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Institutional Support, Technological Capabilities and Domestic Linkages in the Semiconductor Industry in Singapore*

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Abstract: *This article examines the relationships between host-site institutional support and firm-level technological upgrading, and between technological upgrading and domestic production linkages in the semiconductor industry in Singapore. An evolutionary perspective was used to measure technological capabilities using knowledge embodied in machinery, organization, processes and products. The results show that host-site institutional support is important for technological upgrading and technological capabilities are positively correlated with domestic linkages. Also, domestic linkages rather than regional linkages were correlated with technological upgrading, which is a consequence of Singapore's sophisticated infrastructure compared to its neighbours in Southeast Asia.*

***Keywords*:** domestic production linkages; institutional support; semiconductors; Singapore; technological capabilities

JEL Classification: L62, L22, L14, O31

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1. Introduction

Semiconductor firms were among the early multinational corporations to relocate production in Singapore in the late 1960s. National Semiconductor and later Fairchild relocated assembly activities in Singapore in 1969. By the mid-1970s Texas Instruments, Fairchild, Motorola, National Semiconductor, Signetics, Radio Company of America (RCA), Intel, American Microsystems and Mostek had started massive production activities in Singapore. Whereas Fairchild and Motorola have since been sold to Schlumberger and Freescale, national firms such as Carter Semiconductor and Avago entered semiconductor production. Meanwhile, the Taiwanese firms of United Microelectronics Company (UMC), Taiwan Semiconductor Manufacturing Corporation (TSMC) and Advanced Semiconductor Equipment (ASE) have entered production to raise Singapore as a major exporter of semiconductor devices in the world.

The Economic Development Board (EDB) has been at the forefront promoting the relocation of foreign MNCs from the late 1960s, and since the 1980s instrumental in pursuing a leveraging strategy to stimulate technological upgrading into high value added activities such as chip design, wafer fabrication and R&D support activities. The country's sovereign wealth fund, i.e. Temasik Holdings has also supported acquisition of semiconductor firms, such as, Carter Semiconductor.

In light of the questions posed in the first article we seek to test the hypotheses: one, institutions in support for high tech activities are positively correlated with firm-level technological capabilities and two, technological capabilities support positively domestic production linkages. The focus on domestic as opposed to regional production linkages is targeted at analysing Singapore's advanced institutional support activities. The rest of the article is organized as follows. Section 2 discusses the importance of the semiconductor industry to the Singapore's economy. Section 3 reviews past literature on technological upgrading in the semiconductor industry in Singapore. Section 4 presented the methodology and data used in testing the two hypotheses. Section 5 evaluates the importance of institutional support and regional production links on technological capabilities. Section 6 concludes

2. Why the Semiconductors Industry in Singapore?

When National Semiconductor and Fairchild relocated operations in 1969 they were among pioneering foreign MNCs that initiated modern manufacturing in Singapore. Being a high technology industry semiconductor operations have continued to remain important as Singapore grew rapidly to become a developed country where only high value added operations could be sustained in an economy where wages are high. Given the importance of integrated circuits in driving technological upgrading in other industries, the industry has also received massive government support.

2.1. Importance to the National Economy

As shown in Table 1, the contribution of the electronics industry in Singapore's economy has been substantial. Although the employment share fell from 115 thousand in 1990 to 102 thousand in 2000 and 82 thousand in 2010, value added in 1990 prices rose from US$7.4 billion in 1990 to US$14.9 billion in 2000 and US$15.1 billion in 2010. Value added grew at 7.3 percent per annum on average in 1990-2000 but slowed down considerably to 0.13 percent in 2000-2010. The slowdown in the second period is a consequence of the global financial crisis of 2008-09 when electronics exports collapsed.

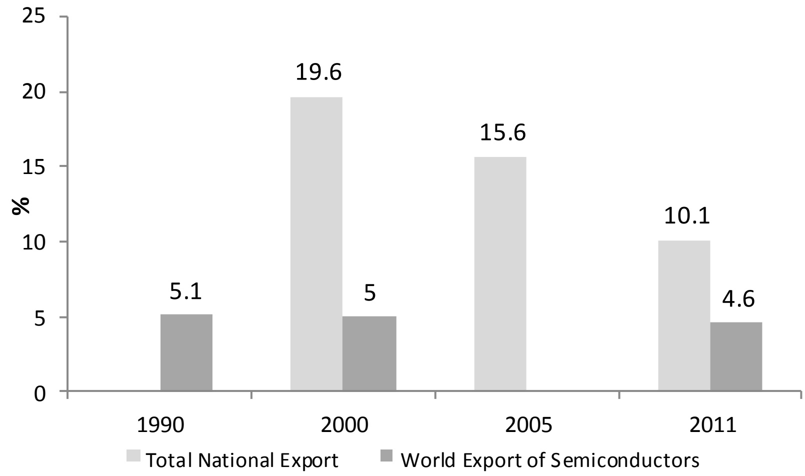
Table 1 Share of employment and value added in manufacturing, electronics, Singapore. 1990-2010

Year	Employment	Value Added (US$ Millions in 1990 prices)	Share in Manufacturing (%)	
			Employment	Value Added
1990	115,166	7,357.9	32.8	79.1
2000	102,149	14,898.6	33.2	71.9
2010	81,950	15,097.1	19.8	41.2

Source: Huff (1994); Singapore Department of Statistics (2012).

The significance of semiconductors to Singapore's economy can also be observed in the share of electronics component exports. Singapore accounted for 5.1 percent of world export of electronics components in 1990, a share that has fell slightly to 4.6 percent in 2011 (see Figure 1). The share of electronics components in the overall exports from Singapore fell from 19.6 percent in 2000 to 10.1 percent in 2011.[1]

Figure 1: Share in exports, semiconductors, Singapore, 1990-2011



Source: Computed from WTO (various issues).

Whereas semiconductor imports have continued to grow strongly over the period 1990-2011, exports fell in the period 2000-2005 (see Table 2). The fall in exports is largely a consequence of restructuring within the industry as less technology-intensive production was relocated out. The expansion in wafer fabrication helped raise exports again in 2011. Hence, the trade balance coefficient rose consistently from a negative -0.14 in 1990 to 0.03 in 2000 and 0.18 in 2011. The revealed comparative advantage (RCA) for semiconductors from Singapore stayed strong over the period 1990-2011 despite falling from 26.7 in 2000 to 14.2 in 2011.

[1] We only considered domestic exports excluding in the process re-exports.

Table 2 Trade indicators, semiconductors, Singapore, 1990-2011

	1990	1995	2000	2005	2011
Exports (US$ Billions)	6.0	25.5	137.8	66.2	101.0
Imports (US$ Billions)	8.0	30.5	40.5	53.2	70.7
TB*	-0.14	-0.09	0.03	0.11	0.18
RCA	22.0	22.8	26.7	21.6	14.2

Note: Trade Balance (TB) coefficient measured using the formula (exports-imports)/ (exports+imports); revealed comparative advantage (RCA) measured by dividing the share of exports of semiconductors in overall national exports with its share in global semiconductor exports.
Source: Computed from COMTRADE (2012).

2.2. Government Promotion

The Economic Development Board (EDB) of Singapore began to attract foreign multinationals since the late 1960s, which were originally focused on just investment and employment generation. As the surplus labour quickly evaporated, the EDB began to target technology transformation into higher value added activities. The government introduced the skills development fund in 1979, which was the targeted at stimulating high value added activities in the country. As the instrument of the government, the EDB coordinated its activities through tripartite lines to restructure the economy through coordination with the National Trade Unions Council and foreign multinational corporations to stimulate technological upgrading (Wong, 1999). Efforts to encourage technological upgrading enjoyed strong firm-level boost as semiconductor assembly and test operations was becoming increasingly knowledge-intensive.

The government of Singapore was the first to promote growth triangles in Southeast Asia following the efforts of then Singapore's first Deputy Prime Minister, Goh Chok Tong, to establish the Singapore, Johore and Rhiau (SIJORI) growth triangle in 1989. The focus then was on encouraging a regional division of labour in which Singapore will specialize on high value added and high technology manufacturing and services, while Johore will specialize on medium technologies and Rhiau on low end labour-intensive technologies. This arrangement was subsequently transformed to a wider arrangement when the Indonesia-Malaysia and Singapore Growth Triangle (IMS-GT) was established in 1994 (Majid, 2010). It subsequently led to the development of the Batam, Bintan, Karimun Free Trade Zone in the Rhiau Islands with strong support from Temasik Holdings, which is sovereign wealth fund from Singapore. The implications of this arrangement are that electronics firms enjoying special incentives in the FTZ in Rhiau only export low end products to Singapore. Similarly, the firms enjoying contract services with electronics firms in Singapore also export low-end inputs to Singapore.[2] Hence, regional linkages will have no bearing for stimulating technological upgrading in Singapore.

The government strengthened its host sites institutions further by offering R&D grants, equity in high tech firms and R&D laboratories from the 1990s (Mathews, 1999). Hence, domestic linkages, especially through the acquisition of fabricated wafers from firms, such as, United Microelectronics Company and Taiwan Semiconductor Manufacturing Corporation, or sales to Advanced Semiconductor Engineering helped spur further technological upgrading in Singapore. Such purchases and sales obviously show higher technological intensities and value added activities than imports from Indonesia and Malaysia.[3] Apart from foreign MNCs, national firms, such as, Avago and Carter Semiconductor began to take advantage of incentives and grants from the government, as well as, wafer fabrication activities by foreign MNCs in Singapore to expand into high tech operations in the semiconductor industry. Indeed, Singapore had upgraded so much that trade with its neighbours of China, Malaysia, Philippines and Indonesia took a technical division of labour that placed Singapore with higher value added against lower value added stages in China, Malaysia, Philippines and Indonesia.

3. Theoretical Considerations

The two key relationships we seek to examine are the influence of host-site institutional support facilities on technological capabilities (*TC*), and the influence of regional trade linkages (*RL*) on technological capabilities. In doing so we have avoided examining the much researched link between exports and technological capabilities. While the former is little tested in the developing regions, the latter is important because of the growing importance of East Asia in global economic growth. The concepts of TC and RL have been defined in Rasiah, Kimura and Oum (2015).

3.1. Host-site Institutional Support and Technological Capabilities

The importance of host-site institutional support to stimulate the upgrading of technological capabilities was first discussed by industrial policy exponents (Smith, 1776;

[2] Interview by the authors with Johore state officials on December 15 2012 in Johor Bharu.
[3] We obtained this evidence from a questionnaire administered to both semiconductor firms and their suppliers and purchasers in 2012.

Hamilton, 1791; List, 1885). North (1991) referred to institutions as the ‘rules of the game’ and organizations and entrepreneurs as ‘the players’. Williamson (1985) associated institutions with “governing structures” that mould economic activity, like a nation’s financial “institutions”, or the way firms tend to be organized and managed.

Host-site institutions and meso organizations associated with generating and stimulating knowledge flows are critical to attract the relocation of high tech firms or for existing firms to upgrade technological capabilities. In the developed countries of United States, Germany and Japan, and the recently developed countries of South Korea, Taiwan and Singapore, the government is a major financier of public goods, including knowledge generation through the provision of R&D grants (OECD, 2013).

Where foreign multinationals have stimulated technology transfer to national firms, they are unlikely to relocate frontier R&D activities at host sites unless it involves the exploration or development of rare host-site resources, or when the host site is endowed with strong research-based universities. Also, there is evidence of multinationals undertaking R&D in pharmaceuticals in the developing economies owing to the availability of rare flora and human capital (Rasiah, 2006), and off-shoring of electronics R&D to benefit from strong high tech support institutions in Taiwan (Ernst, 2006). Motives of multinationals matter in such relocation decisions (see Cantwell and Mudambi, 2005). Also, in the integrated circuits industry there is only evidence of MNCs’ frontier R&D activities being relocated at host-sites endowed with strong research universities, e.g. Samsung Semiconductor and Taiwan Semiconductor Manufacturing Company in the United States (Gartner, 2013).

Although employees in firms gain significant knowledge through training and learning by doing in firms (Marshall, 1890; Penrose, 1959), universities and R&D laboratories are important nodes of knowledge that firms access through hiring graduates, contract training projects and R&D activities. Especially in high tech industries firms rely extensively on hiring competent engineers and scientists to carry out R&D and commercialization activities (Nelson, 1993).

While it is important that host-site organizations participate in generating knowledge, it is also critical that they are cohesively integrated with firms (Mytelka, 2000). Nelson (2008), Lundvall (1992) and Edquist (2004) addressed the importance of interdependent and interactive links between firms and organizations. Connectivity and coordination is critical for knowledge flows – beyond simply codified information that markets can coordinate. The focus is really on technological capabilities that are evolved in firms through linkages with high tech organizations such as training institutes, standards organizations and R&D laboratories. Thus, we hypothesize that firm-level *TC* is correlated with host-site *HI.*

3.2. Domestic Linkages and Technological Capabilities

The rapid expansion of East Asia has attracted a number of theories on regional trade linkages. Regional trade and investment linkages in East Asia can be first traced to Akamatsu (1962). Subsequently, Krugman's (1991) work on the new geography that discusses economic integration and its effects on growth synergies has become important.

Unlike typical developing economies integrating regionally in the presence of technological sophisticated economies, firms in Singapore had already upgraded their technological capabilities significantly over four decades. Hence, the Akamatsu (1962) framework would mean that firms in Singapore (which is a first-tier wedge country behind Japan) would rely little from trade with firms in the less developed economies of East Asia, such as Malaysia, Indonesia and China (Rasiah, Kimura and Oum, 2015). It is for these reasons we chose domestic linkages as sales and purchases to suppliers and buyers in Singapore will apply higher pressure to raise firm-level technological capabilities.

Singapore as a large metropolitan city-state supports Krugman's (1991) new geography argument that explains economic growth on the basis of geographical proximity as economies become increasingly more integrated. The city state has developed extensively its high technology infrastructure to stimulate the upgrading of firm-level technological capabilities.

While firms have evolved strongly in Japan, South Korea and Taiwan, Singapore's high technology infrastructure and sophisticated buyer-supplier networks have ensured that domestic demand-supply buyer-seller influences on firm-level technological upgrading has become important. Because most semiconductor trade in East Asia is conducted with China, Indonesia, Philippines and Malaysia, which are all characterized by technologically inferior firms than Singapore, we examine the influence of domestic linkages on firm-level technological capabilities.[4]

4. Review of past works on Singapore

[4] Econometric tests between regional linkages and technological capability were not significant.

Work on technology development in the semiconductor industry in Singapore is somewhat sketchy and is primarily located within the broader electronics industry. Mathews and Cho (2000) are an exception as they provide the dominant role of the government in pursuing a leveraging strategy to stimulate upgrading in the industry, while Hobday (1995) offered evidence of growing incidence of innovation by semiconductor MNCs in Singapore.

Hence, Hobday (1995) observed considerable incremental innovations taking place in foreign MNCs in Singapore. This initiative received a boost when Hewlett Packard chose to relocate back-end wafer fabrication activities in Singapore in 1985. The government then assumed a leveraging strategy to coordinate further upgrading in the country (see Mathews and Cho, 2000; Mathews, 1999). The government's twin strategy of taking equity and providing buildings and R&D labs, and enhancement of the infrastructure with cutting edge environment-friendly mechanisms to support wafer fabrication activities attracted a massive relocation of wafer fabrication plants. In addition to working directly with the MNCs, the EDB also coordinates upgrading initiatives through strong interaction with the Association of Electronics Industries of Singapore (AEIS) and the Singapore Manufacturers' Federation (Santiago, 2007, 14).

Singapore managed to offer cutting edge waste treatment, uniform band-power, grants for high technology activities – chip design, wafer fabrication, supportive R&D and even high tech assembly and test services – has attract level 5 knowledge activities if one uses Rasiah's (2010) 1-6 classification of knowledge-based activities in the semiconductor industry. Levels 5 and 6 knowledge activities in Rasiah's typology refer to firms undertaking R&D in-house, while level 6 is devoted to frontier R&D in which the firm shapes the technology frontier by launching the products first. Consistent with Amsden and Tschang's (2003) classification of MNC activities in Singapore, the R&D activities undertaken in the country are not new to the universe. The supporting services that have help make the semiconductor industry in Singapore an integrated include the production of silicon wafers, photo-masks and a highly pure hydrogen peroxide (Santiago, 2007, 14).

The aggressive promotional and leveraging efforts of EDB transformed the semiconductor industry to attract almost all the stages of the value chain. There were 10 national and 24 foreign semiconductor firms in Singapore in 2011 (Gartner, 2011a; 2011b). The breakdown of the national firms included Avago attempting to undertake frontier R&D, though, it is still behind Korean and Taiwanese firms in R&D activities.[5] The remaining national firms were engaged in chip design (1), supportive R&D activities (1), wafer fabrication (3) and assembly and test activities (4). No foreign firm was engaged in frontier R&D activities in Singapore, while among foreign MNCs, 7 firms were engaged in chip design, 1 in supportive R&D, 4 in wafer fabrication and 12 in assembly and test activities. Some firms had more than 1 wafer fabrication plants.

5. Methodology and Data

Taking the cue from the introduction to this special issue (Rasiah, Kimura, and Sothea 2015), the exercise focuses on answering the questions of whether host-site institutional support matters to explain technological upgrading, and whether technological capabilities are important in firms' participation in domestic production linkages. As review in the previous section shows no works have examined robustly these relationships on the semiconductor industry in Singapore.

Hence, the analytic framework focuses directly on the statistical relationship between high tech institutional support and technological capability, and technological capability and domestic production linkages. The dependent variables examined in this article are technological capability and domestic production linkages. In the first the focus is on examining the influence of host-site institutional support on technological capabilities, while in the second the focus is on the influence of technological capabilities on domestic production linkages.

5.1. Specification of Variables

The variables for examining the statistical relationships are specified in this section.

5.1.1. Dependent variables

Technological capability (TC) was estimated using the following 6 proxies:

$$TC - f\,(CIQT, AC, PD, RD, TE, PAT)$$

[5] Interviews by authors in 2012.

Where *CIQT* refers to cutting-edge inventory and quality control techniques (*CIQT*) of statistical process control (*SPC*), quality control circles (*QCC*), any one of the international standards organization (*ISO*) series, total preventive maintenance (*TPM*), integrated materials resource planning (*MRP2*) and total quality management (*TQM*). A score of 1 was added for presence of each of these techniques; AC refers to the presence of adaptive capabilities (*AC*) on processes, layouts, machinery and products. A score of 1 was added for the presence of each of them; *PD* refers to the presence of product development (*PD*) which is counted as 1 if it exists and 0 otherwise; *RD* refers to R&D expenditure as a share of sales; *TE* refers to training expenditure as a share of payroll; *PAT* refers to the number of patents taken in the United States. The normalization formula $(X_i-X_{min})/(X_{max}-X_{min})$ was used to convert each of the 6 proxies to the range of 0-1 before they are added; X_i, X_{min} *and* X_{max} refers to the observed, minimum and maximum values respectively.

Domestic production linkages (DL) was estimated using the following formula:

$$DL = DS/TS + DP/TP$$

Where *RS/TS* refers to percentage share of intermediate sales in total sales to firms in East and Southeast Asia; *RP/TP* percentage share of intermediate purchases in total purchases from East and Southeast Asia.

5.1.2. Explanatory Variables

High tech institutional (*HI*) support was estimated using the following formula:

$$HI - f\ (RDG, RU, RDSE)$$

Where *RDG* refers to *R&D* grants enjoyed by the firm from the host government (Yes=1; No=0); *RU* refers to firms' Likert scale (1-5) rating of presence of research universities; *RDSE* refers to firms' Likert scale (1-5) rating of presence of strong supply of R&D scientists and engineers. *TC* is also used as the explanatory variable when examining *RL* as the dependent variable.

5.1.3. Control Variables

Size was dropped from the list of control variables used because of colinearity problems with *HI* and *DL*. Foreign ownership *(FO)*, and age (*A*) were used as the control variables, and were measured as follows:

$$FO = FE/TE$$

Where *FE/TE* refers to percentage share of foreign equity in total equity.

$$A = \textit{age of the firm}$$

All figures used were from year 2011 unless otherwise stated.

5.2. Specification of OLS regressions

We found the ordinary least squares (OLS) regressions robust enough as the constant was not significant suggesting that the model did not suffer from endogeneity problems. The OLS model used to analyse the existence of a statistical relationship between *TC* and *HI*, and between *DL* and *TC* are presented in models (1) and (2). *FO* and *A* are the control variables used in Equation 1. We did not use size as a control variable because of colinearity problems with *HI*.

$$TC = \alpha + \beta_1 HI + \beta_2 FO + \beta_3 A + \mu \qquad (1)$$

The second OLS regression was targeted at examining the relationship between TC and DL. Again FO and A were used as the control variables.

$$TC = \alpha + \beta_1 DL + \beta_2 A + \beta_3 FO + \mu \qquad (2)$$

Where *DL* is the explanatory variable, and *FO* and *A* are the control variables.

5.3. Data

A stratified random sampling procedure based on ownership was adopted to gather data from the semiconductor industry in Singapore. The data collection instrument used comes from a refined version of questionnaires used in previous studies by Rasiah (2010). Although data on employment, sales, exports, R&D expenditure and training expenditure were drawn for the years 2000, 2006 and 2011, the analysis is confined to 2011 as the data on most technological, human capital and institutional support proxies were limited to only 2011.

The survey questionnaire was sent to all semiconductor firms in Singapore. The response rate was 57 percent, which was 11 foreign and 4 national firms of the population of 22 and 7 foreign and national firms respectively in 2012 (Table 3). We managed to obtain responses from all the 9 foreign and 16 national supporting firms strongly production linked but in complementary activities in machinery and equipment and plastic materials. These firms were identified from the 15 semiconductor firms that participated in the survey. Hence, the empirical analysis is based on a semiconductor cluster totalling 40 firms.

Table 3 Semiconductor cluster sample by ownership, Singapore, 2012

	Foreign	National
Sample	**11**	**4**
Population	*22*	*7*
Percentage	*50%*	*57%*
Semiconductor Supporting firms	**9**	**16**
Overall Semiconductor Cluster sample	20	20

Source: Authors' survey (2013); Department of Statistics Singapore (2012).

6. Findings

We analyse in this section the empirical evidence collected from the Singapore semiconductor cluster sample. The first part focuses on technological deepening, export-intensity and domestic purchases and sales in total sales and purchases. The second examines the descriptive statistics using the Levene's two-tailed t-test with a focus on means. The third evaluates the results of the simultaneous equations on the relationship between host-site institutional support and domestic linkages, and firm-level technological upgrading.

6.1. Upgrading, Export-intensity and Domestic Linkages Trends

Firm-level R&D expenditure in sales rose from 1.2 percent in 2000 to 5.6 percent in 2006 and 6.9 percent in 20011 (see Table 4). R&D personnel in the workforce rose from

1.6 percent in 2000 to 3.2 percent in 2006 and 3.5 percent in 2011. Both indicators of technological deepening shows increasing intensities over the 2000-11 period.

Export-intensity of output rose from 20 percent in 2000 to 38.3 percent in 2006 and 48.8 percent in 2011. Domestic linkages (sales to and purchases from Singapore) in total sales and purchases rose from 27.4 percent in 2000 to 38.3 percent in 2006 but fell to 29.4 percent in 2011. Sales to and purchases from Singapore and East Asia in total sales and purchases rose from 70.7 percent in 2000 to 103.3 percent in 2006 before falling to 101.4 percent in 2011.

Table 4 Technology and export structure, semiconductors, Singapore, 2000-2012

	2000	2006	2012
RDE/S (%)	1.2	5.6	6.9
RDP/W (%)	1.6	3.2	3.5
X/Y (%)	20.0	36.8	48.8
DL (%)	27.4	38.3	29.4
RL (%)	70.7	103.3	101.4
N	26	37	40

Source: Authors' survey (2013).

6.2. Descriptive Statistics

The descriptive statistics of the dependent and independent variables are shown in Table 5. The mean and median of the variables TC and DL are fairly even, which explains why the standard deviation is fairly low. The Jarque-Bera statistics show that the distribution for the variables *TC*, *DL*, *RL*, *HI* and *A* are normal (p>0.05). The distribution of the data for the variables *FO* and *S* are not normal. The mean and median of *TC* were 2.1 and 2.1 respectively, while the mean and median of *DL* was 36.4 and 35.0 respectively.

Given the maximum possible score of 15 for *HI*, the mean (9.9) and medians (10.0) are high and the highest score achieved is 14, while the lowest is 3. The firms in the sample show mean and median ages of 16.8 and 14 years respectively with a minimum age of 3 years and a maximum age of 41 years in 2011. The mean (1101.5) and median (550.0) employment sizes were considerably different, which is because of the wide dispersion (std. dev: 1475.0) firm size with the largest firm employing 7,500 employees while the smallest firm employing 9 employees. HC had a mean and median of 58.8 and 53.5 respectively with maximum and minimum percentages of 100 and 21 respectively.

Table 5: Descriptive statistics of selected variables, semiconductor firms, Singapore, 2012

	TC	***DL***	***HI***	***A***	***FO***	***S***	***HC***
Mean	2.095	36.402	9.875	16.800	0.500	1101.450	58.825
Median	2.087	35.000	10.000	14.000	0.500	550.000	53.500
Maximum	6.379	89.999	14.000	41.000	1.000	7500.000	100.000
Minimum	1.000	0.000	3.000	3.000	0.000	9.000	21.000
Std. Dev.	0.591	19.831	1.682	10.008	0.506	1474.977	21.631
Skewness	1.040	0.611	-1.437	0.492	0.000	2.677	0.512
Kurtosis	3.104	3.629	4.802	2.216	1.000	10.944	2.295
Jarque-Bera	4.281	2.993	5.034	2.637	6.667	152.962	2.579
P-value	0.061	0.224	0.056	0.268	0.036	0.000	0.275
Sum	83.806	1383.264	266.000	672.000	20.000	44058.000	2353.000
Sum Sq. Dev.	13.623	14551.73	81.100	3906.400	10.000	84846742	18247.780
N	40	40	40	40	40	40	40

Source: Computed from authors' survey (2013).

6.3. Statistical Relationships

The statistical analysis establishing the relationship between TC and DL, and HI and TC respectively is undertaken in this section. We present technological deepening over the period 2000-2011 in the first sub-section, the descriptive statistics in the second sub-section, and subsequently the two-stage regression results in the next sub-section.

The model fit (*F-stats*.) for the two equations was run to examine the relationship between *TC* and *HI*, and *DL* and *TC* were significant, and hence, the results are interpreted in this section.

6.3.1. Technological Capabilities

The OLS regression results show that the model fit was significant at the 5 percent level (see Table 6). Among the independent variables only HI was significant. The insignificant constant shows that the results do not suffer from endogeneity problems. FO is not significant suggesting that there is no obvious statistical difference in the technological capabilities of foreign and domestic firms in the semiconductor firms in Singapore. The results show that host-site institutional support has a bearing on firm-level technological capabilities of semiconductor firms in Singapore.

Table 6: OLS regression, semiconductors, Singapore, 2012
Dependent variable: *TC*
Explanatory variable: *HI*

	Coeff.	T-stat.	P-value
C	0.298	0.933	0.357
HI	0.060	0.039	0.047^{**}
A	0.117	0.188	0.121
FO	0.002	0.016	0.988
N	40		
R^2	0.144		
$\bar{R}^2$	0.073		
F-stat	3.026		0.051^{*}

Note: * and ** refer to statistical significance at 10% and 5% respectively.
Source: Authors' survey (2013).

6.3.1. Domestic Linkages

The relationship between domestic linkages and technological capabilities was also significant (see Table 7). The OLS regression results show that DL is positively correlated with TC at 1 percent significance level. The influence of DL on TC appears stronger than the influence of host-site high tech institutional support on TC underlining the importance of domestic linkages in stimulating upgrading of firm-level technological capabilities in semiconductor firms. FO was not significant suggesting that there was not obvious difference in domestic sales and purchases by ownership among semiconductor firms in Singapore. The results did not suffer from endogeneity problems as the constant was not significant.

Table 7: OLS Regressions, semiconductors, Singapore, 2012
Dependent variable: *TC*
Explanatory variable: *DL*

	Coeff.	***T-stat.***	***P-value***
C	7.064	0.496	0.623
TC	31.774	3.560	0.001***
A	-1.332	-0.292	0.772
FO	2.109	0.374	0.711
N	40		
R^2	0.280		
$\bar{R}^2$	0.217		
F-stat	4.418		0.009***

Note: *** refer to statistical significance at 1%.
Source: Authors' survey (2013).

Taken together, the results show that TC is correlated with both institutional support, as well as, domestic linkages. The supply of R&D engineers and scientists, R&D grants, and support from universities and R&D labs has been viewed by firms as important in stimulating technological upgrading. Firm-level technological upgrading has also been important to drive strong domestic linkages to purchasers and buyers.

7. Conclusions

The semiconductor industry has obviously been a major industry in the economy of Singapore since its birth in 1969. In addition to contributing significantly to employment, value added and exports, the industry has also been a major platform in which rapid technological upgrading has enabled Singapore to enjoy high per capita incomes. The incentive system in Singapore has attracted significant participation by foreign MNCs and national firms in the high value added activities of chip design, wafer fabrication and R&D support. The aggressive leveraging strategy adopted by the EDB and equity taken by the government have been the focal point of technological upgrading in the country.

The statistical analysis showed that TC is correlated with institutional support, and domestic linkages. The supply of R&D engineers and scientists (including from abroad), R&D grants, and support from universities and R&D labs has been viewed by firms as important in supporting technological upgrading. In addition, firm-level technological upgrading has also been important in stimulating domestic linkages with purchasers and buyers. Technological upgrading in the country is more associated with domestic buyer and supplier firms, than with export and import markets in East Asia, which appears to be consequence of greater demand for high tech inputs in Singapore than in the import and export markets of Malaysia, China, Indonesia and Philippines. The government efforts to strengthen institutional support to stimulate technological upgrading in Singapore began from 1979 and strong buyer-supplier networks have emerged following the relocation of high tech supplier firms.

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