

Knowledge sources of innovation in a small open economy: The case of Singapore

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By tracing the flows of patent citation to prior patents and scientific journal articles, we investigate the sources of knowledge for innovation output in Singapore, a small, highly open economy that has traditionally been significantly dependent on foreign multinational corporations (MNCs). We found that the local production of new knowledge by indigenous Singaporean firms depends disproportionately on *technological* knowledge produced by MNCs with operational presence in Singapore and *scientific* knowledge generated by foreign universities. Locally produced new knowledge by indigenous firms and local universities/ public research institutes constitutes an as yet insignificant, albeit growing, source for innovation in Singapore.

Introduction

It is well established that the innovation performance of firms are partially dependent on knowledge flows from other firms, universities and public research institutes. Empirical work by economists like JAFFE (1986), ACS et al. (1992, 1994) and GRILICHES (1992) have shown that knowledge generated by R&D in private corporations and universities spills over to other firms, which may then exploit this knowledge spillover in their own innovative activities. At a macroeconomic level, such knowledge spillovers have also been incorporated as a key determinant of aggregate

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economic growth in the new class of endogenous growth models pioneered by ROMER (1986, 1990). More recently, management literature has also shown that organizations innovate through combining new and existing knowledge, including knowledge from external sources (KOGUT & ZANDER, 1992; SONG et al., 2001).

The spatial pattern of knowledge spillovers has also been widely investigated by researchers studying the role of geography in the innovation process (JAFJE, 1989; KRUGMAN, 1991; FELDMAN, 1994). Studies on US-based firms by JAFJE et al. (1993) and AUDRETSCH & FELDMAN (1996), among others, empirically established the existence of significant geographic localization of R&D, whereby knowledge spillovers appear to have been largely exploited by firms located in the vicinity of the knowledge originating firms. Similar evidence of geographic localization of knowledge spillovers has also been found in other large advanced countries such as Japan (BRANSTETTER, 2001; GOTO & NAGATA, 1997), France (PIERGIOVANNI & SANTARELLI, 2001), Germany (HERRIGEL, 1993) and Italy (PIERGIOVANNI et al., 1997). There have also been a number of studies on geographic localization of knowledge in specific high tech industries, such as the semi-conductor sector (SORENSEN & STUART, 2000; ALMEIDA, 1996). However, there has been little equivalent empirical literature on the extent and pattern of knowledge spillovers for innovation in newly industrializing and developing countries.

Early empirical studies on knowledge spillovers have typically used data on R&D expenditure and were focused on identifying where spillovers go. JAFJE et al. (1993) pioneered the use of patent citations data to trace the flow of knowledge. Other authors, such as FROST (2001) and ALMEIDA (1996) have adopted this approach of using patents citation to study knowledge flows and spillovers.

Another approach is to use publications citation data. MEYER (2000) and VERBEEK et al. (2002), among others, have highlighted the use of patent-to-paper citation data to measure the flow of *scientific* knowledge to technological innovation activities, as opposed to patent-to-patent citation data, which is more likely to measure the flow of *technological* knowledge. Using bibliographic citation data contained in the Small Business Administration's Innovation Data Base (SBIDB), ACS et al. (1992, 1994), FELDMAN (1994) and AUDRETSCH & FELDMAN (1996) were able to trace the flow of scientific knowledge to innovating firms. Similar empirical work using patent-to-paper citations to identify the knowledge sources of innovation by firms have also been conducted on European countries (see e.g. SCHMOCH, 1993) and among the triads of USA, Europe and Japan (see e.g. VERBEEK et al., 2003).

Many studies on knowledge spillovers have focused on tracing the destination of outgoing knowledge and establishing the geographic bounds to the "reach" of spillovers. The converse approach is to examine the recipient firms and the knowledge sources that are included in their search process when seeking to expand their knowledge stocks. Although less frequently used, this approach has been adopted by

some researchers, e.g. STUART & PODOLNY (1996) and ROSENKOPF & ALMEIDA (2003) found that firms' search for new knowledge is geographically bounded to their immediate vicinity.

A more comprehensive approach would be to integrate both the originating and recipient perspective, i.e., examining both forward and backward citations, in the context of a national or regional innovation system where some of the actors within the system boundary are both the originators and recipients of knowledge flows. At the same time, the extent and pattern of dependency of innovation actors in the system on external knowledge sources located outside the system can also be traced. Despite the attractiveness of such a holistic system approach, there have been few reported studies adopting this approach in the literature, particularly at a national level.

Knowledge sources for innovation in small, open economies

In this paper, we propose to use such a system approach to analyze the scientific and technological knowledge sources of innovation in Singapore by tracing the citations made by USPTO-granted patents to inventors in Singapore. Singapore represents an interesting case for applying the system approach, for two reasons. Firstly, Singapore has a small and highly open economy that traditionally depended heavily on direct foreign investment by global multinational corporations (MNCs) (WONG, 2002a). In the light of increasing globalization and the growing presence of foreign MNCs in developing countries worldwide, the potential role of foreign firms as a source of knowledge for innovation in the host country deserves greater attention. Because of the significant presence of foreign MNCs in her national innovation system, Singapore thus offers a relatively advanced case for studying the role of foreign MNCs as a knowledge source for innovation for local firms.

Secondly, studying sources of knowledge in a small, open newly industrializing economy such as Singapore addresses a gap in the patent citations analysis literature, which is dominated by studies on large advanced economies, or geographical units within such economies. In contrast to the empirical conclusions from large nations, we expect that the knowledge sources for small nations may be less geographically bounded. In addition, small newly industrialized economies at lower level of indigenous technological capability development would also present an interesting contrast to studies on other small, open but advanced economies that typically have large home-grown technology-based firms (e.g. Finland, the Netherlands, and Switzerland), or that typically exhibit high intensity of knowledge flows among innovation actors (e.g. Denmark). Compared to the small advanced economies, we anticipate a lower intensity of knowledge interactions among local firms and other local innovation actors such as local universities and PRIs.

The proposed patent citation analysis also complements the existing work on Singapore's national innovation (see e.g. WONG, 2002a). With the exception of HU (2004), little patent citation analysis has been undertaken by prior research on Singapore, due to the low level of patenting activity in Singapore in the past. While Singapore has been steadily increasing her R&D intensity since the early-1980s, it is really only from the mid-1990s that the pace of technological innovation leading to intellectual property creation started to accelerate. Singapore's R&D expenditure to GDP ratio rose steadily from less than 0.3% in 1980 and less than 1% in 1990 to 2.15% by 2003, which already exceeds the level of many OECD countries. But the level of patenting activity, as measured by patents awarded by the US Patent and Trademark Office (USPTO) with at least one Singapore Inventor, only started to become significant from the late-1990s: Of the cumulative total of 3,027 patents granted by the US Patents and Trademarks Office (USPTO) to Singapore-based inventors at the end of 2003, 1,871, or more than 60%, were granted in the 3 years after 2000. Detailed information on Singapore's R&D expenditure and patenting output trends is given in the Appendix.

The focus of this paper is on tracing the scientific and technological knowledge sources of innovation generated in Singapore, with a particular focus on the knowledge sources for indigenous firms and how they have changed over time. We primarily examine two aspects of patent citation: the *organizational sectors* owning the citing and cited patents (classified into local companies, local universities/public R&D institutions (PRIs), foreign MNCs with subsidiary operations in Singapore, and other foreign sources) and the *geographic origins* of cited knowledge sources. We trace the change in citation pattern by comparing citations across two time periods: 1976–1995 and 1996–2001. The choice of 1996 as the breakpoint reflects the fact that patenting by local firms and universities/PRIs only began to grow rapidly after 1995. In particular, the period from 1996–2001 witnessed the beginning of high-tech entrepreneurial start-up activities in Singapore, similar to the Silicon Valley model, including the emergence of the phenomenon of spin-offs from universities and public R&D institutions. There was also an intensification of R&D and a policy shift towards longer-term basic research in the local universities/PRIs in the latter period (WONG, 2002a). We therefore anticipate that this deepening of local R&D and entrepreneurial activities in Singapore in the latter period would be reflected in a shift towards greater dependence on locally produced knowledge outputs.

The paper is organized as follows. In the next section, we briefly review the methodology for using patent citation data as a means to trace knowledge flows in a national innovation system. Next, we present the profile and recent growth trends of patenting activities in Singapore, showing the growth in patenting activity by local private sector firms and local universities and PRIs. In the subsequent sections we present our key empirical findings on the pattern of technological and scientific

knowledge flows in Singapore. We discuss the implications of our findings and provide a brief conclusion in the closing section.

Methodology

Following MEYER (2002), this study utilizes both patent-to-patent and patent-to-paper citations to capture the technological and scientific sources of Singapore-based innovations that have been granted USPTO patents. We have chosen to use USPTO-granted patents rather than Singapore patents data because innovations in a small open economy such as Singapore are pursued primarily for exports. The protection of property rights is more heavily sought in export-targeted countries than in Singapore. Singapore-invented patents are usually filed with the USPTO and the USA is Singapore's largest trading partner and its most important export market for technology-related product and services. Between 1976 and 2004, the USPTO had granted 3,447 patents invented by Singaporeans compared to only 1,440 Singapore-invented patents granted by the patent office in Singapore, the Intellectual Property Office of Singapore (IPOS).

The research methodology leverages a computerized US patent database (<http://patents.nus.edu.sg>) that the authors have contributed to developing, as well as the Web of Science bibliographic database. These data sources provide us with a lens through which to observe knowledge flows among the different organizational sectors within Singapore's national innovation system.

a) Citing patents

We have constructed a database of all patents granted between 1976 and 2001 by the US Patent and Trademark Office (USPTO) (<http://patents.nus.edu.sg>), from which we extracted the subset of patents that are invented by Singapore-resident inventors. A patent is treated as Singapore-invented as long as one of its inventors was resident in Singapore at the time of the patent application.

From this list of Singapore-invented patents, we identified the patents that are "Singapore-related", based on the characteristics of the assignees. These are the "citing patents" in our research design. For each citing patent, we determine that it is Singapore-related if it is assigned to one of three possible organizational sectors: (a) a locally majority-owned Singapore firm, (b) (i) a Singapore-based subsidiary of a foreign company, or (ii) a foreign-based company (usually a parent or headquarter company) that is known to have an operational presence in Singapore, or (c) a Singaporean tertiary

institution or public research institute (PRIs), including government organization.¹ As our concern is to understand the knowledge flows to Singapore-related organizations, we have excluded patents that are assigned to individuals and to foreign organizations that do not have any presence in Singapore. Cases of the latter are relatively rare, with only 64 patents identified as belonging to organizations with no presence in Singapore. In total, we identified 1,423 citing patents that are Singapore-related. Of these, 128 were design patents, one was a re-issued patent and the other 1,294 patents were utility patents. In instances where a patent has more than one assignee, we classified the ownership of the patent according to its first named assignee.

Although there is a clear legal distinction between (b) (i) and (ii) (patent ownership being assigned to the local subsidiary of a foreign entity in the former and to a foreign entity in the latter), the difference may not be that clear cut in practice and may be caused more by differences in corporate strategy or accounting policy of the foreign firm concerned. In addition, the number of cases in category (i) is relatively small, and moreover, shows little differences in characteristics from the cases in category (ii) in subsequent analysis, hence our decision to group them together.

b) Cited patents

Each citing patent cites a list of other patents that represent the “prior arts” upon which the innovation as embodied in the citing patent is built. We compiled detailed information on these cited patents paying particular attention to their geographic origins and whether the assignees are foreign firms, local firms, or local vs. foreign universities/PRIs. We have categorized the geographic and organizational characteristics of these cited patents according to their first-named assignees. For comparability, we have similarly categorized the assignees of cited patents as belonging to one of the three Singapore-related organizational sectors. Assignees that have no affiliation to Singapore are further classified into three other categories: “foreign firms with no operation in Singapore”, “foreign universities/PRIs” and “patents with no assignees”.

Information on the cited patents is drawn from the NUS patent database that contains complete details on all USPTO patents granted after January 1st 1976. As such, we were not able to compile information on the cited patents that were granted prior to this date. These early patents form a relatively small proportion of the total cited

¹ To determine if a company is locally or foreign majority owned, and whether a foreign company has a subsidiary in Singapore, we consulted sources such as the Accounting and Corporate Regulatory Authority of Singapore (formerly the Registry of Companies and Businesses), the Singapore 1000 directory and online search engines. Ideally, the classification by organizational sector should be based on the status of the organization at the time of the patent application, instead of at the time of the study. As the rate of entry of new foreign subsidiary operations in Singapore has generally exceeded the rate of exit over the years, this would have had the effect of overstating the proportion of foreign MNCs with subsidiary operations in Singapore. This is a limitation that we hope to overcome in the future.

patents. Of the 11,264 patents that were cited by the 1,423 citing patents, only 914 (or 8.1%) were granted prior to 1976. These were excluded from our analysis.

Based on available data for both citing and cited patents, we constructed pairs of citing-cited patents which allow us to match and compare the characteristics of the citing patents and the cited sources of knowledge.

c) Cited journal articles

A citing patent may also cite a list of Non Patent References (NPRs) that encompass references to documents such as scientific journal articles, technical papers, conference proceedings, textbooks etc. NPRs may be cited either by the examiner or the inventor and reflect the “prior-arts” of a patent in the form of state-of- the-art technical and/or scientific literature that is related to the technical invention embodied in the citing patent.

In the scientometrics literature, one approach to measurement of science and technology flows is to distinguish between *papyrocentric* science and *papyrophobic* technology (PRICE, 1965). Science is publication directed while technology leads to patents rather than publications (MEYER, 2002). In this sense, cited patents represent sources of technological know-how, while cited publications represent sources of scientific know-how.

In this paper, we have focused on NPRs in the form of scientific journal articles. For each journal article that is cited by the citing patents, we conducted a search on the Web of Science database, comprising among others, the *Science Citation Index Expanded*, the *Social Science Citation Index*, the *Arts and Humanities Citation Index*, *Index Chemicus* and *Current Chemical Reactions*. While a number of cited articles would be excluded from our analysis because the Web of Science is not exhaustive, it represents the widest available coverage of high-impact scientific journals.

We compiled detailed information on the authors of these cited journal articles, paying particular attention to their organizational affiliation. The geographic origin of the cited article is determined by the location of the organization to which the article’s author is affiliated. We also identify if the organization is a private sector entity or a university, public research institute or other government-related organization. In the cases of joint-authorship, the organizational affiliation of the first-named author is used. In total, there were 230 citing patents that cited 1,003 journal articles listed in the Web of Science database.

Profile of Singapore-invented patents

Overall trends in patenting activities in Singapore

Figure 1 shows that Singapore invented patents are on an upward trend, with a notable increase in the rate of patenting since 1996. In the six year period 1996–2001, the number of Singapore invented patents more than tripled compared to the cumulative total granted in the previous 20 years. The number further doubled in the subsequent 3 years 2002–2004. Very few patents were granted prior to the late 1980s. As MNCs began to establish R&D activities in Singapore from the late 1980s, and some local firms also started to invest in innovation, the number of Singapore-invented patents began to increase. Up to 1995, foreign assignees dominated patenting activity in Singapore, but in subsequent years, local assignees began to exceed foreign assignees, reflecting a deepening of R&D activities by local firms as well as local universities/PRIs.

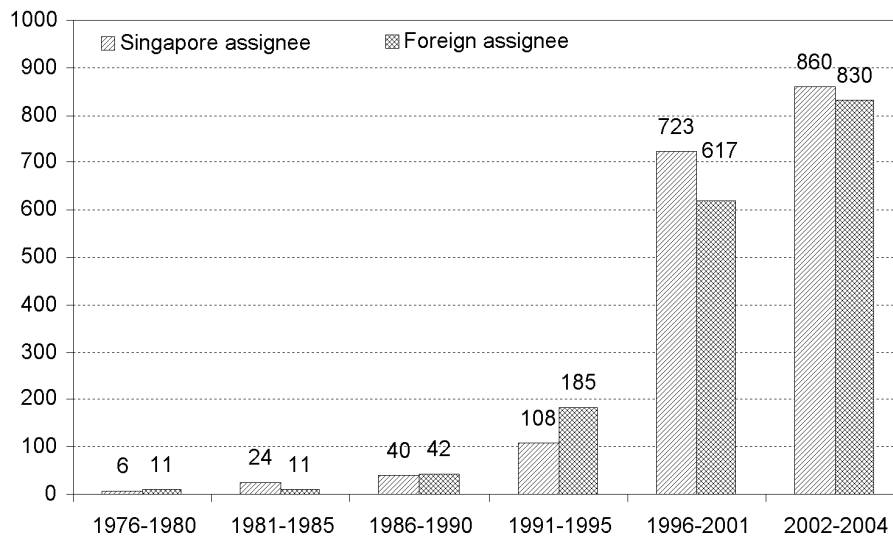


Figure 1. Trend in Singapore invented patents, (where at least one inventor is a Singapore resident), 1976–2004

Source: NUS USPTO patents database: <http://patents.nus.edu.sg>

Table 1. Share of Singapore patenting^a by assignee categories (1976–2001)

<i>Type of assignee</i>	<i>1976–1995</i>	<i>(%)</i>	<i>1996–2001</i>	<i>(%)</i>	<i>Total</i>	<i>(%)</i>
<i>Singapore assignee</i>	178	(41.7)	723	(54.0)	901	(51.0)
1. Individuals	71	(16.6)	88	(6.6)	159	(9.0)
2. Companies	92	(21.5)	535	(39.9)	627	(35.5)
3. Universities and PRIs	15	(3.5)	100	(7.5)	115	(6.5)
<i>Foreign assignee</i>	249	(58.3)	617	46.0	866	(49.0)
1. Individuals	4	(0.9)	5	(0.4)	9	(0.5)
2. Companies	242	(56.7)	584	(43.6)	826	(46.7)
3. Universities and PRIs	3	(0.7)	28	(2.1)	31	(1.8)
<i>Total</i>	427	(100)	1340	(100)	1767	(100)

^a Patents where at least one inventor is a Singapore resident. The first assignee is used to count patents which have more than one assignee.

Source: NUS USPTO patents database: <http://patents.nus.edu.sg>

Table 1 contrasts the composition of Singapore invented patents in the two time periods of interest, 1976–1995 and 1996–2001. As can be seen, the share of patents assigned to local Singapore companies increased from 21.5% to 40.2%, in tandem with a decline in the share of foreign companies from 56.7% to 43.7%. There was also a doubling of the share of patenting by local universities and PRIs over the same period (3.5% to 7.5%).

Notwithstanding the increase in patenting by local organizations, the presence of foreign firms continue to be significant among the largest patent owners in Singapore, accounting for 14 out of the top 20 patent owning organizations at the end of 2001. As late as 1995, the top 5 patent owners in Singapore were all foreign firms. However, by the end of 2001, the top and third largest owners of patents had become Singaporean entities – a local company (Chartered Semiconductor, with 346 patents) and a local university (National University of Singapore, with 66). Reflecting the dominance of patenting by large organizations in Singapore, the top 20 patent owners accounted for 57.8% of all cumulative patented invention in Singapore in 2001.

Characteristics of citing patents

Table 2 presents an overview of the citing patents in our analysis sample. Of the total of 1,423 citing patents, more than half are in the electronics and electrical (35%) and computers and communications (16%) categories respectively, reflecting the heavy focus on electronics manufacturing and information technology in Singapore's industrial development strategy in the 1990's (WONG, 2002b). As expected, patents by foreign firms are on average older than patents by local organizations.

Table 2. Profile of citing patents, 1976–2001

	Number of patents	Age of patent	Average lag between citing and cited patent	Average number of citations made to other patents	% of patents that cite one or more journal publication in Web of Science	Average number of citations made to journal publications
ALL	1423	6.25	6.19	7.92	16.2%	0.70
Local Singapore Company	549	5.62	5.41	7.99	15.1%	0.51
Local University / PRI	115	5.15	6.69	5.52	46.1%	3.47
Foreign MNC with local subsidiary	759	6.86	6.68	8.22	12.5%	0.43
F Statistic for difference between organizational sectors of citing patent		27.1**	20.8**	10.4**		64.6**
Significance of F		0.000	0.000	0.000		0.000

** Significant at 5%

In terms of citation of other patents, on average, each patent cited 7.9 other patents. The propensity to cite other patents was highest for patent holders that are foreign MNCs with operation in Singapore, and lowest for local universities/PRI. Foreign-owned patents also had the longest time-lag between citing and cited patents, while local firms had the shortest.

In terms of citation of journal publications, on average only 16.2% of the citing patents cited one or more journal articles, with the proportion highest for local university/PRI (46%) and lowest for foreign MNC with local subsidiary (12.5%). The average number of citations made to journal publications by the citing patents was less than 1.

Sources of technological knowledge: Citations to patents

Overall propensity to cite local sources of technological knowledge

Table 3 summarizes the citations flow data covering a total of 10,350 citing-cited patent pairs originating from 1,423 citing patents. As can be seen from part (a) of the table, on average, 8.5% of cited patents are owned by the same assignees that own the citing patent. The propensity to self-cite is highest amongst patents owned by foreign MNCs with local subsidiaries (13.3%), reflecting perhaps the deeper technology base of foreign MNCs cumulated through a longer history of patenting.

Table 3. Citing–cited patent citation matrix and changes in the composition of cited patents by organizational sectors, 1976–1995 vs. 1996–2001

	Overall	1976–1995	1996–2001
a) Summary			
Total number of citing patents	299	1124	1423
Local Singapore firm citing	78	471	549
Local University/ PRI citing	15	100	115
Foreign MNC with local subsidiary citing	206	553	759
Total number of cited patents	1657	8693	10350
Local Singapore firm citing	389	3823	4212
Local university/ PRI citing	1186	4334	618
Foreign MNC with local subsidiary citing	82	536	5520
% of cited patents that are self-citations	8.5%	13.9%	7.4%
Local Singapore firm citing	3.1%	2.3%	3.2%
Local university/ PRI citing	1.5%	1.2%	1.5%
Foreign MNC with local subsidiary citing	13.3%	18.6%	11.9%
% of cited patents from Singapore²	1.6% (2.5%)	0.7% (1.9%)	1.7 (2.5%)
Local Singapore firm citing	3.5%	2.8%	3.5%
Local university/ PRI citing	2.9% (3.2%)	1.2%	2.9% (3.2%)
Foreign MNC with local subsidiary citing	0.02% (1.7%)	0% (1.7%)	0.02% (1.7%)
b) Distribution of cited assignee			
Local Singapore firm citing			
No assignee	6.39	15.94	5.41
Local Singapore firm	3.35	2.83	3.40
Local university/ PRI	0.12		0.13
Foreign MNC with local subsidiary ¹	65.81 (0.02)	47.30 (0.00)	67.70 (0.03)
Foreign university/ PRI	3.06	1.03	3.27
Foreign company without local subsidiary	21.27	32.90	20.09
Total	100	100	100
Local university / PRI citing			
No assignee	5.83	12.20	4.85
Local Singapore firm	1.29		1.49
Local university/ PRI	1.62	1.22	1.68
Foreign MNC with local subsidiary ¹	60.36 (0.32)	50.00 (0.00)	61.94 (0.37)
Foreign university/ PRI	8.90	6.10	9.33
Foreign company without local subsidiary	22.01	30.49	20.71
Total	100	100	100
Foreign MNC with local subsidiary citing			
No assignee	6.72	5.06	7.18
Local Singapore firm	0.00	0.00	0.00
Local university/ PRI	0.02	0.00	0.02
Foreign MNC with local subsidiary ¹	67.26 (1.65)	70.07 (1.70)	66.50 (1.79)
Foreign university/ PRI	1.20	0.67	1.34
Foreign company without local subsidiary	24.80	24.20	24.97
Total	100	100	100
Overall citing			
No assignee	6.53	7.97	6.26
Local Singapore firm	1.44	0.66	1.59
Local university/ PRI	0.15	0.06	0.17
Foreign MNC with local subsidiary ¹	66.26 (0.91)	63.73 (1.15)	66.74 (0.82)
Foreign university/ PRI	2.42	1.03	2.68
Foreign company without local subsidiary	23.20	26.55	22.56
Total	100	100	100

¹ Figure in brackets refers to patents with at least one Singapore-resident inventor.² Figure in brackets refers to % of cited patents from Singapore including foreign-owned patents with at least one Singapore resident inventor.

Table 3(a) also shows the overall citing intensity of *locally invented patents*. On average, only 1.7% of the cited patents are from local Singaporean organizations (local firms or local universities/PRI). Even if we count the cited patents owned by foreign MNC subsidiaries which were invented in Singapore as locally generated patents, the propensity to cite locally invented patents remains low at 2.5%. It is true that the propensity to cite local patents is noticeably higher among the local organizations (3.5% for local firms and 3.2% for local universities/PRI) compared to that of foreign MNCs with subsidiaries in Singapore (only 1.7%), but overall, the degree of dependence on local sources of knowledge can be said to be very low. Foreign MNCs appear to rely on knowledge generated elsewhere within their corporate group to a much larger extent than to Singapore-based inventions (13.3% self-citation vs. 1.7% citation of Singapore-based inventions). Among local Singaporean firms, close to 90% of their local citations are accounted for by self-citations, suggesting relatively low utilization of other sources of local knowledge. Local universities/PRI were somewhat better, with slightly more than half of their local citations made to other local sources than themselves.

Analysis of technological knowledge flows among organizational sectors

As earlier described, each citing patent is categorized into one of six categories, of which three correspond to the Singapore-related organizational sector classification of the citing patents (local Singapore firms, foreign MNCs with local subsidiaries, and local university/ PRI) while the other three refer to foreign firms with no known subsidiary operation in Singapore, foreign universities/PRI and patents with no assignees.

The second column of Table 3(b) shows the patent citation flows to and from the different organizational sectors. This matrix of flows is represented graphically in Figure 2, where the width of the arrows indicates the number of citations in the relevant direction. As can be seen from both Table 3(b) and Figure 2, the greatest sources of knowledge for patents owned by all three Singapore-related organizational sectors are foreign companies with local subsidiaries. The flow of knowledge from foreign MNC subsidiaries to local organizations is particularly notable, with 2,772 citations (65.8%) made by local companies and 373 citations (60.4%) made by local universities and PRI. We also observe a high degree of reliance on sources of knowledge outside of Singapore, in particular foreign companies that do not have any presence in Singapore: 896 of the citations made by local Singapore companies are owned by such foreign companies (21.3% of citations), while local universities/PRI also made 136 such citations (22%), more than what they made to foreign universities (8.9%).

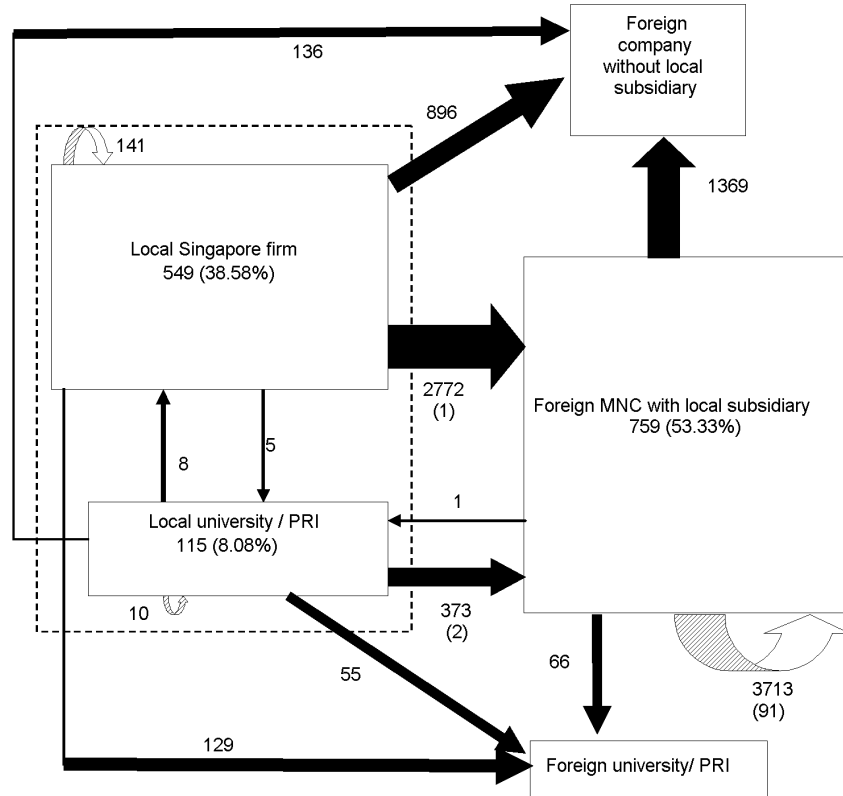


Figure 2. Patent citation flows for Singapore invented patents.

Direction of arrows reflects the direction of citation flow from the citing patent to the cited patent.

Numbers next to arrows indicate the number of citations made. For citations to patents owned by foreign MNCs with local subsidiaries, the figures in parentheses refer to the number of patents that have at least one inventor that was a Singapore resident at the time of the patent application.

Note: Patents with no assignees are excluded

The reliance on knowledge of Singapore-based organizations is only visible among Singaporean organizations. Only about 3% of the 4,830 citations made by local organizations are to patents owned by local organizations. In contrast foreign MNCs with subsidiary operations in Singapore made only one citation to a local university patent, and none to patents owned by local firms, out of 5,520 citations. Even if we include the 94 cited patents owned by foreign MNCs with local inventors as representing local knowledge sources, the overall picture confirms that the degree of reliance on Singapore produced technological knowledge, as measured by patent citations, is negligible in Singapore.

In the third and fourth columns of Table 3(b), we investigate if the pattern of ownership of cited patents has changed over time, with particular focus on the sources of knowledge for local organizations. For both local firms and local universities/PRI, there is a large increase in the share of citations to foreign MNCs with subsidiaries in Singapore, with corresponding reduction in the citation of patents owned by foreign companies without any Singapore presence. Citation of patents with no assignees also appears to have declined significantly. The share of citations made to local companies and local universities/PRI increased for both local firms and local universities/PRI, but not by much; indeed, their citations to foreign universities/PRI had increased by even more.

Overall, the above findings suggest that there has indeed been an increase in the use of local technological knowledge sources in Singapore's innovation activities over time, although the increase was modest, and mainly by local organizations. In addition, the use of knowledge generated by foreign MNCs with subsidiary operations in Singapore appears to have significantly expanded while that of foreign firms with no affiliation with Singapore appears to be declining.

While the above analysis seems to imply that there is a higher (and increasing) propensity for Singaporean inventions to cite MNCs with subsidiary operations in Singapore than without, we cannot rule out the possibility that this may have simply been caused by a higher (and growing) share of the former in the total patenting of the world, rather than by a greater knowledge spillover propensity by the former to Singapore.

To provide a statistical test against such a possibility, we followed the methodology of JAFFE et al. (1993) and HU (2004) by constructing a "control" sample of patents from the rest of the world of comparable age and technological content to test Singapore's dependence on various knowledge sources relative to "what would be expected given the existing distribution of technological activity" (JAFFE et al., 1993, p 582). If locally invented patents have a higher propensity than the control sample to cite patents of MNCs with local subsidiaries, this would suggest that there are indeed higher knowledge spillovers from such sources to the local organizations (HU, 2004). The same argument would apply for citation of patents owned by local organizations.

To construct such a matched sample from the rest of the world, we started with the original sets of 549 citing patents owned by local firms and 115 patents owned by local universities/PRI, and for each of these, we identified all USPTO patents that were issued in the same year and categorised in the same 4-digit US patent class.²

² Where possible, we have selected matching patents that have the same *primary* patent classification as the primary patent class of the original citing patent.

Table 4. Propensity of citing patents owned by local firms & MNCs with subsidiary in Singapore: Singapore organizations versus Rest of the World, 1976–2001

a1) Local firms vs. random matched sample of Rest of the World

Propensity to cite	Citing Organizations		Paired sample t-test	Significance
	Local firms	Matching sample of Rest of World patents		
Patents owned by local organizations				
1976–1995	0.042	0.000	2.631**	0.010
1995–2001	0.035	0.005	7.292**	0.000
Overall	0.036	0.004	7.554**	0.000
Patents owned by MNCs with subsidiary in Singapore				
1976–1995	0.467	0.412	1.678*	0.098
1995–2001	0.672	0.670	0.328	0.743
Overall	0.643	0.635	0.959	0.338

a2) Same as (a1) but excludes local firms in semiconductor

Propensity to cite	Citing Organizations		Paired sample t-test	Significance
	Local firms excluding semiconductor firms	Matching sample of Rest of World patents		
Patents owned by local organizations				
1976–1995	0.048	0.000	2.400**	0.020
1995–2001	0.024	0.001	2.276**	0.025
Overall	0.032	0.000	3.301**	0.001
Patents owned by MNCs with subsidiary in Singapore				
1976–1995	0.380	0.329	1.225	0.226
1995–2001	0.491	0.429	1.983**	0.050
Overall	0.451	0.394	2.333**	0.021

b) Local universities/ PRIs vs. random matched sample of Rest of the World

Propensity to cite	Citing organizations		Paired sample t-test	Significance
	Local universities/ PRIs	Matching sample of Rest of World Patents		
Patents owned by local organizations				
1976–1995	0.033	0.000	1.000	0.334
1995–2001	0.035	0.000	2.232**	0.028
Overall	0.034	0.000	2.458**	0.016
Patents owned by MNCs with subsidiary in Singapore				
1976–1995	0.517	0.538	-0.166	0.871
1995–2001	0.585	0.486	2.375**	0.020
Overall	0.576	0.494	2.043**	0.044

** significant at 5% * significant at 10%

We then eliminated all Singapore-owned patents from the set. From the remaining Rest of the World (ROW) set, we randomly selected a patent to form a “matched pair” with the original Singapore-owned citing patent. Using this method, we obtained two separate matching samples: 549 ROW patents matched to 549 patents owned by local firms and 115 ROW patents matched to 115 patents owned by local universities/ PRIs.

The first part of Tables 4(a1) and 4(b) compares the citing propensities of local firms and local universities/PRIs with those of the matching samples of ROW patents. As expected, patents owned by both local firms and local universities/PRIs exhibit statistically significant higher propensities than ROW patents to cite such locally owned patents, for both time periods. We can thus confirm that the spillover effect from Singaporean technological knowledge is indeed significantly higher for Singapore organizations than for patent assignees outside Singapore.

The second part of Tables 4(a1) and 4(b) shows the propensities of local firms and local universities/PRIs to cite patents owned by MNCs with local subsidiaries. As hypothesized by HU (2004), compared to the randomly matched samples of ROW patents, local organizations are expected to benefit disproportionately from spillover knowledge from the latter. As can be seen from Table 4(b), this hypothesis is supported in the case of local universities/PRIs particularly in the 1996–2001 period. Table 4(a1) also shows that the propensity to cite patents owned by MNCs with local subsidiaries differs significantly for local firms and the matching ROW sample in the 1976–1995 period, consistent with HU’s (2004) findings using 290 patents granted to Singapore companies up to 1999. However, in the period 1996–2001, and for the overall sample covering both periods, no statistically significant difference was found. One possible explanation for this is the growth of semi-conductor related patents by local firms in Singapore since 1999. The global semi-conductor industry includes a sizeable number of Korean and Taiwanese companies that do not have operation in Singapore, and a large number of patent citations made by local semi-conductor related firms in Singapore in recent years are to these companies. To isolate this technology-specific effect, we repeated the analysis of Table 4(a1) by excluding the semi-conductor related patents from the analysis. As shown in Table 4(a2), after removing semi-conductor patents, the propensity to cite MNC patents is found to be indeed higher for local firms than for the ROW sample, thus confirming a continuation of the pattern found by HU’s (2004) earlier conclusion outside of the semiconductor technology sector.

Geographic origins of cited patents

Turning now to the geographic origins of the sources of technological knowledge for Singapore-invented patents, we found a clear pattern of dominance of North America (last column of Table 5), with shares ranging from 55% for local firms to 60% for foreign firms with operation in Singapore. Japanese patents are the next most cited

(19.4%), followed by patents from European countries (7.2%). It is interesting to note, however, that indigenous firms exhibited a very high propensity to cite patents from Taiwan (10.7%, vs. 0.3% to 3.7% for other organizational types), due largely to the high level of patenting by local firms in the semiconductor and electronics field, where

Table 5. Trends in geographic origin of cited patents by ownership of citing patent (1976–2001)

	1976–1995	1996–2001	Overall
Citing assignee is			
Local Singapore firm			
No assignee	15.9	5.5	6.4
North America (USA and Canada)	48.8	55.3	54.7
Japan	21.6	16.9	17.4
<i>Korea</i>	<i>0.5</i>	<i>3.3</i>	<i>3.1</i>
<i>Taiwan</i>	<i>1.5</i>	<i>11.6</i>	<i>10.7</i>
<i>Singapore</i>	<i>2.8</i>	<i>3.5</i>	<i>3.5</i>
Europe	7.5	3.6	3.9
Others	1.3	0.2	0.3
<i>Total</i>	<i>100.0</i>	<i>100.0</i>	<i>100.0</i>
Local university / PRI			
No assignee	12.2	4.9	5.8
North America (USA and Canada)	57.3	58.8	58.6
Japan	13.4	17.7	17.2
<i>Korea</i>	<i>1.2</i>	<i>1.5</i>	<i>1.5</i>
<i>Taiwan</i>	<i>1.2</i>	<i>4.3</i>	<i>3.7</i>
<i>Singapore</i>	<i>1.2</i>	<i>3.2</i>	<i>2.9</i>
Europe	14.6	9.0	9.7
Others		0.7	0.6
<i>Total</i>	<i>100.0</i>	<i>100.0</i>	<i>100.0</i>
Foreign MNC with local subsidiary			
No assignee	5.1	7.2	6.8
North America (USA and Canada)	65.9	58.1	59.8
Japan	14.5	23.0	21.2
<i>Korea</i>	<i>1.1</i>	<i>1.5</i>	<i>1.4</i>
<i>Taiwan</i>	<i>0.3</i>	<i>0.9</i>	<i>0.8</i>
<i>Singapore</i>	<i>0.2</i>	<i>0.1</i>	<i>0.1</i>
Europe	12.8	8.4	9.4
Others	0.2	0.7	0.6
<i>Total</i>	<i>100.0</i>	<i>100.0</i>	<i>100.0</i>
Overall			
No assignee	7.97	6.30	6.6
North America (USA and Canada)	61.44	56.94	57.7
Japan	16.11	20.00	19.4
<i>Korea</i>	<i>0.97</i>	<i>2.30</i>	<i>2.1</i>
<i>Taiwan</i>	<i>0.60</i>	<i>5.82</i>	<i>5.0</i>
<i>Singapore</i>	<i>0.84</i>	<i>1.81</i>	<i>1.7</i>
Europe	11.65	6.33	7.2
Others	0.42	0.49	0.5
<i>Total</i>	<i>100.0</i>	<i>100.0</i>	<i>100.0</i>

Taiwan had a high share of the world total patent counts. Japanese patents were most highly cited in the mechanical fields, while European patents were most frequently cited in the chemical field.

Comparing patenting in the two time periods 1976–1995 vs. 1996–2001, we found significant changes in the pattern of geographic location of knowledge sources (second and third columns of Table 5). For local companies, Japan and Europe as a source of knowledge declined, while that of US, Korea and Taiwan increased. The increase in Taiwan was most dramatic, from a mere 1.5% before 1996 to 11.6% after 1996. Amongst the local universities/PRI, Taiwan similarly emerges as an important source of knowledge, contributing 4.3% of citations over 1996–2001, where there was none prior to 1996. There is also an increase in citations to Singapore and Japanese owned patents, while European owned patents declined in citations received.

Sources of scientific knowledge: Citations to journal publications

We turn next to the results on sources of scientific knowledge as measured by citations to journal publications. There are fundamental differences between citations to patents and citations to journal publications. While a patent represents a minimal level of inventive activity that has passed a thorough examination (GRILLICHES, 1990), scientific publications constitute an imperfect output indicator of research activity (VERBEEK et al., 2002). Only a minority of patents contain citations to non-patent references and more specifically to scientific journal publications (MEYER, 2000). Average publication rates also differ in the various fields of science, implying that the propensity for patents to cite publications would differ across different technological classes. Indeed, various authors such as MEYER-KRAHMER & SCHMOCH (1997) and NARIN & OLIVASTRO (1992) have found the citing frequency of NPRs to be higher in some classes of patents than in others.

In summary, there are fewer patents that make citations to publications than to other patents. Additionally, citations to publications vary by technological class to a greater degree than citations to other patents. Moreover, in the scientific publication community, there is a strong concentration of authors from universities and PRIs. These factors lead us to expect that citations to patents and citations to publications would exhibit different distributions and different patterns of knowledge flows.

Overall propensity to cite local sources of scientific knowledge

As can be seen from Table 6(a), of the 1,003 citations to journal articles in the Web of Science by 231 citing patents, only 9.7% are authored by researchers affiliated with

local firms or local universities/PRI. However, there is significant variation among the three organizational sectors: while local universities/PRI showed a relatively high propensity to cite articles authored by researchers affiliated with local organizations (21%), the propensity was extremely low for local firms and MNCs with local subsidiaries (both 2.2%). It is thus clear that the propensity of local firms to use local sources of scientific knowledge is even lower than their propensity to use local technological sources. Foreign MNCs with subsidiaries in Singapore showed low use of both local scientific and technological knowledge sources. Moreover, it is interesting to note that only 6 out of the 97 cited scientific articles by Singapore-based authors were published in local journals, indicating the strong preference of Singaporean researchers to publish in more prestigious international journals published overseas.

In Table 6(a), we also observed that 8.8% (88 out of 1,003) of the cited articles are authored by the inventors of the citing patent. This proportion varied from 16% (64 of 300 cited articles) for local universities/PRI to 0.7% (2 out of 280 cited articles) for local companies. 26 of the 53 citing patents owned by local universities/PRI cited at least one publication that was authored by one of patent inventors. This appears to indicate that patent inventors in local universities/PRI do rely to a certain on their own scientific research when conducting applied technological research.

Analysis of scientific knowledge flows among organizational sectors

Similar to the citing-cited patents pairs, the publications citation flow pattern are presented in the 2nd column of Table 6(b) and Figure 3 for the different organizational sectors. Unlike patents citations, we found that the bulk (60%) of publication citations are made to foreign universities/PRI, with another 9.6% going to local universities/PRI. This not only reflects the more important role of universities/PRI as sources of scientific knowledge for invention, but also encouragingly, a greater share of local universities as scientific knowledge sources to invention in Singapore, as opposed to technological knowledge, where the local universities contributed only 0.2% of patent citations. While patents by local universities/PRI, as expected, exhibited the highest propensity to cite scientific journal articles produced by the local universities/PRI themselves (21.1%), local firms had very low propensity to cite locally authored journal articles, suggesting that the link between scientific research at local universities/PRI and local enterprises may be quite weak.

Table 6. Citing patent–cited publication citation matrix and trends in organizational origin of cited publications

	Overall	1976–1995	1996–2001
a) Summary			
<i>Number of citing patents</i>	231	42	189
Local Singapore firm citing	83	11	72
Local university/ PRI citing	53	10	43
Foreign MNC with local subsidiary citing	95	21	74
<i>Number of cited articles</i>	1003	113	860
Local Singapore firm citing	280	40	240
Local university/ PRI citing	399	39	360
Foreign MNC with local subsidiary citing	324	64	260
<i>% of cited articles from Singapore</i>	9.7%	7.0%	10.0%
Local Singapore firm citing	2.2%	5.0%	1.7%
Local university/ PRI citing	21.1%	15.4%	21.7%
Foreign MNC with local subsidiary citing	2.2%	3.1%	1.5%
<i>% of cited articles authored by same inventor</i>	8.8%	8.4%	8.8%
Local Singapore firm citing	0.7%	5.0%	0.0%
Local university/ PRI citing	16.0%	18.0%	15.8%
Foreign MNC with local subsidiary citing	6.8%	4.7%	7.3%
b) Distribution of cited publications			
Local Singapore firm citing			
Local firm	0.36	0	0.42
Local university/ PRI	1.79	5.00	1.25
Foreign MNC with local subsidiary	15.36	15.00	15.42
Foreign university/ PRI	61.79	65.00	61.25
Foreign company without local subsidiary	20.71	15.00	21.67
<i>Total</i>	100.0	100.00	100.00
Local university / PRI citing			
Local firm	0	0	0
Local university/ PRI	21.05	15.38	21.67
Foreign MNC with local subsidiary	4.76	17.95	3.33
Foreign university/ PRI	59.65	58.97	59.72
Foreign company without local subsidiary	14.54	7.69	15.28
<i>Total</i>	100.0	100.00	100.00
Foreign MNC with local subsidiary citing			
Local firm	0.00	0	0
Local university/ PRI	2.16	3.13	1.54
Foreign MNC with local subsidiary	21.60	20.31	22.31
Foreign university/ PRI	58.64	57.81	58.85
Foreign company without local subsidiary	17.59	18.75	17.31
<i>Total</i>	100.0	100.00	100.00
Overall citing			
Local firm	0.10	0	0.12
Local university/ PRI	9.57	6.99	9.88
Foreign MNC with local subsidiary	13.16	18.18	12.44
Foreign university/ PRI	59.92	60.14	59.88
Foreign company without local subsidiary	17.25	14.69	17.67
<i>Total</i>	100.0	100.00	100.00

Another interesting observation from Table 6(b) and Figure 3 is that, in contrast to patent citations, there is a larger share of scientific knowledge sources coming from foreign companies that have no operation in Singapore versus those that have. While more than two-thirds of cited patents owned by foreign firms are contributed by foreign firms that have operation in Singapore, more than half of cited journals published by authors with foreign firm affiliation are from foreign firms with no presence in Singapore.

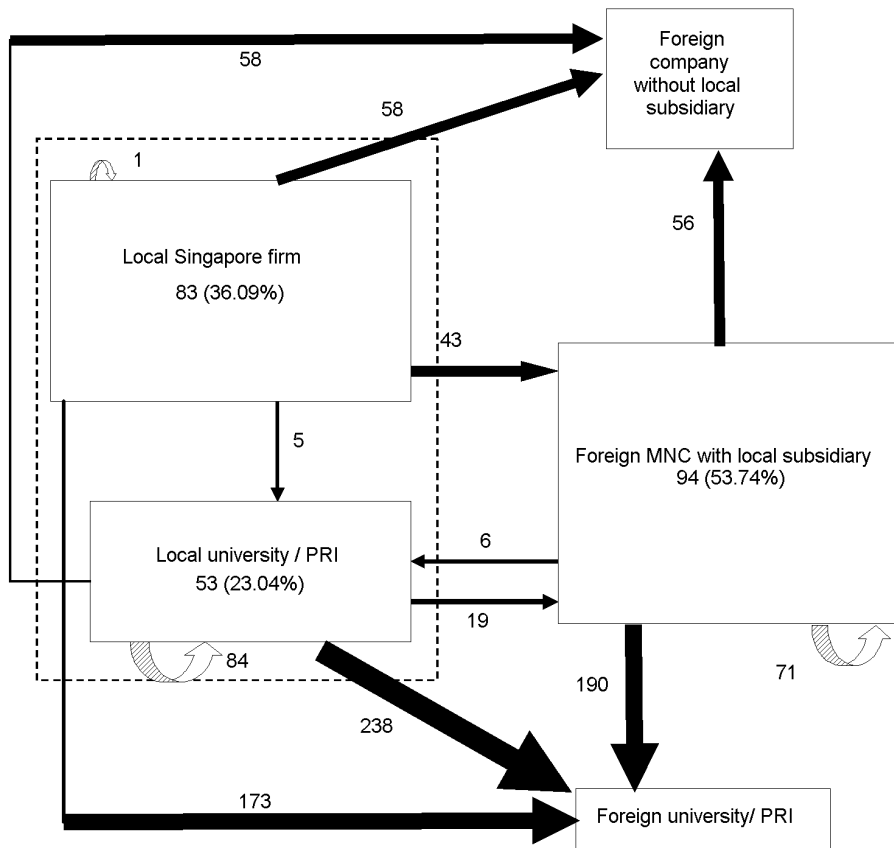


Figure 3. Publication citation flows for Singapore invented patents
 Direction of arrows reflects the direction of citation flow from the citing patent to the cited article. Numbers next to arrows indicate the number of citations made.

Table 7. Trends in geographic origin of cited publications by organizational sector of citing patent

Citing patent assignee is	1976–1995	1996–2001	Overall
Local Singapore firm			
North America (USA and Canada)	67.50	66.25	66.4
Japan	7.50	6.67	6.8
Taiwan		0.83	0.7
<i>Singapore</i>	5.00	1.67	2.1
Europe	10.00	17.08	16.1
Others	10.00	7.50	7.9
<i>Total</i>	100.0	100.0	100.0
Local university / PRI			
North America (USA and Canada)	56.41	41.67	43.1
Japan		9.44	8.5
Taiwan		1.39	1.3
<i>Singapore</i>	15.38	21.67	21.1
Europe	17.95	20.00	19.8
Others	10.26	5.83	6.3
<i>Total</i>	100.0	100.0	100.0
Foreign MNC with local subsidiary			
North America (USA and Canada)	65.63	66.92	66.7
Japan	7.81	8.85	8.6
Taiwan		2.69	2.2
<i>Singapore</i>	3.13	1.92	2.2
Europe	12.50	15.38	14.8
Others	10.94	4.23	5.6
<i>Total</i>	100.0	100.0	100.0
Overall			
North America (USA and Canada)	63.64	56.16	57.3
Japan	5.59	8.49	8.1
Taiwan		1.63	1.4
<i>Singapore</i>	6.99	10.12	9.7
Europe	13.29	17.79	17.1
Others	10.49	5.81	6.5
<i>Total</i>	100.0	100.0	100.0

Unlike the case of patent citations, where local technological knowledge is gaining in importance over time, the third and fourth columns in Table 6(b) show that the share of citations to scientific articles authored by local organizations had actually fallen in the period after 1995, suggesting that innovation activities in Singapore were becoming more dependent on foreign sources of scientific knowledge in recent years. Although there is an increase in the propensity of local universities/PRI to cite locally produced scientific knowledge (from 15.4% to 21.7%), this shift was not sufficiently large to offset the overall decline in local scientific article citation among local firms and foreign firms with subsidiary operations in Singapore. This suggests that, for private sector firms, the need to access the global flow of scientific knowledge outpaces the propensity to tap local sources of scientific knowledge.

Geographic origins of cited publications

As expected, scientific publications by authors from North America are the most cited by all three organizational sectors owning the citing patents (last column of Table 7), with their overall share almost identical to their share of patent citations (see Table 5 earlier). Compared to patent citations, journal articles from Europe are more frequently cited, especially by local organizations, while Japan as a source of scientific knowledge appears to be much lower than as a technology source.

An examination of the changes in the pattern of geographic origins of cited articles over time also reveals interesting differences from cited patents (Table 7). While Europe as a source of cited patents declined over time as observed earlier, there was a notable increase in the share of Europe as source of cited journals, especially by local Singapore companies. The share of locally authored publications showed a modest aggregate increase, the result of two opposing trends: While local universities increased their propensity to cite locally authored articles, the trend is opposite for local and foreign firms.

Discussion and conclusion

Several observations can be highlighted based on the above exploratory empirical analysis. Firstly, by examining the citation flows for the entire stock of patents generated in an economy, and integrating both the source and recipient perspectives, we were able to develop a *systemic* view of *sources* and *flows* of one important type of knowledge in a national innovation system – *codified* knowledge as contained in patents and journal publications. It is true that there are other important sources and flows of knowledge used in innovation activities that our methodology does not cover, for example, tacit knowledge embodied in people that are transferred through collaboration networks or the movement of people from one organizational sector to another, and knowledge embodied in software, equipment and systems. However, since knowledge as codified in patents and scientific articles that are actually cited by a patented invention represents the most proximate and accurate measure of the antecedent knowledge inputs upon which the new invention is developed, we believe that our methodological approach does provide a valuable window to observe the working of an entire national innovation system in terms of the pattern of innovation activities among different organizational sectors and the knowledge flows between them, at a point in time as well as changes over time.

By applying such a systemic approach, we were able to provide deeper insights on the specific roles that foreign firms play in the national innovation system of small, open newly industrialized economies like Singapore. Not only do foreign firms contribute a significant share of the innovation activities in the host country (as

measured by their share of patenting output in Singapore), but that they appear to generate significant knowledge spillover that contribute to further innovation activities in the future (as measured by patent citations). In addition, we were able to document the relatively low contribution of local universities and public research institutes as technological knowledge sources for the innovating activities of both local and foreign firms. We were also able to trace changes over time as Singapore increases her innovating intensity. Thus, although prior research (e.g. HU, 2004) has investigated the knowledge spillover impact of foreign firms in Singapore using similar patent citation tracing method, its partial focus on one organizational sector limits a more comprehensive understanding of the entire national innovation system. Overall, we suspect that our characterization of the knowledge sources and flows in Singapore's national innovation system may be representative of other newly industrialized economies adopting a similar open-economy, foreign investment-leveraging approach.

Secondly, while most prior research focused on the use of patent citation data, we were able to combined data on citation of patents as well as scientific journals from citing patents to provide a more holistic picture of the pattern of sources and flows of knowledge in a national innovation system. By combining information on *scientific* knowledge (measured by journal article citations) as well as *technological* knowledge (measured by patent citations), this more comprehensive approach allows us to develop a number of new insights. In particular, we found that not only was the relative importance of various organization sectors (local firms, local universities and foreign firms) different for scientific vs. technological knowledge, but that their pattern of change over time may vary as well. On the whole, scientific knowledge sources appear to be more globally diversified.

Thirdly, we believe that the systemic approach adopted in this paper can potentially provide a common framework for international comparative research on how national innovation systems differ among countries. By comparing and contrasting differences in the structure of knowledge sources and flows of national innovation systems, we can begin to develop a better understanding of the common factors that influence national innovation system characteristics (e.g. size of domestic economy, degree of openness to foreign investment and trades, stage of economic development, strengths and depths of local university/PRI sector, etc.), and how and why they exhibit different innovation performance. For example, we suspect that countries like Ireland may share some of the features we found in Singapore's innovation pattern due to their similarly strong reliance on R&D by foreign firms. With foreign R&D accounting for 65.2% of private sector R&D expenditure in Ireland⁴ and 57.6% in Singapore,⁵ these two nations rank as among the most dependent on foreign R&D. Patent ownership data similarly reveal the

⁴ Source: *OECD Main Science and Technology Indicators 2005*.

⁵ Source: *National Survey of R&D in Singapore*, Agency for Science, Technology and Research.

extent of foreign control over domestic inventions: 66% of Irish patents and 59% of Singapore are foreign owned.⁶ On the other hand, countries like Finland and Korea have relatively low reliance on foreign R&D and a lower degree of foreign ownership of domestic inventions. The share of foreign R&D is 14.2% in Finland⁷ and 0.55% in Korea.⁸ Contrasting with the high percentages seen in Singapore and Ireland, only 20% of Finnish patents and 12% of Korean patents are foreign owned. Such countries are likely to exhibit quite different patterns, due to the presence of large, technologically advanced domestic firms which could serve as important sources of technological knowledge for other domestic firms (see, e.g., VERSPAGEN, 2000). The more advanced development of the university and public research system in these technologically more advanced countries may also suggest a stronger local scientific knowledge role than was observed in our study of Singapore. Lastly, we can also investigate change over time among countries to see if there is a trend towards convergence or divergence over time.

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⁶ Share of foreign-owned patents in locally invented patents is computed from USPTO data on cumulative patents granted between 1976 and 2001. A patent is regarded as a domestic invention if at least one inventor is from the specified country. A patent is regarded as foreign owned if at least one assignee is not from the specified country. This might overstate slightly the extent of foreign ownership as patents might be jointly owned by foreign and local organizations. GUELLEC & VAN POTTELSBERGHE DE LA POTTERIE (2001) use a comparable indicator based on fractional patent counts for multiple-inventor patents. Their indicator applied to USPTO patents granted in 1998 similarly shows high foreign control of domestic patents in Ireland and low foreign control in Korea and Finland.

⁷ Source: *OECD Main Science and Technology Indicators 2005*.

⁸ Source: *Survey of R&D Activities*, Ministry of Science and Technology, Republic of Korea.

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Appendix

Growth of R&D and patenting in Singapore, 1978–2003

Year	GERD (S\$ m)	GERD/ GDP (%)	Research scientists & engineers (RSE)	RSE/10,000 labour force	USPTO Patents ¹
1978	37.80	0.21	818	8.4	3
1981	81.00	0.26	1,193	10.6	5
1984	214.30	0.54	2,401	18.4	4
1987	374.70	0.86	3,361	25.3	16
1990	571.70	0.85	4,329	27.7	28
1991	756.80	1.01	5,218	33.6	21
1992	949.50	1.17	6,454	39.8	41
1993	998.20	1.06	6,629	40.5	61
1994	1,174.98	1.09	7,086	41.9	79
1995	1,366.55	1.15	8,340	47.7	81
1996	1,792.14	1.38	10,153	56.3	124
1997	2,104.56	1.49	11,302	60.2	132
1998	2,492.26	1.82	12,655	65.5	181
1999	2,656.30	1.90	13,817	69.9	207
2000	3,009.52	1.88	14,483	66.1	299
2001	3,232.68	2.10	15,366	72.5	387
2002	3,404.66	2.15	15,654	73.5	533
2003	3,424.47	2.15	17,074	79.4	564
Compound average growth rate per annum (%)					
1978–1990	25.4		14.9		20.5
1990–1995	19.0		14.0		23.7
1995–2003	12.2		9.4		27.5

¹ Patents where at least one inventor is a Singapore resident

Source: *National Survey of R&D Expenditure and Manpower* (various years), Science Council of Singapore (prior to 1990); *National Survey of R&D in Singapore* (various years), National Science & Technology Board (for 1990–2000) and Agency for Science, Technology & Research (2001 to 2003), NUS USPTO patents database: <http://patents.nus.edu.sg>