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Technological dynamism in Asia

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Abstract

We analyze innovation in emerging and newly industrialized economies over the past 30 years, with the emphasis being on Asian economies. We use US patent data to study how the innovative capabilities of Taiwan, South Korea, Hong Kong and Singapore have expanded in relation to emerging economies in Asia and Latin America. We then carry out a sector-level analysis of innovation for South Korea, Taiwan, Singapore, Hong Kong, India and China. We also study the relative importance of foreign multinationals, business groups, individuals, domestic firms and research institutes in innovation. Finally, we study the overall concentration of innovative activity in Asian economies.

Keywords: Innovation; Technology; Patents; Growth; Asia

1. Introduction

Over the past few decades, Asian economies like South Korea, Taiwan, Hong Kong and Singapore have achieved high growth rates (Table 1). Proponents of the "accumulation" view of growth (Krugman, 1994; Young, 1995; Collins and Bosworth, 1996) argue that this is merely the result of high savings and investments that have made it possible for these countries to better use technologies inherited from the world's technological leaders. In contrast, proponents of the "assimilation" view (Dahlman, 1994; Hobday, 1995; Nelson and Pack, 1998; Kim, 1998) insist that the critical source of growth in East Asia has been productivity growth resulting from the learning, entrepreneurship and innovation that these economies have gone through, which has made not only adoption of foreign technologies but also development of indigenous technologies possible.

In this paper, we investigate the extent of innovation in East Asia. While doing so obviously does not conclusively settle the assimilation versus accumulation debate, evidence of substantial increase in innovation-related capabilities lends some support to the plausibility of the assimilation view. We examine patent data to study if these economies have built indigenous technological and entrepreneurial capabilities. Most of previous literature using patent data has focused on patenting activity of developed countries (e.g. US and western European countries) because the extent of patenting from other countries was often too small to be considered statistically meaningful. However, in the past two decades, many other countries have also started to patent heavily, opening up an opportunity for more research using patent data.

We find that Taiwan, South Korea, Hong Kong and Singapore now have a much higher US patenting

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Table 1
Annualized real GDP growth rate (%): 1970–1999

Recipient countries	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
Newly industrialized economies						
Taiwan (ROC)	NA	NA	6.7	9.2	7.1	4.6
South Korea	8.2	7.2	8.1	10.0	7.5	3.1
Hong Kong	6.7	12.0	5.7	7.6	5.3	1.4
Singapore	9.6	8.5	6.3	8.5	9.2	4.3
Emerging Asian economies						
India	3.2	5.4	5.4	6.4	5.2	5.0
China	5.2	5.5	10.8	7.7	12.1	6.7
Indonesia	7.8	7.9	5.7	7.1	7.8	0.0
Malaysia	7.2	8.6	5.2	6.9	9.5	3.1
Thailand	5.8	8.0	5.4	10.3	8.6	−0.3
Emerging Latin American economies						
Mexico	6.3	7.1	2.0	1.7	1.6	4.1
Brazil	10.3	6.7	1.2	2.1	3.2	1.3
Argentina	3.1	3.0	−2.4	−0.3	6.7	2.9
Chile	−1.1	7.3	1.1	6.8	8.7	3.4
Venezuela	3.0	2.5	−0.9	2.8	3.5	−0.2

Source: authors' calculations based on data from World Development Indicators and EIU country data.

activity than the emerging economies both in Asia (India, China, Indonesia, Malaysia and Thailand) and in Latin America (Mexico, Brazil, Argentina, Chile and Venezuela). The results are most dramatic for Taiwan and South Korea, though less so for Hong Kong and Singapore. Taiwan and South Korea appear to be far ahead of Hong Kong and Singapore in innovation, indicating that the "Asian Tigers" might actually differ in the extent of innovation and hence possibly in the mechanisms that have led to their rapid growth. It appears that Taiwan already saw a surge in patenting activity in the late 1980s, while the rapid increase in patenting is primarily a 1990s phenomenon for South Korea. Hong Kong, Singapore and India have also recently begun to increase the extent of their US patenting, though the remaining emerging economies in our sample do not show any evidence of significantly exceeding the average overall growth rates in patenting. All the results mentioned here continue to hold even if we account for differences in exports across countries.

Sector-level analysis sheds additional light on innovation in Asia. The areas of specialization for any given country are found to be somewhat persistent, evolving only slowly over time. Both South Korea and Taiwan have managed to gradually shift more towards fast-growing industries. Even though South Korea has been a little behind Taiwan in the aggregate patenting activity, it has been quicker in making a transition to fast-growing industries and also achieving a higher degree of specialization. Unlike South Korea and Taiwan, Hong Kong and Singapore have seen a fall in the overall degree of specialization, even though they have also managed a transition towards the fast-growing sectors.

We also compare the sources of innovation across the Asian economies. We find that the relative contribution to innovation by multinational subsidiaries has been highest in Singapore and India, minimal in Taiwan and South Korea, and something in between for Hong Kong and China. Business groups have been behind more than 80% of the patents arising from South Korea in the 1990s, while their contribution in Taiwan has been less than 4%. The importance of individual inventors seems to be declining over time across all countries. However, they still own 59% of the recent patents in Taiwan but a mere 7% in South Korea. Individual inventors are also important in Hong Kong and China, but not so much for Singapore and India. We also study how concentration of innovative activity differs across different economies by calculating the fraction of the country's patents held by its top 50 assignees. This number is found to be the highest for South Korea (85%), followed by Singapore (70%), India (63%), Hong Kong (32%), Taiwan (26%) and finally China (24%).

The paper is divided into the following sections. In Section 2, we summarize our data and methodology for comparing innovation across countries. In Section 3, aggregate data for the past three decades is used to compare the newly industrialized countries with other emerging countries in Asia and Latin America. The remaining sections focus on detailed study of innovation in six Asian economies—four of them being newly industrialized countries (Korea, Taiwan, Singapore and Hong Kong) and two being emerging economies (India and China). The other Asian economies are not included in this detailed analysis because of the relatively small number of patents they have, making detailed analysis statistically uninteresting for these countries. Sections 4 and 5 present sector-level analysis of innovation in the six Asian countries. Sections 6 and 7 study the role of multinational subsidiaries, business groups, domestic firms, government-affiliated institutes and individual players in innovation, and examine the degree of concentration of patenting activity. Section 8 offers concluding thoughts.

2. Comparing innovation across countries: methodology

Both patents and R&D expenditure data are commonly used indicators of innovation. The absence of uniform international accounting standards as well as unavailability of detailed R&D data makes R&D data analysis impractical for our purposes. An alternative is to use patent data. However, patent counts from different patent offices are not comparable to each other because of different patent breadths, patenting costs, approval requirements and enforcement rules for patenting in different countries. A common remedy is to use patent data from a single patent granting country like US to standardize the unit of innovation, making cross-country comparisons possible. Since the US is the largest and technologically most advanced market in the world, any sufficiently big invention being patented anywhere with a global market in mind is likely to be patented in the US as well. Over the past two decades or so, the increasing number of patents taken out by the countries in Asia and Latin America now allows us to do statistically meaningful analysis. While patenting data does not always capture the cumulative and incremental aspect of learning and innovation (Amsden and Hikino, 1994), it still is perhaps the best means of making large-scale comparisons of innovation (Pavitt, 1988b; Griliches, 1990).

Our dataset, which includes successful applications registered with the US Patent Office (USPTO) during 1970–1999, was obtained by combining data obtained directly from USPTO with an enhanced dataset by Hall et al. (2001). We divide the entire period of 30 years into six consecutive 5-year periods based on the grant year (1970–1974, 1975–1979, ..., 1995–1999) in order to reduce the erratic year-to-year variation in the data. As is common practice in use of patent data, we take the country listed in the address of the first inventor for a patent to be the country where innovation takes place.

3. Comparing innovation across countries: results

Table 2 summarizes the trends in US patents granted to inventors based in several Asian and Latin American economies from 1970 to 1999. This helps us compare the newly industrialized countries in Asia (Taiwan, South Korea, Hong Kong and Singapore) with other emerging economies in Asia (India, China, Indonesia, Malaysia and Thailand) and Latin America (Mexico, Brazil, Argentina, Chile and Venezuela). As the data indicate, the overall patenting activity of the NICs had been quite low during the earlier part of this time period, but has gone up substantially in recent years relative to the trend in aggregate worldwide patenting as well as that of emerging economies in Asia and Latin America. The growth in patenting has been much more dramatic for Taiwan and South Korea than for Hong Kong and Singapore, suggesting that former in particular have experienced a massive increase in innovative capabilities.

As Table 3 indicates, the countries in our sample differ substantially in the extent of foreign exports. It can be argued that the incentive of inventors from a country to patent abroad would depend on the extent to which they participate in world markets. Therefore, one fear in reading too much into raw patent

Table 2
US patents granted to country's inventors: 1970–1999

Recipient countries	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
Newly industrialized economies						
Taiwan (ROC)	1	176	397	1,772	5,271	12,366
South Korea	24	43	91	424	2,890	11,366
Hong Kong	59	75	113	177	279	570
Singapore	21	9	20	47	148	499
Emerging Asian economies						
India	83	67	40	64	126	316
China	61	2	7	129	239	332
Indonesia	19	5	5	10	26	18
Malaysia	2	13	6	13	43	89
Thailand	4	3	7	11	15	56
Emerging Latin American economies						
Mexico	243	246	191	202	189	257
Brazil	86	100	110	156	260	353
Argentina	126	113	100	82	109	183
Chile	22	20	12	18	32	44
Venezuela	36	35	50	103	121	145
Total worldwide	367,943	322, 385	309, 387	398,816	484,223	623,999

The numbers indicate the number of US patents granted for inventions made in these countries in the indicated time period. Source: authors' calculations based on the US Patent Office data.

Table 3
Country exports: 1970–1999

Recipient countries	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
Newly industrialized economies						
Taiwan (ROC)	NA	NA	256.7 (52.9%)	399.8 (54.4%)	477.3 (45.0%)	697.1 (48.0%)
South Korea	87.6 (21.5%)	181.0 (28.9)	289.0 (34.3%)	470.6 (35.7%)	549.5 (27.9%)	983.4 (37.3%)
Hong Kong	125.0 (88.9%)	184.0 (87.5%)	311.0 (95.6%)	561.0 (123.0%)	838.0 (139.3%)	1002.8 (137.0%)
Singapore	87.1 (121.9%)	178.3 (171.6%)	304.3 (192.9%)	390.4 (187.6)	595.1 (185.8)	823.6 (174.5)
Emerging Asian economies						
India	23.6 (4.0%)	45.8 (6.4%)	52.5 (6.0%)	70.9 (6.2%)	136.0 (9.2%)	226.0 (11.3%)
China	15.7 (2.9%)	32.8 (4.8%)	84.8 (8.6%)	204.0 (12.4%)	506.0 (20.1%)	932.0 (22.4%)
Indonesia	41.1 (20.0%)	75.8 (25.6%)	118.0 (28.0%)	127.4 (22.9%)	215.2 (26.5%)	344.1 (32.9%)
Malaysia	35.1 (40.0%)	61.7 (49.0%)	94.4 (54.4%)	140.4 (62.6%)	272.0 (79.8%)	507.9 (103.3%)
Thailand	27.3 (18.1%)	43.6 (20.3%)	65.8 (22.5%)	121.5 (29.7%)	243.0 (36.9%)	409.8 (48.7%)
Emerging Latin American economies						
Mexico	53.1 (8.1%)	84.4 (9.6%)	171.0 (14.6%)	221.3 (18.2%)	234.1 (16.4%)	493.0 (13.9%)
Brazil	108.9 (7.5%)	151.9 (7.1%)	254.9 (10.2%)	295.1 (9.9%)	300.0 (9.6%)	297.6 (8.1%)
Argentina	59.2 (6.7%)	77.6 (7.9%)	77.7 (7.5%)	101.4 (10.0%)	89.0 (7.7%)	145.8 (10.2%)
Chile	16.3 (13.8%)	27.2 (22.9%)	30.8 (21.2%)	56.7 (31.9%)	78.9 (30.8%)	104.5 (28.6%)
Venezuela	62.6 (25.7%)	73.5 (24.7%)	73.3 (25.0%)	75.1 (24.2%)	111.8 (30.7%)	105.7 (26.8%)

The numbers indicate the exports in billions of constant 1995 US$ for the countries in the indicated time period. The numbers in parentheses indicate exports as a percent of the country's total GDP. Source: authors' calculations based on data from World Development Indicators and EIU country data.

Table 4
US patents granted per billion constant 1995 US$ of exports: 1970–1999

Recipient countries	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999
Newly industrialized economies						
Taiwan (ROC)	NA	NA	1.55	4.43	11.04	17.73
South Korea	0.27	0.24	0.31	0.90	5.26	11.56
Hong Kong	0.47	0.42	0.36	0.32	0.33	0.57
Singapore	0.24	0.05	0.07	0.12	0.25	0.61
Emerging Asian economies						
India	3.52	1.46	0.76	0.90	0.93	1.40
China	3.89	0.06	0.08	0.63	0.47	0.36
Indonesia	0.46	0.07	0.04	0.08	0.12	0.05
Malaysia	0.11	0.05	0.07	0.08	0.06	0.11
Thailand	0.15	0.07	0.11	0.09	0.06	0.14
Emerging Latin American economies						
Mexico	4.58	2.91	1.12	0.91	0.81	0.52
Brazil	0.79	0.66	0.43	0.53	0.87	1.19
Argentina	2.13	1.46	1.29	0.81	1.22	1.26
Chile	1.35	0.74	0.39	0.32	0.41	0.42
Venezuela	0.58	0.48	0.68	1.37	1.08	1.37

Source: authors' calculations based on Tables 2 and 3.

counts from Table 2 is that the extent of US patenting might simply reflect different size of the economies or different export orientation rather than genuine differences in innovativeness. In order to control for this possibility, we carry out a robustness check suggested by Archibugi and Pianta (1998) by dividing each country's number of US patents by their exports, giving us the normalized patenting numbers reported in Table 4. Even after controlling for differences in foreign exports, we find that Taiwan and South Korea turn out to be far ahead of the rest in recent years.

4. Sector-level analysis of innovation: methodology

Aggregate patent data hide important sector-level details of innovation. The assessment of national capabilities and performance in specific fields of technology is important because technological progress, particularly within a specific paradigm, seems to proceed cumulatively along the "technological trajectories" defined by the paradigm (Dosi, 1982; Archibugi and Pianta, 1992). The path dependency and the cumulative nature of technology together imply that a nation's technological capabilities are likely to be in the technological neighborhood of previous successes, a claim that is corroborated by evidence provided by Pavitt (1988a) and Cantwell (1989). In the context of developed countries, it has been shown that analysis of technological convergence at the aggregate level can be very misleading, and only a sector-level analysis gives a clear picture of differences in technological capabilities of a country (Soete, 1987; Guerrieri and Milana, 1998; Patel and Pavitt, 1998; Archibugi and Pianta, 1998; Laursen, 1999). With this in mind, we focus on identifying the fields in which different Asian countries have an advantage or weakness relative to their overall scientific and technological activities.

4.1. *Definition of sectors*

In coming up with our definition for industries, we used three-digit SIC codes as a starting point, but aggregated some of these up to give a total of only 33 sectors. We felt that 33 sectors was a reasonable trade-off between the richness of sectoral data and the number of patents per sector as a reliable measure of innovativeness in that sector. Our entire list of sectors, along with its mapping to SIC and ISIC codes, appears in Table 5. We also want to classify the sectors in order to help capture the "quality" of national patterns of technological specialization. In an approach analogous

Table 5
List of industries

Number	Name	SIC code(s)	ISIC code(s)
1	Food, other related products and beverages	20	311–313
2	Textiles, apparel, leather and footwear	22, 23, 31	321–324
3	Basic industrial chemicals (organic and inorganic)	281, 286	3511
4	Plastic materials and synthetic resins	282	3513
5	Agricultural chemicals	287	3512
6	Soaps, detergents, cleaners, perfumes, cosmetics and toiletries	284	3523
7	Paints, varnishes, lacquers, enamels and allied products	285	3521
8	Miscellaneous chemical products	289	3529
9	Drugs and medicine	283	3522
10	Petroleum, natural gas and related products	29	353–354
11	Rubber and plastic products	30	355–356
12	Stone, class, glass and non-metal minerals	32	361, 362, 369
13	Ferrous and non-ferrous metals	33	371, 372
14	Fabricated metal products	34 (ex. 3462, 3463, 348)	381
15	Engines and turbines	351	3821
16	Farm and garden machinery and equipment	352	3822
17	Metal working machinery and equipment	354	3823
18	Computers and office	357	3825
19	Special industry machinery, except metal working	355	3824
20	Other non-electric machinery and equipment	353, 356, 358, 359	3829
21	Electric industrial machinery and equipment	361, 362, 3825	3831
22	Electric household appliances	363	3833
23	Electric miscellaneous apparatus and supplies	364, 369	3839
24	Electronics, radio, television, communication	365, 366, 367	3832
25	Motor vehicles and other motor vehicle equipment	371	3843
26	Guided missiles and space vehicles and parts	376	3829
27	Ship and boat building and repairing	373	3841
28	Railroad equipment	374	3842
29	Motorcycles, bicycles and parts	375	3844
30	Miscellaneous transport equipment and ordinance	379, 348	3849
31	Aircraft and parts	372	3845
32	Professional and scientific equipment	38	385
33	Other manufactured products	99	390

to Archibugi and Pianta (1992), we sort the 33 sectors in decreasing order of their patenting growth rate. The top 11 sectors are classified as "fast-growing" sectors, the next 11 as "medium-growing" sectors and the last 11 as "slow-growing" sectors. The complete list of sectors according to the classification for each of these periods appears in Table 6.

4.2. Measuring sector-level specialization

A general problem with using raw patent counts is that sectors vary in the propensity to patent (Scherer, 1983). Also, the raw numbers are obviously sensitive to our choice of sector definitions. We follow previous research (Soete, 1987; Archibugi and Pianta, 1992) in using a "relative technological advantage" (RTA) index that measures the *relative* distribution of a country's inventive activity in each field. Formally, the RTA index for country i in sector j is defined as the ratio of country i's share of total world patents in sector j to country i's share of total world patents, i.e.

$$\mathrm{RTA}_{ij} \equiv \frac{n_{ij}/\sum_i n_{ij}}{\sum_j n_{ij}/\sum_i \sum_j n_{ij}}$$

where n_{ij} is the number of patents of country i in sector j.

By definition, this index equals 1 if the country holds the same share of worldwide patents in a given technology as in the aggregate, and is below (above) 1 if there is a relative weakness (strength). This allows

Table 6
All 33 sectors sorted by decreasing growth rate of all US patents

1980–1984	1985–1989	1990–1994	1995–1999
Top 11 (fast growing)			
Computers and office	Computers and office	Computers and office	Computers and office
Petroleum, natural gas and related products	Guided missiles and space vehicles and parts	Drugs and medicine	Drugs and medicine
Electric household appliances	Electronics, radio, television, communication	Plastic materials and synthetic resins	Electronics, radio, television, communication
Agricultural chemicals	Motorcycles, bicycles and parts	Electronics, radio, television, communication	Soaps, detergents, cleaners, perfumes, cosmetics and toiletries
Drugs and medicine	Ship and boat building and repairing	Electric miscellaneous apparatus and supplies	Agricultural chemicals
Professional and scientific equipment	Motor vehicles and other motor vehicle equipment	Paints, varnishes, lacquers, enamels and allied products	Electric industrial machinery and equipment
Aircraft and parts	Professional and scientific equipment	Professional and scientific equipment	Electric miscellaneous apparatus and supplies
Engines and turbines	Drugs and medicine	Soaps, detergents, cleaners, perfumes, cosmetics and toiletries	Professional and scientific equipment
Electric industrial machinery and equipment	Other manufactured products	Rubber and plastic products	Textiles, apparel, leather and footwear
Stone, class, glass and non-metal minerals	Electric industrial machinery and equipment	Stone, class, glass and non-metal minerals	Other manufactured products
Plastic materials and synthetic resins	Miscellaneous transport equipment and ordinance	Agricultural chemicals	Motorcycles, bicycles and parts
Middle 11 (medium growing)			
Rubber and plastic products	Agricultural chemicals	Basic industrial chemicals (organic and inorganic)	Motor vehicles and other motor vehicle equipment
Electric miscellaneous apparatus and supplies	Aircraft and parts	Other manufactured products	Miscellaneous chemical products
Electronics, radio, television, communication	Metal working machinery and equipment	Food, other related products and beverages	Electric household appliances
Textiles, apparel, leather and footwear	Fabricated metal products	Farm and garden machinery and equipment	Rubber and plastic products
Soaps, detergents, cleaners, perfumes, cosmetics and toiletries	Electric miscellaneous apparatus and supplies	Guided missiles and space vehicles and parts	Stone, class, glass and non-metal minerals
Motor vehicles and other motor vehicle equipment	Soaps, detergents, cleaners, perfumes, cosmetics and toiletries	Miscellaneous chemical products	Special industry machinery, except metal working
Fabricated metal products	Other non-electric machinery and equipment	Ship and boat building and repairing	Basic industrial chemicals (organic and inorganic)
Farm and garden machinery and equipment	Ferrous and non-ferrous metals	Motor vehicles and other motor vehicle equipment	Aircraft and parts

Table 6 (*Continued*)

1980–1984	1985–1989	1990–1994	1995–1999
Miscellaneous chemical products	Food, other related products and beverages	Ferrous and non-ferrous metals	Other non-electric machinery and equipment
Other non-electric machinery and equipment	Electric household appliances	Aircraft and parts	Fabricated metal products
Other manufactured products	Rubber and plastic products	Miscellaneous transport equipment and ordinance	Paints, varnishes, lacquers, enamels and allied products
Bottom 11 (*slow growing*)			
Railroad equipment	Textiles, apparel, leather and footwear	Special industry machinery, except metal working	Food, other related products and beverages
Food, other related products and beverages	Engines and turbines	Motorcycles, bicycles and parts	Farm and garden machinery and equipment
Paints, varnishes, lacquers, enamels and allied products	Special industry machinery, except metal working	Other non-electric machinery and equipment	Engines and turbines
Motorcycles, bicycles and parts	Stone, class, glass and non-metal minerals	Fabricated metal products	Railroad equipment
Special industry machinery, except metal working	Plastic materials and synthetic resins	Engines and turbines	Ship and boat building and repairing
Metal working machinery and equipment	Miscellaneous chemical products	Textiles, apparel, leather and footwear	Metal working machinery and equipment
Ferrous and non-ferrous metals	Petroleum, natural gas and related products	Electric industrial machinery and equipment	Miscellaneous transport equipment and ordinance
Guided missiles and space vehicles and parts	Farm and garden machinery and equipment	Railroad equipment	Ferrous and non-ferrous metals
Miscellaneous transport equipment and ordinance	Railroad equipment	Metal working machinery and equipment	Guided missiles and space vehicles and parts
Basic industrial chemicals (organic and inorganic)	Basic industrial chemicals (organic and inorganic)	Electric household appliances	Petroleum, natural gas and related products
Ship and boat building and repairing	Paints, varnishes, lacquers, enamels and allied products	Petroleum, natural gas and related products	Plastic materials and synthetic resins

cross-sectional as well as longitudinal comparison of *relative* technological strengths and weaknesses of countries.

4.3. Measuring overall degree of technological specialization

As a country slowly diversifies out of sectors associated with abundant endowments of the conventional factors of production like textiles, mining and food processing towards advanced sectors like machinery, transportation and chemicals, their overall specialization might fall initially (Bell and Pavitt, 1993; Amsden and Hikino, 1994). However, as they eventually approach the technological frontier, the need for internal or external economies of scale in R&D suggests that the country would start to specialize on a narrow set of new industries. Thus, a country's technological specialization could be expected to first decline and then rise as it moves from traditional to more high tech sectors.

In order to measure how evenly or unevenly the patenting activities of a given country are distributed across all the sectors, we follow previous literature in using the χ^2-index, which is defined as

$$\chi_i^2 = \sum_j \left[\frac{(p_{ij} - p_{\mathrm{w}j})^2}{p_{\mathrm{w}j}} \right]$$

where j is the sector, $p_{\mathrm{w}j}$ the percentage of total world patents in class j and p_{ij} the percentage of patents held by country i in sector j. The more diverse a country is in relative sectoral strengths and weaknesses, the greater the value of χ^2. Since the χ^2-indices are calculated on the country's percentage distribution and not levels of activities across sectors, they make cross-country comparisons in specialization meaningful.

5. Sector-level analysis of innovation: results

Table 7 reports the top five sectors in terms of RTA as well as the overall χ^2-index for each time period for six Asian economies: Taiwan, South Korea, Hong Kong, Singapore, India and China.[1] We start by making some general observations based on Table 7. First, we see that the countries are quite different in their areas of specialization, and these areas tend to be persistent for each country in the short run. Second, countries differ in their degree of overall specialization, and the degree of specialization evolves differently over time for different countries. For Taiwan, Singapore and Hong Kong, the degree of specialization (as measured by the χ^2-index in Table 7) seems to have steadily fallen over time, consistent with the theory of natural evolution of a "latecomer industrializing economy" as it makes the transition from a borrower to an innovator of technology (Amsden, 1989). Interestingly, South Korea does not show this pattern—instead, it shows an *increase* in the degree of specialization from the 1980s to 1990s (though the degree of specialization is somewhat lower in the late 1990s compared with early 1990s). India and China have both maintained relatively stable degrees of specialization, though the degree of specialization for India has been consistently higher (between 1.9 and 2.7) than for China (between 0.2 and 0.4).

5.1. South Korea

As Table 7 shows, the top five RTA sectors have changed completely between 1980–1984 and 1995–1999 for South Korea. However, this change has been gradual as there has been a significant overlap in the top five lists between any two adjacent periods. This suggests that country-specific factors prevent rapid change in areas of specialization, though these areas do change over a sufficiently long period. During 1980–1984, none of the top five RTA sectors for South Korea appear in the "fast growing industries" list for patenting activity as defined in Table 6. In contrast, during 1995–1999, four of the top five RTA sectors for South Korea are drawn from the fast growing industries list. This is consistent with the explanation given by Hobday (1995) that South Korea has only recently developed strong technological capabilities because of increased exposure to foreign markets and competition through increased exports in the 1970s and 1980s.

[1] We exclude Indonesia, Malaysia and Thailand because of the their low levels of patenting at the sector level. Additionally, data for 1970s and early 1980s has small sample sizes even for the selected countries (especially China, Singapore and India), and should therefore be interpreted with caution. In the 1990s, however, the sample sizes become sufficiently large for us to have more confidence in sector-level analysis using patent data.

Table 7
The χ^2-index and top five RTA sectors for Taiwan and South Korea

Taiwan	South Korea
1980–1984	
$N = 397$, $\chi^2 = 0.75$	$N = 91$, $\chi^2 = 0.37$
Motorcycles, bicycles and parts (4.1)	Ship and boat building and repairing (3.8)
Other manufactured products (3.3)	Electric miscellaneous apparatus and supplies (2.4)
Fabricated metal products (2.3)	Other manufactured products (2.3)
Electric household appliances (2.0)	Basic industrial chemicals (1.6)
Electric miscellaneous apparatus and supplies (1.4)	Fabricated metal products (1.5)
1985–1989	
$N = 1772$, $\chi^2 = 0.74$	$N = 424$, $\chi^2 = 0.35$
Motorcycles, bicycles and parts (5.2)	Electric household appliances (3.6)
Other manufactured products (2.7)	Motorcycles, bicycles and parts (3.1)
Fabricated metal products (2.7)	Ship and boat building and repairing (3.0)
Electric miscellaneous apparatus and supplies (2.3)	Other manufactured products (1.9)
Electric household appliances (1.9)	Electric industrial machinery and equipment (1.8)
1990–1994	
$N = 5271$, $\chi^2 = 0.64$	$N = 2890$, $\chi^2 = 0.84$
Motorcycles, bicycles and parts (6.5)	Electronics, radio, television, communication (3.0)
Other manufactured products (2.7)	Electric household appliances (2.4)
Fabricated metal products (2.4)	Computers and office (1.6)
Electric miscellaneous apparatus and supplies (2.2)	Electric industrial machinery and equipment (1.0)
Electric household appliances (1.8)	Electric miscellaneous apparatus and supplies (0.8)
1995–1999	
$N = 12366$, $\chi^2 = 0.46$	$N = 11366$, $\chi^2 = 0.60$
Motorcycles, bicycles and parts (6.0)	Electric household appliances (3.1)
Electric miscellaneous apparatus and supplies (2.1)	Electronics, radio, television, communication (2.5)
Other manufactured products (2.1)	Electric industrial machinery and equipment (1.2)
Fabricated metal products (1.9)	Computers and office (1.1)
Electronics, radio, television, communication (1.6)	Other non-electric machinery and equipment (1.0)

N indicates the number of US patents granted to the country in the particular period; χ^2 measures the overall degree of specialization of the country (as explained in the text). The five industries are the top five industries in terms of RTA for that country in that period, with the numbers in bracket indicating the RTA values.

The χ^2-values over time for South Korea reveal that the *overall* degree of technological specialization is much higher in the 1990s than in the 1980s. The increasing value of the χ^2-index suggests that South Korea has been making the transition from a scale-intensive phase to a technology-intensive phase of development (Bell and Pavitt, 1993). When we examine this finding in light of South Korea's sectoral patterns of specialization in Table 7, this seems to be a plausible conclusion. The "heavy and chemical industries" drive was initiated by President Park in the 1970s to enhance South Korea's self-sufficiency in industrial raw materials and to upgrade its industrial structure from being labor-intensive to being capital-intensive stage. Special legislation singled out six strategic industries—steel, petrochemicals, nonferrous metals, shipbuilding, electronics and machinery—to receive support, including tax incentives, subsidized public services and preferential financing. This was followed by industrial policies of the subsequent regimes that emphasized the development of specialized industries such as semiconductors and electronics. The patenting growth for South Korea as reported in Table 1 and the specialization outcomes reported in Table 7 seem consistent with these policy measures.

5.2. Taiwan

Unlike South Korea, the areas where Taiwan has focused have remained remarkably consistent during the past 20 years. This once more highlights that country-specific drivers of technological specialization are indeed quite stable. As reported in Table 7, four out of the top five RTA sectors have remained the same from 1980–1984 to 1995–1999. The most notable change that took place is in "electronics, radio, television and communications", where the RTA value has gone up from 0.8 during 1980–1984 to 1.6 in 1995–1999. Taiwan's top RTA industry has remained "motorcycles, bicycles and parts", where its RTA has in fact steadily increased from 4.1 in 1980–1984 to 6.0 in 1995–1999. Comparing Taiwan's and South Korea's top RTA lists, we find that the two have specialized in different sectors, with "electronics, radio, television and communications" being the only common sector.

During the period 1980–1984, only one of the top five RTA sectors for Taiwan appears in the "fast growing industries" list for patenting activity as defined in Table 6. In contrast, during 1995–1999, three of the top five RTA sectors for Taiwan are drawn from the fast growing industries list. Taiwan, like South Korea, seems to have developed stronger technological capabilities in areas with high overall percentage rate of increase worldwide. However, just like it lags behind South Korea in the level of technological complexity, it also seems to lag behind South Korea a little in its focus on the fast-growing industries.

The χ^2-values over time for Taiwan reveal that the *overall* degree of technological specialization is just marginally lower in the 1990s than in the 1980s. This result is consistent with the evidence of relatively consistent profiles of RTA for the past 20 years. Since the l980s, an important beneficiary of the government's industrial policies in Taiwan has been the information and communication science sector. In addition to low interest loans, investment credits and favorable tariff rates for imported computer components, the government has established research institutes to facilitate the generation of new technology and the diffusion of existing technology. By 1990, Taiwan had become the sixth largest producer of computers in the world. This may explain why "electronics, radio, television and communications" is a part of the top five RTA sectors in Taiwan.

5.3. Singapore and Hong Kong

From Tables 2 and 4, it appears that the patenting activity in Singapore and Hong Kong has consistently been much lower than in South Korea and Taiwan. Singapore and Hong Kong have not been as innovative as these other newly industrialized economies, indicating much weaker technological capabilities. Therefore, the innovative performance of the so-called "Asian Tigers" is actually quite different, indicating that the drivers of growth have also been different. The number of patents for Singapore and Hong Kong has been particularly small during the earlier periods, making a detailed sector-level analysis relatively meaningful only for the 1990s, which shall be the focus of our discussion.

Table 8 shows how the top five RTA sectors have evolved for Singapore and Hong Kong over time. Unlike South Korea and Taiwan, areas of high RTA seem to change substantially in Singapore and Hong Kong from one period to the next. For example, the only industry that appears in Singapore's top-five list for RTAs for both 1990–1994 and 1995–1999 is "electronics, radio, television and communications." There is, however, a clear move from relatively low-tech areas in the 1980s to high-tech areas in the 1990s. Although Singapore appears to have developed relative specialization in electronics and other high technology areas, a large fraction of Singapore's patenting activity continues to actually be a result of multinationals rather than domestic entities, as discussed later in this paper. The χ^2-values for Singapore and Hong Kong reveal that the *overall* degree of technological specialization has been consistently falling over time. This is similar to the trend observed in the context of developed countries wherein countries move from niche positions to much broader bases of innovation during the transition phase. Compared with the case of Singapore, the top five RTAs have been slightly more stable over time for Hong Kong. There is a fair bit of overlap in specialization of Hong Kong and Singapore, though Singapore has developed a leadership in electronics as well as electrical goods and Hong Kong focuses on just a wider variety of electrical goods.

5.4. India and China

Table 2 reveals that, although India and China are still not very large players in US patenting, they have shown a substantial surge in patenting in the 1990s. However, as Table 4 shows, this increase begins to appear smaller for India and actually negative for China

Table 8
The χ^2-index and top five RTA sectors for Hong Kong and Singapore

Hong Kong	Singapore
1980–1984	
$N = 113$, $\chi^2 = 1.16$	$N = 20$, $\chi^2 = 8.26$
Electric miscellaneous apparatus and supplies (4.0)	Miscellaneous transport equipment and ordinance (28.6)
Other manufactured products (3.8)	Ship and boat building and repair (17.4)
Motorcycles, bicycles and parts (2.5)	Food, related products and beverages (6.6)
Railroad equipment (1.7)	Electric miscellaneous apparatus and supplies (2.7)
Computers and office (1.5)	Engines and turbines (2.2)
1985–1989	
$N = 177$, $\chi^2 = 0.82$	$N = 47$, $\chi^2 = 1.48$
Electric household appliances (5.1)	Farm/garden machinery and equipment (8.5)
Electric industrial machinery and equipment (2.9)	Miscellaneous transport equipment and ordinance (4.8)
Other manufactured products (2.8)	Metal working machinery and equipment (3.3)
Electric miscellaneous apparatus and supplies (2.2)	Electric household appliances (2.6)
Railroad equipment (1.4)	Other non-electric machinery and equipment (2.4)
1990–94	
$N = 279$, $\chi^2 = 0.92$	$N = 148$, $\chi^2 = 1.15$
Electric household appliances (3.9)	Ship and boat building and repair (4.6)
Electric industrial machinery and equipment (3.8)	Electronics, radio, television, communication (3.2)
Other manufactured products (2.8)	Computers and office (2.4)
Electric miscellaneous apparatus and supplies (2.5)	Farm/garden machinery and equipment (1.6)
Fabricated metal products (1.4)	Miscellaneous chemical products (1.4)
1995–1999	
$N = 570$, $\chi^2 = 0.74$	$N = 499$, $\chi^2 = 0.66$
Electric household appliances (4.1)	Petroleum, gas and related products (2.8)
Other manufactured products (3.2)	Electronics, radio, television, communication (2.4)
Electric industrial machinery and equipment (2.3)	Food, related products and beverages (1.9)
Electric miscellaneous apparatus and supplies (2.3)	Electric industrial machinery and equipment (1.8)
Ship and boat building and repairing (1.9)	Electric household appliances (1.8)

N indicates the number of US patents granted to the country in the particular period; χ^2 measures the overall degree of specialization of the country (as explained in the text). The five industries are the top five industries in terms of RTA for that country in that period, with the numbers in bracket indicating the RTA values.

once we normalize for increase in foreign trade. Since the number of patents is not too large, it is perhaps not worthwhile trying to read too much into the time trends in RTAs reported in Table 9. It seems worth noting, however, that both Indian and China seem to be building up substantial innovative capabilities in all kinds of chemicals as well as drugs and medicine. Additionally, India seems to be quite strong in plastic materials and synthetic resins.

6. Comparing type of innovators: methodology

Next, we turn to comparing sources of innovation across the Asian economies. In particular, we want to document the fraction of innovation arising from multinational subsidiaries, business groups, individual inventors and other domestic firms and organizations in each of these countries.[2] Given the differences in the national systems of innovation across different countries (Porter, 1990; Lundvall, 1992; Nelson, 1993;

[2] Ideally, we would have liked to break up the components of "other domestic firms and organizations" that are for-profit firms and non-profit research institutes. Unfortunately, since both of these are listed as "non-government organization" in the US patent data, this is a non-trivial exercise. While US patent data does sometimes separately list patents assigned to governments, the numbers of these are trivial since they do not include research institutes. For this reason, we have simply included them in the "other domestic firms and organizations" category.

Table 9
The χ^2-index and top five RTA sectors for China and India

India	China
1980–1984	
$N = 40$, $\chi^2 = 1.92$	$N = 7$, $\chi^2 = 5.71$
Motorcycles, bicycles and parts (9.6)	Motorcycles, bicycles and parts (41.1)
Stone, class, glass, non-metal minerals (5.0)	Farm/garden machinery and equipment (10.4)
Agricultural chemicals (4.7)	Engines and turbines (4.2)
Ferrous and non-ferrous metals (4.4)	Aircraft and parts (4.1)
Miscellaneous chemical products (4.2)	Other manufactured products (3.7)
1985–1989	
$N = 64$, $\chi^2 = 2.66$	$N = 129$, $\chi^2 = 0.31$
Soaps, detergents, cleaners, perfumes, cosmetics and toiletries (8.0)	Motorcycles, bicycles and parts (7.0)
Drugs and medicine (7.7)	Electric miscellaneous apparatus and supplies (2.8)
Agricultural chemicals (6.9)	Miscellaneous transport equipment and ordinance (2.4)
Railroad equipment (3.8)	Ferrous and non-ferrous metals (2.0)
Plastic materials and synthetic resins (3.3)	Drugs and medicine (1.9)
1990–1994	
$N = 126$, $\chi^2 = 2.17$	$N = 239$, $\chi^2 = 0.22$
Basic industrial chemicals (5.2)	Ferrous and non-ferrous metals (3.0)
Drugs and medicine (5.0)	Miscellaneous chemical products (2.1)
Agricultural chemicals (4.8)	Electric miscellaneous apparatus and supplies (2.0)
Plastic materials and synthetic resins (3.7)	Basic industrial chemicals (2.0)
Ferrous and non-ferrous metals (2.4)	Petroleum, gas and related products (1.8)
1995–1999	
$N = 316$, $\chi^2 = 2.45$	$N = 332$, $\chi^2 = 0.41$
Basic industrial chemicals (6.6)	Miscellaneous chemical products (3.6)
Drugs and medicine (4.3)	Basic industrial chemicals (2.8)
Plastic materials and synthetic resins (3.3)	Ship/boat building and repairing (2.6)
Agricultural chemicals (3.3)	Agricultural chemicals (2.2)
Soaps, detergents, cleaners, perfumes, cosmetics and toiletries (2.6)	Drugs and medicine (2.1)

N indicates the number of US patents granted to the country in the particular period; χ^2 measures the overall degree of specialization of the country (as explained in the text). The five industries are the top five industries in terms of RTA for that country in that period, with the numbers in bracket indicating the RTA values.

Edquist, 1997; Freeman and Soete, 1997), we expect the composition of the set of innovators to vary substantially across countries as well.

Business groups are known to play an important role in the overall economic activity of Asian economies (Khanna, 2000; Khanna and Rivkin, 2001). Therefore, we try to study their specific contribution to patenting. We were able to obtain data on business groups for South Korea, Taiwan and India, so we classified all domestic patent assignees from these countries into whether they had a group affiliation or not.[3] This enabled us to calculate the fraction of patents arising from business groups for these countries. We also study role of individuals in innovation. For our purposes, patents assigned to individuals are those that are marked as either "individual" or "unassigned" in the US patent data.

Next, we turn to calculating the fraction of patents attributable to local subsidiaries of foreign multinationals, since the role that foreign multinationals play in an economy's system of innovation can differ significantly across countries (Singh, 2002; Khanna and Singh, 2002). In order to determine whether a given patent originates from the local subsidiary of a foreign multinational, we check whether the home country of the assignee organization is the same as the country of the first inventor. A crucial step in building the dataset

[3] We used two datasets for business group data: one was the dataset used in Khanna and Rivkin (2001) kindly made available to us by Tarun Khanna and the other was data we downloaded from the web site of the Center for International Data at UC Davis (http://data.econ.ucdavis.edu/international/).

was therefore identifying whether an assignee firm had its home base in the country of patenting, or if it was part of a foreign firm.[4] To achieve this, we undertook the following extensive data cleaning exercise, details of which can be found in Singh (2002). First, we used Compustat-based CUSIP numbers (from year 1989) included in the database by Hall et al. (2001) to make sure that the subsidiaries of companies that have CUSIP numbers are correctly matched to their respective corporate parents identified using the same CUSIP number. Next, we used Stopford's (1992) directory of 428 largest multinationals to manually associate all their major subsidiaries correctly with the corporate parent. Finally, for every remaining assignee, we calculated the home country as the country in which maximum numbers of patents originated for that assignee.

We also study the list of top 50 players for each of the six countries considered here. This has several goals: First, it helps identify important individual players for innovation. Second, it gives an idea of the role of non-profit research institutes versus for-profit domestic firms since both of them show up simply as "domestic firms and organizations" in US patent database. Third, calculation of the fraction of patents held by the top 50 players helps identify the extent to which innovative activity in a country is concentrated among a few players rather than dispersed among many players in the economy.

7. Comparing type of innovators: results

Table 10 gives the composition of the set of innovators in the six Asian economies we study. Consistent with previous research (Hobday, 1995; Cheng-Fen and Sewell, 1996; Kim, 1998; Choung, 1998), we find that business groups or *chaebols* have played a key role in developing South Korea's innovative capabilities. About 81% of all South Korean patents arose from business groups. In contrast, the fraction attributable to business groups is less than 4% for the case of Taiwan. On the other hand, individual inventors own a mere 7% of the patents coming from South Korea but as much as 59% of the patents from Taiwan. Industrial policies seem to have played an important role in shaping the innovative fabric of these countries. Unlike South Korea, where large business groups dominate, Taiwan's national system of innovation has a much greater role for small and medium sized enterprises (SME).[5] Individual inventors are also relatively important in China (40%) and Hong Kong (31%), though less so in India (18%) and Singapore (10%).

Singapore has relied quite heavily on multinationals, which account for 46% of the patenting arising from Singapore in the 1990s.[6] In analysis not reported in Table 10, it appears that the relative role of domestic entities is beginning to go up—only 59 of the 148 patents for 1990–1994 were granted to domestic entities, while 287 of the 499 patents in 1995–1999 were owned by domestic entities. Thus, it seems that recent adoption of a more R&D-oriented policy by the government is helping Singapore to begin developing strong indigenous innovative capabilities as well.

Unlike Singapore, Hong Kong seems to have been less reliant on foreign multinationals for the patenting

[4] We defined the subsidiary as being a company in which the multinational has a majority stake. While one can argue that even a "high enough" minority stake can give a multinational enough control over a foreign company, we wanted to avoid the situation in which a company could not be identified with a unique parent. For cases where two multinationals had exactly 50–50 stake in a company, we broke the tie by assuming it was a part of the multinational whose name appeared first in the joint venture.

[5] Based on analysis of a dataset for 1994–2000 (with a different industry classification) obtained from CHI research, we find that institutes in Taiwan focus on areas such as "biotechnology", "plastics, polymers and rubbers," etc. SMEs are dominant in industries such as, "motor vehicle and parts," "other transportation equipment," "textiles and apparels," "miscellaneous machinery," etc. In terms of absolute patent numbers, SMEs are most productive in "semiconductors and electronics" with 1111 patents (31.41% of the patents), "computers and peripherals" with 249 patents (28% of the patents), and "electronics appliances and components" with 261 patents (28% of the patents). Interestingly, in the field of "semiconductors and electronics," MNEs dominate with 1830 patents (52% of total).

[6] Analysis based on CHI research data reveals that local entities—mostly research institutes or government backed SME—constituted 81% of the total 253 patents in "semiconductors and electronics" and 94% of the 17 patents in biotechnology during 1994–2000. On the other hand, multinationals in Singapore were the main source of innovation in "electrical appliances and components" and "telecommunications equipment." However, there has been an increase in the share of patents held by local entities in industries traditionally dominated by MNEs. For instance, 90% of the 20 patents in "telecommunications equipment" industry over 1986–1993 went to multinationals while the 68% of 121 patents for 1994–2000 went to multinationals.

Table 10
Break-up of patenting activity by inventor type

Economy	Period	Multinationals (%)	Business groups (%)	Individuals (%)	Domestic firms and organizations (%)
Taiwan	1970–1979	2.9	0.0	87.7	9.4
	1980–1989	1.9	0.5	87.0	10.6
	1990–1999	1.9	3.5	59.0	35.6
Korea	1970–1979	14.7	2.9	69.1	13.2
	1980–1989	2.5	31.4	47.3	18.8
	1990–1999	0.8	80.7	6.8	11.7
Hong Kong	1970–1979	26.1	–	45.5	28.4
	1980–1989	17.3	–	31.5	51.2
	1990–1999	16.6	–	30.7	52.7
Singapore	1970–1979	50.0	–	43.3	6.7
	1980–1989	19.7	–	47.0	33.3
	1990–1999	45.7	–	9.6	44.7
India	1970–1979	54.5	0.6	24.7	20.1
	1980–1989	48.1	6.5	22.2	23.1
	1990–1999	29.6	11.1	18.3	41.0
China	1970–1979	14.5	–	76.8	8.7
	1980–1989	14.4	–	39.6	46.0
	1990–1999	17.2	–	40.1	42.7

originating from inventions done there, with multinationals accounting for only 17% of the patents. Instead, the innovative landscape in Hong Kong is dominated by small and medium sized enterprises.[7] The emergence of Hong Kong's SMEs sector dates back to the 1950s, when Hong Kong's entrepot trade with China was stopped. Most of the local enterprises began as small family ventures and therefore fostered the reinvestment of all revenues back into the business itself. The local government also provided several agencies like Hong Kong Productivity Council to facilitate the development of local industries, which helped increase the innovative capacity of SMEs (Hobday, 1995).

The results from Table 10 highlight that innovation in Taiwan and South Korea has been almost exclusively the result of innovation by domestic entities, with multinational subsidiaries being responsible for less than 2% of the patents in the past two decades. Also, multinationals seem somewhat important in India (30%) but less so for China (17%).[8] The enormous variation in the relative role of subsidiaries of foreign multinationals in innovation in different countries is explored in more detail in Singh (2002), and in Khanna and Singh (2002).[9]

Tables 11–16 lists the top 50 patent holders from each of the six countries considered here. The lists illustrate our analysis above. For example, the Taiwanese list is dominated by "other domestic firms or organizations," the South Korean list is dominated by business groups, Singapore list is dominated by "foreign multinationals or organizations," and the Hong Kong, India and China lists are a combination of "domestic firms or organizations" and "foreign multinationals or organizations." An additional insight from

[7] Our analysis based on CHI research data suggests the industries in Hong Kong where small and medium sized enterprises have been the main source of patenting include "other industries," "industrial process equipment," "office equipment and cameras," and "electric appliances and components."

[8] For both India and China, multinational enterprises are the dominant source of patenting in "Computer & Peripherals" and "Telecommunications Equipment" while domestic entities that have been responsible for most of the patenting in "Chemicals".

[9] Among other countries that we discussed in the aggregate analysis but have not included in the detailed analysis, foreign multinationals subsidiaries are most important for innovation in Malaysia, somewhat important in Brazil, Mexico and Argentina, and least important in Thailand, Chile and Venezuela.

Table 11
Top 50 patent winners for Taiwan (1970–1999)

Assignee name	Affiliation	Patent count
Industrial Technology Research Institute	Domestic firm or organization	1,229
United Microelectronics Corporation	Domestic firm or organization	946
Taiwan Semiconductor Manufacturing Co.	Domestic firm or organization	752
National Science Council	Domestic firm or organization	367
Vanguard International Semiconductor	Domestic firm or organization	301
Winbond Electronics Corp.	Walsin Lihua Group	216
Hon Hai Precision Ind. Co. Ltd.	Domestic firm or organization	107
Mosel Vitelic Incorporated	Pacific Electric Wire and C	85
Acer Peripherals Inc.	Acer Group	70
Texas Instruments Inc.	Foreign multinational	60
Acer Incorporated	Acer Group	56
Macronix International Co. Ltd.	Domestic firm or organization	55
Holtek Microelectronics Inc.	Domestic firm or organization	48
Mustek Systems Inc.	Domestic firm or organization	47
Umax Data Systems Inc.	Umax Group	47
Silitek Corporation	Liton Enterprise Group	44
Primax Electronics Ltd.	Domestic firm or organization	40
United Semiconductor Corp.	Domestic firm or organization	36
Greenmaster Industrial Corp.	Domestic firm or organization	31
Etron Technology Inc.	Domestic firm or organization	29
Powerchip Semiconductor Corp.	Umax Group	28
Tong Lung Metal Industry Co. Ltd.	Domestic firm or organization	27
Behavior Tech Computer Corp.	Domestic firm or organization	26
E. Lead Electronic Co. Ltd.	Domestic firm or organization	25
Delta Electronics Inc.	Domestic firm or organization	24
Development Center For Biotechnology	Domestic firm or organization	22
Hwa Shin Musical Instrument Co. Ltd.	Domestic firm or organization	22
Enlight Corporation	Domestic firm or organization	21
Inventec Corporation	Domestic firm or organization	21
Fu Tai Umbrella Works Ltd.	Domestic firm or organization	20
Shin Jiuh Corp.	Domestic firm or organization	19
Taiwan Fu Hsing Industrial Co. Ltd.	Domestic firm or organization	19
Duracraft Corporation	Foreign multinational	18
Shin Yeh Enterprise Co. Ltd.	Domestic firm or organization	17
Quarton Inc.	Domestic firm or organization	17
China Textile Institute	Domestic firm or organization	17
Must Systems Inc.	Domestic firm or organization	16
Chung Cheng Faucet Co. Ltd.	Domestic firm or organization	16
Chicony Electronics Co. Ltd.	Domestic firm or organization	15
Institute of Nuclear Energy Research	Domestic firm or organization	15
Kalloy Industrial Co. Ltd.	Domestic firm or organization	15
Compal Electronics Inc.	Domestic firm or organization	15
China Steel Corporation	Domestic firm or organization	13
Pan-International Industrial Corporation	Domestic firm or organization	13
Food Industry Research And Development	Domestic firm or organization	13
Teh Yor Industrial Co. Ltd.	Domestic firm or organization	12
Silicon Integrated Systems Corp.	Domestic firm or organization	12
Formosa Saint Jose Corporation	Domestic firm or organization	12
Yuan Mei Corp.	Domestic firm or organization	12
Foxconn International Inc.	Foreign multinational	12
Total patents for top 50 assignees		5,100
Other patents		14,883
Overall total 1970–1999 for Taiwan		19,983
Fraction of patents held by top 50 assignees (%)		25.5

Table 12
Top 50 patent winners for South Korea (1970–1999)

Assignee name	Affiliation	Patent count
Samsung Electronics Co. Ltd.	Samsung Group	5,350
Daewoo Electronics Company Ltd.	Daewoo Group	1,008
Hyundai Electronics Industries Co. Ltd.	Hyundai Group	931
Goldstar Company Ltd.	LG Group	892
LG Semicon Co. Ltd.	LG Group	696
LG Electronics Inc.	LG Group	566
Electronics And Telecommunications Res.	Domestic firm or organization	397
Hyundai Motor Co. Ltd.	Hyundai Group	347
Gold Star Electron Co. Ltd.	LG Group	252
Samsung Display Devices Co. Ltd.	Samsung Group	243
Korea Institute of Science And Tech.	Domestic firm or organization	238
Samsung Electron Devices Co. Ltd.	Samsung Group	214
Samsung Aerospace Industries Ltd.	Samsung Group	131
Samsung Electro-Mechanics Co. Ltd.	Samsung Group	124
Korea Advanced Institute of Science	Domestic firm or organization	105
Korea Research Institute of Chem. Tech.	Domestic firm or organization	100
Korea Telecommunication Authority	Domestic firm or organization	96
Samsung Heavy Industries, Co. Ltd.	Samsung Group	71
Lucky Ltd.	LG Group	68
LG Industrial Systems Co. Ltd.	LG Group	65
Kia Motors Corp.	Kia Group	62
SKC Limited	Sunkyong Group	51
Daewoo Telecom Co. Ltd.	Daewoo Group	42
Daewoo Heavy Industries Co. Ltd.	Daewoo Group	36
Pohang Iron and Steel Co. Ltd.	POSCO Group	35
Mando Machinery Corp. Ltd.	Halla Group	30
Korea Atomic Energy Research Institute	Domestic firm or organization	29
Agency For Defence Development	Domestic firm or organization	27
LG Chemical Ltd.	LG Group	25
Korea Kumho Petrochemical Co. Ltd.	Kumho Group	25
Kwangju Electronics Co. Ltd.	Samsung Group	24
Samsung Semiconductor and Telecom.	Samsung Group	23
Kolon Industries Inc.	Kolon Group	23
Sindo Ricoh Co. Ltd.	Domestic firm or organization	22
Toray Industries Inc.	Foreign multinational or organization	20
Samsung Heavy Industry Co. Ltd.	Samsung Group	19
Yukong Limited	Sunkyong Group	19
Orion Electric Co. Ltd.	Daewoo Group	18
Anam Industrial Co. Ltd.	Anam Group	17
Sunkyong Industries Co. Ltd.	Sunkyong Group	16
Cheil Industries Inc.	Samsung Group	16
Pacific Corporation	Pacific Group	16
Cheil Foods and Chemicals Inc.	Domestic firm or organization	14
Dong Kook Pharmaceutical Co. Ltd.	Domestic firm or organization	13
Anam Semiconductor Inc.	Anam Group	13
Medison Co. Ltd.	Domestic firm or organization	12
Volvo Construction Equipment Korea Co.	Domestic firm or organization	12
Korea Chemical Co. Ltd.	Domestic firm or organization	11
Samsung Corning Co. Ltd.	Samsung Group	11
Korea Institute of Machinerv and Metals	Domestic firm or organization	10
Total patents for top 50 assignees		12,585
Other patents		2,253
Overall total 1970–1999 for South Korea		14,838
Fraction of patents held by top 50 assignees (%)		84.8

Table 13
Top 50 patent winners for Hong Kong (1970–1999)

Assignee name	Affiliation	Patent count
Astec International Ltd.	Domestic firm or organization	44
Johnson Electric S.A.	Domestic firm or organization	33
Johnson Electric Industrial Manuf.	Domestic firm or organization	24
Motorola Inc.	Foreign multinational or organization	23
W. Haking Enterprises Limited	Domestic firm or organization	20
The Hong Kong University of Science and Tech.	Domestic firm or organization	15
Worldwide Stationery Manufacturing Co.	Domestic firm or organization	14
China Pacific Trade Ltd.	Domestic firm or organization	12
Chiaphua Industries Ltd.	Domestic firm or organization	12
Playart Limited	Domestic firm or organization	11
Polycity Industrial Ltd.	Domestic firm or organization	10
Arco Industries Ltd.	Foreign multinational or organization	10
Solar Wide Industrial Limited	Domestic firm or organization	8
T.K. Wong and Associates Limited	Domestic firm or organization	7
Pentalpha Enterprises Ltd.	Domestic firm or organization	7
Leco Stationery Manufacturing Co. Ltd.	Domestic firm or organization	7
Outboard Marine Corp.	Foreign multinational or organization	7
John Manufacturing Limited	Domestic firm or organization	6
Mego Corp.	Foreign multinational or organization	6
Mr. Christmas Incorporated	Foreign multinational or organization	6
Asm Assembly Automation Ltd.	Domestic firm or organization	5
The Chinese University of Hong Kong	Domestic firm or organization	5
The Hong Kong Polytechnic University	Domestic firm or organization	5
Wing Shing Products (Bvi) Co. Ltd.	Domestic firm or organization	5
Alza Corp.	Foreign multinational or organization	5
Computer Products Inc.	Foreign multinational or organization	5
Windmere Corp.	Foreign multinational or organization	5
Achiever Industries Limited	Domestic firm or organization	4
G.E.W. Corporation Limited	Domestic firm or organization	4
International Quartz Ltd.	Domestic firm or organization	4
Meyer Manufacturing Company Limited	Domestic firm or organization	4
Payview Limited	Domestic firm or organization	4
Tradebest International Corporation	Domestic firm or organization	4
United Chinese Plastics Products Co.	Domestic firm or organization	4
Pacusma Co. Ltd.	Domestic firm or organization	4
East Asia Services Ltd.	Domestic firm or organization	4
Addway Engineering Limited	Domestic firm or organization	4
Conair Corp.	Foreign multinational or organization	4
General Electric Company	Foreign multinational or organization	4
Polaroid Corp.	Foreign multinational or organization	4
Recoton Corp.	Foreign multinational or organization	4
Tiger Electronics Inc.	Foreign multinational or organization	4
Timex Corporation	Foreign multinational or organization	4
Concord Camera Corp.	Foreign multinational or organization	4
Heep Tung Manufactory Limited	Domestic firm or organization	3
Kwoon Kwen Metal Ware Company Limited	Domestic firm or organization	3
Maxpat Trading and Marketing	Domestic firm or organization	3
Refined Industry Company Limited	Domestic firm or organization	3
Simatelex Manufactory Company Limited	Domestic firm or organization	3
Sonca Industries Limited	Domestic firm or organization	3
Total patents for top 50 assignees		403
Other patents		870
Overall total 1970–1999 for Hong Kong		1,273
Fraction of patents held by top 50 assignees (%)		31.7

Table 14
Top 50 patent winners for Singapore (1970–1999)

Assignee name	Affiliation	Patent count
Chartered Semiconductor Manufacturing	Domestic firm or organization	122
Hewlett-Packard Co.	Foreign multinational or organization	43
National University of Singapore	Domestic firm or organization	35
Texas Instruments Inc.	Foreign multinational or organization	35
Motorola Inc.	Foreign multinational or organization	28
Thomson S.A.	Foreign multinational or organization	23
Molex Inc.	Foreign multinational or organization	23
Tritech Microelectronics International	Domestic firm or organization	21
Matsushita Electric Industrial Co. Ltd.	Foreign multinational or organization	18
Philips	Foreign multinational or organization	11
SGS-Thomson Microelectronics (Pte) Ltd.	Domestic firm or organization	9
Sun Industrial Coatings Private Ltd.	Domestic firm or organization	8
Tritech Microelectronics Ltd.	Domestic firm or organization	8
Chartered Industries of Singapore Priv	Domestic firm or organization	7
Institute of Microelectronics	Domestic firm or organization	7
Nestec, S.A.	Foreign multinational or organization	6
Berg Technology Inc.	Foreign multinational or organization	6
Seagate Technology	Foreign multinational or organization	6
Siemens Aktiengesellschaft	Foreign multinational or organization	5
Eastern Oil Tools Pte Ltd.	Domestic firm or organization	5
Singapore Computer Systems Limited	Domestic firm or organization	5
Institute of Microelectronics	Domestic firm or organization	5
Sunright Limited	Domestic firm or organization	5
Advanced Systems Automation Limited	Domestic firm or organization	5
Apple Computer Inc.	Foreign multinational or organization	5
Du Pont	Foreign multinational or organization	5
Advanced Materials Technologies Pte Ltd.	Domestic firm or organization	4
Enteron, L.P.	Domestic firm or organization	4
United Technologies Corp.	Foreign multinational or organization	4
Whitaker Corporation	Foreign multinational or organization	4
Creative Technology Limited	Domestic firm or organization	4
Varta Batterie A.G.	Foreign multinational or organization	3
Sumitomo Chemical Company, Limited	Foreign multinational or organization	3
Nortrans Shipping And Trading Far East	Domestic firm or organization	3
Abb Vetcogray Inc.	Foreign multinational or organization	3
Litton Industries	Foreign multinational or organization	3
Black and Decker Corp.	Foreign multinational or organization	3
Chevron	Foreign multinational or organization	3
Rmt Inc.	Foreign multinational or organization	3
Thomas and Betts Corp.	Foreign multinational or organization	3
Symtonic Sa	Foreign multinational or organization	2
Rhone Poulenc Industries	Foreign multinational or organization	2
Hitachi Chemical Company Ltd.	Foreign multinational or organization	2
Toshiba Corporation	Foreign multinational or organization	2
Sandvik	Foreign multinational or organization	2
Multiscience System Pte Ltd.	Domestic firm or organization	2
Port of Singapore Authority	Domestic firm or organization	2
Singapore Institute of Standards And I	Domestic firm or organization	2
Aztech Systems Ltd.	Domestic firm or organization	2
Matsushita Refrigeration Industries	Foreign multinational or organization	2
Total patents for top 50 assignees		523
Other patents		221
Overall total 1970–1999 for Singapore		744
Fraction of patents held by top 50 assignees (%)		70.3

Table 15
Top 50 patent winners for India (1970–1999)

Assignee name	Affiliation	Patent count
Council of Scientific And Industrial Research	Domestic firm or organization	141
Hoechst	Foreign multinational or organization	45
Ciba-Geigy Corporation	Foreign multinational or organization	38
Ranbaxy Laboratories Limited	Ranbaxy Group	20
Unilever	Foreign multinational or organization	19
NASA	Foreign multinational or organization	18
Texas Instruments Inc.	Foreign multinational or organization	17
Dr. Reddy'S Research Foundation	Dr. Reddy's Group	10
Lupin Laboratories Limited	Lupin Group	9
Indian Explosives Ltd.	Domestic firm or organization	8
General Electric Company	Foreign multinational or organization	8
National Institute of Immunology	Domestic firm or organization	7
Monsanto Co.	Foreign multinational or organization	7
Panacea Biotec Limited	Domestic firm or organization	6
Iowa India Investments Company Limited	Domestic firm or organization	4
Indian Oil Corporation Ltd.	Domestic firm or organization	4
Union Carbide Corp.	Foreign multinational or organization	4
Elf Aquitaine	Foreign multinational or organization	3
Cadbury India Limited	Domestic firm or organization	3
Indian Petrochemicals Corporation Ltd.	Domestic firm or organization	3
Gem Energy Industry Limited	Domestic firm or organization	3
Aktiebolaget Astra	Foreign multinational or organization	3
Procter and Gamble	Foreign multinational or organization	3
Fiberstars Inc.	Foreign multinational or organization	3
Xerox Corp.	Foreign multinational or organization	3
Novartis (Sandoz)	Foreign multinational or organization	2
Forschungszentrum Julich Gmbh	Foreign multinational or organization	2
Licentia Patent-Verwaltungs-Gmbh	Foreign multinational or organization	2
Boots Company Plc	Foreign multinational or organization	2
Imperial Chemical Industries	Foreign multinational or organization	2
Zeneca Limited	Foreign multinational or organization	2
All India Institute of Medical Science	Domestic firm or organization	2
Hawkins Cookers Limited	Domestic firm or organization	2
Iel Limited	Domestic firm or organization	2
Indian Space Research Organisation	Domestic firm or organization	2
Karamchand Premchand Private Limited	Domestic firm or organization	2
Sree Chitra Tirunal Institute For Medical	Domestic firm or organization	2
National Chemical Laboratory	Domestic firm or organization	2
The Chief Controller, Research And Dev	Domestic firm or organization	2
GEC	Foreign multinational or organization	2
Westinghouse Electric Corp.	Foreign multinational or organization	2
American Cyanamid Co.	Foreign multinational or organization	2
Analog Devices	Foreign multinational or organization	2
Avnet Inc.	Foreign multinational or organization	2
Johnson and Johnson	Foreign multinational or organization	2
Mobil	Foreign multinational or organization	2
Sri International	Foreign multinational or organization	2
United States of America, Air Force	Foreign multinational or organization	2
University of California	Foreign multinational or organization	2
University of Minnesota	Foreign multinational or organization	2
Total patents for top 50 assignees		439
Other patents		257
Overall total 1970–1999 for India		696
Fraction of patents held by top 50 assignees (%)		63.1

Table 16
Top 50 patent winners for China (1970–1999)

Assignee name	Affiliation	Patent count
China Petrochemical Development Corp.	Domestic firm or organization	26
United Microelectronics Corporation	Foreign multinational or organization	21
Tsinghua University	Domestic firm or organization	10
Autry Industries Inc.	Foreign multinational or organization	8
Industrial Technology Research Institute	Foreign multinational or organization	7
China Petrochemical Corporation	Domestic firm or organization	5
Fujian Institute of Research	Domestic firm or organization	4
North China Research Institute of Elec.	Domestic firm or organization	4
Peking University	Domestic firm or organization	4
Shanghai Institute of Biochemistry	Domestic firm or organization	4
Taiho Pharmaceutical Company Limited	Foreign multinational or organization	4
Acer Incorporated	Foreign multinational or organization	4
Beijing Research Institute of Chem.	Domestic firm or organization	3
Chinese Academy of Medical Sciences	Domestic firm or organization	3
Huazhong Institute of Technology	Domestic firm or organization	3
Institute of Physics, Chinese Academy	Domestic firm or organization	3
Shanghai Institute of Organic Chemistry	Domestic firm or organization	3
Tianjin University	Domestic firm or organization	3
CSL Opto-Electronics Corp.	Domestic firm or organization	3
Nan Kai University	Domestic firm or organization	3
Central Iron and Steel Research Institute	Domestic firm or organization	3
Bayer	Foreign multinational or organization	3
Leco Stationery Manufacturing Co. Ltd.	Foreign multinational or organization	3
Beijing Polytechnic University	Domestic firm or organization	2
China Metallurgical Import and Export Co.	Domestic firm or organization	2
China National Seed Corporation	Domestic firm or organization	2
Jilin University of Technology	Domestic firm or organization	2
Luoyang Petrochemical Engineering Corp.	Domestic firm or organization	2
Qing-Yang Machine Works	Domestic firm or organization	2
Research Institute of Petroleum Proces	Domestic firm or organization	2
Science and Technic Department of Dagang	Domestic firm or organization	2
Shanghai Lamp Factory	Domestic firm or organization	2
Institute of Materia Medica	Domestic firm or organization	2
Chinese Building Technology Services	Domestic firm or organization	2
University of Electronic Science And Tech.	Domestic firm or organization	2
South China University of Technology	Domestic firm or organization	2
Research Institute of Petroleum Proc.	Domestic firm or organization	2
Traditional Chinese Medicine Research	Domestic firm or organization	2
Dalian Institute of Chemical Physics	Domestic firm or organization	2
University of Science And Technology	Domestic firm or organization	2
Shanghai Yue Long Nonferrous Metals Ltd.	Domestic firm or organization	2
Vasomedical Inc.	Domestic firm or organization	2
Panzhihua Iron And Steel (Group) Co.	Domestic firm or organization	2
Wonder and Bioenergy Hi-Tech International	Domestic firm or organization	2
Pacific Sources Inc.	Domestic firm or organization	2
Fushun Research Institute of Petroleum	Domestic firm or organization	2
Plastic Advanced Recycling Corp.	Domestic firm or organization	2
Institute of Materia Medica, An Institute	Domestic firm or organization	2
Liache Petroleum Exploration Bureau	Domestic firm or organization	2
Jianasu Goodbabv Group. Inc.	Domestic firm or organization	2
Total patents for top 50 assignees		188
Other patents		582
Overall total 1970–1999 for China		770
Fraction of patents held by top 50 assignees (%)		24.4

these lists is that research institutes play an important role in innovation in most countries. Industrial Technology Research Institute and National Science Council in Taiwan, Electronics and Telecommunications Research Institute and Korea Institute of Science and Technology in South Korea, Hong Kong University of Science and Technology in Hong Kong, National University of Singapore in Singapore, Council of Scientific and Industrial Research in India and Tsinghua University in China are examples of important patent holders from their respective countries. Therefore, it appears that public research institutes have played an important role not just in assimilating and diffusing foreign technology but also in generating new ideas. For example, Korea Institute of Electronics Technology (KIET) started out as a "demonstration laboratory" for showing the efficient implementation of complex imported production processes such as integrated circuit wafer fabrication. With the development of private R&D, Electronics and Telecommunications Research Institute (ETRI), which evolved from KIET, shifted its focus from technology transfer and applied R&D to basic research and innovation. Similarly, Singapore's National Technology Plan and National Science and Technology Board made major investments to fund R&D and increase the number of local researchers in the 1990s, which may account for the increase in patents during the late 1990s by institutes such as the National University of Singapore and domestic SMEs affiliated with it. For China and also India to some extent, the top 50 inventors list seems to have a disproportionately high number of research institutes and government-affiliated organizations, indicating that private-sector R&D and innovation has not developed much yet in these countries.

We can also calculate the fraction of the country's patents held by its top 50 assignees in order to get a measure of how concentrated innovative activity is in different economies. This number is found to be the highest for South Korea (85%), followed by Singapore (70%), India (63%), Hong Kong (32%), Taiwan (26%) and finally China (24%). This is not surprising, given that economic activity in South Korea and Singapore is dominated largely by large players (whether domestic or multinational) while that in Taiwan and China is dominated by individuals and SMEs.

8. Concluding thoughts

We have used US patent data to study innovation in Asian economies. Our results are consistent with prior evidence (Dahlman, 1994; Rausch, 1995; Choung, 1998) that there has been a rise in technological capability over time in East Asian economies, and dramatically so for South Korea and Taiwan. Another key finding of our paper is that the emerging economies are quite heterogeneous bunch in their technological capabilities. In particular, they differ a lot in extent of patenting, areas of specialization and driving players behind innovation. We demonstrate that the newly industrialized countries have achieved leadership even in sectors that are on the frontier of technological progress, and are not specializing in just the more mature sectors where the developed countries might not compete in anymore. Further, the areas of specialization for each country have evolved very slowly over time. Thus, our analysis extends previous research that reached analogous conclusions in study of patenting activity by developed countries (Patel and Pavitt, 1998; Archibugi and Pianta, 1998). More generally, it contributes to the literature that shows that the sources and areas of technological specialization are heavily dependent on the individual national systems of innovation (Lundvall, 1992; Nelson, 1993; Edquist, 1997; Freeman and Soete, 1997).

Previous research has established that wide differences in nations have led to a great deal of variation across countries in the economic role played by multinationals, business groups, individuals, private firms and government institutes. Our analysis of patent data is consistent with this finding. For example, while large-scale conglomerates like Samsung, Daewoo, Hyundai and LG Group dominate innovation in South Korea, innovation in Taiwan and Hong Kong is a result of domestic individuals and independent firms and that in Singapore is heavily influenced by foreign firms. We find innovative activity to be most concentrated in South Korea, fairly concentrated in Singapore and much less concentrated in Taiwan and Hong Kong.

While the data and analysis presented in this paper do not conclusively settle the accumulation versus assimilation debate, we feel that they do make new and interesting contribution to the discussion. While South Korea and Taiwan are now definitely two of the world's leading innovators, Singapore and Hong Kong do not seem to have made any such transition yet (though the recent trends are promising). This may partially be explained by the fact that while the former two have been taking aggressive policy steps to develop indigenous technological capabilities, the latter two have been quite content (until recently) in importing foreign technologies rather than making cutting-edge innovations themselves. An important lesson is that the "Asian Tigers" are actually a heterogeneous bunch, and different mechanisms could be behind economic success in different countries. While the evidence in this paper informally suggests that innovation might play an important role in growth, more needs to be done to address this problem formally. Important contributions have already been made in studying this subject (e.g. see the excellent discussions and references in Archibugi and Michie, 1998a,b; Archibugi et al., 1999; Laursen, 2000). However, most research has focused only on developed countries, leaving room for further research on innovation in other parts of the world. We hope that our paper will be useful in motivating further research in this area.

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