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NATIONAL TECHNOLOGICAL COMPETITIVENESS

AND THE REVOLUTION IN MILITARY AFFAIRS

Final Report, Phase II

FINAL PROJECT REPORT

by

David Roessner and Michael Salomone

Prepared for the Director, Office of Net Assessment
Office of the Secretary of Defense
June 1, 1999

Contract No. DASW01-96-C-0042
Report No. JMSTR 99.6.1

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Findings of the Study

China, Taiwan, and Singapore, and perhaps to a lesser extent, India, have identified and articulated the national policies and capabilities that are required to achieve state-of-the-art, national competitiveness in high technology. In summary form, the objectives of such policies -- policies in place to differing degrees in each of the countries we studied -- are as follows:

- Develop an indigenous capacity in science and technology, including human capital.
- Develop high technology capabilities in both civilian and military sectors of the economy.
- Facilitate the flow of knowledge and technology between military and civilian sectors in both directions -- both spin-on and spin-off.
- Invest substantially in R&D in both civilian and military sectors of the economy.
- Create economic, political, and institutional environments that make the nation an attractive location for foreign investment.

China, Taiwan, and Singapore have in place formal plans, policies, and programs to accomplish these objectives. India can claim this, but the reality is that both plans and implementation are highly uneven. While the incentives involved and the subjects of these plans differ from country to country, with the exception of India it is possible to identify specific national objectives and programs linked to each of the above. The question to be addressed in our case studies and analyses is, therefore, whether these incentives and policies will work, given the institutional, political, cultural, and organizational factors that inevitably influence their effectiveness. To summarize our findings regarding this question, the following paragraphs identify the influences in each country that will, in our judgment, affect the likelihood that these objectives will be achieved within the next 15-20 years. Stated differently, these are the factors to watch, because we have identified them as the keys to future capacity. The bases for our judgments are summarized in the "case summaries" and fully documented in the full cases appended to this report. We end each country-specific finding, below, with our assessment of the level of militarily-relevant technological capabilities that each nation is likely to achieve in the foreseeable future -- 15-20 years.

India

India's technological future is not optimistic. If India is to achieve even modest capabilities in indigenously produced military technology or operations, civilian-military relationships must change dramatically. In particular, the military must exhibit considerably more influence over civilian decision-making than is now the case. A second indicator of required change would be a serious commitment by the Indian government to implement far-reaching economic development plans without weakening them to account for the possibility that some groups will resist or be negatively affected. We conclude that there is no significant possibility that India will achieve indigeneous technology-based military capability of a competitive level during the next 15-20 years.

China

Although we do not believe China will achieve world competitive status within the time frame of our study, a number of events over the next 15-20 years would signal significant movement in this direction. The first focuses on two key technology development programs, 863 and Torch. Both are currently being evaluated by the Chinese Government. If the results of these evaluations are positive, and the scale of these programs is substantial, then China's civilian and military technical capacity will demonstrate signs of substantial growth. Second, the Chinese need to invest substantially more in civilian R&D, so signs of this occurring are worth watching for. Third, the Chinese are attempting to form large industrial conglomerates that would span both civilian and military sectors. The success of these endeavors will signal an increased flow of knowledge and technology between sectors as well as the capacity for large scale system integration. Finally, it will be important to monitor the flow of scientific and technical manpower in China. Mobility has increased dramatically recently, but state enterprises have suffered as the private, civilian sector has gained. Whether the proposed conglomerates or some other situation can harness the new technical entrepreneurs for military ends remains to be seen. China will be a regional power during the next 15-20 years. It will not be a major technological threat, at least in high technology, during this period. Subsequently, that could be a possibility if the several factors we identified all work together in the appropriate direction.

Singapore

Singapore's future rests primarily on the question of national will: does this small but highly competent nation wish to allocate large proportions of its wealth to technology-based, military development? If it does, Singapore could become in capability, if not in scale, a major competitor in high technology. Singapore also needs to continue to invest larger proportions of GNP in R&D, as it has just recently begun to do. It would be worthwhile to watch for evidence that the nation can produce large-scale, integrated systems such as an indigenously-produced fighter aircraft. Finally, it will be significant if Singapore can actually increase the innovative capacity of its educated populace, as several current programs are intended to accomplish. Singapore's size means that it will pose no serious military threat in the foreseeable future. With a national commitment to high-tech military development, it could develop a state-of-the-art capability in particular weapons systems in the next 15-20 years.

Taiwan

Taiwan's industrial structure, currently lacking large conglomerates that span several industries and especially the civilian-military sectors, acts as an impediment to achieving high-tech military capabilities in the near term. The resources commanded by such conglomerates could, potentially, help Taiwan attain the capability to design and produce large scale integrated weapons systems. Another sign of improved capacity would be visible, formal evidence that the existing, strong civilian electronics industry is becoming linked to the military. Currently, substantial national funds are being used to procure military equipment from external suppliers. If this priority is superseded by investment in the national science and technical infrastructure, it would boost Taiwan's movement toward indigenous high technology capacity. At present, however, there are few indications that Taiwan can do more than mount a conventional level of defense against an invasion from the mainland, at least over the next 15-20 years.

National Technological Competitiveness and the Revolution in Military Affairs

Final Report

David Roessner

Michael D. Salomone

Joint Management Services

1.0 Description of the Project

We began this project in August 1997 with the following assumption: *To identify potential participants in the revolution in military affairs (RMA), it follows that one must identify nations that exhibit a set of characteristics that are predictive of technology-based competitiveness.* Granted, this alone does not fully accomplish the desired goal since nations may choose to channel their competitive capacities primarily in military directions, or may choose a short-run strategy that builds economic/military strength at the expense of citizens' standard of living.

However, most contenders to future competitiveness must pass through a series of development stages. These include, first, the absorption of new technology from abroad, which is frequently manifested as platform manufacturing. Absorption is followed by the adaptation and application of external technology to local conditions of production. Eventually, the nation may progress to the use of locally-developed technology and technical expertise to create products that compete successfully in international markets, or on the battlefield.

We concluded that this type of comparison would place nations into one of four discrete categories: (1) nations that will never be able to manufacture or absorb advanced technologies; (2) nations with limited manufacturing but high absorbtion capabilities that may be able to use new technologies in unconventional ways; (3) those nations that can both buy and absorb and manufacture advanced technologies in some sophisticated mix; (4) technology producers. Consequently, the analysis would permit us to identify those nations where participation in the RMA was most likely, and the extent to which it may occur.

The project was divided into two phases. In Phase I we employed quantitative analysis to identify a subset of Asian nations that, based upon our indicators of technological competitiveness and other data, appeared to be contenders to produce and field advanced defense technology products in sizeable and broad arrays. In Phase II we developed four case studies -- China, India, Singapore, and Taiwan -- to explore the technology absorptive and development capacities of these nations with respect to the development of a broad range of cutting edge defense technologies. These case studies are provided as appendices to this summary report. In terms of the richness of the data, the cases may be ranked as follows: India, China, Singapore, and Taiwan.

2.0 Phase I Summary

The primary objective of Phase I was to identify a subset of "particularly interesting" nations in the Pacific Rim that demonstrate (1) a relatively rapidly growing technological capacity, (2) an ability to rapidly absorb technology from external sources, and (3) a particular orientation toward utilizing nonstandard models of diffusion to acquire technology quickly (e.g., via multinational corporations operating in the context of economic globalization and/or the coordination of complex international acquisition of technology from multiple sources). Once the target nations were identified, a series of case studies were conducted in Phase II that examined civilian and military organizations and institutions and their interactions with the surrounding national culture. The focus in these cases was on each nation's current and future capacity to develop a sustained, innovation-based, indigenous military capability based in high technology.

Phase I may be regarded as simply the means to an end, identifying the nations to be studied in detail in Phase II. Still, there are a number of interesting outcomes from Phase I that warrant reporting in their own right. They are:

- the initial analytical framework and the data sets that were intended to be examined using it;
- what could actually be accomplished, and why;
- results at the national level that have implications for East Asian security.

The following sections address these points.

2.1 *Initial analytical framework for Phase I*

The work accomplished during Phase I was premised upon a number of assumptions that are consistent with, and emerge from, recent analyses of national and international processes of technological change. First, industrialized nations are experiencing a shift from military spin-off to spin-on, a phenomenon first identified in the U.S. and examined carefully by John Alic and his colleagues in *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Alic, et al., 1992). Civilian technology is now at the technological forefront, with military technology lagging behind or borrowing from it. Military strength is increasingly dependent, therefore, on the civilian economy's capacity in cutting-edge technology. Second, the global oversupply of military technology has created a buyer's market. Third, as noted earlier, a number of nontraditional technology diffusion practices have emerged, most notably attributable to the activities of multinational corporations, "knowledge capture" via indigenous emphasis in newly emerging economies on education and skill development, and strategic acquisition of technology from multiple external sources (Bracken, 1997; Mathews, 1996). Finally, the continued (at least until recently) rapid economic growth among nations of the Pacific Rim has enabled these nations to spend considerable resources on expanding their military capabilities.

2.2 *Data for Phase I analysis*

Given these premises and the objectives of the overall project, we sought data that could be used to rank nations of the Pacific Rim on one or more dimensions suggesting the potential for a rapidly developing and/or substantial future potential for technologically-based military prowess. In particular, the data should reflect each nation's current economic strength, especially in high technology; the extent to which each nation chose to use economic resources to purchase and develop military goods; and the future orientation of the project. Three categories of data at the national level were developed:

1. Evidence of current economic growth and strength.

2. Evidence of a national emphasis on military strength and assessment of military technological capabilities.

3. Evidence of current and future international competitiveness in high-technology sectors of the economy.

The basic economic data included:

- gross national product
- total national exports
- central government expenditures
- total imports.

Military expenditure and technology data included:

- total arms exports
- total arms imports
- military expenditures

- Military Critical Technologies List (MCTL) data.[1]

High Technology Indicators data developed by researchers at Georgia Institute of Technology for the National Science Foundation, which included:

- National Orientation
- Socioeconomic Infrastructure
- Technological Infrastructure
- Productive Capacity
- Technological Standing
- Rate of Technical Change.[2]

---

[1] The Military Critical Technologies List contains technologies that the Department of Defense thinks are critical to maintaining superior U.S. military capability. The Report includes Foreign Technology Assessments that estimate foreign nations' capabilities in each technological area.

[2] National Orientation (NO): Evidence that a nation is undertaking directed action to achieve technological competitiveness. Such action can be manifested at the business, government, or cultural levels, or any combination of the three.
Socioeconomic Infrastructure (SE): The social and economic institutions that support and maintain the physical, human, organizational, and economic resources essential to the functioning of a modern, technology-based industrial nation.
Technological Infrastructure (TI). Institutions and resources that contribute directly to a nation's capacity to develop, produce, and market new technology. Central to the concept are the ideas of economic investment and social support for technology absorption and utilization, which could take the forms of monetary payments, laws and regulations, and social institutions. Also included is the physical and human capital currently in place capable of developing, producing, and marketing new technology.
Productive Capacity (PC): The physical and human resources devoted to manufacturing products, and the efficiency with which those resources are used.
Technological Standing (TS): An indicator of a country's recent overall success in exporting high technology products.
Rate of Technological Change (RTC): An indicator of how rapidly a country is improving its high technology export performance.

The first four of these indicators are "lead" indicators, intended to suggest the level of national technological competitiveness in approximately 15 years. The last two are current indicators of national competitiveness in high tech industries. Each indicator is a composite of survey data from experts and existing data sets. For details see Roessner, et al. (1996) and Porter, et al. (1996).

The basic approach to the analysis was to seek correlates among these data to identify those measures that appeared to best capture the underlying concepts, and then to rank nations on a reduced set of factors.

The MCTL and Foreign Technology Assessment data were major disappointments and turned out to be useless for our purposes. The data are inconsistent across years in both country and technology coverage. Countries were rated on each technology by a panel of experts on a four-point scale, but several countries of interest to us were missing altogether. Our analysis had to proceed using the remaining data.

2.3 Data analysis

A correlational analysis among all the remaining data revealed two interesting results. *First*, there is a significant positive relationship between the growth of the economies in the Asian Pacific region and the growth of military expenditures in the region. *Second*, arms exports from the Pacific Rim nations correlate strongly with both GNP growth and the growth of military expenditures.

Having thus identified GNP and national military expenditures as the most useful key indicators of economic strength and military expenditures, we then sought linkages between these current measures and the "lead" indicators from the NSF high-technology competitiveness study. This phase of the analysis showed that national expenditures for electronic data processing equipment (EDP) was highly correlated with both GNP and military expenditures (ME).

Then, a series of scatterplots were generated that enabled ten countries of the Pacific Rim to be compared on the militarily- and economically-relevant indicator (EDP) and "lead" indicators of future technological capability (NO, TI, PC). In addition, each nation's commitment to expanding military capacity was charted by plotting change in GNP against change in military expenditures. In each case, the objective was to observe, by overlaying scatterplots generated at two points in time, how far each country of interest had moved relative to others during the period 1990-1996.

2.4 Results

Figure 1 on the following page [EDP v. TI, 1990-1996] shows that, on these indicators of economic/military strength (EDP) and a lead indicator of technological infrastructure (TI), China, Korea, and Singapore showed the greatest movement, while India, Taiwan, and Indonesia showed the least.

Figure 1

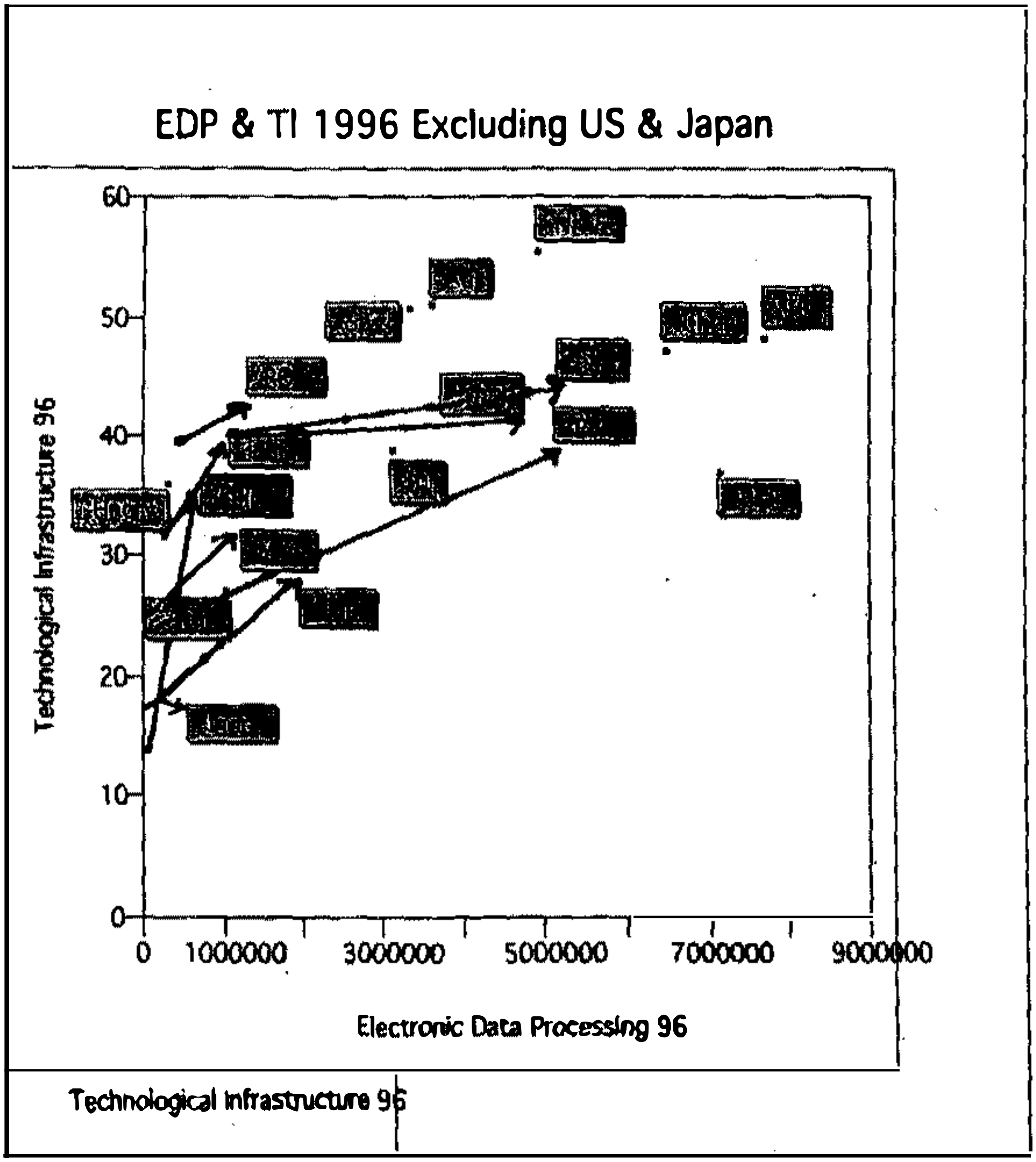
EDP & TI 1996 Excluding US & Japan
Technological Infrastructure 96
60
50
40
30
20
10
0
0
1000000
3000000
5000000
7000000
9000000
Electronic Data Processing 96
Technological Infrastructure 96

Figure 2 [NO v. PC, 1990-1996] plots one lead indicator against another. On these indicators, the Philippines, China, Thailand, Singapore, and Taiwan lead the Pacific Rim nations. Figure 3 [change in GNP v. change in ME, 1990-1995] shows that China is in a class by itself, relative to its neighboring countries, in devoting very large amounts of the growth in its GNP to military expenditures despite a dramatic decline in its aggregate force structure.. These three scatterplots plus data on the extent of change each nation exhibited during 1990-96 on Technological Standing (TS) and Rate of Technical Change (RTC) constituted the basis for our rankings of nine nations on their potential for future technology-based military capability.

These figures are on the following two pages.

Figure 2

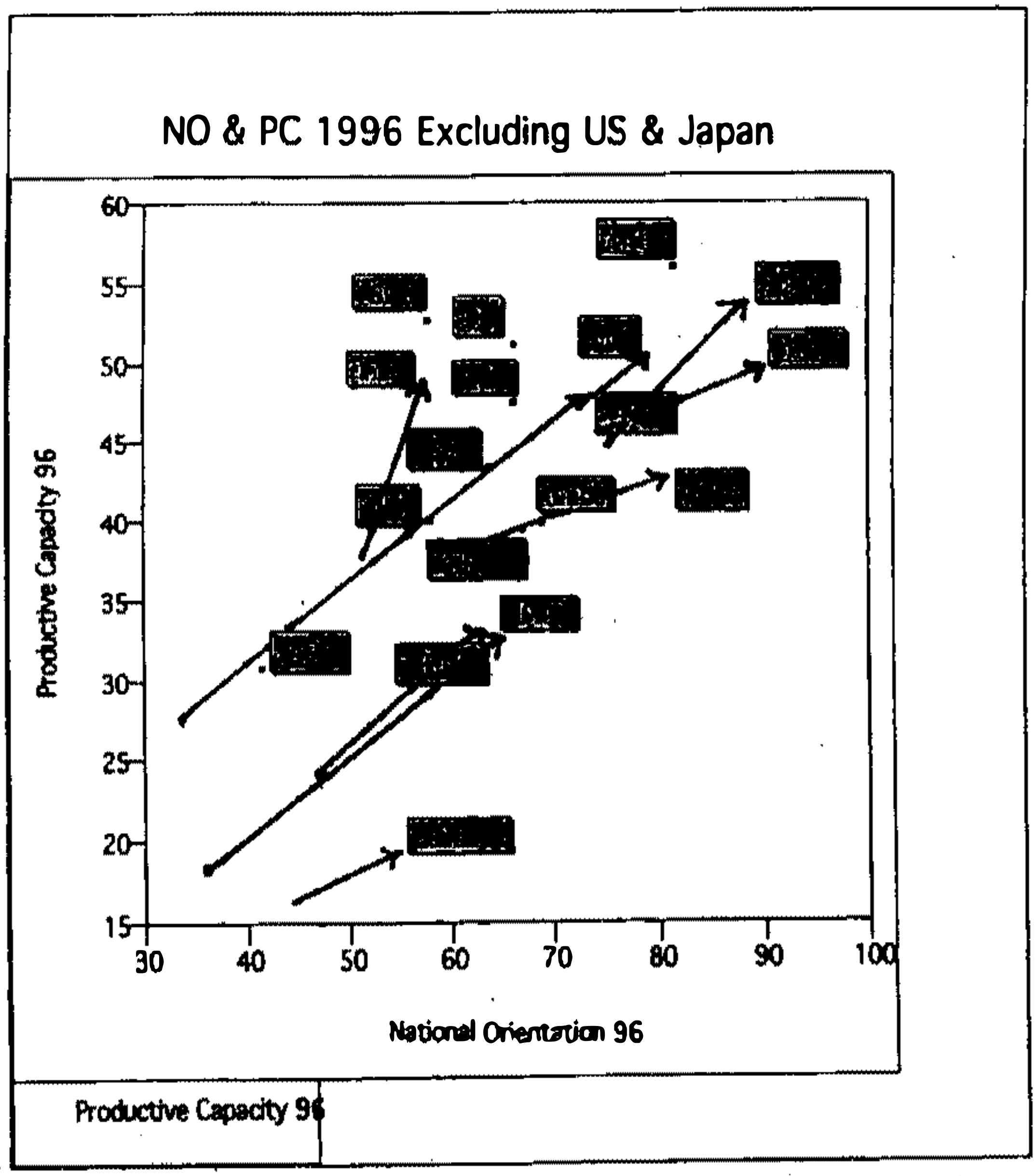
NO & PC 1996 Excluding US & Japan
Productive Capacity 96
60
55
50
45
40
35
30
25
20
15
30
40
50
60
70
80
90
100
National Orientation 96
Productive Capacity 96

Figure 3

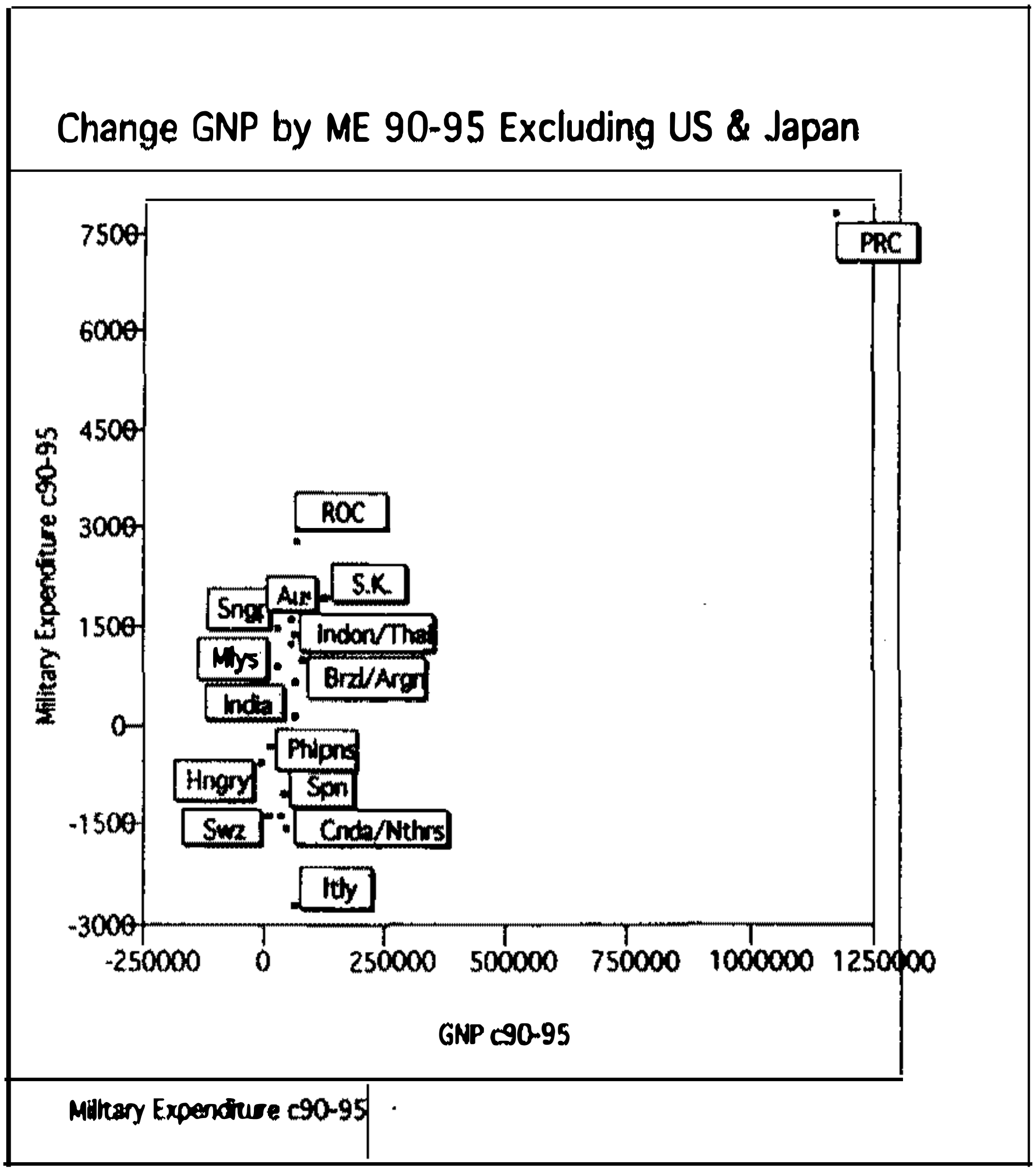
Change GNP by ME 90-95 Excluding US & Japan
7500
6000
4500
3000
1500
0
-1500
-3000
Military Expenditure c90-95
-250000
0
250000
500000
750000
1000000
1250000
GNP c90-95
PRC
ROC
S.K.
Aur
Sngr
Indon/Thai
Mlys
Brzl/Argn
India
Phlpns
Hngry
Spn
Swz
Cnda/Nthrs
Itly
Military Expenditure c90-95

Table 1 [National Rankings by Multiple Criteria] shows the rankings of nine nations of the Pacific Rim on the five measures of the potential competitiveness of nations in the context of the revolution in military affairs. We summed the rank order from the first three columns of Table 1 and recorded whether each nation had a positive change in its Technical Standing and Rate of Technical Change. Table 1 follows.

EDP v. TI 1990-96	NO v. PC 1990-96	ΔGNP v. ΔME 1990-95	ΔTS 1990-96	+ or - Δ	ΔRTC 1990-96	+ or - Δ
CHINA	PHILIPPINES	CHINA	SINGAPORE	+	INDONESIA	+
KOREA	CHINA	TAIWAN	CHINA	+	SINGAPORE	+
SINGAPORE	THAILAND	KOREA	MALAYSIA	+	TAIWAN	+
THAILAND	SINGAPORE	SINGAPORE	PHILIPPINES	+	PHILIPPINES	+
PHILIPPINES	TAIWAN	INDONESIA	THAILAND	+	KOREA	+
MALAYSIA	INDIA	THAILAND	TAIWAN	0	MALAYSIA	0
INDIA	MALAYSIA	MALAYSIA	INDONESIA	0	THAILAND	-
TAIWAN	KOREA	INDIA	INDIA	0	INDIA	-
INDONESIA	INDONESIA	PHILIPPINES	KOREA	-	CHINA	-

Note: Shaded cells indicate clusters of countries that grouped together on the ranking criterion.

EDP = total purchases of electronic data processing equipment
TI = Technological Infrastructure
NO = National Orientation
PC = Productive Capacity
ME = military expenditures
TS = Technological Standing
RTC = Rate of Technological Change
GNP = gross national product

The results are reported in Table 2 below: "Cumulative Ranking and Change in Technological Standing and Rate of Technical Change, 1990-1996". China's cumulative performance far exceeds that of nay nation in the sample. In addition, while China's technological standing continues to increase, its rate of technological change has begun to slow. This may indicate a maturation within the Chinese economy. It may also indicate a series of policy decisions prior to a new period of high intensity growth or renewed expansion in the economy and science and technology policy reform. Table 2 follows.

COUNTRY	TOTAL RANK	+Δ TS	+Δ RTC
CHINA	26	yes	
SINGAPORE	18	yes	yes
THAILAND	18	yes	
KOREA	15		yes
TAIWAN	15		yes
PHILIPPINES	15	yes	yes
MALAYSIA	12	yes	
INDIA	9		
INDONESIA	7		yes

2.5 *Conclusions from Phase I*

The conclusions from Phase I may be summarized as follows:

1) There is a significant correlation between the growth of Asia Pacific regional economies and the growth of their military expenditures.

2) Arms exports from this region are strongly correlated with both GNP growth and military expenditures.

3) EDP equipment purchases are significantly correlated with both GNP and arms exports, suggesting that EDP may be a valid measure of these countries' physical efforts to improve their competitiveness in militarily-related areas.

3) China appears to be fulfilling the conditions necessary to become militarily competitive within the next fifteen to twenty years.

4) Taiwan and Singapore have also exhibited long term commitment to expansion of their high technology capacity by allocating sufficient resources to technological infrastructure and allowing firms to operate in a stable, non-intrusive environment. However, because of their size, these nations cannot begin to rival the PRC as likely militarily competitive nations.

5) Other nations of the Pacific Rim have shown mixed results. Indonesia and Malaysia have shown evidence of future capacity, but their overall performance has been tempered by inconsistency of purpose. As the recent economic crisis has shown, many complications continue to plague these nations.

6) The most perplexing case is that of India. It would seem to have many of the resources necessary to advance rapidly but has experienced evidence of both rapid growth and decline in important high technology indicators.

2.6 References for Phase I

References for Phase I of the project included the following:

Alic, J., L. M. Branscomb, H. Brooks, A.B. Carter, and G. Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World.* Boston: Harvard Business School Press, 1992.

Bracken, P. "Non-standard Models of the Diffusion of Military Technologies: An Alternative View." Unpublished paper prepared for Joint Management Services, 1997.

Mathews, J. "High Technology Industrialization in East Asia." *Journal of Industry Studies*, 3, 2 (December, 1996): 1-78.

Porter, A., David Roessner, Nils Newman, and David Cauffiel, "Indicators of High-Tech Competitiveness of 28 Countries," *International Journal of Technology Man gement*, **12**, 1 (1996): 1-32.

Roessner, D., Alan Porter, Nils Newman, and David Cauffiel, "Anticipating the Future High-Tech Competitiveness of Nations: Indicators for Twenty-Eight Countries," *Technological Forecasting and Social Change*, **51**, 1 (January 1996): 133-149.

Sperling, J., David Louscher., and Michael Salomone, "A Reconceptualization of the Arms Transfer Problem, *Defense Analysis*, **11**,3 (December 1995):.293-311.

Sperling, J., David Louscher., and Michael Salomone, "Taking a Walk on the Supply Side: The Prospects for Weapons and Weapons Technology Diffusion and Control"

3.0 Phase II: Case Study Summary

In consultation with the sponsor, it was decided that case studies would be written for China, India, Singapore, and Taiwan that would explore the extent to which military technology development and absorption were facilitated or inhibited by a number of socio-economic, organization, and institutional factors as well as deliberate governmental plans and policies. To do this we established a common conceptual framework for all cases. In assessing the future military capacity of selected Asian nations, we began with a working hypothesis: "that the future military capacity of these nations will be increasingly linked to, and dependent upon, their technological prowess in international, civilian markets". In other words, increasingly, military capacity will be a result of spin-on scientific and technological flows.

This hypothesis is based on a number of interlinked assumptions:

-- that technological change, especially breakthrough innovation, increasingly will occur in the civilian sector rather than in the military.

-- that the average development time for new products and processes, whether civilian or military, will decrease.

-- that bureaucratic and organizational rigidities limiting the pace of technological innovation are more pervasive and entrenched in military organizations than civilian ones.

-- that most nations' total investment in R&D will increasingly be targeted toward the civilian sector.

-- that a nation's ability to compete in high technology will depend, ultimately, on the strength of its indigenous scientific and technological capabilities.

We pose several questions in our case studies:

1. To what extent does the economic, political, and organizational situation in the country under study reflect the assumptions that underlie our working hypothesis?

2. What are the deviations from these assumptions in particular cases, and what are the implications?

3. What are the inter-institutional, inter-organizational, political, and cultural factors that will influence the flow of ideas and technology between civilian and military sectors? Stated differently, what factors affect the separation and collaboration between civilian and military sectors?

4. What elements of "national orientation" influence the nation's commitment of resources to military vs. civilian technological development?

5. To what extent does spending on military development translate into future military capacity? Is the nation's strategy to develop an indigenous technology base for its military and/or civilian development, or to rely upon procurement from abroad? What cultural, organizational, or other factors limit or enhance a nation's ability to translate spending on military goods and services into actual military capacity?

In developing the actual case studies, provided as stand alone appendices to this report, we examined the available scholarly and public literature, employing standard social science qualitative case study methodology. The research process was accomplished by a number of graduate students in the Sam Nunn School of International Affairs at the Georgia Institute of Technology working under the guidance of Professor Roessner and Professor Salomone. In addition, we used the subject nations as the research focus in a ten week national security policy graduate seminar at the Institute that we directed, as well as acquiring information and perspective from ongoing seminars over the past two and a half years at Georgia Tech.

To implement this conceptual framework, we organized the material contained in each case around five specific issues that reflected the framework described above. We then summarized each case along these five issues in order to facilitate comparative analysis. The five specific issues explored to drive the write-ups of each case were:

1. Technological Innovation in the Civilian and Military Sectors;

2. Indigenous Scientific and Technological Capabilities;

3. Relationships between Civilian and Military Sectors;

4. Commitment of Resources to Civilian vs. Military Technological Development;

5. Factors that Inhibit or Enhance the Translation of Military Spending into Military Capacity.

These are addressed to greater or lesser degree in each summary depending on the available information for each country. The four case summaries appear immediately below and are followed by the comparative analysis that address the fundamental questions raised in this project, followed by a concluding section. Footnotes and references for the individual country sections in this document have been omitted. They may be found in the case studies for each country, furnished as separate appendices.

3.1 *Case Summary: China*

Introduction

Only since 1978 has China's leadership been able to target sustained high technology innovation as a national goal on a continuing basis. Between the period of extreme isolationism ushered in by the Sino-Soviet rift and prior to the Deng Xiaoping era of reform that began in 1978, China insulated itself from the grim reality of its technological standing. The PRC's only window on the technological development that was occurring in the West was its diplomatic core, and until President Nixon's visit in 1972, even this was limited due to the formal recognition by a majority of nations of the Guomindang government on Taiwan. Deng's accession to the position of preeminent leader ushered in profound transformations in China's self view and in S&T development strategies. China today is focused on technological progress, and the quest for high technology has acquired a strong following in some Chinese decision-making circles.

China's basic level of technological competence has improved dramatically since the reform period, and in 1991 there began a further shift in the types of technologies designated for external acquisition. Instead of "advanced, appropriate" technology, the emphasis has been on "high or new" (new to China) technologies. The government also explicitly promoted rapid development of high-technology industries. During the mid to late 1990's, Chinese leaders appeared to believe that the country had reached a level of scientific and technical development that permitted more rapid absorption of advanced, even cutting-edge, technologies. The leadership on occasion pointed out that the maturation and liberalization of the Chinese domestic market forced a change in this direction. They noted that the rapid development of the Chinese economy has meant that domestic firms faced increased competition from foreign firms entering the Chinese market; by 1998 over one half of the 500 largest firms in the world were actively participating in the Chinese domestic market.

Whether China will be able to achieve a capacity to innovate and produce effective, state-of-the-art weapons technologies indigenously will determine how the U.S. military must respond and prepare to meet the needs of the 21st century. While the ability of the Chinese to achieve this goal is still in doubt, it is clear that Chinese leaders are well aware of the link between a high-technology capacity and national power. General Ding Gengao, Chairman of the Commission on Science, Technology and National Defense Industry (COSTIND), stated in 1994 that "Weapons modernization is, in the final analysis, determined by the modernization of our defense science, technology, and industry." In our view, China's future capacity to produce indigenously a military force capable of challenging the most powerful nations in the world will depend substantially on its ability to develop an indigenous design, development, and production capacity in state-of-the-art civilian technology. The following sections summarize our assessment of that possibility.

Technological Innovation in the Civilian and Military Sectors

One of the most important strategies that the PRC has followed to reform its S&T system has been the targeting of specific higher technologies for acquisition. This has been accomplished by direct government involvement in determining what types of foreign investment and involvement will be allowed in the domestic market. The Ministry of Foreign Affairs, after consultation with the State Commission on Science and Technology, annually publishes in the *Beijing Review* a three-tiered list of technology areas that are 1. "Prohibited from foreign involvement", 2. "Restricted in specific ways from foreign involvement", or 3. "Encouraged to have foreign involvement." In addition to promoting the development of certain technologies, the list also helps prevent Chinese firms from attempting to purchase technologies that are already well established in the nation, thereby avoiding duplication and the outflow of needed capital.

The government also plans to strengthen the nation's manufacturing enterprises and have them play a key role in S&T-based growth and development, calling manufacturing "the main battlefield for technology development." Organizational change will be the major factor in accomplishing this goal. In the past, manufacturing facilities had very little influence on, or access to, R&D resources. In order to improve the nation's responsiveness of R&D in high technology to manufacturing, manufacturing facilities will be encouraged to cooperate with and develop ties to nearby institutes and universities.

Decision-makers responsible for S&T development have also tried to encourage closer relationships between R&D and production departments through incentives. Part of this organizational reconstruction is making the likely overall economic benefits and manufacturing potential of individual research proposals a consideration in selecting a portion of the basic research that will be supported. This reform is also intended to encourage closer relationships between R&D, production, and design, hopefully leading to a more rapid cycle for the development and implementation of new technologies.

A major concern of the S&T community in China is that, although the government gives lip service to building a research and development capacity free from government control, implementation of this policy has been lacking. Critics of the government's performance note that most of the funding for research and development is still tied to the government, especially military research, and that the target goal of devoting 5% of GNP to R&D has not occurred. According to State Science and Technology Commission statistics, in 1995 national expenditures for R&D were only 28.6 billion RMB, or 0.5% of Chinese GDP.

Many scientists point out that they still have a long road to travel before they overcome the traditional hurdles that resulted from the separation of the intelligentsia from the labor and production forces. Few senior scientists can forget that not so long ago researchers were punished by banishment to industry. In addition, the greater level of workforce mobility that has developed among the S&T labor force has had some negative results. Instead of freeing up human resources to modernize state enterprises, the new mobility has resulted in a net drain from the state enterprises. New and promising scientists and engineers have greater freedom to choose where they will work. They have largely chosen to work abroad if possible, find employment in foreign firms within China, or begin their own ventures. State enterprises appear to be the employment choice of last resort. On the other hand, as the Chinese industrial base continues its current trend of consolidation, the gigantic firms that emerge from the competition will be able to draw upon a large number of small but flexible firms that have been founded by entrepreneurs or as spin-offs of government research institutes.

While the reform of the Chinese economy has certainly affected every domestic firm, information on the specific effects of the reforms on large firms that produce technologically sophisticated products is not readily available. One case that illustrates the effects of the reform processes and the courses of action for the development of high technology military equipment that the Chinese government is advocating is the Sichuan Changhong Electronics Group. Changhong was formed as a defense firm producing airborne radar systems for the PLA Air Force, and has existed in some form for over thirty years. Since the beginning of the defense industry conversion period, Changhong has advanced from simply filling television shells to developing circuits. Evidence of their improving quality standards can be found in their expansion into product export to most of Asia in direct competition with Japanese and Korean giants. More important for its ability to develop high technology innovations is Changhong's commitment to research and development, which has largely been driven by market forces. Even the most successful firms such as Changhong are constantly attempting to upgrade their production techniques through a variety of strategies, including arrangements with technology leaders such as America's Amiga, C-Cube, Philips, and Universal and Japan's Toshiba Corporation.

Reforms related to innovative capacity are not restricted to the business sector. After decades of stagnation, the PLA has entered into a period of profound change and significant reform. Part of this modernization effort has been reform of PLA training. The training reform can be characterized by its experimental nature. The Chinese use different commands to experiment in different aspects of modern warfare. This emphasis on experimentation bodes well for Chinese innovation in operational strategies and could be the foundation for innovation in the organization of the PLA. An important part of this experimentation has been the attempt to find "new methods using existing equipment to defeat high technology weapons of a potential enemy while providing selected units with limited amount of newer, more modern technology."

Indigenous Scientific and Technological Capabilities

The Chinese government has established several programs that support the development of a capacity for indigenous, cutting-edge innovation in high technology. Although the success of the United States Armed Forces in the Gulf War using high technology weaponry is often identified as the impetus for the increase in Chinese aspirations for high technology weaponry, the 863 program is evidence that other factors influenced the PRC's push toward modernization. The "863 program" (so called because the program was launched during a March 1986 meeting of the State Science and Technology Commission) is a fifteen year program that promotes research in selected fields of high technology. The plan intends to facilitate national economic growth through the use of advanced science and technology in manufacturing. Through the 863 program, high technology research and development centers have been opened inside China and, as of 1996, 20,000 "high technology researchers", from Ph.D. scientists to technicians, had been trained through the program. At a meeting celebrating the tenth anniversary of the 863 program, it was determined that during the remaining five years of the program, biology, information technology, automation, energy, and new materials would be the focal points for supported research.

The 863 program has been supplemented by the creation of research centers whose task it is to bring together the results of 863-supported research. These centers "attack" advanced technology and merge the results of selected nation-wide research teams. The centers integrate and apply the results of the research conducted under the program in order to produce marketable high technology. One example of this type of center is the National Research Center for Intelligent Computing Systems (NCIC) in Beijing, part of the Chinese

Academy of Sciences. The center is staffed by 15 Ph.D. scientists and more than 20 post-graduates. In order to accomplish its mission of producing marketable computer technology, the center carries out academic exchanges and other efforts that encourage international cooperation and information transfers, such as hosting foreign guest lecturers.

In 1997, after the ten-year anniversary of the start of 863, China began planning the second stage of the 863 program. The so-called "super 863" program is a ten year plan that will cover the period 2001-2010. This effort is expected to be broader than the original 863 and is to include even greater funding for selected programs. The initial direction of the program was laid out five years before its implementation in order to "ensure persistent development of high technology in China" according to Zhu Lilan, vice-minister of the State Science and Technology Commission.

In 1988 the State Science and Technology Commission created the "Torch" program "designed to develop China [sic] high and new technology industries." The Torch program was created with five goals in mind. The first goal of the program was to create an appropriate environment for the development of "high and new" technology industries. This was to be accomplished through integrated medium-term and long-term planning, information exchanges, and the creation of a venture investment mechanism. Representatives of the Torch program are also tasked to help formulate policies, laws, and regulations that would assist in the development of high technology industry. The second goal of the program was to assist in the creation of effective and well managed High and New Technology Industry Development Zones. The third goal was to identify localities and industrial research institutions that, when supported, would develop technologies in five key fields: new materials, biotechnology, electronics and information, mechatronics (automated production), and energy technologies, essentially the same fields emphasized in the 863 program. The fourth goal of the program was to internationalize the high technology sector in China. Cooperative relationships were to be established with leading S&T, financial, industrial, and commercial communities around the world. These relationships would not only allow for technology transfer, but they would create opportunities for Chinese products to compete on the international market through the use of partners' market access and distribution networks. The fifth task of the Torch program was to identify and train qualified technical personnel and S&T entrepreneurs. Although evaluations of these programs are under way, it is too soon to determine the extent to which they have achieved their objectives.

There are signs that the "brain drain" from China is slowing. Though many of the students who participated in international student exchanges since the beginning of the reform period in 1978 have decided to remain in their adopted nations, a considerable number of students have returned to the PRC. Of the over 250,000 Chinese students who have gone abroad to study at foreign institutions of higher learning, over 80,000 have returned home. As Chinese living standards continue to increase, and should the PRC continue the current trend toward a more open society, it is reasonable to assume that an greater proportion of students will return from their overseas studies.

Perhaps the most important element of China's high technology development plans has been the more sophisticated use of available foreign technology. Past emphasis on domestic development through copying and reverse engineering in order to maintain self sufficiency at all costs has declined. Instead, the S&T community has recognized that, while acquisition of foreign technology is important, more resources must be devoted to assimilation and absorption of available technologies. The additional "know how" required for actual operation of the technology can often constitute over 20% of the transfer costs.

The shift in the focus of technology transfer is not the only major change in Chinese S&T policy. The government has encouraged concurrent management reforms that are structured to encourage innovation. At the individual level, the core mechanism of the management reforms that promotes high technology growth is to treat high technology as a "commodity", or intellectual property, and compensate those responsible for information creation. Reforms seek to put into place an active technology market with a large and mobile core of scientists, engineers, and technicians. Several types of reform policies have been implemented that support this mechanism. One of these focuses on the mechanisms for R&D project support. In the past, the state was the only source of funding for S&T research. Under the latest round of reforms, the government and the S&T community are attempting to diversify the sources of research funding. One way this is being accomplished is through encouragement of developmental research and applied research that promise near term benefits. Once a small amount of seed money has been granted by the state, industry is expected to become interested in the research earlier and contribute funding earlier in the development cycle.

The government's success in attracting funds from industry into all but a few very promising projects may be limited. However, in the near term a general shortage of scientists, engineers, and technicians seems to be attracting industry support for the technical institutes: fifty-seven research institutes that used to receive all of their funding from the central ministry are already raising more than half of their funding from outside sources.

In addition, the government is attempting to facilitate greater mobility of intellectual resources. This is being accomplished by permitting scientists to resign from institutes and universities, take long leaves of absence, or even hold concurrent jobs in order to move into industrial work. The PRC has already seen the development of spin-off firms from its best institutions of higher learning, one notable example being Legend Computers. However, the legal system is just beginning to define the boundaries of these operations and movements.

Relationships between Civilian and Military Sectors

The S-863 program described in the previous section is directly linked to the modernization of China's domestic weapons production. Infrastructure expansion supported by the State Science and Technology Commission and COSTIND are believed to provide the ability for China to domestically produce large warships, potentially including carriers in the 300,000-ton range.

The PLA has used its heavy involvement in the commercial sector to acquire high technology goods suitable for both civilian and military applications. In 1993, the PLA used a company that they controlled, Galaxy New Technology, to acquire high-speed telecommunications systems from Lucent Technologies. In 1997 and 1998 over 46 super-computers were also transferred to the PRC without direct approval from the U.S. Commerce Department. Some of these unmonitored technology transfers have involved extremely sensitive equipment with broad military and civilian applications. The Chinese

Academy of Sciences received, without approval, a Silicon Graphics computer that performs 6 billion operations per second. The Academy is responsible for coordinating research on long-range missiles and nuclear weapons. The U.S. General Accounting Office (GAO) also reported that SCM Brooks Telecommunications, a U.S. limited partnership, also transferred sensitive technologies to the PRC through Galaxy New Technology. In addition, the GAO found that sensitive machine tools that had been sent to China as part of a joint venture agreement with McDonnell Douglas were diverted to a Chinese facility engaged in military production.

Commitment of Resources to Civilian vs. Military Technological Development

The post-reform defense sector has suffered from "a problem of identity; one day they are told to go out and make money, and the next told to pay attention to political objectives." However, the indigenous industries that supply the PLA also realize that they can look forward to a growing Chinese defense budget, one of the few growing defense budgets in the world. Like the many other large state- owned enterprises, some of these defense firms are still having difficulty adapting to rapidly changing conditions and increased competition, especially on the international front. For example, after almost a decade of semi-dormancy, Eastern European nations are reemerging as competition for foreign military sales.

As the Middle East arms buying boom of the early 1990's declined, China's spending continued to increase, and it became a premier purchaser of advanced weapons. China's growing economic strength made it a target for sales growth for most defense manufacturers, often despite the concerns of the companies' governments. In 1994 China purchased over a billion dollar's worth of high technology weaponry from Russia alone, including advanced Su-27 fighter aircraft and missile systems. The Chinese have also taken advantage of economic turmoil in the former Soviet states by attracting top weapons scientists to assist in their ability to assimilate Russian defense technologies.

Factors Influencing the Translation of Military Spending into Military Capacity

Although the defense industries remained outside Deng's economic reforms during the decade following 1978, the entire S&T sector benefited from the influx of new technology and information from abroad. The focus within Chinese industry changed from developing indigenous, cutting edge technology to using outside technology for gradual improvement of Chinese industry. The strategy of using foreign technology as a driver for innovation within the state's high tech sectors seemed to be working quite well for the Chinese, yet in 1989 a significant change of policy came about that created private corporations that could sell heretofore military products abroad.

Since 1990 eleven Presidential waivers have been granted to U.S. corporations to sell restricted material with an estimated value of $300 million to China. These waivers have involved satellite and encryption technology related to communication satellites. These technology transfers would not have been possible if part of the Chinese organizational structure had not been privatized. Much of the justification for U.S. waivers has been based on the arguments of U.S. corporations that their deals are trade issues, rather than security, issues and thus subject to lower government scrutiny.

Many Chinese commercial firms have developed as a shadows of the former governmental organizations in the same sector, rather than being built from the ground up. While Chinese corporations like Great Wall are doing a brisk trade in satellite technology, there is no corresponding R&D or productive capacities within most of these new entities. Thus initial design requirements are most likely still being made by the military, while R&D and actual production are still carried out by state entities like CALT. Thus China enjoys the trade benefits of commercial technology without the risk of dependency on non-government organizations for the defense-industrial base. Although this has allowed these firms to establish themselves quickly, it is likely that by treading in such well worn paths they will not begin to bring real innovation into the sectors that they represent. The weak or nonexistent R&D base of other commercial sectors does not permit them to supply high quality products or services in the civilian market. Most other technology exports are in the directly military sector, so there is little opportunity for either spin-off or spin-on. In this the manner of commercialization may inhibit China's long term ability to develop cutting edge technology.

Concluding Observations

One of the most obvious indicators of China's prospects for achieving indigenous technological innovation is the amount of R&D spending in the country. The target goal of devoting 5% of GNP to R&D has simply not been achieved, and it does not appear that this goal will be reached anytime in the foreseeable future. If China continues to spend only .5% of the GNP on R&D, there is little chance that they will be able to develop sustained innovation in high technology industries.

On the other hand, China's prospects for impressive gains in the human component of its socioeconomic infrastructure appear bright. Educational resources in China continue to improve, albeit slowly, and the vast numbers of Chinese students studying at foreign institutions will almost certainly produce dramatic increases in both the quantity and quality of qualified S&T human resources available to the Chinese military-industrial complex. By observing how improving living standards, the opening of Chinese society, and increasing opportunities affect the number of student returning from study abroad, we will have the opportunity to better predict the pace of technological advance in China.

In the long term, China's prospects for eventually developing a capacity for innovation in high technology industries with military applications seem good. However, the pace of development is likely to remain slow. The Chinese will almost certainly develop a capacity to manufacture many of the advanced weapon systems of the current era, including cruise missiles and aircraft carriers (if they choose), but the Chinese military industrial complex is unlikely to create platforms that will be on par with U.S. systems deployed at that time. The Chinese will become a military force in the region, but in today's military terms, they are unlikely to become a peer competitor during the next twenty years.

The Chinese appear to be taking a dual track to weapons modernization, one short-term and one long-term. Their short-term plans are to acquire the best available foreign military technologies and production expertise through co-production, joint ventures, technology transfer offsets and hiring of foreign weapons scientists. Their long-term strategy is to gradually build their basic technology base through commercial activities, especially technology transfers through foreign multinationals, while concurrently improving domestic technological infrastructure and the quality of the S&T community. If they are able to maintain the stability of their S&T system for an extended period of time, and increase the level of national investment in R&D, this strategy is likely to create the conditions necessary for broad-based innovation in high technology industries, probably within fifteen to thirty years. Over the next decade or two, however, China will be constrained by its under-investment in civilian R&D and by the institutional barriers that impede the flow of knowledge and technology between the civilian and military sectors.

3.2 *Case summary: India*

Introduction

India has long been a nation marked by division. With chasms of religion, race, caste, language, region, and economic status cutting across its core, India is as Winston Churchill noted, more a geographical term than a nation. Despite these fissures, India has also been marked by a powerful desire for independence, whether from centuries of colonial subjugation or, after 1947, from the burdens of alignment during the Cold War. One area where this desire for independence has manifested itself is in the effort to develop an indigenous Indian defense industry. This program of military self-sufficiency has met with mixed results, at best, as the examples described below illustrate. While many weapons systems being developed indigenously have experienced delays, gone over budget, or simply do not work, an exception is the Indian Integrated Guided Missile Development Program. What does this mixed pattern of technology-based military development say about the ability of the Indian military, civilian economy, and society to adapt and develop indigenously new civilian and military technologies?

The following sections illustrate how overarching political and cultural factors influence the "innovativeness" of India's military and civilian sectors, the ability of the two sectors to collaborate with one another to achieve technical advance, and the likelihood that India will garner either the resources or the national will to become a future competitor in the revolution in military affairs.

Relationships between Civilian and Military Sectors

The fragmentation of Indian society affects the ability of the country's institutions to communicate and collaborate effectively. The case of military and civilian institutions is perhaps the most dramatic example of how the larger cultural setting can inhibit inter-institutional cooperation. We first summarize some of these larger cultural features, then show how they have constrained economic reforms generally and military-civilian relationships specifically.

Although more than 80% of Indians belong to the Hindu faith, this potentially unifying force is in fact a "census fallacy." As with any great religion, there are different sects with different values and interpretations that clash with those of other Hindus. But India is also divided along lines of caste, ethnicity, economic well-being, region and language, and these divisions have proven highly resistant to change. Despite calls for "unity through diversity," the fact remains that Indian society is fundamentally divided by its hundreds of millions of impoverished, its complicated and rigid caste system, and its religious and regional tensions.

At a slightly lower level of analysis, at least four factors hinder India's ability to implement economic and social reforms and, more importantly for our purposes, attract the kinds of foreign investment that could enhance the technological capacity of both civilian and military sectors of the economy. The first of these factors is a generally weak infrastructure, with scattered areas of strength. Unlike China, India did not pursue economic reforms according to an ideological blueprint. Change was pragmatic and limited to ensure that few people would be hurt by reform. Although some industries were liberalized, others (as a result of political pressure) continued to receive substantial subsidies. Investment in education and infrastructure necessarily suffered, and these kinds of inconsistencies threatened a balanced approach to economic reforms. The result is that technology parks and economic zones exist in some areas with sound infrastructures, while other areas are essentially closed to industrial relocation and foreign investment because of their poorly developed infrastructures.

Bureaucracy is a second significant hindrance to India's ability to consistently attract foreign investment. Some progress has been achieved in reducing bureaucratic red tape, but it remains a significant obstacle. Foreign investment in India totaled almost $40 billion in 1996, but much of this fails to reach its intended target due to "bureaucracy-created clearance snarls and a damaging lack of confidence." The third hindrance, corruption, probably also hinders the level of foreign investment in India. Until Indian industries can compete internationally without subsidy, the problem is likely to continue. Companies will remain tempted to give "tea money" to hasten the approval process rather than waiting the months to years a legitimate process might require.

A fourth obstacle to increased foreign investment in India is the uncertain future of existing reform efforts. As we suggested above, India has been careful in its reforms not to cause pain to any major interest or segment of the population. The need to make reforms palatable for all is partly due to the desire to avoid exacerbating the numerous existing divisions within society. Also, the desire to minimize suffering from liberalization reflects the strong moral foundations that have influenced Indian social, political and economic institutions. India has been characterized as having "two minds about foreign investment": the influx of more multinational corporations and foreign money is regarded by some as a new form of colonization. The political will for continuing the reforms has narrowed, and this trend threatens to continue as a reaction both to sanctions imposed upon India for its recent nuclear tests, and to the continuing Asian economic crisis.

The cultural context outlined above has specific implications for civilian-military relations in India. In the words of one observer, the relationship is unique: "In no other democracy in the world are the armed forces given so insignificant a role in policy-making as in India. In no other democracy in the world do they accept it with the docility evident in India." The British emphasized strict separation of civilian and military institutions during the colonial period, with clear civilian control over the military. Distrust of the military is also rooted in the philosophies, strengths, and types of institutions that emerged from the process of independence. A significant and influential segment of the Congress party held to the legacy of Mahatma Gandhi, and therefore had a dim view of the military in general. Thus the colonial experience supported the political values of those who subsequently led the independence movement, and these values are clearly evident in the realm of civilian-military relations.

Strong civilian control of the military is reflected in the organizational structure of the Indian Armed Forces. Each of the three separate services, Army, Navy, and Air Force, is run by an individual service chief. There is no overall chief of the Indian Armed Forces, although the question of introducing this position has been long debated. The Chief of Defense Staff office has been resisted primarily because it runs counter to the Indian instinct to distrust military officers and to the long-standing tradition of overriding civilian control of the military. Anything considered to be threatening to this control is unlikely to be implemented.

Civilian and Military Innovativeness, Especially in Technology

As suggested by our discussions of the rigidities and schisms that permeate Indian society, the Indian defense decision-making process does not lend itself to quick, flexible development or adaptation of new technologies and systems. This process, purposefully inefficient, puts the services in direct competition with one another for resources and influence. The current structure of the defense decision-making process and the strong civilian distrust of the military that has inspired the process "have seriously affected the adaptability of the armed forces to likely changes, and are likely to be obstacles for future adaptability."

Defense research, development, and production in India are almost entirely in the public sector. Defense production is nearly all state run, with the private sector accounting for only 6-7% of domestic arms production. The main actors in domestic arms production are eight Defense Public Sector Undertakings (DPSU) and the Defence Research and Development Organization (DRDO), the latter established in 1958. DRDO, with fifty labs under its purview, is the government agency responsible for developing weapons systems that the DPSUs produce. Separation of the DRDO from the production units, the DPSUs, creates a structural problem in the Indian defense industry. DRDO develops weapons and systems for sale to its own armed forces, thus placing the three services and the DRDO in the roles of buyer and seller rather than partners. The split creates inconsistencies and conflict between the designers and producers, which in turn result in inefficiencies. According to the SIPRI Yearbook, public sector defense production is "inefficient and over dimensioned and constitutes a burden on the economy."

The most visible of the DRDO's current projects is the Main Battle Tank, Arjun. Work on Arjun began in 1974, and 25 years later it is still in the early testing stages, years away from mass production. The program has received much recent criticism, largely focused on the tank's inaccurate and unpredictable fire control system, tendency to overheat in desert conditions, unsatisfactory overall reliability, and excessive width. By the time the Arjun is actually ready it is likely to be obsolete.

The history of the Light Combat Aircraft (LCA) is similar to that of the Arjun. Begun in 1983, the project is several years overdue and substantially over budget. The LCA also has become reliant upon foreign technologies that are vulnerable to sanctions arising from India's nuclear tests.

There is one area of military technology in which India has met with success: its more advanced missile projects known as the Prithvi and Agni. Prithvi, a short-range ballistic missile, is currently in production, and work is being done on an air force version to increase the payload from 500 kg to 1000 kg and a range of 250 km. The intermediate range ballistic missile, Agni, was tested in 1989 and 1991 and then shelved due to strong American pressure. With the recent nuclear tests and increasingly tense security environment, the Agni, capable of delivering a nuclear payload, is being revived. What sets the missile program apart from other weapons development programs is the political importance placed on it. India sees missile strength as the "idiom" of a country's political and strategic diplomacy.

Our case study was unable to develop extensive material on the innovativeness of the Indian civilian sector, especially advanced technologies. However, we did find that there is little or no competition or private sector ethos to stimulate the DRDO and, as we have seen, coordination and communication among the DRDO, the services and the DPSUs frequently is lacking. Furthermore, despite India's substantial technological base and reserve manpower in technology-related fields, according to one student of the subject it possesses a weak research and development culture:

> "Indian scientists and engineers have demonstrated that they can conduct high-quality theoretical research, develop modem components and produce working prototypes of simple systems. Yet, when it comes to making a large number of components work together the record of Indian applied science, engineering and project management is less impressive."

Within the civilian sector, there is at least one island of success in a field of advanced technology: software. Possibly because software requires relatively little capital investment, relying instead on human capital, it is largely immune from problems such as lack of foreign investment capital that face many other technology-intensive industries.

According to the Executive Director of India's major software industry trade association, India's natural resources lies in its abundant, technically skilled manpower. "And this natural resource easily transforms India into a software superpower." There are perhaps 700 software firms in India and an estimated 1,000 startups just beginning. Many large multinational corporations (GE, AT&T, Citibank, British Aerospace, GM) are already in partnerships with Indian software houses. By 2000, the Indian software industry is expected to export over $3.5 billion worth of software, primarily to the U.S. India's large population and its excellent training centers at the Indian Institutes of Technology suggest that the Indian software industry will continue to grow.

India's Indigenous Scientific and Technological Capabilities

Despite recent cooperative agreements with Russian and South Africa in the defense arena (see below), the Indian government has for a long time sought to make the defense industry largely independent of foreign technology. Since independence, some form of indigenous development of defense production has been favored for both practical and political reasons. Practically, the rupee's soft-currency status creates limits on foreign exchange: politically, India has pursued indigenous development as an extension of its Cold War policy of non-alignment and self-reliance. But India did not have the resources to make indigenous development of its arms industry a feasible goal, and so it relied on sales from the Soviets and licensing agreements from whomever would grant them. At the core of this push for an Indian defense industry was the public sector. "India relies to a great extent on foreign technologies particularly through major programs of licensed production . . . the R&D resources to meet this goal (Plan 2005) may become an unacceptable burden for the Indian economy."

Technological ties between Russia and India remain strong, as evidenced by a recent, ten-year defense cooperation agreement that will go into effect in 2000. The agreement shifts the focus from outright purchases, which India cannot afford and which foster technical dependency, to joint development likely to lead to some form of technology transfer. The focus of the deal are six s-300V ATBM systems, the upgrading of about 125 Mig-21 bis fighters, joint development of the Su-30 MK1 fighters, and improvements to the Akash low to medium altitude surface to air missile. India has also agreed with South Africa to jointly develop military hardware. So far things have not gone entirely smoothly: delivery of the second group of Su-30 MK1 fighters was delayed due to Indian Air Force indecision concerning specifications of avionics and weapons systems to be integrated into the aircraft. This suggests that the services themselves are having a difficult time deciding exactly what they want their specific forces of the future to look like.

Highly visible defense projects such as Arjun were initially envisioned to be designed and produced indigenously, but this has not proven feasible. During the last 11 years the imported content of the tank has risen from 27% to 60%, and the recently adopted turret system probably will be licensed from South Africa. The Light Combat Aircraft has also become highly reliant on foreign technologies, particularly from the U.S. India is now vulnerable to sanctions arising from its nuclear tests.

Commitment of Resources to Military vs. Civilian Objectives

It is apparent from the foregoing discussion that, with the exception of its ballistic missile program, India has a strong predilection to allocate scarce economic resources to civilian rather than military objectives. The reasons are at once cultural, social, and political. The processes by which financial decisions are made within the government help ensure that the military will nearly always occupy a secondary position in allocation of public moneys. Mistrust of the military and a strong commitment to civilian social objectives reinforce this prioritization.

The government's Financial Advisor controls not only how much is spent on defense, but also on what to spend the limited resources allocated to defense. The Financial Advisor, a civil servant, can veto weapons purchases even after procurement decisions have been made by the Ministry of Finance and Parliament. "The system allows the Finance Ministry to control the Defense Ministry, and the Defense Ministry to control the Armed Services headquarters--all through resource allocation." Advice from the three armed services plays a minuscule role in these decisions, and as a consequence the military -- with some minor exceptions -- is unlikely to command attention when budget priorities are being set.

Factors Inhibiting India's Ability to Translate Spending on Military Goods and Services into Military Capability

It is one thing to devote resources to weapons development and production: it is quite another to translate the resulting weapons into a functional capacity to wage war. While the Agni and Prithvi have been successes in a technical and budgetary sense, there appears to be little attention to a second, equally important aspect of exploiting a new technology: implementation. In the case of the Prithvi, for example, the exceptionally volatile nature of its liquid propellant requires that it be loaded immediately prior to launch. A sophisticated simulator has been developed to help train the men of the 333rd Missile

Group, but the training suffers from a fundamental lack of military participation in the design. Further, the issue of command and control of both missiles is problematic and as yet unresolved. As of mid-1998, no formal discussion had taken place within the Ministry of Defence on the formation of a command and control structure for the resurrected Agni.

The need to divert military resources to internal problems -- counterinsurgency -- reduces the ability of the armed forces to respond to external threats, much less to develop an offensive capability. India must deal with internal violence as well as contested borders with Pakistan and China. Increasingly, the Army is being called upon rather than paramilitary forces to quell any uprisings. Currently, 6.5 of the Army's 33 divisions, or just under 20%, are committed to internal security duties. These counterinsurgency and internal security concerns demand such a significant portion of the Army's resources that in April of 1997 Jane's *International Defense Review* reported that the Indian Army had made counter-insurgency operations their number one priority, taking precedence over external security or power projection. The current overriding internal security concerns in India divert organizational focus and seriously hinder the ability of the Armed Services to devote time and resources to the development of new weapons systems. The situation seriously compromises the Army's ability to conduct the training, maintenance, and organizational changes that must accompany effective implementation of advanced weapons systems.

Concluding Observations

Perhaps more than the other countries examined in this study, India's future technological and military capabilities are substantially shaped -- mostly negatively -- by the nation's political culture and broad institutional setting. India is a strongly democratic nation bolstered by strong political institutions. Such reforms as have been proposed and implemented since independence are incremental, sectorally focused, and sometimes inconsistently applied: politicians have been unwilling to offend or cause harm to any segment of society. India is a nation disposed to more subtle changes that require periods of time to take hold. Change will come slowly to India, including the changes required to create a modern industrial society that can rapidly adapt its institutions and decision-making processes to the requirements of producing and implementing cutting edge technology.

Another key feature of Indian society that influences its technological and military future is its fragmentation along numerous lines: religious, ethnic, economic, and class. Ironically, the strength of India's political institutions may help to sustain the social, economic, and cultural divisions that split the nation. Flexibility is not a term that accurately describes most inter-institutional relationships in India. Particularly in the arena of civilian-military relations, and within the military itself, mistrust and multiple barriers to communication and cooperation place fundamental limits on the Indian military's ability to advance technologically. Together, the social, cultural, and political realities of India portray a nation capable of modest changes, developments and adaptations -- especially in nuclear and missile technology -- but wholly unsuited to move rapidly towards becoming a peer competitor.

3.3 *Case Summary: Singapore*

Introduction

As one of the four "Asian Tigers," Singapore has enjoyed extremely high rates of economic growth over the past fifteen years. Its stable, if authoritarian, political system coupled with effective economic and social planning has produced a nation with a very strong socio-economic and technological infrastructure and a level of global economic competitiveness that belies its small size. Singapore is now seeking to hone its already strong technical infrastructure and to create a more creative, inventive capacity among its scientific and technically-trained citizens in order to enhance its indigenous capacity to create and manage technological innovation. Whether the latter objective can be accomplished through government plans and incentives, and whether Singapore's substantial infrastructure and institutional strengths translate into an ability to produce indigenously the complex technological systems and components likely to constitute the core of the next generation of military weapons (and the ability to integrate and manage them), remain open questions.

The following sections examine how political and institutional factors influence the "innovativeness" of Singapore's military and civilian sectors, the ability of the two sectors to collaborate with one another to achieve technical advance, and the likelihood that Singapore will combine both the resources and the national will to become a future competitor in the revolution in military affairs.

Relationships between Civilian and Military Sectors

As a small island nation lacking natural resources and a significant domestic market, Singapore's government focuses heavily on developing manpower, technology, and business. Effective cooperation among the various sectors of the economy allows Singapore to pursue goals of self-reliance and sustainability of essential defense materials and services. Furthermore, Singapore has a large public sector comprised mainly of government-linked companies (which have private shares as well) that account for nearly 60 per cent of GDP. This relationship highlights the strong ties between the civilian and public sectors and is exemplified by the defense industry.

The cornerstone of Singapore's defense industry is Singapore Technologies (ST), created in 1997 when what was originally Chartered Industries of Singapore was consolidated, becoming four individually operated units within one unified company. ST is owned by the government but listed publicly, and it has a virtual monopoly in the defense industry. The units making up ST include engineering, automotive, shipbuilding, and aerospace divisions. Although defense accounts for the bulk of ST's activity, civilian businesses are an important aspect of the company's market. For example, two business groups comprise Singapore Technologies Aerospace (STAe): the Military Business Group (MBG) and the Commercial Business Group (CBG). It is not uncommon for work of the Commercial and Military Business Groups to overlap. Civil activity is not confined solely to the CBG and involves, to an extent, the five aerospace divisions that comprise the MBG. MBG's responsibilities also extend to smaller joint ventures covering civil and military work.

Military upgrades have been, and remain, the mainstay of ST; 60 per cent of its work is from the Singapore Air Force alone, and 80 percent of STAe's revenue comes from military customers. Nevertheless, upgrade work has not been limited to the maintenance and improvement of military aircraft. In fact, the Singapore aerospace industry has expanded its expertise into the commercial arena, performing upgrades for several commercial airlines such as Japan Airlines. Also, STAe has become a key supplier for such leading manufacturers as Boeing, McDonnell Douglas, Aerospatiale and Pratt and Whitney.

Civilian and Military Innovativeness, Especially in Technology

Singapore's recent plans for economic development focus explicitly on promotion of technological innovation. Government programs target three areas: educational reform, increased innovative research and development, and improvement of 'soft' infrastructure. In the area of education, the government has launched a program to change a traditional mindset characterized (according to official statements) by conformity, predictability and lack of imagination. In the February 1998 budget, education received a 30 percent increase in funding for a total of US$3.3 billion or 3.6 percent of GDP.

Increased funding for education is only part of the picture however. A National Innovation Framework for Action was set up in January 1998, building on previous initiatives encouraging industry to be more creative in research and development. About US$1.3 billion will be spent in the next five years to install computers in every school to encourage pupils to "engage in more active and independent learning." Academics from Cambridge University, Harvard and Japanese universities have been contracted to advise the government on overhauling its entire educational system. Additionally, the government is encouraging links between educational institutions and industry as a way of fostering innovation. Aztech, a local Singaporean company that is the world's third largest producer of modems, recently forged an R&D and academic partnership with the National University of Singapore.

In 1992, Singapore released its Information 2000 report that called for the creation of a national information infrastructure. This information network envisioned linking businesses, schools, factories, home consumers and government agencies together in one unified network. In the five years since the issuance of the IT 2000 report, Singapore has made significant gains in achieving its goals. Already, the entire island nation has been wired with high-speed fiber optic cable, and important governmental ministries, companies, the port and airport, and individual households have been connected to the information network. Recently, the country was named one of the most IT-literate nations in the world by the World Competitiveness Report.

Singapore's emphasis on the development of human capital, particularly in science and engineering, is by no means directed exclusively toward the civilian sector. Despite the fact that all Singapore males must submit to national service, Singapore has recognized the need for highly trained, professional soldiers. Singapore offers many incentives for young males to make careers out of the military, including scholarships not only to national universities but to prestigious international ones as well. In addition, Singapore regularly sends its recruits to technical institutes for additional education. For its officer corps, the Singapore Armed Forces routinely sends its officers to study in foreign nations, and has developed several indigenous training institutions. Overall, the Singapore Armed Forces is a competent and highly skilled organization that owes much to the influence of Israeli advisors and the traditions of Great Britain.

Singapore's Indigenous Scientific and Technological Capabilities

Singapore's initial success at industrialization and economic development benefited from strong leadership: a visionary prime minister, strong finance ministers, and dedicated civil servants. The leadership established a public sector ethos based on efficiency, meritocracy and intolerance of corruption. Some of the best minds in Singapore were recruited into the public sector by awarding students scholarships to prestigious overseas universities in exchange for their pledge to serve in the government upon their return. If it were not for the efficiency and vision of the nation's public administration, the initial economic and industrial development efforts in Singapore would not have produced the sound foundation that helps account for its early success as a developing industrial nation. This early investment in a strong socio-economic infrastructure bodes favorably for Singapore's future capacity in both civilian and military capabilities based in high technology.

Singapore's foreign investment promotion program and focus on providing state of the art infrastructure facilities was highly successful and attracted major investments by multinational corporations, especially in the electronics sector. To meet the rising demand for skilled workers, technicians and technically competent supporting industries, the government embarked on a massive program of industrial training to upgrade the skills of the workers and to increase the supply of technicians and engineers. In addition, infrastructure investments were also intensified.

Until the latter half of the 1980s, the government of Singapore did not make significant investment in R&D institutions. It is only within the past ten years that several new research institutions have been established. These include the Information Technology Institute to pursue R&D in information technology; the Institute for Molecular and Cell Biology to conduct R&D in biotechnology; the Institute for Manufacturing Technologies to carry out R&D in advanced manufacturing; and the Defense Science Organization to provide the Singapore Armed Forces with defense-related R&D. In addition, several existing training institutions were expanded to cover R&D as well. These include the Institute for Systems Sciences and the Japan Singapore Institute for Software Technology. In recent years, the effort to promote private R&D has expanded to cover a wider range of services. An R&D incubator scheme and a design and development support service were introduced to speed up the process of commercialization of R&D outputs, while a new R&D grant scheme called INTECH was introduced to encourage new initiatives in technology development.

While Singapore has made significant strides in catching up to its Asian economic rivals and the OECD nations in their emphasis on innovative R&D, the government is now focusing on a new set of priorities for the turn of the century. Past development plans concentrated on technology absorption from abroad, but this new phase of economic development envisions a much greater need to invest heavily in the indigenous capacity to create new technology. In response to this need to increase the nation's innovative capacity, the Singapore government has recently announced a new National Technology Plan (NTP) to focus R&D activities on nine key technology areas. They include biotechnology, medical sciences, food and agro-technology, microelectronics, electronics systems, information technology, manufacturing technology, materials technology, and energy, water and environmental resources. Under the National Technology plan the National Science and Technology Board will be the main coordinating body for the various programs funded. In addition to being the administrative and approving authority on various grant programs, one of the NSTB's responsibilities will be to take over coordination of the various research institutions and centers that have already been set up by the government.

The intent of the Singapore government has been to build up its indigenous capabilities through close support of companies like Singapore Technologies as well as through technology transfers to the local defense industry in support of the maintenance and upgrade capabilities required for equipment and systems they have procured. Singapore has been careful in its acquisitions to require some type of package that includes technology training. Such requirements for technology transfers have not only permitted Singapore to gain access to some of the most advanced aerospace technology, but also has enabled the local defense oriented industries to hone their engineering skills. For example, this provides the opportunity to quickly create a niche in the aerospace industry by exporting the technologies they have learned to modify or create. It is important to note, however, that despite its technological successes and significant government support, STAe has not achieved the capacity to develop fighter aircraft on its own.

Commitment of Resources to Military vs. Civilian Objectives

Although the published data do not provide an extensive base on which to assess Singapore's priorities regarding civilian vs. military objectives, there are specific illustrations of the close relationship between these two objectives that appears to underlie much of Singapore's planning. For example, much of Singapore Technologies' success, both in the military and commercial sectors, can be attributed to a unique and close relationship with the government of Singapore, and that government support is vital to achieving Singapore's goal of becoming an aerospace industry leader. The government has supported numerous manufacturing process flow improvement projects through training grants and the Innovation Development Scheme supported under the Economic Development Board. Improvements under this program are in line with the industry thrust to shorten turnaround time, reduce cost and implement better quality control. Such government support undoubtedly maximizes the extent to which STAe is able to support the Singapore Air Force. The National Technology Plan (NTP) has also aided Singapore's evolution into a world class aero-component manufacturing and overhaul center by targeting development in several high value-added industries, especially aerospace.

Factors Inhibiting Singapore's Ability to Translate Spending on Military Goods and Services into Military Capability

There are few published documents that address the specific issue of Singapore's ability to realize, in the form of effective and efficient military capabilities, the results of public expenditures intended to achieve this outcome. It seems apparent to us, though, that this capably administered, stable, affluent, and somewhat autocratic nation-state can do an excellent job of realizing increased military capabilities if the political decision is made to make this a priority. At the same time, it seems evident that Singapore's economic and social planning recognizes that close ties exist between strong civilian capabilities in high technology and military strength. As a technology-based, industrializing nation that approaches levels of technological competitiveness achieved by many OECD member nations, Singapore seems well-positioned to realize substantial advances in military technology if it chooses to do so.

Concluding Observations

Singapore possesses a number of key characteristics that are predictive of a future capacity for indigenous development, production, and deployment of state-of-the-art military technology. Among these characteristics are effective cooperation among the several sectors of the economy, especially among government, civilian, and military institutions. This cooperation is facilitated by the nation's small size, homogeneous population, and authoritarian mode of governing. The government has been stable and has produced and implemented a number of appropriately targeted plans for developing the national socioeconomic and physical infrastructure and, more recently, the high-technology sector. Human capital is recognized as an essential ingredient in the nation becoming a major player in high technology competition among nations. If Singapore decides to devote a substantially increased proportion of its national income to defense, it can do so quickly and achieve the results of that investment both effectively and efficiently. With the possible exception, in the short term, of large-scale weapons systems such as fighter aircraft, the capabilities of an indigenously-developed military force would make it a formidable competitor in performance if not in scale.

These positive features are offset to some extent by several weaknesses Singapore must overcome. Significant national investment in R&D has taken place only over the past ten years, a relatively short time for any substantial base of indigenous design and development (and management) to have accumulated. Further, movement from successfully upgrading military and commercial aircraft with state-of-the-art components to the capacity to develop complete systems requires know-how that cannot easily or quickly be acquired via traditional forms of technology transfer. Finally, the government's plan to foster greater creativity and innovation among its students and R&D professionals is well-intentioned but extremely difficult to accomplish. On the other hand, it is not obvious that the current level of creativity is a significant damper on technical advance. For example, Japan reportedly has suffered from a similar lack of creativity among its scientists and engineers but, if true, this does not seem to have prevented that country from achieving an extremely high level of technical competence.

3.4 *Case Summary: Taiwan*

Introduction

Taiwan's unique political and societal characteristics play an important role in its success as an economic competitor, and its unique geopolitical situation has had a corresponding impact on its defense technology development strategy. Since 1978 the government has been following a multifaceted reform program focused on building a strong political, economic, and social base of support for the regime. Critical elements of this reform program have included many changes to facilitate improved economic and technological performance and independence, and have emphasized a relatively egalitarian distribution of wealth, mass political participation, equality, and social-educational benefits.

Over the same period Taiwan's economic focus was on creating a broad, balanced structure of light industries, intermediate goods, and capital goods industries. This resulted in the development of a large percentage of small and medium scale enterprises with short to medium-term time horizons driven to capitalize on emerging financial, property, and industrial opportunities. This differs greatly from the development strategies adopted in Japan and South Korea, which emphasized diversified, conglomerated enterprises with longer-term business horizons, strongly influenced by government efforts to direct investment into promising industrial sectors. Ultimately, the manner in which the Taiwanese industrial structure has evolved may hinder the government in its recent pursuit of defense self sufficiency because of the absence of large enterprises with the capital and political leverage to undertake large scale research and development projects in the defense sector.

Relationships between Civilian and Military Sectors

Research and development related to national defense has been a crucial component of national modernization. The Ministry of National Defense has available to it a National Defense Industrial Development Fund to assist public and private enterprises in cultivating qualified technical personnel and purchasing facilities, transferring advanced technology, and enhancing the technology base. Investments from the Fund are guided by the recently issued Defense Science and Technology Development Plan, which focuses on strengthening cooperation between academic and industrial sectors. The government has also established an Executive Conunittee for the Development of Defense Science and Technology to employ academic resources to conduct research on defense technology and to contract with private sector industries to develop and manufacture weaponry and armaments.

Civilian and Military Innovativeness, Especially in Technology

The primary institution for research, design, and development of defense technology in Taiwan is the Chungshan Institute of Science and Technology (CIST). CIST consists of 6,000 scientists and more than 8,000 technicians. Its facilities stretch over 6,000 acres throughout Taiwan, and it is divided into four major divisions: aeronautics, missiles and rockets, electronics, and chemistry. The CIST jointly conducts independent research and development of weapon systems with the Aero Industry Development Center (AIDC: Taiwan's only aerospace conglomerate), academic institutions, and public and private industries.

Perhaps the greatest factor retarding the development of an indigenous defense industry has been Taiwan's necessary dependence on the international arms market to provide immediate solutions to its security problems through the acquisition of sophisticated end items and platforms. Taiwan has, however, produced a contemporary fighter aircraft, the Indigenous Defense Fighter (IDF). This was accomplished by the Aero Industry Development Center, with enormous external assistance. For example, the aircraft's development was assisted by General Dynamics (airframe), Garrett (engines), and General Electric (radar), to name just a few partners. Working with corporations outside Taiwan has provided the opportunity to enhance the non-production aspects of the development process at the AIDC.

Most of Taiwan's innovations in defense technology have been in the areas of the design and re-design of components and subsystems, maintenance, repair, and upgrades.

Currently, however, a national priority has been established to pursue self-sufficiency in defense production. This is going to be a long and arduous process with no guarantee of success. The problems that Taiwan faces in achieving this goal are three fold: the necessity of constantly addressing the immediate and future threat from China, the industrial structure of the economy, and the late start in pursuing self sufficiency.

With respect to the latter point, historically Taiwan has been an atypical arms buyer: it generally has not required the offsets and technology transfers to augment indigenous industries that many other countries have insisted upon as a condition of purchase. This situation appears to be changing. Because of the "buyers market" that has characterized the arms trade in the 1990s, Taiwan now is in a much stronger position to exact greater demands from sellers. Politicians are demanding technology transfers as a condition of future purchases. According to *Jane's Defense Weekly*, "Taiwan is now a major defense market after establishing itself as a successful economy."

Taiwan's Indigenous Scientific and Technological Capabilities

In Taiwan the highly authoritative, centralized state limited the growth of private conglomerates. For those entities that did prosper, the relationship between the bureaucracy and private firms was facilitated by government policies that institutionalized relationship among the public, bureaucrats, and private capitalists. This cooperation has been crucial to the formulation of an effective industrial policy and to a high rate of economic development. The ruling party (KMT) and business elites found ways to improve government-industry relationships. Business associations provided a means for constructing dense networks between businesses and state officials. The government appointed former officials known for their loyalty to run these business associations. Institutional ties between central economic officials and public enterprise officials continue to be tight, consisting of a policy network that links them together and to public banks. Thus the government has become the chief force behind the move to enhance domestic technological capabilities.

In addition to fostering private R&D investment and technology development, the government has pursued R&D in many areas on its own. In 1973 the government established the Industrial Technology Research Institute to pursue applied R&D. Sixty percent of its operating funds come from government. It now consists of six labs and three research centers that employ 4,000 people. There is currently an effort to increase the amount of contracts with private firms. Prototype products developed by the Institute are licensed to private firms at low fees for manufacture.

The core of Taiwan's high technology program exists in the government run Hsinchu Science and Industry Park, created in 1980. It is Taiwan's engine for growth in the 21st century. In 1995 it consisted of 134 companies and 20,000 employees, 4,000 of whom were engineers. A unique aspect of the park is its close cooperation with other research institutions and the government. R&D spending as a percent of sales by firms in the park exceeds that of other local firms by a ratio of 5 to 1. Many of these firms have been start-ups with investments from engineers and scientists, some of whom have come from the US as part of a reverse brain-drain. Ideas for new products often come from small, Taiwan-invested companies located in Silicon Valley.

The aerospace industry has been designated by the government as one of the high technology areas essential to future economic development. However, the AIDC is the only large conglomerate in the Taiwanese aerospace industry. Established in 1969 under the Ministry of National Defense as a purely military organization, it was restructured under the Ministry of Economic Affairs in 1996. The government's support of AIDC has enabled it to gain a substantial amount of industry experience, state of the art facilities, and nationally unique capabilities in aircraft development and production.

Despite the success of the IDF project, there is little evidence that the technological capacities developed within AIDC have spun off into the commercial aerospace industry. There appear to be several reasons for this, including the lack of qualified counterpart businesses in the commercial sector and a divergence between military and civilian specifications for aircraft and components. Taiwan's commercial aircraft industry remains highly dependent on external acquisition or purchasing of end use products.

Commitment of Resources to Military vs. Civilian Objectives

Taiwan suffered a prolonged slow down in domestic private consumption, stagnant real estate, and a sluggish stock market combined with a series of bank runs that dampened growth in 1995. Yet with a growth rate of only 6.06% (low for that region, as well as for Taiwan) in general export-related sectors, manufacturing and information technology industries performed extremely well while other sectors such as housing and service related industries suffered slow-downs. During the past few years government consumption has actually recorded a 5.2% real growth (1996) while private consumption has declined. This growth has mainly been due to an increase in military procurement necessitated by the continuing threat from China.

Factors Inhibiting Taiwan's Ability to Translate Spending on Military Goods and Services into Military Capability

Taiwan has been able to fashion a capable national defense through the international arms market, and has augmented the capability of these forces through licensing and co-production arrangements with foreign corporations. It has also developed the capacity to design and produce a range of improvements to foreign-designed and manufactured subsystems and components and upgrades of foreign systems. It has developed and produced a fighter aircraft, albeit with considerable foreign assistance and content.

However, because of the necessity of relying foreign sources for major defense equipment on a time urgent bases, and because of the nature of its industrial structure, Taiwan does not today have the basis to develop military self sufficiency or procurement autonomy. Taiwan's security problems continue, but the government believes that it has sufficient flexibility to begin promoting and funding private sector industrial, government, and academic collaboration toward the goal of developing high technology defense industries and conglomerates that could, in the future, design and manufacture contemporary major defense equipment. The costs of continued heavy military procurement of foreign made contemporary systems, however, will further burden any progress toward this goal.

The second obstacle that Taiwan faces is its industrial structure. The industrial base consists of a large majority of small and medium scale enterprises with short to medium term time horizons driven to capitalize on emerging financial and industrial opportunities. There is only one large firm (conglomerate) operating in the defense sector, the AIDC, and there are few qualified counterparts in the civilian sector to generate either "spin-off" or "spin-on" opportunities. Furthermore, because of the AIDC's limited product line, there appear to be limited opportunities for collaboration between it and potential partners in the private sector in terms of new dual-use product development.

Concluding Observations

Taiwan has had considerable success in military sub-system and component manufacturing, licensing and co-production, and repair, upgrade and product modification in the targeted areas of naval and air systems. With respect to the design and production of a complete fighter aircraft, it remains distant from the capability to produce domestic components, parts, processed materials, etc. for an indigenously designed system.

Taiwan does, however, have an strong commercial electronics industry, with expertise in the areas of information and data processing and semiconductor manufacturing. Consequently, it is not surprising that they have had considerable success in upgrades and modifications to imported systems.

Taiwan has also produced a contemporary fighter aircraft using domestic and imported components and copy and re-design skills but with the sources of major components, systems and subsystems, as well as technical assistance, from foreign manufacturers. This effort appeared to be driven by the perceived necessity of providing for its own air defense following a 1982 negative US decision on an F-16 purchase.

The production of this aircraft appears to be a somewhat isolated event. Taiwan remains dependent on the international arms market for the major instruments of its security, and these purchases have priority within the national economy. Nonetheless, the government has attempted to foster greater integration within the economy through encouraging closer collaboration between the private sector, government institutions, and academia. This process has been slow to take effect with regard to significant defense developments, and part of the problem may be the lack of a critical mass of large industries for which investment in military development makes financial success. Another barrier may be that military research and development for major defense equipment is an expensive proposition requiring guaranteed initial markets to amortize research and development costs and production costs as well as accelerate the manufacturing learning curve. Internationally, the market for major defense equipment is extremely competitive and saturated with a number entrenched competitors.

Defense budgets in Taiwan are oriented to solving immediate needs and perceived shortfalls. Military technologies are capital intensive and military products may be too specialized, inappropriate, or capital intensive to attract investment from commercially oriented firms. In short, we found little evidence of "spin-on" or "spin-off" in the case of the Taiwanese defense industry.

4.0 Cross-cutting Analysis of Cases

China and India offer obvious opportunities for comparison and contrast in technology-based development--their sheer size, long and complex histories, and geographic location on the one hand, and very different cultural, religious, and political settings on the other, suggest superficial similarities and deep-seated differences in the areas of interest here. This is indeed the case. We begin our comparative analysis with China and India, and follow with Singapore and Taiwan. We then conclude by making observations about our working hypotheses, drawing evidence from all four cases.

4.1 *China and India*

China and India contrast strongly in virtually every feature we have deemed significant for predicting the technology-based capabilities of nations. An assessment of these two nations' *current* strengths and weaknesses reflects our overall judgment about the future: India will not be a major competitor for the foreseeable future, while China will be a regional power in the short term, effectively absorbing and adapting high technology from abroad. In perhaps 20 years, China has the potential to compete with the major industrialized nations in high technology, provided it invests substantially more in civilian R&D.

With regard to civilian and military innovativeness, especially in technology, we found that India is weak in both but especially weak in the military sector because of fundamental cultural factors that create and sustain built-in inefficiencies there. The military sector is characterized by inflexibility, mistrust, separation of research and production functions, and bureaucratic pathologies, and to a lesser extent these are present in some civilian sectors as well. Even in the case of missile technology, one of the Indian military's few technical successes, largely inherent weaknesses appear to preclude its effective implementation.

In contrast, China exhibits greater strength in the military than civil sector due to a strong national commitment to military spending, especially in R&D. Emphasis is shifting from acquisition of new-to-China technologies to absorption and adaptation of advanced, cutting edge technologies. Weapons are seen as deriving from a strong defense research and industrial base. Although the Chinese government exercises strong influence over civilian technology development and production, including the management of innovation, the national commitment to R&D is relatively low, with military priorities dominating. The picture is complicated by the recent exodus of technical talent from state enterprises, leaving them weakened, while the expected consolidation of firms in the industrial base may, in the future, enable these conglomerates to draw upon a number of new, innovative startups. How these opposing trends will balance out is unclear.

India professes policies to create "self-sufficiency" in civilian and defense technology, but there is an empty ring to these claims because, in addition to the cultural bias against the military, India's strong democratic tradition precludes implementation of comprehensive policies for economic reform. Societal fragmentation, bureaucratic inefficiency, and selective implementation of reforms produce slow, incremental, and uncoordinated change.

Again in contrast, China's commitment to indigenous production of military weapons is backed by a clear policy of short-term technology acquisition and longer term investment in R&D and human capital. The 863 and Torch programs support indigenous development of science-based industries, but it is unclear how significant these programs will be for overall civilian technical capacity, even if they are successful. However, China's heavy emphasis on technological development in the military means that, at least in the short run (up to 15-20 years), civilian capabilities in indigenous science and technology will lag those in the military.

As our case study of India clearly indicates, deeply-rooted cultural and political factors will continue to keep the military weak, internally inefficient, and poorly linked to the civilian sector. In China, there are some areas of cooperation between civil and military sectors, notably in satellite launch technology and in commercial areas controlled by the PLA, but recent incentives to promote labor mobility and spin-offs from state enterprises will, we suspect, increase the separation between military and civilian sectors. The gap may be exacerbated by continued emphasis on military R&D at the expense of investment in civilian research and technology.

India's military objectives will continue to rank considerably below civilian and social goals. Even in missile technology, the military's strongest area, major funding increases are unlikely. In contrast, China evidences a strong commitment to military spending and technological development. The favored position of the military over civilian programs is especially evident in the allocation of public R&D funds. The new civilian "spin-off" industries, based in former government or military enterprises, do not attract government R&D funds that would fuel significant internal technical advance.

Nearly all the features of Indian society we have described mitigate against that nation's achieving a strong, efficient, effective military, even in priority areas. China, on the other hand, appears to have no significant barriers to achieving significant, technology-based military capability in the short term -- 15-20 years. After that, weaknesses in indigenous civilian S&T capability will limit opportunities for the military to benefit from spin-on of domestic, cutting edge technologies.

4.2 *Taiwan and Singapore*

Taiwan and Singapore do not invite the same obvious call for comparative analysis as do India and China. Still, their geographic location and labels as "Asian Tigers" suggest similarities that would make such an analysis informative. Both nations have enjoyed very high rates of economic growth in recent decades and are competitive with several European nations in high technology products. This is particularly surprising in view of Singapore's extremely small size and lack of natural resources. But nations such as Singapore, Finland, and Sweden clearly show that small size does not prevent a nation from becoming a peer competitor in the international high technology marketplace.

With respect to innovation in civilian and military sectors, Singapore Technologies (ST) is the cornerstone of that nation's national defense industry, but includes civilian and military business groups whose markets overlap. The small size of the country, together with its homogeneous population and efficient administrative structure, means that, intrinsically, exchange of knowledge and information across the two sectors is relatively easy. Taiwan, too, exhibits a variety of civilian-military cooperative linkages, fostered by direct government action and facilitated by programs encouraging business newtworking and academic-industry cooperation in both civilian and military areas. CIST, the Chungshan Institute of Science and Technology, is the primary institution for research, design, and development of defense technology--and links academic and public and private institutions. In this area of our inquiry, there are strong similarities between Taiwan and Singapore, symbolized by the central role played by CIST and ST, respectively.

Singapore evidences close integration of civilian and military sectors, again facilitated by the country's small size -- indeed, the two sectors blur to an extent not evident in the other countries we studied. Both Singapore and Taiwan have been particularly dependent on external acquisition for achieving their defense capabilities, only recently attempting to develop indigenous capacities. Singapore has developed strong capabilities in civilian microelectronics (initially disk drives) and military and civilian aircraft upgrades; similarly, Taiwan has emphasized computer components and military aircraft technology. Most of Taiwan's defense innovations are in design and redesign of components and subsystems, maintenance, repair, and upgrades; only recently has it gone to offsets and transfers of know-how as conditions of acquisition. There is little evidence that Taiwan's innovative capacity in either sector has substantial influence on the other.

Singapore possess a very strong basic socioeconomic infrastructure, including linkages among major societal institutions. This includes commitments to development of human capital and information infrastructure in addition to physical and technological infrastructures. But, only recently has Singapore invested in civilain R&D institutions at a significant level. Taiwan also enjoys the fruits of past investments in physical infrastructure and inter-institutional linakges. Strong business networks have been fostered by government, and government policies have supported both public and private investments in R&D. However, there is not much evidence of spinoff from military to civilian innovation.

In Singapore, R&D investments by the government have tended to favor the military sector until recently. Singapore Technologies is the prominent example. Taiwan, preceiving the threat from mainland China, has reacted similary and devoted considerable resources to military procurement.

Singapore's small size, efficient and competent government, authoritative structure, and strong technical and human resources indicate a clear potential for realization of significant military strength in high technology -- if the national orientation moves in this direction. Taiwan, in contrast, is somewhat limited by its history of reliance on foreign sources for defense equipment and by the absence of large firms in the defense sector. The latter, in particular, appears to preclude substantial benefits from either spin-off or spin-on. It is primarily in this last category of comparisons that we observe major differences between Taiwan and Singapore, differences that bode more favorably for Singapore as a future peer competitor in high technology.