.68	0.70	0.72	0.83	0.67	0.62

Notes: Robust clustered standard errors in parentheses. The error terms are corrected for clustering for each firm. All the regressions include firm fixed effects and year dummies. The dependent variable is log output in 1998 price. The right-hand side variables include capital stock, labor, and materials in log terms deflated to 1998 price, adjusted for double-counting of R&D stock by subtracting R&D capital stock from capital, and R&D staff from labor. All the regressions exclude upper 1% outliers of capital, labor and material.
R&D performers are those firm-year observations with positive R&D stock.
*, **, *** significant at 10%, 5%, and 1% level.

Table 10. Return to R&D stock and spillovers in all manufacturing industries 1998-2005

Dependent Variable: Log industrial output (in 1,000 Yuan)

	(1) All manufacturers	(2) All manufacturers: R&D performers	(3) All manufacturers	(4) All manufacturers: R&D performers
Log Capital	0.0257	0.0262	0.0252	0.0256
	(0.0028)***	(0.0031)***	(0.0030)***	(0.0034)***
Log Labor	0.1184	0.0932	0.1195	0.0896
	(0.0052)***	(0.0062)***	(0.0057)***	(0.0072)***
Log Material	0.7352	0.7692	0.7336	0.7754
	(0.0083)***	(0.0104)***	(0.0091)***	(0.0124)***
Log K_own	0.0017	0.0172	0.0019	0.0155
	(0.0006)***	(0.0024)***	(0.0006)***	(0.0026)***
Log K_ext	0.0089	0.0131		
	(0.0019)***	(0.0023)***		
Log K_ext_foreign			-0.0002	0.0067
			(0.0006)	(0.0015)***
Export ratio * Log K_own	0.0026	-0.0058	0.0019	-0.0061
	(0.0013)**	(0.0054)	(0.0014)	(0.0059)
Export ratio * Log K_ext	-0.0089	-0.0153		
	(0.0034)***	(0.0055)***		
Export ratio * Log K_ext_foreign			-0.0022	-0.0104
			(0.0012)*	(0.0028)***
Number of observations	175146	88806	160763	74423
Number of firms	57236	25583	55079	23153
R-squared	0.75	0.77	0.75	0.76

Notes: Robust clustered standard errors in parentheses. The error terms are corrected for clustering for each firm. All the regressions include firm fixed effects and year dummies. The dependent variable is log output in 1998 price. The right-hand side variables include capital stock, labor, and materials in log terms deflated to 1998 price, adjusted for double-counting of R&D stock by subtracting R&D capital stock from capital, and R&D staff from labor. All the regressions exclude upper 1% outliers of capital, labor and material.
R&D performers are those firm-year observations with positive R&D stock.
*, **, *** significant at 10%, 5%, and 1% level.

Table 11. Return to R&D stock and spillovers in all manufacturing industries 1998-2005, with interactive terms

Dependent Variable: Log industrial output (in 1,000 Yuan)

	(1) All manufacturers	(2) All manufacturers: R&D performers	(3) All manufacturers	(4) All manufacturers: R&D performers
Log Capital	0.0256	0.0260	0.0253	0.0255
	(0.0028)***	(0.0031)***	(0.0030)***	(0.0034)***
Log Labor	0.1188	0.0931	0.1198	0.0894
	(0.0052)***	(0.0062)***	(0.0057)***	(0.0072)***
Log Material	0.7350	0.7688	0.7335	0.7753
	(0.0083)***	(0.0104)***	(0.0091)***	(0.0124)***
Log K_own	-0.0217	-0.0422	-0.0098	-0.0018
	(0.0037)***	(0.0123)***	(0.0017)***	(0.0073)
Log K_ext	0.0011	-0.0220		
	(0.0024)	(0.0075)***		
Log K_own*log K_ext	0.0016	0.0040		
	(0.0003)***	(0.0008)***		
Log K_ext_foreign			-0.0011	-0.0049
			(0.0006)*	(0.0050)
Log K_own*log K_ext_foreign			0.0010	0.0014
			(0.0001)***	(0.0006)**
Export ratio * Log K_own	0.0026	-0.0048	0.0015	-0.0061
	(0.0013)**	(0.0054)	(0.0014)	(0.0059)
Export ratio * Log K_ext	-0.0058	-0.0163		
	(0.0034)*	(0.0055)***		
Export ratio * Log K_ext_foreign			-0.0025	-0.0104
			(0.0012)**	(0.0028)***
Number of observations	175146	88806	160763	74423
Number of firms	57236	25583	55079	23153
R-squared	0.75	0.77	0.75	0.76

Notes: Robust clustered standard errors in parentheses. The error terms are corrected for clustering for each firm. All the regressions include firm fixed effects and year dummies. The dependent variable is log output in 1998 price. The right-hand side variables include capital stock, labor, and materials in log terms deflated to 1998 price, adjusted for double-counting of R&D stock by subtracting R&D capital stock from capital, and R&D staff from labor. All the regressions exclude upper 1% outliers of capital, labor and material.
R&D performers are those firm-year observations with positive R&D stock.
*, **, *** significant at 10%, 5%, and 1% level.

Figure 1: Spillovers between key segments of the Chinese semiconductor industry

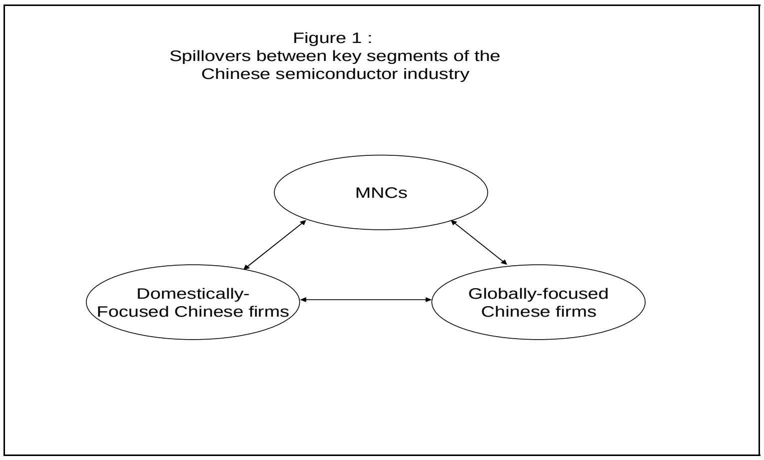


Figure 2: Export ratio of semiconductor industry firms

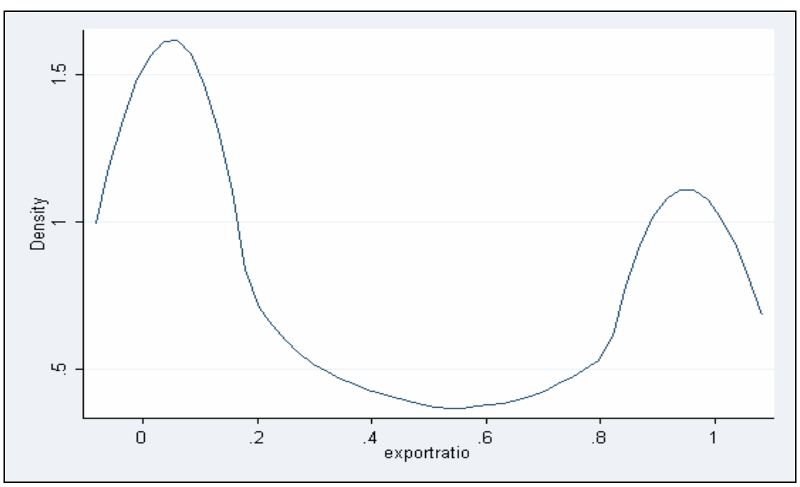


Figure 3: Total output of the two segments in semiconductor industry

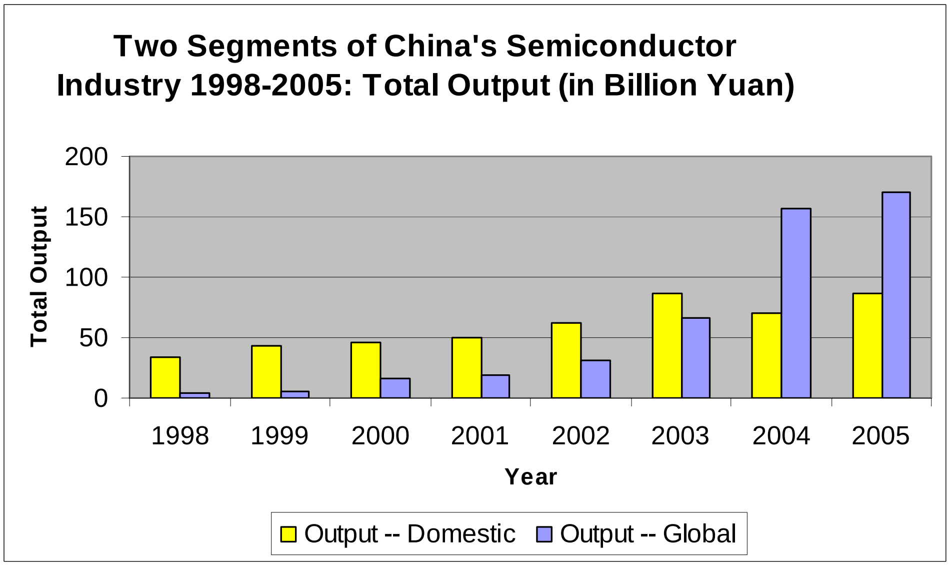


Figure 4: Total employment of the two segments in semiconductor industry

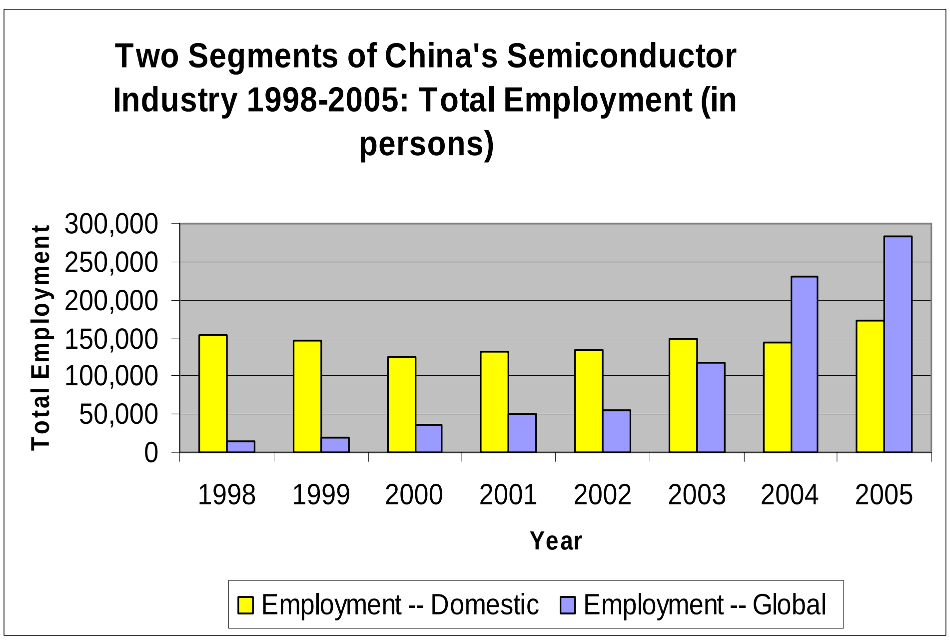


Figure 5: Total number of firms in the two segments in semiconductor industry

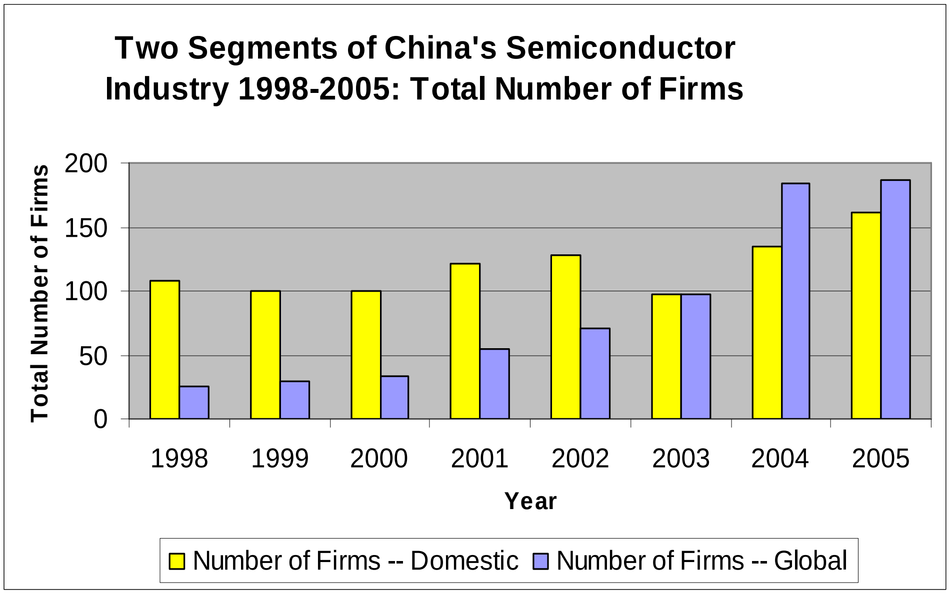
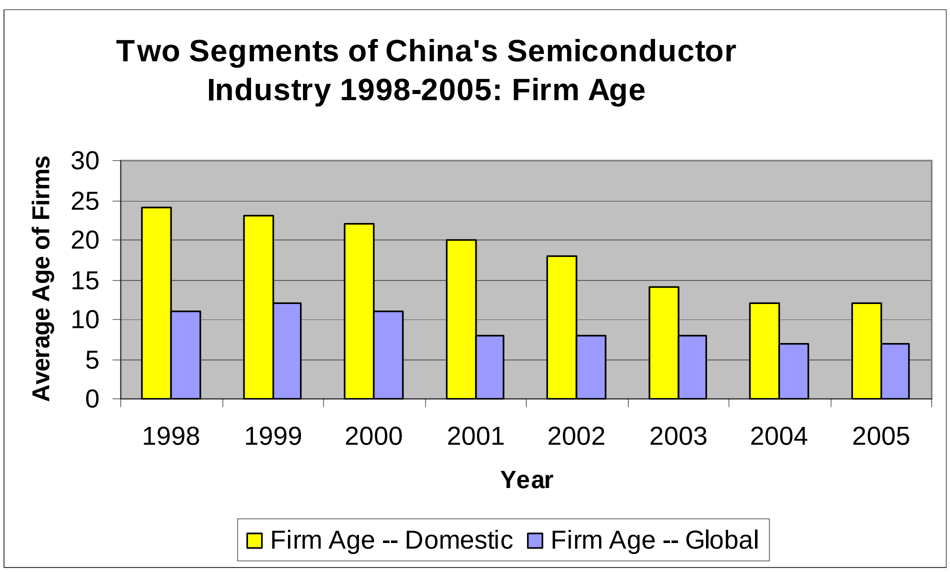


Figure 6: Firm age in the two segments in semiconductor industry



Appendix: Additional Tables and Graphs

Table A1. Summary statistics of all manufacturing firms in China 1998-2005

Variable	Number of Observations	Mean	Standard Deviation	Min	Max
Output (1,000 Yuan*)	188,092	335,720.10	1601451.00	0	139,000,000
Value-added (1,000 Yuan)	188,403	101,155.90	757122.40	-38,600,000	125,000,000
Employment (persons)	188,092	1,320.05	3760.19	0	194,410
Fixed Asset (1,000 Yuan)	188,076	186,364.30	1145554.00	-10,180	125,000,000
Material (1,000 Yuan)	188,075	248,730.70	1171629.00	0	119,000,000
Long-term Investment (1,000 Yuan)	188,076	28,777.46	1311404.00	-425,223	410,000,000
Profit (1,000 Yuan)	188,075	20,714.17	432788.30	-4,859,210	101,000,000
Return on Asset	186,939	-0.03	0.10	-3.68	2.98
Export Ratio	186,397	0.17	0.32	0	1
R&D Expenditure/Sales	142,340	0.01	1.06	0	392.37
R&D Staff/Employment	187,322	0.02	0.25	0	51
Firm Age	188,839	20.61	18.26	0	208
Science & Technology Expenditure (1,000 Yuan)	188,332	5,787.75	49150.31	0	4,641,700
Science & Technology Stock (1,000 Yuan)	185,098	22,608.30	159340.40	0	16,000,000

* The official exchange rate between Yuan and US$ is 8.27 Yuan/US$ 1998-2005.

Table A2. Pair-wise correlation matrix of key variables for all manufacturing firms

	1	2	3	4	5	6	7	8
1. Log Output	1							
2. Log C	0.53	1						
3. Log L	0.53	0.51	1					
4. Log M	0.93	0.55	0.51	1				
5. Log knowledge stock	0.27	0.25	0.28	0.25	1			
6. Log external knowledge stock	0.22	0.15	0.15	0.20	0.18	1		
7. Log external foreign knowledge stock	0.11	-0.08	-0.07	0.11	0.11	0.51	1	
8. Export ratio	0.11	-0.08	0.05	0.10	-0.11	-0.09	0.14	1

Note: All the correlations are significant at 1% level.

Table A3. Summary statistics of the two segments in the semiconductor industry 1998 and 2005

Variable	Domestic-oriented segment		Global-oriented segment	
	1998	2005	1998	2005
Number of firms	108	161	25	187
Output (1,000 Yuan*)	309,218.69	533,085.60	154,990.28	913,839.68
Employment (persons)	1,429	1,077	612	1,509
Fixed Asset (1,000 Yuan)	223,049.04	286,956.10	142,126.88	452,064.36
Profit (1,000 Yuan)	2,814.66	10,481.65	1,026.84	18,824.34
Return on Asset	0	0.05	0	0.04
Export Ratio	0.07	0.13	0.8	0.88
R&D Expenditure/Sales	--	0.03	--	0.02
R&D Staff/Employment	0.03	0.07	0.01	0.02
Firm Age	24	12	11	7
State-owned share	0.67	0.12	0.19	0.02
Foreign-owned share	0.06	0.26	0.2	0.57

* The official exchange rate between Yuan and US$ is 8.27 Yuan/US$ 1998-2005.

Note: The statistics shown in this table are means of the variables except the number of firms.