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# The Development of Technological Capability: Macro- and Micro-Scopic Approaches to Policy Research

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Larry E. Westphal, Kopr Kritayakirana,
Kosal Petchsuwan, Harit Sutabutr, and Yungyuth Yuthavong

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Department of Economics, Swarthmore College
Swarthmore, PA 19081, U.S.A.
and
Science and Technology Development Program (STDP)
Thailand Development Research Institute (TDRI)
Bangkok, 10110, THAILAND

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## Acronym Usage

For various reasons, acronyms are often used in this paper in place of the full names they represent. In particular, acronyms are used for individual and aggregate technological capabilities and for firm descriptors such as size class. Several tables provide correspondences between acronyms and what they represent. These tables are starred (with an *) and the corresponding acronyms identified in the List of Tables on the previous page. Other tables use distinct acronyms as row and column headings; these acronyms are defined in notes to the tables in which they appear. Some other commonly used shorthand is indicated below.

ALL = with reference to attribute regressions: regression includes dummy variables for characteristics of all attributes;
with reference to capability regressions: regression includes parameters associated with the characteristics of all attributes.

All = includes all firms in the Area or Pool sample regardless of characteristics.

Area = BIO Tech, ELEC Tech, or MAT Tech; as the case may be.

BIO Tech = industries based on biotechonology; in particular, the sample of firms surveyed in the research project.

Bio = shorthand for BIO Tech.

ELEC Tech = industries based on electronics and information technology; in particular, the sample of firms surveyed in the research project.

Elec = shorthand for ELEC Tech.

IND = industry.

MAT Tech = industries based on materials technology; in particular, the sample of firms surveyed in the research project.

Mat = shorthand for MAT Tech.

n.a. = not applicable (or, infrequently, not available).

NONE = capability regression includes no parameters specifically associated with the characteristics of any attributes.

OMIT = capability regression includes parameters associated with the characteristics of all but one attribute.

ONE = with reference to attribute regressions: regression includes dummy variables for characteristics of only one attribute;
with reference to capability regressions: regression includes parameters associated with the characteristics of only one attribute.

Pool = BIO, ELEC, and MAT Tech samples combined, using standardized scores.

PRO = this is the only acronym that has two very distinct meanings:
with reference to TCs: production capability;
with reference to attributes: BoI promotional status.

TC = technological capability (or, in the case of resources, capacity).

0.0+ = value greater than zero but less than +0.005.

0.0- = value less than zero but greater than -0.005.

The notion of technological capability has gained broad acceptance within the community of scholars and practitioners concerned with Third World development. Nonetheless, certain of its more important implications have yet to find widespread practical expression. One such implication has to do with the appropriate focus of the formal science and technology (S & T) plans that are episodically promulgated in a number of countries. From the capability perspective, Third World technological development is a matter of acquiring the requisite capabilities needed to make effective use of existing technology through assimilation and adaptation. This implies that S & T plans should focus on the broad range of issues that arise in connection with the acquisition of technological capability. S & T plans in the past have typically not had this focus. Instead, they have generally been concerned with issues more appropriately addressed in the context of R & D in technologically advanced countries, "on the global frontier."

There is reason to believe that more is involved here than a simple difference in perspectives about what drives -- or ought to drive -- Third World technological development. Most of our knowledge about the acquisition of technological capability comes from microscopic empirical research on the internal workings of productive enterprises. This is natural given that fundamental issues related to capability acquisition can only be comprehended in the microcosmic realm. But it is at best very difficult to fit the findings of microscopic research into the inherently macroscopic orientation of an S & T plan. It is far easier to maintain the appearance of comprehensive scope and systematic formulation by concentrating, for example, on various aggregate indices of ostensibly crucial inputs and outputs. Plans require clear analytical frameworks in which to be formulated. It is doubtful that there will be a widespread change in the focus of formal S & T planning until there is an adequate framework for systematically incorporating the microscopic issues of capability acquisition into the macroscopic orientation of S & T

planning.

This paper is about an attempt to focus research for S & T planning on capability issues. As will be seen, the attempt failed to achieve its objectives in some important respects. It did, however, succeed in others. Section 1 gives a sketch of the microscopic approach that served as the starting point for the effort. During the course of the research, the essentials of this approach were abandoned in favor of a macroscopic derivative. Sections 2 through 4 deal with various aspects of that approach and give some of the salient findings from the research. Section 5 contains a few reflections on the attempt. We have several purposes in writing the paper: First, to provoke discussion about how systematically to incorporate capability issues into S & T planning. Second, to state some apparent lessons about policy research of a comprehensive scope in the area of S & T planning. Third, to demonstrate the nature of the results from an exercise in macroscopic research with the expectation of eliciting peer review of its utility.

## 1 A Microscopic Approach to Policy Research

How well do key industries in Thailand utilize technology? How does government policy, including the activities of public entities, affect its utilization? What new policies or changes in existing policies, if any, would enhance the utilization of technology? These were the central questions posed at the outset of the research. The researchers expected to find the following answers to the respective questions: Not very well; Ineffectively, if not adversely; Many. Thus one central objective was to develop a set of concrete, immediately implementable policy recommendations. However, the researchers also recognized that many senior policy makers were not fully persuaded of the need for government action to promote technological development (this notwithstanding the government's quite impressive record of recent investments in S & T infrastructure and R & D funding). Thus another central objective was to demonstrate that technological development was and would continue to be

inadequate under the current policy regime. This was to be done by isolating capabilities that were clearly warranted in the context of Thai industrialization but that required government action to develop and diffuse.

Historical experience is the natural laboratory for research on how government policy affects market-mediated technological development. Analysis of the behavior of firms operating under current and past policies provides necessary insights into the effects of particular policies on the choice of technology as well as on the extent and direction of technological change. But, given the way that this type of research is conventionally designed and accomplished, it can not be expected to yield sufficient information about technological changes that should have taken place but did not, or about the indigenous capabilities that were warranted to accomplish these changes but were not developed. Of course, research on the past could be designed to uncover failures of these kinds. But this could not be accomplished without using scarce technical expertise that is better employed working more directly on current and future technological development. These considerations led to a research approach that aimed at capitalizing on the lessons of past experience while focusing on what was needed for the future.

The distinguishing feature of the approach was its focal concern with "key" capabilities; that is, with capabilities that were absent in Thai industry but that were clearly warranted either in the sense that they should have been developed in the past or should be developed in the present or very near term future. The domain of the search for these capabilities was to be three technological areas already chosen for priority attention in the government's existing efforts toward technological development. The areas include biotechnology, materials technology, and electronics & information technology.

Key capabilities were to be identified through a systematic process involving a number of distinct elements:

- analysis of the underpinnings of Thailand's dynamic comparative advantage in tradeables, to insure the economic appropriateness of the production activities involved;

- search among the technologies available globally that could fruitfully be applied in Thai industry, to arrive at a small set of the most promising ones;

- economic and technical evaluation of potentially rewarding technologies in specific industrial areas;

- determination of alternative means of acquiring the selected technologies through using different mixes of Thai and foreign technological capabilities;

- economic and technical assessment of these alternatives, to identify the key capabilities and to establish an appropriate sequence for their development; and,

- identification of the policy changes (if any) needed for their development.

These elements, like the others involved in the research, were to be undertaken in successive iterations of decreasing breadth and increasing depth. Thus, as the range of prospective choices became narrower, the information requirements would become increasingly more detailed and the analysis increasingly more refined.

The pursuit of key capabilities is obviously an ambitious undertaking. But the resources committed to the quest were relatively ample in quantitative and qualitative terms. Moreover, it was clearly understood that the sought for capabilities constituted only a sampling of the capabilities needing development in the present and near-term future; there was no pretense of comprehensive identification or even of obtaining a somehow objectively representative sample. Furthermore, the elements enumerated above were seen as being indicative of the factors to be considered with as much care as time permitted; there was no pretense of rigorous application to derive conclusive evaluations. Stated simply, what was wanted was a sample that could reasonably be considered as having been drawn from Thailand's present and near future technological needs rather one drawn from its past development. However revolutionary the idea of drawing a sample from the future may be, one can't easily deny its potential relevance, particularly where scarce technological

talent (scientists and engineers) is to be actively involved in the research.

The identification of key technological capabilities can not be accomplished without intimate knowledge of existing capabilities. Thus the approach was to involve an examination of existing Thai capabilities in the areas of concern. Likewise, the determination of necessary policy changes can not be accomplished without an understanding of the dynamics of market-mediated technological development, or of decision-making and implementation processes in public agencies active in these areas. Thus the approach was also to include an investigation of the factors conditioning past performance. In this respect it was to contain a component of the conventional analysis of technologically oriented past behavior. But, unlike much conventional analysis, the approach was expected -- because of its unique sampling frame -- to uncover capabilities that should have been developed in the past, but were not, and to yield important insights into the reasons why they were not.

The research was to be divided into three stages, with a division of labor between economists and technologists that would exploit the comparative advantages of each specialization. This is shown in Table 1 which gives a summary statement of the approach. Close collaboration was called for in the first and third stages (top-left and bottom-right cells respectively) which were respectively to focus on the survey of existing conditions and the final determination of policy needs. Mutual consultation rather than close collaboration was foreseen in the second stage, where the technologists were to concentrate on developing the sample of key capabilities (bottom-left cell); the economists, on gaining the necessary understanding of past technological behavior (top-right cell).

[ Table 1 about here. ]

The approach sketched here entails many compromises between breadth and depth of analysis. These compromises are a matter of necessity in any exercise to identify development priorities across a reasonably wide set of

possibilities. Thus the identification of key capabilities was not expected to do more than determine choices deserving of conclusive evaluation by agents responsible for their implementation. In turn, the economic analysis of market-mediated technological development was expected to be somewhat impressionistic and to be based largely on "targets of opportunity" uncovered in the first stage of the research. In the second stage, small samples involving case studies of the technological histories of particular firms and agencies were to be the norm.

By design, and consistent with the comprehensive scope of S & T planning, the research was to touch on many if not most of the generic issues related to government policy in Thailand's technological cum industrial development. Indeed, it was hoped that the research would accumulate more information relevant to these issues than could be thoroughly analyzed under its immediate auspices. Likewise, it was hoped that the research would demonstrate -- or reinforce prior knowledge about -- the need to obtain further information before certain issues could adequately be addressed. In these respects the research, as the first major undertaking of its kind in Thailand, was seen as but the first step in an evolving program of research. It was thought to have an important function in this regard, which was to provide the broad-guaged empirical knowledge required to design a program of more narrowly targeted research for the future.

In the foregoing discussion the term "approach" has been used in place of "framework" because a central element was missing from the research design. There was no explicit, predetermined means for systematically incorporating the findings from microscopic research to identify key capabilities and to understand past behavior into the kind of comprehensive yet reasonably detailed policy synthesis that is wanted in S & T planning. The absence is simply explained. There is no recipe that can easily be followed to develop a well reasoned and clearly structured statement of significant central tendencies

from largely anecdotal evidence about technological behavior. Nor is there is any simply stated formula for how to go from the identification of key capabilities and an understanding of central behavioral tendencies to a statement of the appropriate policies to insure the development of these capabilities, let alone to generalize on this basis across the entire domain of S & T policy.

The adoption of the microscopic approach at the outset of the research was a gamble of the kind frequently taken in innovative policy research. The gamble was that a means for bringing the pieces of the puzzle together would evolve out of the conduct of the research. It will never be known whether the pieces would in fact have come together in fruitful outcome, for the approach was hardly followed. The research effort was actually concentrated on the top-left cell in Table 1, with only passing forays into the bottom-left and top-right cells. One could infer from this either that the research got unnecessarily bogged down in the first stage or that the first stage required a good deal more effort than was anticipated. But neither inference would be correct, at least not with respect to the microscopic approach outlined above. This is because that approach was essentially abandoned with the first substantive decision that was made about its detailed implementation. But this fact was not recognized by anyone involved in the research until it was too late to do anything meaningful about it.

The critical decision concerned how to evaluate existing capabilities within firms in the three technological areas. One can contemplate various ways of accomplishing this task. Some of them focus in the small on specific episodes in a firm's use, or failure to make effective use, of technology. Others focus in the large on evaluating a firm's overall technological competence in various activities. The way that was chosen falls squarely in the second category. The consequence was a diversion of the researchers' attentions away from microscopic concerns at the very outset of the research.

Owing to the momentum established during the course of any large research undertaking, the diversion was never effectively overcome. It is also pertinent that the chosen method of evaluation took a great deal of time and effort, considerably more than would probably have been required had the evaluation focused on specific episodes in the firms' technological histories.

## 2 Ingredients of a Macroscopic Approach

Existing capabilities were evaluated using a generalization of a method employed, but never to our knowledge formally published, by Frederick Moore and various colleagues in the World Bank's operationally oriented work on industry. Firms were numerically scored with respect to their capabilities in some twenty general areas of technological activity. Without going into the actual details of how the scores were determined, this section of the paper discusses the principal ingredients of the macroscopic approach that was actually followed in the research. The next section summarizes the elements of the statistical analysis of the scores. To our knowledge, this is the first time that such scores have been subjected to a reasonably thorough statistical analysis. The fourth section of the paper presents a sampling of the kind of policy relevant findings that can be derived from such analysis. Readers who wish to concentrate on essentials may do so without too much loss of substance by reading the rest of this section -- including 2.1 and 2.2, section 3.3 -- omitting 3.3.1 and 3.3.2, and all of section 4.

As already noted, the research was centered on three technological areas: biotechnology (hereafter referred to by the acronyms BIO Tech, or Bio); materials technology (MAT Tech, or Mat); and electronics & information technology (ELEC Tech, or Elec). Full details regarding scoring methodology and other salient aspects, including the raw scores, are contained in the reports of the three Area research teams [Petchsuwan, K. et al. (1988), ELEC Tech; Sutabutr, H., et al. (1988), MAT Tech; and, Yuthavong, Y., et al. (1988), BIO Tech -- these are Draft Final Reports]. Details concerning the statistical

analysis are contained in a separate report [Westphal (1989)].

Technological capability scores were awarded on the basis of evaluations made during plant visits by members of the respective Area research teams. The scoring was generally done jointly by economists and technologists familiar with the particular industry in Thailand and in general. The scores reflect their attempt to consolidate a good deal of both objective and subjective information into coherent indices of firms' abilities in utilizing technology across a number of dimensions pertinent to the transfer, assimilation, and adaptation of industrial technology.

## 2.1 Technological Capabilities

Table 2 lists the various technological capabilities (TCs) that were identified and scored by the Area research teams. Each team used a somewhat different set of capabilities. Indeed, while two teams (those working on BIO Tech and MAT Tech) identified and scored twenty distinct capabilities, the other (ELEC Tech) worked in terms of eighteen capabilities. Moreover, some capabilities having identical names are in fact distinct capabilities (see, for example, "skills in use," acronym OP-SKIL, for BIO Tech and ELEC Tech). In turn, three of the common so-called capabilities are not really capabilities in the sense of reflecting ability in using resources. Rather, given the way they were defined and scored, they reflect capacities in the sense of resource endowment. They are (in the order listed in Table 2) maintenance [acronym OP-MAIN], training [OP-TRAI], and R & D [IN-RAND].

[ Table 2 about here. ]

Notwithstanding their differences regarding detailed capabilities, the Area research teams aggregated the individual capabilities into four ostensibly common groups: AQuisitive, OPerative, ADaptive, and INnovative (capital letters give the first element of the individual capability acronyms given in Table 2) capabilities. Acquisitive capability relates to the ability to search for, assess, and transfer technology. Operative capability -- in particular,

OP-OPER -- is as close as the researchers came to measuring financial cum economic profitability; in fact, there is good reason to think that it can be used as a proxy -- albeit an imperfect one -- for financial profitability. It can not be used as a proxy for economic profitability insofar as some firms may not have opted for the economically (or socially) optimal choice of technology and insofar as market prices diverge from economically appropriate (efficiency or shadow) prices.

Adaptive and innovative capabilities relate to technological efforts that are central to the effective assimilation of technology and to its simultaneous cum subsequent adaptation to better fit local circumstances. Neither is to be understood in terms of research and development on the global frontier of technological change. Rather they are to be understood in terms of activities related to technological development that takes place through transfers of technology complemented by indigenous efforts of assimilation, adaptation, and extension. [For one articulation of this perspective, see Dahlman, Ross-Larson, and Westphal (1988).]

For purposes of statistical analysis, a rather different aggregation scheme was used, one designed to achieve greater uniformity among the Areas and thereby to facilitate common analysis. The five aggregate capabilities and their constituents are identified in Table 3; they include technological RESources, INVestment capability, PROduction capability, MINor change capability, and MAJor change capability (capital letters give the second element of the aggregate capability acronyms given in the table). Not all of the individual capabilities could meaningfully be included within the aggregate capabilities; that is, they could not be included without undue sacrifice of comparability across Areas. Thus some individual capabilities are considered as being "related to" instead of "included within" particular aggregate capabilities.

[ Table 3 about here. ]

The first of the aggregates, "technological resources," includes the three individual capacities-not-capabilities discussed above. The remaining four aggregates -- capabilities in investment, production, minor change, and major change -- are respectively akin to the Area research teams' groups of acquisitive, operative, adaptive, and innovative capabilities. However, there are some pronounced differences in the two clusterings. It is largely for this reason that distinct labels were used for the aggregate capabilities employed in the statistical analysis. [The use of the investment capability label here is something of misnomer relative to other usage which emphasizes different aspects of investment activity; see, for example, Westphal, Kim, and Dahlman (1985).]

As regards the difference between minor and major change: Minor changes affect neither the basic product mix being produced nor the basic production methods being used. They relate to such things as design and quality changes in existing products and changes in operating practices (as distinct from the basic methods which are embodied in core capital equipment) which might entail modifications in existing equipment or the addition of ancillary equipment. Major product changes substantially affect the product mix, for example by the addition of a product that is obviously or substantially differentiated from those already produced. Major process changes similarly substantially affect the basic production methods, for example by changing the technique or by internalizing some previously hired out activity. With respect to the capabilities for both kinds of change, it is very important to recognize that their scoring was based on evidence of actual changes having been made. The R & D capability (IN-RAND), in contrast, was scored on the basis of R & D budget, staff, facilities, and the like.

The scoring scales used by the Area research teams are given in Tables 4 and 5. It is to be noted that the MAT Tech research team used an ostensibly quite different scale, one that places considerable weight on technological

self-sufficiency at the firm level. Their scale has the very real merit that the scores have somewhat more objective content than do those in the other Areas. However, there is absolutely no good reason to think that firms should be technologically self-sufficient. Thus, to the degree that they in fact do reflect technological self-sufficiency at the firm level, the MAT Tech scores have no prescriptive significance. That is, there is no reason to associate higher scores with economically (or socially) more desirable results. But, for a different reason (which also pertains for MAT Tech), the same caveat is equally relevant to the scores in BIO Tech and ELEC Tech.

[ Tables 4 and 5 about here. ]

Two quite separate aspects were mixed in scoring firms' technological capabilities. Economists make a clear distinction between choice of technology and the efficiency with which a technology in use is utilized. In the context of the present research this translates into a distinction between the level of sophistication (relative to the global frontier) of the technology in use and the capability with which that technology is employed. These aspects were not systematically separated in the scoring by any Area research team, as an economist would strongly argue they should have been, except perhaps in those industries -- like computer hardware -- where international competitiveness is clearly contingent upon using frontier technology. There is no a priori reason to think that only the most sophisticated technologies are appropriate to Thai industry; in fact, all the a priori reasons go the other way. High levels of efficiency or capability, on the other hand, are by definition -- assuming some care in the definition, and the measurement -- desirable.

The BIO Tech research team did come to recognize the importance of the distinction, but the recognition came too late to do much in the way of acknowledging it in their capability scores. Nonetheless, because they were led by their research to suspect that true capabilities were inversely correlated with the level of sophistication of the technology in use, they also

scored the latter in all of the firms they surveyed. Table 4 includes the relevant scoring scale (Table 12, discussed in section 3.2, gives the scores.)

In sum: the TC scores are biased estimates with respect to the measurement of capabilities cum capacities per se. The degree of the bias depends on the respective weights placed on capability and sophistication in the researchers' scoring. (The weight given to technological self-sufficiency in the MAT Tech scores results in a bias with respect to the measurement of appropriate capabilities cum capacities, but not with respect to the measurement of capability cum capacity as defined by the MAT Tech research team.) Unfortunately, it is not possible to state these weights. However, the bias that is present in the absolute values of the scores does not necessarily affect the relative values obtained when scores are considered in comparison to one another.

Intra-firm comparisons (across TCs for one firm) and inter-firm comparisons (across firms for one TC) are biased with respect to indicating differences in capabilities cum capacities only to the extent that sophistication levels differ intra- and inter- firm respectively. Since most of the analysis that follows is (explicitly or implicitly) concerned with relative values, it is at least possible that the bias has minimal consequences for the analysis. (Absent information about each firm's choices of technology in terms of sophistication levels, it was not possible to control for this aspect in the analysis. In turn, by using estimation techniques that allow for errors in variables, it would have been possible formally to incorporate the bias into the analysis; however, this approach was not followed.)

There is one more aspect which is central to comprehending the meaning of the TC scores. In a word -- they measure <u>Thai</u> capabilities. Only insofar as a firm's personnel are Thai do the scores measure the <u>firm's</u> technological capabilities. In particular, scores for foreign owned and/or managed firms reflect the capabilities of the Thai nationals employed in those firms rather

than the capabilities of the firms per se. As a consequence, the scores are highly pertinent to gauging a central element of the effectiveness with which foreign invested firms transfer technology.

2.2 Sample Composition

Table 6 states the industries surveyed in each area and indicates the principal activities or products of the firms surveyed. All told, 119 firms in eighteen industries were surveyed; literally, not just figuratively, the products span the range from chicken feed to microcomputers. The sampling frame for selecting firms was in principal that of a stratified random sample, except that the MAT Tech research team purposefully chose to concentrate on technologically more advanced firms. (This difference is controlled for in the statistical analysis insofar as it includes industry-specific dummy variables.) There are two reasons for saying "in principal." First, there was no attempt to achieve an evenly balanced sample (or proportional sample design) across the characteristics considered as being relevant to the stratification. Second, some of the randomness in the researchers' selection was undoubtedly destroyed by purposive self-selection among the firms that chose not to participate in the survey; technologically weaker firms were the most likely to refuse participation.

Table 7 gives the typology, apart from industry membership, used to stratify the sample and to classify firms in the statistical analysis; Table 8 shows the samples' composition in terms of the typology. Five attributes were distinguished: industry; SIZe; nationality of OWNership (and, in the case of BIO Tech and MAT Tech, of management); MarKeT orientation of sales; and BoI -- Board of Investment -- PROmotional status (capital letters, apart from those in terms capitalized throughout, give the first element of the non-industry characteristic acronyms used in the table).

[ Tables 6, 7, and 8 about here. ]

The characteristics included in each non-industry attribute,

respectively, are as follows:

- Large, Medium, Small;

- Thai -- for ELEC Tech, Joint venture, Foreign subsidiary;
  for BIO Tech and MAT Tech, Thai managed, Foreign managed;

- principally Export, Both export and domestic, principally Domestic;

- No, has no BoI promotional status; Yes, has BIO promotional status;

(capital letters, apart from those in terms capitalized throughout, give the second element in the characteristic acronyms). It is to be noted that the precise definitions of the size, ownership, and market orientation characteristics differ among the Areas. Some of these differences -- those with respect to size, for example -- largely reflect legitimate, well-considered distinctions among the Areas. Others reflect either ad hoc'ery or problems in gaining access to data. When pooling data across the Areas, the differences are assumed to be non-consequential except with respect to ownership cum management, where two distinct OWN attributes -- one for ELEC Tech, the other for BIO Tech and MAT Tech together -- are used.

The attributes chosen for analysis reflect several underlying hypotheses concerning the nature of markets for technology. One is the expectation that large firms on average possess greater technological capability across the board than do small firms. The argument here concerns factors on both the demand and supply sides. On the demand side, the public good aspects of technology operate to a lesser degree for large firms. Similarly, being large, they may be better able to internalize resources necessary for the effective articulation of demand for technology than are small firms. In turn, there are many reasons to expect that larger firms have easier access to the supply of technology, in particular to foreign technology markets. The policy implication of this hypothesis -- and of the finding, if true -- is that technology markets are more likely to fail where small firms are concerned and that government actions of various kinds may be warranted to

facilitate greater access to technology by small firms.

Another set of hypotheses relates to differences in capabilities between Thai and foreign firms. ("Foreign firms" is used consistently throughout this paper to include all firms with any nontrivial degree of foreign ownership; i.e., to refer to firms that have characteristics OWN-J, -F, -NT, and -NF.) For much the same reasons that large firms are expected technologically to outperform small firms, foreign firms can be expected to have higher productive capability than Thai firms. However, insofar as this difference is grounded in dependence upon the capabilities of expatriate personnel or of the overseas parent, foreign firms may have lesser Thai capabilities in other areas. Some analysts also perceive additional reasons to expect them to have lesser minor and major change capability, especially in regard to adapting technology to local circumstances.

Export markets are generally considered to be more competitive than are domestic markets. Correspondingly, firms that export a good deal of their output probably have greater motivation, in the form of competitive pressure, to achieve high levels of technological capability. Moreover, they must necessarily meet world standards of quality in relation to price. These considerations lead to the hypothesis that export oriented firms have higher capabilities than firms whose sales are oriented toward the domestic market. In turn, just as it is difficult to know what to hypothesize about medium size firms relative to large and small ones, so it is rather hard to form expectations about firms that are both export and domestic market oriented relative to those that sell primarily in one or the other market. However, there are reasons to think that they would have the highest capability among firms classified by market orientation. As exporters, they face the competitive pressure of world markets; but, as sellers on the domestic market, they also have motivation -- probably much greater than that of a wholly export oriented firm -- to adapt technology to local circumstances. With both factors

at play, they may technologically outperform firms for which only one of the factors is particularly relevant.

As regards the impact of BoI promotion: Because it is ostensibly granted to firms in infant industries where the acquisition of technological capability is particularly costful, one might hypothesize that BoI promoted firms have less technological capability, at least in production, than do non-promoted firms. However, if BoI promotion succeeds in its objectives, it is only those BoI promoted firms that started operation relatively recently (and so remain in their infancy) that would have relatively low capabilities. But even for them, another aspect of BoI promotion implies, if anything, the opposite hypothesis. BoI promotional incentives include a number that give promoted firms far easier access to foreign technology markets than is typically enjoyed by non-promoted firms. For example, BoI promoted firms have strong preferential rights to import foreign technical assistance in the form of expatriate personnel. To the degree that these firms are able to assimilate technology transferred by foreign technical assistance, they should therefore have higher capabilities. [In the data, BoI promoted firms include all those that have ever received BoI promotion in relation to the scored activities. However, age data largely pertain to firms rather than to scored activities, which makes it problematic whether one could use the data set meaningfully to analyze age (of the activity) specific hypotheses.]

A cautionary note must be made with respect to these and other hypotheses that might have been entertained: The statistical analysis pertinent to their investigation (that in section 3.1) was not done from a stance of comprehensively rigorous hypothesis testing. This is not to say that important issues relating to statistical significance were entirely disregarded; it is merely to indicate that the requisite covariance analysis was not performed. This part of the statistical analysis was done from the position of simply trying to uncover any apparent regularities present in the

data. For this reason, as well as others, it follows that all of the apparent regularities -- in the form of seemingly significant differences in relative scores -- should be taken as hypotheses which need to be subjected to further scrutiny (based on other information and methods of analysis) before being accepted as valid.

3 Statistical Analysis

Table 9 provides salient statistics for the TC scores in all Areas. Those given in the first three-row set of values are undoubtedly more reflective of differences in scoring approaches among research teams than of real differences among technological areas. In turn, it is interesting to observe from the second set of values that differences among firms contribute less -- indeed, substantially less -- to the total variance among the scores than do differences among capabilities except in BIO Tech. The high degree of correlation (third set of values) present among the scores for different capabilities is striking, but the correlations are neither so great nor so uniform (when one examines them in detail) as to suggest failures to discriminate among capabilities in the scoring. The fourth set of values shows that aggregation -- simple averaging was used -- of individual capabilities results in substantial loss of information; but, as will be seen in section 3.1.3, the loss is not so great as to make the aggregate capabilities meaningless. (Aggregate capabilities appear across the columns of Table 9 in the order of their functional dependence in the discussion in section 3.3; this is the order that will be used hereafter.)

[ Table 9 about here. ]

In part to simplify the analysis, but more importantly to test (informally) for possible differences in the association of capabilities with non-industry attributes of the firm, the three Area samples were pooled into a single sample. As just indicated, there is no reason to believe that the different Area research teams scaled their scoring in the same way with respect

to average and standard deviation. Thus, when combining scores from the three Areas to obtain the Pool sample, standardized rather than absolute scores were used.

Let: r:a,i,j = in Area a, the i'th firm's raw score for the j'th TC;
s:a,i,j = the corresponding standardized score;
avg:a = the average of the r:a,i,j scores for all firms i and TCs j in Area a; and,
std:a = the corresponding standard deviation of the r:a,i,j scores.
Then: s:a,i,j = ( r:a,i,j - avg:a ) / std:a.

The last two four-row sets of values in Table 9 pertain to the aggregate capabilities and include the Pool sample. These values can be compared with comparable values for individual capabilities in the three Area samples to see how aggregation and pooling affect several indices of interest.

There are three parts to the statistical analysis of the scores. The first uses dummy-variable regression estimation to do two things simultaneously. One is to remove the effect of sampling bias to obtain estimates of average scores among all firms within the corresponding populations. (The sampling bias at issue here is that due to the uneven composition of the samples in each area with respect to firm characteristics of possible consequence for technological performance.) The other is to estimate TC score differentials for firms of different types. These differentials are differences between estimates of two average scores: one is an average score for all firms in the population; subtracted from it is the average score for all firms of a particular type in the population.

To the extent that they can be used to examine the validity of various hypotheses that lead one to expect different kinds of technological behavior among the different types of firms, estimates of score differentials among different types of firms are useful when trying to explain observed levels of technological capability. But there are other, often more direct, ways of trying to explain observed capability levels. The second and third parts of the analysis use regression estimation to explore two of them. One seeks to

relate capability levels to particular characteristics of the technologies being employed. Insofar as proficiency levels are indeed systematically related to technological characteristics, this kind of analysis can provide diagnostic information that is highly pertinent when trying to characterize and understand the particular strengths and weakness of technological development processes. The other examines various relationships among the technological capabilities themselves. Insofar as some critical capabilities are dependent upon or derive from others, this genre of analysis can indicate means of systematically developing technological capabilities.

A caveat having potentially serious implications is relevant at this point. It is possible that, owing to their nature, the TC scores should be analyzed using techniques appropriate to qualitative (multi-) response models [for a survey of such models, see Amemiya (1981).] If so, since standard techniques were used throughout, statements concerning statistical significance in the following discussion are incorrect. However, it is far from clear to us that these techniques are relevant. Owing to aggregation, the variables employed in most of the analysis are continuous, albeit bounded, though without values bunched at the boundaries. The only use of discrete variables is in the ALL Area regressions for individual TCs that are discussed in section 3.1, and even here it is not obvious to us that the techniques are relevant insofar as the method used is essentially analysis of variance and our interest centers almost exclusively on averages rather than individual scores. In any event, we did not have the resources during the course of the work to resolve the issue. Nor would we have had access to the requisite computational software had we determined that the techniques were relevant. Moreover, we understand that it is not uncommon to employ standard techniques in initial explorations using qualitative response data.

## 3.1 Associations with Attributes of the Firm

This section discusses the estimation of population average scores and sub-population score differentials; both were estimated simultaneously. First, the general regression model is given. Then the alternative specifications used in sensitivity analysis are discussed. Lastly, the results of that analysis are summarized. Presentation of the estimates is deferred to section 4 where findings for policy are discussed.

### 3.1.1 Attribute Regression Model

The same general, dummy-variable regression model was used for all of the "attribute" regressions that are discussed in this section. It is stated

below:

$$y:i = a + SUM:M,J/m\ (b:j/m\ d:j/m,i) + SUM:L\ (c:l\ x:l,i) + e:i, \quad (1)$$

for all i in I; where:

$$SUM:J/m\ b:j/m = 0, \text{ for all } m \text{ in } M; \quad (2)$$

y:i = i'th observation's, or firm's, value for some TC score;

d:j/m,i = i'th firm's value for the attribute variable associated with characteristic j/m:

d:j/m,i = 1, if the firm has the characteristic;
= 0, if the firm does not have the characteristic;

x:l,i = i'th firm's value for non-attribute variable l;

Age was the only non-attribute variable employed in this analysis.

e:i = error term associated with the i'th firm;

SUM:... denotes the summation over the set(s) indicated by the specified index(ices):

I = the set of firms; i denotes an individual firm;

M = the set of attributes by which firms are categorized for purposes of analysis; m denotes an individual attribute -- industry, or market orientation, for example;

J/m = the set of characteristics included under attribute m; j/m denotes an individual such characteristic -- aquaculture versus consumer electronics, or export versus domestic market oriented, for example;

L = the set of non-attribute variables included in the analysis; l denotes an individual non-attribute variable -- age, for example;

The sets of variables -- M and L -- here refer to those that are included within the particular regression, not to the entire set of variables that were incorporated in the overall analysis.

in the designation of a variable, a colon (:) separates the variable symbol (on the left) from the relevant first-order indices, or subscripts (on the right). In the absence of a blank space before and after it, a slash (/) separates first- (on the left) and second- (on the right) order indices, or subscripts. A slash with blank spaces in front and behind indicates division;

a, b:j/m, and c:l denote parameters.

In equation (1) above, a is the constant term. Its estimated value serves as the estimate of the average TC score in the population (from which the sample is drawn). The parameter b:j/m is the score differential, or "own

effect," that is associated with a firm's having the characteristic j/m. In other words, it is the average effect of having that characteristic. The terminology, "own effect," comes from the analysis of variance, which is closely related to the estimation of regressions of the form given above.

Equation (2) imposes a normalizing condition in the form of a statement that the sum of the own effects for the characteristics of any attribute must equal zero. This condition merely stipulates that each attribute has no overall effect; that is, that each is "on balance" -- or on average across all the characteristics included within it -- neutral.

For certain sample designs, the estimated values of the parameters have a straightforward interpretation in terms of sample and sub-sample averages. Suppose, for example, that the number of observations in each cell is the same for all cells. (A "cell" refers a particular combination of characteristics across all attributes.) To keep matters simple, further suppose that there are no non-attribute variables in the model. Then:

the estimated value of a is equal to the average TC score in the sample;

the estimated value of b:j/m is equal to --
the average TC score for all observations having characteristic j/m
<u>minus</u> the average TC score in the sample.

Alternatively, and somewhat less restrictively, suppose that the number of observations for each characteristic of an attribute is the same, which yields a "proportional" sample design. (Equal numbers of observations in all cells is a special case of a proportional sample design -- the number of observations per characteristic for each attribute is the same across attributes.) The only difference this makes in the foregoing statement of estimated values is that "the simple average of the cell means" replaces "the average TC score in the sample." As regards non-attribute variables: their inclusion simply leads to the adjustment of the averages to reflect their estimated impact. (In the model, the parameter c:l states the linear effect of non-attribute variable l.)

Sample bias exists when the model includes more than a single attribute

and the sample design is nonproportional; in such cases, parameter estimates can not be interpreted in terms of sample and sub-sample averages. All of the samples employed here -- those for BIO Tech, ELEC Tech, and MAT Tech, as well as the sample obtained by pooling them -- are nonproportional. More than this, many of their cells are empty. Some of these cells probably have no members within the population. However, the large number of empty cells is importantly due to small sample sizes relative to the numbers of attributes and characteristics included in the analysis. (To take the most extreme case: one observation per cell implies 432 observations for BIO Tech; the actual number of observations is 32.) The presence of so many empty cells has a serious consequence: the parameter estimates are far less reliable than they would otherwise be.

Attribute variables defined as in the statement of the model in equation (1) can not be used in regression estimation. This is because, due to the inclusion of a separate constant term and -- where relevant -- of more than one attribute, with the attribute variables so defined, the matrix from which the parameters are estimated contains linearly dependent columns, making estimation impossible. Thus a consistent but distinct, reduced set of variables for each attribute has to be constructed for use in estimation. This is done by using the normalizing condition in equation (2) both to express the b:j/m coefficient for one characteristic of an attribute in terms of the others and to remove the corresponding attribute variable.

### 3.1.2 Alternative Specifications

There is necessarily a good deal of uncertainty about the proper specification of the attribute regressions. Underlying equation (1) are the assumptions that own-effects are linearly additive and that there are no peculiar interaction effects among characteristics of different attributes. Are these assumptions appropriate? Other questions also arise: Can individual capabilities legitimately be aggregated? Is it warranted to pool the Area

samples? Are all the attributes necessarily relevant? No attempt was made to answer these questions in way that would formally or definitively resolve the uncertainty. Instead, the sensitivity of the results along each of these dimensions was analyzed in a somewhat informal manner, with particular attention being paid to the sign and significance of individual estimates of score differentials from different specifications.

The relative merits of the additive specification were examined using the ELEC Tech sample (only) in early experimentation with a multiplicative specification in which the natural log of the TC scores replaced the raw TC scores as the dependent variable. The general pattern of coefficient signs and significance was quite similar to that in the regressions using the raw TC scores. The additive specification was chosen for use in all subsequent analysis because it gave generally higher R-squares.

The possible existence of peculiar two-way (only) interaction effects among characteristics was investigated somewhat more systematically at a later point in the analysis.

> To test for interaction effects between attributes m and m', equation (1) is augmented with terms of the form
> SUM:J/m,J'/m' (b:j/m,j'/m' d:j/m,i d:j'/m',i),
> and the significance of the difference between the estimated value of b:j/m,j'/m' and zero is evaluated.

The investigation focused on adding interaction effects to the specification of the ALL Pool regressions discussed below. Separate regressions were estimated, one pair at time, for each of the six possible pairs of attributes obtained when the industry attribute is omitted from consideration; interactions between industry and other attributes were not examined. It was determined that interaction effects are relatively unimportant by noting that: a) their introduction led to relatively few changes -- vis-a-vis the corresponding regressions in which they did not appear -- in the sign and significance of the own-effect estimates; and b) relatively few of the interaction effect coefficient estimates were significant. Moreover, there did not appear to be

any clear or strong pattern to the results that came from introducing interaction effects.

To address the other questions about proper specification that were stated above, four distinct specifications were estimated; three for each aggregate TC and one for each individual TC:

For the aggregate TCs --

- ALL Pool regressions: These are regressions in which the dependent variable is the standardized score for an aggregate TC; they were estimated only for the Pool sample. The independent variables include one set of industry attribute variables for the industries in each Area, one set of dummy variables for each of the other attributes, and the age of the activity. (Given how the industry attribute variables are used in these regressions, the characteristic for each industry is a composite that includes its Area.)

- ALL Area regressions: These regressions are virtually identical to the ALL Pool regressions in the specification of independent variables -- the only difference is that they include only the industry attribute variables for the corresponding Area. The dependent variable is the raw score for an aggregate TC and the samples consist of firms in only one Area. The sensitivity of the estimates to the pooling of Areas was analyzed by comparing estimates from these regressions with those from the corresponding ALL Pool regressions.

- ONE Area regressions: These are regressions of the raw score for an aggregate TC against the dummy variables for a <u>single</u> attribute; they were estimated for each attribute and each Area separately. The sensitivity of the results to the inclusion of one versus all attributes was analyzed by comparing estimates from these regression with those from the comparable ALL Area regressions.

For the individual TCs --

- Regressions comparable to the ALL Area regressions: Separate regressions equivalent in specification and sample to the ALL Area regressions were estimated for each individual TC either included in or related to each aggregate TC. The sensitivity of the results to aggregation was analyzed by comparing estimates from these regression with those from the ALL Area regressions for the corresponding aggregate TCs.

The objective of the sensitivity analysis across these specifications was to find the most all encompassing specification that seemed best to "fit the facts." That is, in order to keep the analysis relatively simple, it was decided to employ a uniform specification for all of the aggregate capabilities and, if pooling appeared to be inappropriate, Areas. The hope was that the ALL Pool regressions would be the chosen specification. This hope was fulfilled,

as is partially indicated in the two summary tables that are discussed immediately below.

### 3.1.3 Overview of the Results

Tables 10 and 11 report statistics about the extent of sign agreement among the different estimates of the same parameter and about the extent to which the individual estimates reveal significant associations. Table 10 concerns the estimates from the ALL Area regressions for aggregate and individual TCs. It is germane to assessing the sensitivity of the estimates to aggregation. Table 11 pertains to estimates from the ALL Pool and ALL as well as ONE Area regressions for the aggregate TCs. It is relevant to gauging the sensitivity of the estimates to pooling and to the inclusion of ONE versus ALL attributes.

[ Tables 10 and 11 about here. ]

Consider first Table 10 and the issue of aggregation. For each attribute, there is one three line cell for each aggregate TC and for all of the aggregate TCs considered together. [Columns in the detailed tables in Westphal (1989) from which this table is drawn include both characteristics and attributes.] The entry on the first line (acronym A.AS.) indicates the percentage of cases in which the algebraic sign of a parameter in the ALL Area regressions for the individual TCs agrees with the corresponding parameter's algebraic sign in the ALL Area regression for the aggregate TC in which they are included or to which they are related. Thus, the first entry in the top-left cell in the table, for example, indicates that in 80 percent of the cases, the indicated direction (negative or positive) of the association between OP-TRAI, IN-RAND, and OP-MAIN scores and the industry to which a firm belongs is the same as the direction of the association between AG-RES score and industry.

As can be seen from the first entry in the cell at the intersection of the last row and next to last column of cells, there is sign agreement in 78

percent of the cases across all attributes and aggregate TCs. Moreover, there is sign agreement with respect to the association of scores with age in 84 percent of the cases (bottom-right cell). These considerations suggest -- and a careful perusal (including attention to the significance of comparable parameter estimates of different sign) of the underlying estimates confirms -- that it is not illegitimate, at least not with respect to coefficient signs, to aggregate the individual TCs as is done in this analysis. This is not to claim that the aggregation scheme in Table 3 is in any formal sense an optimal one. Nor is it to say that aggregation does not hide information of considerable interest about differences among the individual capabilities included in or related to the aggregate TCs. It is rather to affirm that one can meaningfully reduce the number of dimensions in which capabilities are considered without doing too much violence to the underlying reality.

Turn now to Table 11, which is identical in design to Table 10. Recall that this table is relevant to judging whether it is warranted to pool the samples and to focus on estimates from the specification that includes all attributes together. Here entries on the first line of each cell indicate the percentage of cases in which the algebraic sign of a parameter in the ALL and ONE Area regressions for an aggregate TC agree with the corresponding parameter's algebraic sign in the ALL Area regression. The overall extent of sign agreement comparing these specifications is again quite high, as can be seen by looking at the first entries in the bottom, right-most two cells. This implies -- and a careful perusal (including attention to the significance of comparable parameter estimates of different sign) of the underlying estimates again confirms -- that it is not illegitimate, with respect to coefficient signs, to focus on the estimates from the ALL Area regressions. This is not to suggest that these estimates are the "right" ones in all cases. Rather it is to indicate that one can legitimately take the ALL Pool results as a starting point in looking for any regularities present in the underlying data,

qualifying particular regularities so found only where there appears to be strong disagreement between them and the evidence from other specifications.

Consider finally the entries on the second and third lines of each cell in these tables. In the work underlying them, parameter estimates were identified as being significant "with respect to the sample" (S.S. is the acronym in the tables) if they exceed their respective standard errors; "with respect to the population" (S.P.), if they are statistically, significantly different from zero, using a t-test, at the 0.10 level of significance. The notion of significance with respect to the sample is an ad hoc way of distinguishing estimates that imply seemingly meaningful differences among firms within the sample, if not necessarily within the population. In turn, it should be recognized that the 0.10 significance level used in evaluating significance with respect to the population is the lowest level of significance conventionally employed in statistical work such as this. [Data provided in Westphal (1989) permits one to employ stronger tests of significance.]

The entries in the tables for sample and population significance indicate the number of correspondingly significant parameter estimates as a percentage of the total number of relevant estimates. In Table 10, the relevant estimates are those from the ALL Area regressions for individual and aggregate TCs; in Table 11, from the ALL Pool and ALL as well as ONE Area regressions for aggregate TCs. (Within each cell, the number of cases underlying these entries is greater than that underlying the entry on the first line, which involves comparisons against one specification; correspondingly, S.S. and S.P. values can exceed A.AS. value.) The information given in these entries indicates that there are a number of seemingly significant associations between technological capabilities and firm attributes. From the last row of cells in each table, one sees that size, industry, and ownership appear to matter more than do market orientation and promotional status. Also, that the age of the firm is significant with respect to the population in relatively few

cases. In turn, from the next to last column of cells, one observes that associations between attributes and capabilities are strongest in the realms of production and investment capability.

3.2 Associations with Attributes of the Technology

The preceding analysis looked for associations between capabilities and various attributes of firms. Another potentially useful approach is to look for regularities in relationships between capability levels and particular attributes of the technologies being employed. Thanks to the BIO Tech research team's efforts, this approach can be explored with respect to one attribute in one Area.

During the course of their work, the team developed the hypothesis that, among firms in the BIO Tech area, technological capabilities are inversely (or negatively) related to the sophistication of the technology in use. To examine the validity of this hypothesis, linear regressions were estimated in which the dependent variable is an industry's (estimated population) average score for an aggregate TC and the independent variable is its overall average score with respect to the sophistication of the technology in use. The latter scores are shown at the bottom of Table 12, which gives the full set of scores for the technologies in use by the sampled firms in the BIO Tech area. [See Table 3 for the scoring scale; Yuthavong (1988) gives details of how the scoring was carried out.] Separate linear regressions were estimated for each aggregate TC using average capability score estimates from the ALL Pool and ALL Bio attribute regressions.

[ Table 12 about here. ]

The sample for these regressions consists of the eight BIO Tech industries. It obviously would have been preferable to examine the relationship at the firm, rather than industry, level. But this was precluded by the way the BIO Tech team assembled their information in the course of their work. In turn, it is important to recognize that the overall average

sophistication scores do not incorporate any judgement about the relative sophistication of the different technologies (indicated by the row labels in Table 12). This means that they do not fully capture differences (or, for that matter, similarities) among industries with respect to the overall sophistication of the technology they use.

Table 13 gives the regression estimates. The slope coefficients are negative -- implying an inverse relationship -- for all TCs except AG-RES. However, in only two of the cases is the relationship significant (and then only at the 0.10 level). Thus one can at best say that the evidence is at most consistent with the hypothesis of an inverse relationship.

[ Table 13 about here. ]

The positive (though insignificant) relationship for AG-RES is not contrary to the BIO Tech research team's hypothesis, because AG-RES is a measure of technological resources, not of some capability in using them. In turn, since one would expect -- other things being equal -- a positive relationship between the sophistication of the technology and the technological resources needed to employ it, the fact that this relationship is positive is one of many small pieces of concrete evidence in favor of the validity of the relative values of the TC scores. In a similar vein, the fact that the relationships for the other aggregate TCs are negative implies that the BIO Tech research team's scoring pertains more to capabilities than to sophistication of technology (see the discussion of the distinction and its importance toward the end of section 2.1).

### 3.3 Relationships among Capabilities

Examination of the relationships that are present among scores for different TCs may enable one to learn a great deal about what underlies the development of technological capability. Indeed, one might reasonably think that the analysis of these relationships is more revealing than the search for regularities among score differentials across firm attributes. But potentially

most revealing is to put the results of both kinds of analysis together, as is done in section 4.

In discussing Table 9 it has already been observed that there is a high degree of correlation among the individual and aggregate scores respectively. This finding is consistent with patterns observed elsewhere in the Third World [Dahlman, Ross-Larson, and Westphal (1987)] and in previous research on Thai industry [Bell and Scott-Kemis (1987), Chantramonklarsi (1985), and Santikarn (1981).] To summarize the most pertinent findings: Bell and Scott-Kemis clearly demonstrate that firms do not acquire a high degree of productive capability without investing in the technological resources required for technological change activity. Chantramonklarsi shows with equal force the importance with respect to productive capability of purposive efforts to acquire some proficiency in investment activity. In turn, virtually all of the research done to uncover the underpinnings of productive capability has arrived at the conclusion that technical efficiency in production can not be achieved without engaging in substantial minor change activity.

In sum: The evidence about technological development in semi-industrial countries suggests that the following relationships should hold:

AG-PRO = f ( AG-MAJ, AG-MIN, AG-INV, AG-RES ); (3)

AG-MAJ = f ( AG-MIN, AG-INV, AG-RES ); (4)

AG-MIN = f ( AG-INV, AG-RES ); (5)

where f(...) denotes functional dependence. These relationships are arranged above in a hierarchical order only for aesthetic cum expositional purposes. While one might investigate their presence in the context of a formal system of simultaneous or recursive equations, that is not done here. Instead, each relationship is examined separately. In turn, technological resources and investment capability are autonomous, or exogenous, with respect to both our discussion and the examination.

Two distinct kinds of qualification are warranted with respect the hypothesized relationships. One concerns the appearance of AG-MAJ in equation (3) and its functional dependence upon AG-MIN in equation (4). Major changes tend to be disruptive, at least in the short run, so that major change capability (since it reflects actual changes) may have a more complex relationship to AG-PRO than is suggested here. In turn, major and minor changes do not appear to coexist on a smooth spectrum of continuous gradations, so that major change capability may not be very closely associated with minor change capability [see Bell, Ross-Larson, and Westphal (1984), especially section 5].

The other qualification concerns the fundamentally important difference between the short and medium-to-long run determinants of capabilities. To again concentrate in the productive realm: All of the evidence hastily reviewed above pertains to the underpinnings of a high degree of proficiency that can be considered self-sustaining over at least the medium-run. There is no reason to think that firms can not be relatively proficient in the short run owing to what is essentially good luck. This consideration is especially significant here, where the analysis involves relative scores among firms that are typically not high achievers in regard to their capabilities. Thus the finding of a weak relationship between productive capability and the capabilities which have been found in other studies to underlie self-sustaining proficiency can be taken as indicative of poor technological strategies among the firms included in the sample being analyzed. The term "technological strategy" refers to a firm's ability to manage its technological development; in particular, to achieve self-sustaining proficiency on the basis of investments in the underlying capabilities.

As the first step in examining the strength of these functional relationships among the sampled firms, simple correlation coefficients between dependent and independent TCs were calculated ("dependent" and "independent"

are with respect to one of the hypothesized relationships stated above). Coefficients were separately obtained for all firms taken together and for sub-samples of firms having the same characteristic for each attribute, one attribute at a time. For simplicity, in this analysis, as in all of that which follows, all foreign firms are considered together so that it is not necessary to distinguish the ownership attribute between firms in Bio and Mat TECH versus those in Elec TECH.

The correlation coefficients for all firms taken together included many highly significant ones, implying that the functional relationships are indeed strongly present within the Thai industrial sector. But, the fact that these relationships appear to hold for all firms considered together does not imply that they hold with equal strength for distinct types of firms. Indeed, comparable correlation coefficients for complementary sub-samples of firms were often far apart in value, suggesting that the strength of particular relationships differs greatly among firms of different types. Moreover, the differences in correlations by type of firm appeared potentially relevant to understanding important aspects of Thai technological development.

### 3.3.1 Capability Regressions

Regression analysis was used formally to examine the functional relationships and to test for differences in their strength among distinct types of firms. Stated in linear form, equations (3) through (5) have the following general appearance:

$$y_i = A + \sum_l B_l x_{l,i} + e_i; \text{ where:} \qquad (6)$$

$y_i$ = i'th firm's value for the dependent capability;

$x_{l,i}$ = i'th firm's value for the l'th independent capability; and,

A and $B_l$ denote parameters.

For convenience, the model given by equation (6) will hereafter be referred to as the NONE regression.

This model can be extended to incorporate possible differences in the

relationships among firms classified by one or more attribute(s) by distinguishing separate parameters for each of the included characteristics. The augmented model is shown below:

$$y_i = \sum_{M,J/m} (A_{j/m}\, d_{j/m,i}) + \sum_{L} \sum_{M,J/m} [B_{l,j/m}\, (x_{l,i}\, d_{j/m,i})] + e_i, \quad \text{for all } i \text{ in } I; \text{ where:} \tag{7}$$

$A_{j/m}$, and $B_{l,j/m}$ denote parameters; and,

all other symbols are as defined previously.

In equation (7): $A_{j/m}$ is the "partial" constant term associated with characteristic j/m; $B_{l,j/m}$ gives the "partial" linear dependence of the dependent capability on the l'th independent capability for firms having characteristic j/m. Here "partial" denotes with respect to the other attributes included in the set M. By estimating this model for distinct specifications of the attributes present in the set M, one can investigate the influence of the different attributes as determinants of the functional relationships among capabilities.

Analysis of covariance provides a formal means of testing the significance of each attribute -- the analysis involves computing F-statistics and examining their level of significance [see Johnston (1972), pp. 192 ff.]. Two modes of the analysis were employed. The first controls for the possible influence of all other attributes; the second does not control for the possible influence of any other attribute. To accomplish the analysis, three different specifications of the augmented model are required:

- ALL regression: Separate parameters associated with the characteristics of all the attributes appear in this regression.

- OMIT regressions: These regressions omit separate parameters associated with the characteristics of one attribute but include them for all other attributes. With the ALL regression considered as the unrestricted model, an OMIT regression constitutes the restricted model in which the omitted attribute is assumed to exercise no influence. Here covariance analysis tests the significance of the omitted attribute while controlling for the possible influence of all other attributes.

- ONE regressions: Separate parameters associated with the characteristics of one (only) attribute appear in these regressions. With the NONE regression

considered as the restricted model, a ONE regressions constitutes the unrestricted model in which the specified attribute is assumed to exercise an influence. Here covariance analysis tests the significance of the specified attribute without controlling for the possible influence of other attributes.

These regressions were estimated only for the Pool sample.

### 3.3.2 Estimates of Interest

Before turning to consider the significance of individual attributes as apparent determinants of the functional relationships among capabilities, it is pertinent to consider the significance of all attributes taken together. The F-statistic from comparing the ALL versus NONE regressions for AG-PRO is 1.954 with (56,54) degrees of freedom, which is significant at the 0.01 level; for AG-MAJ, 1.268 (44,71), not significant at the 0.05 level; for AG-MIN, 2.130 (32,84), significant at the 0.01 level. From these results one can conclude that a firm's attributes do appear to exercise an influence over the functional relationships associated with productive and minor change capabilities. To investigate which are the influential attributes, it is necessary to test their significance one at a time.

The results of the detailed analysis are inconclusive in important respects. None of the F-statistics for the ALL versus OMIT regressions for the three dependent capabilities are significant at the 0.05 level. Correspondingly, none of the attributes appears to be significant when controlling for the possible influence of all other attributes. However, owing to potential mis-specification from the inclusion of all other attributes in the OMIT regressions, this does not necessarily imply that no attribute is significant when considered either by itself or in combination with other truly significant attributes. In fact, a number of the F-statistics for the ONE versus NONE regressions are significant: for AG-PRO, all attributes are significant at the 0.01 level; AG-MAJ, the industry attribute is significant at the 0.05 level; AG-MIN, the industry and market orientation attributes are significant at the 0.01 level.

One is led to the following conclusions: First, several, if not all, of the attributes appear to exert a significant influence on the relationship of productive capability to its underpinnings. One could go further in attempting to identify the attribute(s) by examining regressions that include parameters associated with pairs, triples, ... of attributes, but this was not done. The non-proportionality of the sample design leads to considerable multicollinearity among the (x:l,i d:j/m,i) variables, making it questionable whether such a search would yield conclusive findings. Second, no attribute, with the possible exception of the industry to which a firm belongs, appears to have a significant influence over the association of major change capability with the other capabilities on which it arguably depends. Third, industry and market orientation appear to exercise a significant influence over the association of minor change capability with its underpinnings.

As implied previously, it is differences in the strength -- measured by R-square -- of the functional relationships among types of firms that are of primary interest. Separate regressions of the NONE form were estimated for distinct sub-samples of firms are required to obtain the desired values of R-square. (Apart from summary statistics such as R-square, estimation of these regressions merely reproduces information contained in the ONE regressions required for covariance analysis.) Before estimating these equations, analysis of covariance was used to test for redundant characteristics among attributes having more than two (i.e., three) characteristics. There is a redundant characteristic if the influence of any two characteristics is ostensibly identical. The search for redundant characteristics involves comparing the ONE regression for an attribute with (three) variants of that regression in which each pair of characteristics is (separately) collapsed into a single composite characteristic. The null hypothesis of redundancy was accepted if the F-statistics involved were not significant at the 0.05 level. On this basis, there is only one redundant characteristic among the attributes that are

seemingly significant: for AG-PRO there appears to be no significant difference between medium and small firms.

[ Table 14 about here. ]

Table 14 gives estimates for capability regressions of the ONE form. In addition to estimates for the entire sample, estimates are also given for those non-industry characteristic sub-samples for which the functional relationships appear to be significantly distinct (at the 0.05 significance level). [Estimates for industry sub-samples are not given in order to conserve space and because these sub-samples do not figure in the discussion in section 4.] It will be observed, from the estimates for all firms, that the functional relationships are indeed strongly present within Thailand's industrial sector. But it will also be seen that the relationships are much stronger for some types of firms than for others. In turn, the relationship of productive capability to major change capability is often found to be negative. This is consistent with the qualification regarding equation (3) that was noted previously. The negative association of productive capability with minor change capability is not meaningfully significant in those few cases where it is observed.

## 4 Some Salient Findings for Policy

Table 15 gives one way of summarizing both the overall results of most of the preceding analysis and some its implications for an understanding of technological dynamics in Thailand's industrial sector. It gives measures of aggregate capabilities, in the TC rows, and of the strength of the relationships among them, in the FC rows. The capabilities are identified by the second element of their acronyms in the column of row labels. Other columns of the table pertain to different types of firms.

[ Table 15 about here. ]

The measures appearing in the TC rows are from the ALL Pool attribute regressions. They pertain to standardized scores, which have an average across

all firms and TCs of virtually zero. The values in the first column (excluding the column of row labels from the count) pertain to all firms; they are estimates of population average scores. Values are in standard deviation units, thus an estimate for the population average of 1.0 implies a value one standard deviation from the simple average of the TC scores in each Area respectively. Likewise, score differentials (given in the other columns, see below) are in standard deviation units.

It will be observed that capabilities are much stronger in production than in other aspects of technology utilization. In view of the long-run functional relationships that exist among capabilities, this does not auger well for the future, for it implies a failure to accumulate important, requisite underlying capabilities. Of particular concern in this regard is the relatively (and significantly so) low score for technological resources.

Values of the TC measure in the other columns are estimates of sub-population score differentials associated with the various characteristics. Because each score differential is "controlled" for differences among firms with respect to other attributes, one must add values shown in the table to determine corresponding TC measures at the firm level. With respect to this analysis, no firm is simply, for example, an export firm; it is an export firm of a particular size and ownership, either having or not having promotion, and existing within a particular industry. The values to be added include the corresponding population average and the score differentials for the corresponding characteristics (including industry, which is not shown in the table).

The adjectives descriptive of the quality of the capability that appear below these values are an attempt to make their meaning more transparent. They basically indicate where each value falls among the quintiles of the distribution of all the score differentials reported in the table. The quintile breakdown was, however, adjusted to reflect major breaks in the

distribution of the values. (The adjustments were minor; it is also pertinent to note that the break points between "GOOD" versus "good" and "BAD" versus "bad" were very close to being one standard deviation away from the mean value.) "GOOD" is applied to values in the highest adjusted quintile; "good," the next highest; and so on in the order "AVERAGE," "poor," "POOR." "MIXED" indicates that there is considerable heterogeneity in the underlying estimates. It is applied only with respect to the ownership attribute where, as already noted, all foreign firms have been combined together (thus, with respect to the TC measures, several estimates have been collapsed into single, simple average ones). The exclamation and question marks that appear below some of these words indicate whether the judgement should be considered robust (i.e., with respect to alternative specifications of the underlying regression). Robustness was judged using information that underlies Table 11.

The measures appearing in the FC rows are R-square's from capability regressions of the ONE form for the corresponding sub-sample of firms. Values are given for all sub-samples, not just for those for which functional relationships appear to be significantly distinct (as in Table 14). The adjectives descriptive of the strength of the relationship that appear below these values are -- as before -- an attempt to make their meaning more transparent. "HIGH" indicates significance at the 0.01 or 0.05 level; "high," the 0.10 level; "low," the 0.25 level; and "LOW," not significant. The exclamation and question marks that appear below some of these words indicate whether the characteristic has a statistically significant influence on the functional relationship. Exclamation marks denote significant at the 0.01 level; questions marks, not significant at the 0.05 level. The single question marks appearing under medium and small opposite PRO denote lack of significance individually but not taken together. In turn, the words, if any, that appear on the bottom line of an FC cell indicate independent variables which have negative coefficients in the estimated regression; upper case letters are used

if the coefficient is significantly different from zero at the 0.25 level.

The FC values in the first column (again excluding the column of row labels from the count) are for all firms considered together. Those in the other columns are for firms of different types. A strong functional relationship coupled with GOOD (or good) capability implies that firms having the characteristic indicated have adequate or better than adequate technological strategies, at least with respect to the dependent capability involved. In turn, a strong functional relationship coupled with a POOR (or poor) capability implies that firms having the characteristic lack effective technological strategies. Their capability is weak because they have failed to manage their technological development properly; they have failed to accumulate the requisite underlying capabilities.

The characteristic of being foreign owned is associated with GOOD productive capability in the presence of a LOW functional relationship between it and its underpinnings. Since the capabilities in question are Thai capabilities, this result is not inconsistent with the validity of the functional relationship for foreign owned firms. Rather, it seemingly reflects their mixed performance in transferring technology to Thai nationals. It is also pertinent that foreign ownership is associated with MIXED minor and major change capability as well as MIXED investment capability. Taken together these results at least suggest one of two things: either that Thailand is not exploiting the full potential of direct foreign investment for its technological development; or that direct foreign investment is not a particularly powerful vehicle of technological development.

Two additional findings are particularly salient. One is the result that BoI promotion is associated with only good productive capability coupled with a low functional relationship. A possible interpretation is that BoI promoted firms do not take full advantage of the preferential right that they enjoy to import technical assistance. That is, they use imported technical

assistance to improve their production performance in the short run without taking full advantage of the opportunities for assimilation that are afforded when making use of foreign technical assistance. This result suggests that BoI promotional incentives may give firms too little incentive to utilize technology transfers effectively.

The other particularly salient finding concerns the AVERAGE production capability that is associated with being an exporter and the low functional relationship between production capability and its underpinnings among export firms. Both results strongly suggest that Thailand's industry is not at all in the same league with Korea, Taiwan, and Singapore at comparable points in their industrial development. Sticking to Korea, whose technological development is relatively well researched: There can be little question that a similar study conducted in the late 1960s or early 1970s in Korea would have found clear evidence both that Korea's export firms had the "BEST" production capability and that they had clear and intelligently formulated technological strategies. Moreover, Korea's export firms were its leading firms in the sense of leading the country's technological development within industry. It appears from the evidence here presented that the same statements can clearly not be made about Thailand's export firms. (The POOR capabilities in major and minor change, also the POOR technological resources, that are associated with being an exporter reflect a quite distinct aspect -- namely, the very low technological intensity of Thailand's manufactured exports.)

To put the general conclusion another way: it is both interesting and relevant to consider whether Thailand, in respect to its industrial development, is more like an East Asian or a Latin NIC. (Relevance follows from the widespread belief, reflected in the press and elsewhere, that Thailand is closely following in the footsteps of the East Asian Gang of Four.) Generally speaking, the evidence from comparative research on technological development suggests that many -- probably most -- firms in the Gang of Four

East Asian NICs (i.e., the three countries mentioned previously plus Hong Kong) have long had active, aggressive technological strategies. They have recognized the importance of technological development to their future success and they have been as concerned to ensure their future success as to generate the present-day profits needed to fuel it. Thus they have had clearly thought out and consistent strategies (which are nonetheless flexible and pragmatic).

Most firms in the Latin NICs, on the other hand, appear to have long been characterized by passive, reactive technological "strategies" (it is questionable whether the term really applies). They generally have undertaken technological changes only in response to shocks or crises of one kind or another (including those induced by seemingly ill-advised government policy). They have simply paid very little systematic attention to managing their technological development. [This is not to say that poor technological strategies at the firm level are largely responsible for the Latin NIC's comparatively poor industrial performance; poor macro policies (eg., their "stop-go" alternation) together with flawed industrial policies are undoubtedly more important contributors, even to extent that they may well be responsible for the absence of good technological strategies at the firm level.]

The pattern of the coupled TC and FC values in Table 15 strongly suggests that firms in Thailand by and large have passive rather than active technological strategies. In particular, one finds no case in which GOOD capability is coupled with a HIGH functional relationship. For this and other reasons, one can conclude that Thailand, to the degree it is or is becoming a NIC, is much more a Latin NIC than an East Asian NIC. It is not for us alone to say whether this is a "good" or a "bad" thing. It is of concern only to the degree that Thailand aspires to become, in the truest senses of the word, an East Asian NIC. But, more to the point, we are led to conclude that Thailand's current industrial success is principally due to favorable short-to-medium term trends in world markets and in the factors determining the location of direct

overseas investment; it is seemingly not due to well conceived technological strategies that form one of the requisites for self-sustaining industrial development. Thus we would argue that it may not be very long before Thailand's economic development is seriously hindered by the absence of adequate attention to technological development in industry and of effective technological strategies within its industrial firms.

Anecdotal evidence compiled during the course of the research strongly points to the same conclusions and concerns. Nonetheless, it is necessary to state several caveats about the validity of coupling TC and FC values as is done here. The first caveat: To the degree that the TC scores reflect the sophistication of the technology in use rather than the capability with which it is used, the FC values can not be interpreted -- at least not in the direct fashion that they have been interpreted above -- simply in terms of the presence or absence of an effective technological strategy. The second caveat: The TC values for particular characteristics are controlled for differences among firms with respect to attributes other than that to which the characteristic belongs. The FC values are not similarly controlled, since they come from regressions in which the overall sample is split only among the characteristics of one attribute. Thus there is some unknown degree of sampling bias in the FC values. The third caveat: FC values computed from similar regressions among individual capabilities may have a quite different pattern than do the FC values shown in the table. However, this caveat is important only insofar as one considers the aggregate capabilities to be of derivative or secondary analytical significance.

## 5 Reflections

Microscopic research on technological capability is undeniably expensive in terms of time as well as resources. This makes it of arguably questionable relevance when what is wanted is a reasonably comprehensive overview of past and present technological development. The macroscopic

scoring method that was employed in this research is clearly less expensive, but the savings is not obtained without cost. One of these costs is unlikely to be immediately apparent from the foregoing discussion. Macroscopic scoring affords little, if any, insight into the nature of the technological environment in which individual firms operate or the dynamics of their interactions with other firms and public agencies of various relevant kinds. Thus externalities of all kinds are effectively outside of its purview. (For this reason, macroscopic scoring was supplemented with other modes of investigation in the research.) Other limitations may be apparent from the discussion, but it is nonetheless worthwhile to review the more important ones.

It is warranted to be somewhat doubtful about the utility and validity of the scores. In particular: What does a score of, for example, 3 <u>really</u> mean? Doubtless the scorers know, but they were generally unable successfully to communicate the full or precise meaning to others not intimately involved in the scoring; perhaps this is inherent in the nature of quasi-quantitative cum quasi-qualitative scoring. However, the tacitness of the absolute scores is not sufficient cause seriously to suspect the validity of the relative scores among capabilities and across firms. At the very least, the relative scores and the implications from the patterns contained within them merit serious attention. Continued skepticism is warranted, but not at the expense of carefully considering the findings from the scoring exercise.

The discussion in section 4 indicates that one can find out a great deal of relevance by analyzing the scores; at least, that is what we think. Most important, their analysis can be used to ~~obtain~~ suggest broad areas where policy effort might most usefully focus. In turn, the discovery of associations between capabilities and attributes of potential consequence helps to explain the observed scores, but it does so only to the degree that one can establish definite links between the associations and the firms' underlying technological behavior. And to ascertain and verify these connections requires

a microscopic approach, one centered explicitly on analyzing firm behavior in different circumstances. In short, the analysis of macroscopic scores can not by itself lead to detailed policy recommendations. A snapshot at a point in time can not, by its very nature, demonstrate anything about behavior over time. But another analogy is even more revealing: Giving capability scores to firms is like giving examinations to students. The activity may disclose a great deal about levels of competence among those scored, but it can not reveal very much of immediate operational relevance about the reasons why some individuals or firms score highly and others score poorly.

In the original design of the research, technology utilization and actual or potential policy impact were to be analyzed simultaneously through in-depth case studies within individual firms. These case studies were to focus on salient micro technological events in the evolution (or lack thereof) of the firms' capabilities. The failure to follow this design owes much to the use of macroscopic scoring, which had the consequence of separating the explicit evaluation of technological capability from the analysis of policy. And this separation meant that the policy-focused analysis was accomplished without benefit of micro technological evaluations. This is undoubtedly the most serious of the limitations of macroscopic scoring. Of course, it can be overcome by supplementing macroscopic scoring with microscopic evaluation. But why use macroscopic scoring at all if it is to be so supplemented?

In conclusion: One can not fairly appraise the full extent of the immediate results of the research simply on the basis of what is reported in this paper. Quite the contrary: one would have carefully to peruse the separate final reports of each Area research team as well as the overall final report. Nonetheless, the contents of this paper are indicative of the degree to which the researchers achieved their principal objectives. Recall that these objectives were to achieve a conclusive demonstration of poor performance in technological development under the existing policy regime and to develop a

set of concrete, immediately implementable policy recommendations. Apart from supporting anecdotal evidence, the essentials of the demonstration are contained in section 4. Readers will form their own opinion of its conclusiveness; the reaction of Thai policy makers is unknown at the time of writing. In turn, the research failed to develop policy recommendations of the kind that were sought. It did identify some specific areas where policy reforms and initiatives appeared to warrant further investigation. Likewise, it accumulated a mass of information of potentially great value for subsequent policy research in narrower domains. Perhaps these outcomes are the most that should reasonably be expected from an exercise such as that discussed in this paper. But this is an issue that can only be addressed by objective observers not involved in the research.

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Table 1

Sketch of a Microscopic Approach to Policy Research

| | IDENTIFICATION | POLICY |
|---|---|---|
| PAST AND PRESENT | **ASSESSMENT OF PRESENT CAPABILITIES**<br><br>Objective: Determine the nature and effectiveness of existing capabilities, in preparation for identifying key capabilities and for analyzing past technological development.<br>- - - - - - - - - - - - - - - - - - - -<br>Method: Survey of existing producers and local suppliers of technology in the key sectors; survey to use broad sampling frame and ask general questions.<br>- - - - - - - - - - - - - - - - - - - -<br>Responsibility: Shared effort between economists and technologists. | **ANALYSIS OF PAST DEVELOPMENT**<br><br>Objective: Develop understanding of the factors influencing technological behavior by market and public agents, for use to uncover possible needs for policy changes and direct actions.<br>- - - - - - - - - - - - - - - - - - - -<br>Method: Field research to obtain technological case-histories, for analyzing the choice and transfer of technology and the dynamics of technological change.<br>- - - - - - - - - - - - - - - - - - - -<br>Responsibility: Economists, with technical support from technologists. |
| FUTURE | **CHOICE OF FUTURE CAPABILITIES**<br><br>Objective: Identify selected capabilities that should be developed, both for their own sake and to use as cases for analyzing future policy needs.<br>- - - - - - - - - - - - - - - - - - - -<br>Method: Sequential economic and technical evaluation to select appropriate technologies in specific sectors, and then to determine key capabilities needed for their efficient use and effective means for their development in proper phasing over time.<br>- - - - - - - - - - - - - - - - - - - -<br>Responsibility: Technologists, with technical support from economists. | **POLICIES FOR ACCELERATED DEVELOPMENT**<br><br>Objective: Determine the need, and make recommendations, for reforming policies and public agents — and for new initiatives — in areas that have direct and indirect impacts on the rate and direction of technological development.<br>- - - - - - - - - - - - - - - - - - - -<br>Method: Generalization from case studies of key capabilities, using knowledge of past technological behavior to isolate which capabilities would not be developed without changes in public interventions in markets, and then to determine the warranted changes in policies and actions.<br>- - - - - - - - - - - - - - - - - - - -<br>Responsibility: Shared effort between economists and technologists. |

Table 2.A
Definitions of Technological Capabilities by Area

| Capability | Bio Tech | Mat Tech | ElecTech |
|---|---|---|---|
| Search AQ-SRCH | 1. To seek new technology. | 1. General definition same as for Bio- and/or Elec-Tech; for specifics see separate table giving MatTech scoring scales. | 1. To find the required technology. |
| Assessment AQ-ASES | 2. To assess various technological options. | 2. See first cell above. | 2. To evaluate merits of a technology; to compare among technologies. |
| Negotiation AQ-NEGO | 3. To obtain favorable transfer terms. | 3. See first cell above. | 3. To obtain reasonable terms for the chosen technology. |
| Procurement AQ-PRCU | 4. To buy new technology. | 4. See first cell above. | 4. To successfully purchase the chosen technology. |
| Transfer AQ-TRAN | 5. To complete a successful transfer. | 5. See first cell above. | -. Not applicable. |
| Installation and Startup AQ-INST | 6. To successfully install new technology. | 6. See first cell above. | 6. To install/startup new machines; perform tests necessary to achieve satisfactory performance. |
| Design and layout AQ-LAYO | -. Not applicable. | -. Not applicable. | 5. To design and layout new production lines. |
| Operation OP-OPER | 7. To effectively operate current or new technology. | 7. [... and Control] See first ceil above. | 7. [Process] To efficiently operate the production process. |
| Maintenance OP-MAIN | 8. To maintain production equipment. | 8. See first cell above. | 8. To keep machinery and process in proper operating condition; calibrate test & measuring instruments. |
| Skills in Use OP-SKIL | 9. To carry out technical activities. | 10. See first cell above Refers to competitiveness of production. | -. Not applicable. |

Note: Notes appear at the bottom of the last (third) page of this table.

Table 2.B
Definitions of Technological Capabilities by Area

| Capability | Bio Tech | Mat Tech | ElecTech |
|---|---|---|---|
| Management OP-MANG | 10. To manage efficient production. | 11. See first cell above. | -. Not applicable. |
| Training OP-TRAI | 11. To train manpower. | 9. See first cell above. | 11. [Manpower development] Quality of and investment in programs, both in-house and external. |
| Quality Control OP-QUAL | -. Included within operation capability. | -. Included within operation capability. | 9. To insure yield, uniformity, and performance. |
| Inventory Control OP-INVN | -. Not applicable. | -. Included within operation capability. | 10. To monitor/control inventories for continuous production at reasonable cost. |
| Minor Product Change AD-MIPD | 12. To make minor product modifications. | 14. See first cell above. | 13. To make minor changes in product design or raw material use; to suit local conditions and reduce costs. |
| Minor Process Change AD-MIPC | 13. To make minor process modifications. | 15. See first cell above. | 14. To make minor changes in process; to increase efficiency and reduce costs. |
| Knowledge Acquisition AD-KNOW | 14. To acquire relevant new knowledge, with specific reference to adapting technology. | 12. See first cell above. Without specific reference to adapting technology. | -. Not applicable. |
| Digestion of Technology AD-DIGT | 15. To successfully apply new knowledge, with specific reference to adapting technology. | 13. See first cell above. Without specific reference to adapting technology. | 12. To acquire new product designs through reverse engineering. |
| Major Product Change IN-MJPD | 16. To make major product changes. | 17. [Radical ...] See first cell above. | 16. [Radical...; New Product Design] To make major/significant changes in product appearance, function, & performance. |

Note: Notes appear at the bottom of the last (third) page of this table.

Table 2.C
Definitions of Technological Capabilities by Area

| Capability | Bio Tech | Mat Tech | ElecTech |
|---|---|---|---|
| Major Process Change IN-MJPC | 17. To make major process changes. | 18. [Radical ...] See first cell above. | 17. [Radical...; New Process Design] To make major changes in process that lead to significant gains in productivity. |
| R & D IN-RAND | 18. To carry out true R&D. | 16. See first cell above. | 15. [RD&E] To conduct RD&E; as reflected in budget, facilities, number and quality of specialized personnel. |
| Invention IN-INVE | 19. To create new products. | 20. See first cell above. | 18. To create completely new products. |
| Major Changes IN-MJCG | 20. To undertake major diversification of activities. | 19. To make major (between 'minor' and 'radical' in significance) changes in processes or products. | -. Not applicable. |

Source: Westphal (1989), Table 1.

Notes: Unless the context indicates otherwise, the capability is that 'To ...'. The seven place abbreviated labels — in the format, XX-YYYY — appearing in the left-most column are shorthand labels used in statistical analysis; the first two characters -- i.e., XX — denote ACquisitive, OPerative, ADaptive, and INnovative capabilities respectively; that is, as these adjectives are used in the reports on each technological area. Numbers within '....Tech' columns indicate the order in which capabilties are listed in the respective reports. Given within [...] are the titles used in the respective reports, if titles there differ from those shown in the left-most column. 'Not applicable' indicates that a capability similar to that identified for (an)other area(s) — and indicated by the contents of the adjacent cell(s) — was not SEPARATELY identified and assessed, though it may have been examined implicitly in connection with the evaluation of some other, included capability(ies).

Table 3.A
Aggregation Scheme and Commonality Mapping for TCs

| General Categories | Included in aggregate; simple average | | | | Related, but excluded from the aggregate | | | |
|---|---|---|---|---|---|---|---|---|
| | Common among areas | Peculiar to area indicated | | | Common among areas | Peculiar to area indicated | | |
| | | Bio | Mat | Elec | | Bio | Mat | Elec |
| Technological resources AG-RES | OP-TRAI Train | | | | | | | |
| | - - - - | | | | | | | |
| | IN-RAND R & D | | | | | | | |
| Related but not included | | | | | OP-MAIN Maint. | | | |
| Investment capability AG-INV | AQ-SRCH Search | | | | | | | |
| | - - - - | | | | | | | |
| | AQ-ASES Assess | | | | | | | |
| | - - - - | | | | | | | |
| | AQ-NEGO Terms | | | | | | | |
| | - - - - | | | | | | | |
| | AQ-PRCU Procure | | | | | | | |
| | - - - - | | | | | | | |
| | AQ-INST Install | | | | | | | |
| Related but not included | | | | | | AQ-TRAN Assimi-lation | AQ-TRAN Assimi-lation | |
| | | | | | | | AD-KNOW General | |
| | | | | | | | AD-DIGT General | |
| | | | | | | | | AQ-LAYO Design, layout |

Table 3.B
Aggregation Scheme and Commonality Mapping for TCs

| General Categories | Included in aggregate; simple average | | | | Related, but excluded from the aggregate | | | |
|---|---|---|---|---|---|---|---|---|
| | Common among areas | Peculiar to area indicated | | | Common among areas | Peculiar to area indicated | | |
| | | Bio | Mat | Elec | | Bio | Mat | Elec |
| Production capability AG-PRO | OP-OPER Operate | | | | | | | |
| | | | OP-SKIL Competitiveness | | | | | |
| | | | | OP-QUAL Q.C. | | | | |
| | | | | OP-INVN Inventory C. | | | | |
| Related but not included | | | | | | OP-MANG Manage | OP-MANG Manage | |
| | | | | | | OP-SKIL Tech. skills | | |
| Minor change capability AG-MIN | AD-MIPD Product | | | | | | | |
| | AD-MIPC Process | | | | | | | |
| Related but not included | | | | | | AD-KNOW Specifc | | |
| | | | | | | AD-DIGT Specifc | | |

Table 3.C
Aggregation Scheme and Commonality Mapping for TCs

| General Categories | Included in aggregate; simple average | | | | Related, but excluded from the aggregate | | | |
|---|---|---|---|---|---|---|---|---|
| | Common among areas | Peculiar to area indicated | | | Common among areas | Peculiar to area indicated | | |
| | | Bio | Mat | Elec | | Bio | Mat | Elec |
| Major change capability AG-MAJ | IN-MJPD Product | | | | | | | |
| | IN-MJPC Process | | | | | | | |
| | IN-INVE Invent Product | | | | | | | |
| | | IN-MJCG Divers-ifcat'n | | | | | | |
| | | | IN-MJCG Inter-mediate | | | | | |
| | | | | AD-DIFT Reverse engin'g | | | | |

Source: Westphal (1989), Table 2.

Table 4
Scoring Scales for Technology Assessment

| | Score | Bio Tech | Mat Tech | ElecTech |
|---|---|---|---|---|
| LEVEL OF SOPHISTI-CATION OF THE TECHNOLOGY IN USE | 5 | Equals MOST ADVANCED used in industrial countries. | Not applicable: sophistication of technology in use not separately assessed. | Not applicable: sophistication of technology in use not separately assessed. |
| | 4 | Equals AVERAGE used in industrial countries. | | |
| | 3 | BELOW AVERAGE in industrial countries; HIGHER than that of most local firms. | | |
| | 2 | WELL BELOW AVERAGE in industrial countries; EQUALS local average. | | |
| | 1 | BELOW local average or NOT IN USE. | | |
| LEVEL OF CAPABILITY IN USING TECHNOLOGY The same scale is used for all capabilities | 5 | Equals that of firms on world FRONTIER. | Not applicable; each capability is scored on a separate scale specific to it (see table giving Mat Tech scoring scale). | Comparable to leading firms in industrial countries. |
| | 4 | Equals AVERAGE found in industrial countries. | | Adequate for export except to most competitive markets. |
| | 3 | BELOW AVERAGE in indust-countries; GREATER than in most local firms. | | Acceptable for expansion within local markets. |
| | 2 | WELL BELOW AVERAGE in industrial countries; EQUALS local average. | | Acceptable for low end of the local market. |
| | 1 | BELOW local average or NO CAPABILITY. | | Unacceptable quality due to deficiency in design and production. |
| | 0 | Not applicable. | [Zero used in some cases.] | Absence of capability. |

Source: Westphal (1989), Table 3.

Table 5.A

Scoring Scale for Assessing Capabilities in Materials Technology

| Capability | Score: | Considerations | | |
|---|---|---|---|---|
| Search AQ-SRCH | - | SYSTEMATIC | SOURCES | PIONEER STATUS |
| | 5: | Yes | Several | n.a. |
| | 4: | No | " | Local pioneer |
| | 3: | " | " | Not pioneer |
| | 2: | " | One or few | " |
| | 1: | " | Copy local firms | " |
| | | Note: Possible sources include technical literature, seminars, exhibitions, professional associations, etc. | | |
| Assessment AQ-ASES | - | ASSESSMENT | EVALUATE | STAFF QUALIFICATIONS |
| | 5: | Complete | All components | Fully qualified |
| | 4: | " | Some or all components | Partly qualified |
| | 3: | " | Overall system | " |
| | 2: | Rough | " | " |
| | 1: | No technical evaluation | | |
| Negotiation AQ-NEGO | - | SOURCES | LOCALIZATION OPTION | |
| | 5: | Several | Yes | |
| | 4: | " | No | |
| | 3: | Only a few | " | |
| | 2: | One | " | |
| | 1: | Negotiation on basis of very little information | | |
| Procurement AQ-PROC | - | SOURCES OF COMPONENTS | | LOCAL FABRICATION TO OWN SPECIFICATIONS |
| | | LOCAL | FOREIGN | |
| | 5: | Several | n.a. | Yes, for some elements |
| | 4: | " | Several | n.a. |
| | 3: | " | One | " |
| | 2: | None | One | No |
| | 1: | Turnkey project | | |
| Transfer AQ-TRAN | - | UNDERSTANDING | OWN R&D INVOLVED | RELIANCE ON FOREIGNERS |
| | 5: | In-depth | Yes | n.a. |
| | 4: | " | No | " |
| | 3: | Weak | " | " |
| | 2: | " | " | Extensive, for long period |
| | 1: | Very poor | " | Continued, for routine problems |
| Installation and Startup AQ-INST | - | REQUIRES | | |
| | 5: | No external assistance | | |
| | 4: | Some local assistance | | |
| | 3: | Some foreign assistance | | |
| | 2: | Largely foreign expertise | | |
| | 1: | Turnkey project | | |

Source: Westphal (1989), Table 4.

Notes: " denotes 'ditto' or 'as immediately above'.
n.a. denotes not applicable; that is, not an explicit consideration.

Table 5.B

Scoring Scale for Assessing Capabilities in Materials Technology

| Capability | Score | Considerations |
|---|---|---|
| Operation and Control OP-OPER | 5: | Efficient operation with: good plant layout and environment; good inventory and quality control; adequate safety programs; etcetera |
| | 4: | Inferior to 5 in plant environment or several other aspects |
| | 3: | Inferior to 4 in plant layout or several other aspects |
| | 2: | Inferior to 3 in safety programs or several other aspects |
| | 1: | Poor in all respects |
| Maintenance OP-MAIN | 5: | Planned maintenance, employing appropriate method(s), using special equipment to monitor machinery performance |
| | 4: | Inferior to 5 in not using special equipment or several other aspects |
| | 3: | Inferior to 4 in method used or several other aspects |
| | 2: | Maintenance improperly planned or largely unplanned |
| | 1: | Maintenance only upon machine failure |
| Training OP-TRAI | - | COVERAGE / PROGRAMS: OVERSEAS / IN-HOUSE |
| | 5: | Extensive, systematic; using local sources / Yes / Yes |
| | 4: | " / Limited / " |
| | 3: | " / " / No |
| | 2: | Limited to only some areas / " / " |
| | 1: | Very limited training |
| | 0: | No training program |
| Skill OP-SKIL | - | OVERALL COMPETITIVENESS OF PRODUCTION |
| | 5: | Internationally competitive |
| | 4: | Superior to most local firms |
| | 3: | Strong competitor in local market |
| | 2: | Weak competitor in local market |
| | 1: | Unable to produce with acceptable quality |
| Management OP-MANG | 5: | Modern, by international standards |
| | 4: | Somewhat inferior to 5, but well organized, with clear functional specialization |
| | 3: | Less well organized |
| | 2: | No clear functional specialization |
| | 1: | Poorly organized individual or family management |
| Knowledge Aquisition AD-KNOW | - | SYSTEMATIC / SOURCES |
| | 5: | Yes / Many, including overseas travel |
| | 4: | " / Several |
| | 3: | No / Few |
| | 2: | " / Customers and/or suppliers only |
| | 1: | Copies other local firms |

Notes: see bottom of first page of table.

Table 5.C

Scoring Scale for Assessing Capabilities in Materials Technology

| Capability | Score | Considerations | |
|---|---|---|---|
| Technology Digestion AD-DIGT | - | PROCESS KNOWLEDGE | R&D UNIT |
| | 5: | Complete, from in-depth study | Yes |
| | 4: | Incomplete | " |
| | 3: | " | No |
| | 2: | Personnel lack qualifications for in-depth understanding | |
| | 1: | No analysis of the technology in use | |
| Research and Development IN-RAND | 5: | Distinctly funded R&D activities within separate R&D unit having adequate facilities | |
| | 4: | Inferior to 5 | |
| | 3: | Inferior to 4 | |
| | 2: | Some R&D activities within technical department | |
| | 1: | Technical personnel lack adequate qualifications | |
| | 0: | Firm has no R&D activities | |
| Change: see specific capabilities listed below | - | REQUIRES | |
| | 5: | No external assistance | |
| | 4: | Some local assistance | |
| | 3: | Some foreign assistance | |
| | 2: | Extensive foreign assistance | |
| | 1: | Purchase of foreign technology | |
| | 0: | No such changes made | |

Specific change capabilities to which the scoring scale above applies:

Minor Product Modification, AD-MIPD
Minor Process Modification, AD-MIPC
Radical Product Modification, IN-MJPD
Radical Process Modification, IN-MJPC
Major Change, IN-MJCG; in terms of the significance of the change that is entailed, "major" comes between "minor" and "radical."
New Invention, IN-INVE; here a score of 1 is not applicable.

Notes: see bottom of first page of table.

Table 6
Industries Included in the Area Samples

| Area and Industry | Principal activities or products |
|---|---|
| **BIO Tech** | |
| Aquaculture | Large and small shrimp, 4; shrimp feed, 2; fish, 1. |
| Animal feed | Chicken feed, 2; duck feed, 2; fish feed, 2; pig feed, 2; fish, 1; fodder, 1; shrimp feed, 1; starch (simple & modified), 1. |
| Seed production | For: cabbage, 3; melon, 3; chile, 1; chinese kale, 1; tomato, 1; various other vegetables. |
| Dairy | Fresh milk, 2; U.H.T milk, 2; butter, 2; animal feed, 1; condensed, evaporated, and sterilized milk, 1; ice-cream, 1; yogurt, 1. |
| Ornamental flowers | Orchids, 4. |
| Organic acids | Mono sodium glutamate, 3; chili sauce, vinegar, and miscellaneous seasonings, 1. |
| Alcohol | Alcohol, 2; liquor, 2; beer, 1; wine, 1. |
| Health products | Antibiotics, 2; cosmetics, etc., 2: drugs, 2; chemicals, 1; diagnostic elements, 1; oils and fats, 1; vaccines: human, 1; animal, 1. |
| **MAT Tech** | |
| Metal products | Fabrication of industrial and agricultural machinery, 8; casting, 6; die making and press work, 6; machining, 3; forging, 2; engine parts, 2; heat treatment, 2. |
| Plastic products | Resins, 4; blow and injection moulding, 3. |
| Ceramic products | Refractories, 4; floor and wall tile, 3; sanitary ware, 3; compound clay, 1; insulators, 1; tableware, 1. |
| Rubber products | Engineering rubber, 5; latex products, 1. |
| **ELEC Tech** | |
| Consumer electronics | Color televisions, 5; radio-cassette combinations, 4; car and home stereo sets, 3; microwave ovens, 1. |
| Communication equipment | Radio transceivers, 2; telephones and related equipment, 1. |
| Computer hardware | Microcomputers, 2; Thai cards, 1; monitors, 1. |
| Industrial electronics | Education kits, 1; electronic parts, 1; microwave components, 1; power line stabilizers, 1; uninterrupted power supplies, 1; solar cell panels, 1. |
| Electronic components | Integrated circuit assembly, 3; printed circuit boards, 3; ball bearings, 1; cables, 1; condensers, 1; disk drive assemblies, 1; coils, resistors, speakers, transformers, tuners, 1. |
| Computer software | Various kinds of software, 3. |

Source: Westphal (1989), Table 5.
Notes: Numbers indicate the number of firms producing the respective products; they do not necessarily sum to the total number of firms shown in Table 7 owing to the production of multiple products by individual firms.

Table 7
Summary of Firm Descriptor Information

| Attributes and Characteristics | * | Bio Tech | Mat Tech |
|---|---|---|---|
| Size: | SIZ | Same as for Mat Tech. | Loosely based on registered plus paid-up capital, K, in M bhat, and labor force, L, in persons: |
| Large | -L | | K >= 25, L >= 250 |
| Medium | -M] | | 25 > K >= 5, 250 > L >= 50 |
| Small | -S | | 5 > K, 50 > L |
| Ownership and management: | OWN | Thai share of ownership, T, and nationality of senior manager: | Thai share of ownership, T, and nationality of senior manager: |
| - Thai | -T] | T = 1.0 | T >= 0.9 |
| - Joint venture | -J | [n.a.] | [n.a.] |
| Foreign sub. | -F | [n.a.] | [n.a.] |
| - For., Thai | -NT | T < 1.0 with Thai management | T < 0.9 with Thai management |
| For., For. | -NF | T < 1.0 with foreign management | T < 0.9 with foreign management |
| Market orient: | MKT | Export share in total sales, E: | Same as for Elec Tech. |
| Export | -E | E = 1.0 | |
| Dom. & exp. | -B | 1.0 > E > .0 | |
| Domestic | -D] | 0.0 = E | |
| BoI status: | PRO | BoI promotional status: | Same for all areas. |
| Promoted | -N] | has never received promotion | |
| Not promoted | -Y | has received promotion | |

| | | ElecTech |
|---|---|---|
| Size: | SIZ | Based on labor force, L, in persons, and sales revenue, S, in M bhat: |
| Large | -L | L >= 300 or S >= 500 |
| Medium | -M] | 300 > L >= 100 and 500 > S >= 50 |
| Small | -S | 100 > L or 50 > S |
| Ownership and management: | OWN | Thai share of ownership, T: |
| - Thai | -T] | T >= 0.9 |
| - Joint venture | -J | 0.9 > T >= 0.1 |
| Foreign sub. | -F | 0.1 > T |
| - For., Thai | -NT | [n.a.] |
| For., For. | -NF | [n.a.] |
| Market orient: | MKT | Export share in total sales, E: |
| Export | -E | E >= 0.8 |
| Dom. & exp. | -B | 0.8 > E > 0.2 |
| Domestic | -D] | 0.2 >= E |
| BoI status: | PRO | Same for all areas. |
| Promoted | -N] | |
| Not promoted | -Y | |

Source: Westphal (1989), Table 6.
Notes: * Acronyms.
] Denotes implicit characteristic in statistical analysis; significance levels not determined for associated parameters.
n.a. Not applicable.
M, million.

Table 8
Sample Composition by Individual Characteristics

| Technological areas and industries | No. of Firms | Age | | SIZ- | | | OWN- | | | MKT- | | | PRO- | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Old | New | L | M | S | T | NT /J | NF /F | D | B | E | Y | N |
| BIOTECHNOLOGY | 32 | 67 | 1 | 16 | 12 | 4 | 20 | 6 | 6 | 14 | 9 | 9 | 15 | 17 |
| Aquaculture | 4 | 4 | 1 | 3 | 1 | 0 | 1 | 3 | 0 | 0 | 2 | 2 | 4 | 0 |
| Animal feed | 4 | 42 | 7 | 2 | 2 | 0 | 3 | 0 | 1 | 2 | 1 | 1 | 1 | 3 |
| Seed production | 3 | 67 | 4 | 2 | 1 | 0 | 2 | 0 | 1 | 2 | 1 | 0 | 1 | 2 |
| Dairy | 3 | 26 | 15 | 1 | 1 | 1 | 2 | 0 | 1 | 3 | 0 | 0 | 2 | 1 |
| Ornamental flowers | 4 | 13 | 5 | 0 | 2 | 2 | 4 | 0 | 0 | 0 | 0 | 4 | 1 | 3 |
| Ogranic acids | 4 | 27 | 2 | 3 | 1 | 0 | 2 | 1 | 1 | 0 | 4 | 0 | 2 | 2 |
| Alcohol | 4 | 12 | 5 | 2 | 2 | 0 | 3 | 1 | 0 | 1 | 1 | 2 | 1 | 3 |
| Health care products | 6 | 58 | 9 | 3 | 2 | 1 | 3 | 1 | 2 | 6 | 0 | 0 | 3 | 3 |
| MATERIALS | 55 | 27 | 3 | 34 | 14 | 7 | 45 | 6 | 4 | 8 | 24 | 2 | 28 | 27 |
| Metal products | 29 | 27 | 3 | 18 | 7 | 4 | 23 | 4 | 2 | 5 | 16 | 1 | 16 | 13 |
| Plastic products | 7 | 25 | 6 | 7 | 0 | 0 | 7 | 0 | 0 | 0 | 1 | 0 | 3 | 4 |
| Ceramic products | 13 | 20 | 5 | 7 | 5 | 1 | 11 | 2 | 0 | 2 | 5 | 0 | 6 | 7 |
| Rubber products | 6 | 25 | 3 | 2 | 2 | 2 | 4 | 0 | 2 | 1 | 2 | 1 | 3 | 3 |
| ELECTRONICS | 32 | 28 | 1 | 15 | 9 | 8 | 17 | 6 | 9 | 18 | 0 | 14 | 19 | 13 |
| Consumer electronics | 8 | 24 | 1 | 4 | 4 | 0 | 4 | 3 | 1 | 7 | 0 | 1 | 5 | 3 |
| Communication equipment | 3 | 20 | 1 | 1 | 1 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 | 1 |
| Computer hardware | 4 | 14 | 2 | 2 | 0 | 2 | 2 | 0 | 2 | 3 | 0 | 1 | 1 | 3 |
| Industrial electronics | 4 | 10 | 3 | 0 | 1 | 3 | 3 | 1 | 0 | 2 | 0 | 2 | 2 | 2 |
| Electronic components | 10 | 16 | 3 | 7 | 2 | 1 | 3 | 2 | 5 | 1 | 0 | 9 | 9 | 1 |
| Computer software | 3 | 20 | 3 | 1 | 1 | 1 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| POOLED SAMPLES | 119 | 67 | 1 | 65 | 35 | 19 | 82 | 18 | 19 | 40 | 33 | 25 | 62 | 57 |

Source: Westphal (1989), Table 7.

Notes: Age is in years; entries under Old give age of oldest firm in the sample; New, the youngest firm.

In the SIZ, OWN, MKT, and PRO columns, cell entries indicate the number of firms having the stated characteristic.

In the OWN columns: NT and NF apply to Bio Tech and Mat Tech; J and F, to Elec Tech.

A number of Mat Tech firms were not classified by the MKT attribute: in metal products, 7 firms; plastic products, 6; ceramic products, 6; rubber products, 2; overall, 21.

Table 9
Selected Sample Statistics

-*-*-*-*- RAW SCORES, INDIVIDUAL TCs -*-*-*-*-

| | Average | Standard Deviation | Coefficient of Variation |
|---|---|---|---|
| Bio | 3.13 | 1.25 | 0.40 |
| Mat | 3.04 | 1.47 | 0.48 |
| Elec | 2.40 | 1.42 | 0.59 |

-*-*- PROPORTIONAL CONTRIBUTION TO TOTAL VARIANCE -*-*-
-*-*- ALL INDIVIDUAL TCs TOGETHER -*-*-

| | Firm Effects | TC Effects | Interaction Effects |
|---|---|---|---|
| Bio | 0.33 | 0.26 | 0.41 |
| Mat | 0.20 | 0.37 | 0.43 |
| Elec | 0.21 | 0.43 | 0.37 |

-*-*-*-*- CORRELATIONS AMONG INDIVIDUAL TCs -*-*-*-*-

| | Average | Standard Deviation | Maximum | Minimum |
|---|---|---|---|---|
| Bio | 0.44 | 0.17 | -0.07 | 0.93 |
| Mat | 0.29 | 0.23 | -0.19 | 0.80 |
| Elec | 0.36 | 0.29 | -0.41 | 0.87 |

-*-*- PROPORTION OF VARIANCE LOST IN AGGREGATION -*-*-

| | AG-PRO | AG-MAJ | AG-MIN | AG-INV | AG-RES | All |
|---|---|---|---|---|---|---|
| Bio | 0.59 | 0.50* | 0.57 | 0.47 | 0.55 | 0.47 |
| Mat | 0.42 | 0.70* | 0.25* | 0.69 | 0.51 | 0.44 |
| Elec | 0.11* | 0.77* | 0.30* | 0.25 | 0.67 | 0.39 |

-*-*- PROPORTIONAL CONTRIBUTION TO TOTAL VARIANCE -*-*-
-*-*- ALL AGGREGATE TCs TOGETHER -*-*-

| | Firm Effects | TC Effects | Interaction Effects |
|---|---|---|---|
| Bio | 0.40 | 0.34 | 0.26 |
| Mat | 0.32 | 0.42 | 0.27 |
| Elec | 0.35 | 0.33 | 0.33 |
| Pool | 0.35 | 0.34 | 0.31 |

-*-*-*-*- CORRELATIONS AMONG AGGREGATE TCs -*-*-*-*-

| | Average | Standard Deviation | Maximum | Minimum |
|---|---|---|---|---|
| Bio | 0.54 | 0.08 | 0.42 | 0.70 |
| Mat | 0.42 | 0.19 | 0.17 | 0.78 |
| Elec | 0.41 | 0.30 | -0.13 | 0.77 |
| Pool | 0.43 | 0.10 | 0.19 | 0.56 |

---

Sources: Westphal (1989), Tables 9 & 19, and later computations.

Notes: Totals may not reconcile due to round-off error.
Contributions to total variance: firm effects -- variance of average scores across firms; TC effects -- variance of average scores across TCs; interaction effects -- variance of residuals, raw scores minus corresponding firm and TC averages.
Variance lost in aggregation: variance of residuals, scores for included and related individual TCs minus scores for corresponding aggregate TC(s).
* Variance of aggregate TC relative to variance of included and related individual TCs equals one minus proportion of variance lost in aggregation, this because all individual TCs are "included" (none are "related"). In all other cases but one, the relative variance of the aggregate TC across firms exceeds one minus the proportion lost.

Table 10

Attribute Regressions for Individual TCs: Summary Statistics

| Memo | | Industry Attributes | Other Attributes: SIZ | OWN | MKT | PRO | All | Age Variable |
|---|---|---|---|---|---|---|---|---|
| PRO | A.AS. | 80 | 93 | 78 | 75 | 67 | 79 | 89 |
| | S.S. | 27 | 83 | 29 | 25 | 25 | 45 | 33 |
| | S.P. | 8 | 50 | 8 | 5 | 8 | 23 | 0 |
| MAJ | A.AS. | 78 | 72 | 67 | 75 | 67 | 72 | 92 |
| | S.S. | 40 | 33 | 37 | 36 | 33 | 35 | 80 |
| | S.P. | 27 | 3 | 33 | 16 | 20 | 16 | 27 |
| MIN | A.AS. | 73 | 88 | 63 | 82 | 75 | 78 | 88 |
| | S.S. | 31 | 50 | 32 | 26 | 18 | 35 | 73 |
| | S.P. | 17 | 0 | 9 | 5 | 9 | 4 | 9 |
| INV | A.AS. | 85 | 87 | 82 | 70 | 75 | 78 | 75 |
| | S.S. | 43 | 72 | 41 | 18 | 13 | 42 | 65 |
| | S.P. | 23 | 48 | 17 | 8 | 4 | 23 | 13 |
| RES | A.AS. | 76 | 93 | 78 | 75 | 56 | 80 | 89 |
| | S.S. | 32 | 25 | 25 | 15 | 25 | 25 | 17 |
| | S.P. | 15 | 17 | 4 | 5 | 8 | 13 | 0 |
| All TCs | A.AS. | 80 | 86 | 75 | 74 | 69 | 78 | 84 |
| | S.S. | 36 | 55 | 34 | 24 | 22 | 37 | 56 |
| | S.P. | 19 | 27 | 16 | 8 | 10 | 17 | 11 |

Source: Westphal (1989), Table 16.

Notes: PRO denotes productive capability; MAJ, major change capability; MIN, minor change capability; INV, investment capability; RES, technological resources.

A.AS. = Coefficients of regressions for individual TCs included in and related to the corresponding aggregate TC that have the same algebraic sign as that in the ALL Pool regression for the aggregate TC, percent of maximum number possible.

S.S. = Coefficients — of ALL Pool regression for the corresponding aggregate TC, and of regressions for (included and related) individual TCs that have the same algebraic sign as that in the ALL Pool regression — that exceed their respective standard errors, percent of maximum number possible.

S.S. = Coefficients — of ALL Pool regression for the corresponding aggregate TC, and of regressions for (included and related) individual TCs that have the same algebraic sign as that in the ALL Pool regression — that significantly differ from zero at the 0.10 level, percent of maximum possible.

Table 11

Attribute Regressions for Aggregate TCs: Summary Statistics

| Memo | | Industry Attributes | Other Attributes: SIZ | OWN | MKT | PRO | All | Age Variable |
|---|---|---|---|---|---|---|---|---|
| PRO | A.AS. | 86 | 83 | 94 | 63 | 67 | 79 | 67 |
| | S.S. | 31 | 93 | 44 | 42 | 71 | 61 | 75 |
| | S.P. | 9 | 79 | 25 | 8 | 71 | 43 | 0 |
| MAJ | A.AS. | 86 | 72 | 78 | 81 | 67 | 76 | 100 |
| | S.S. | 47 | 29 | 38 | 67 | 43 | 43 | 100 |
| | S.P. | 36 | 0 | 31 | 33 | 0 | 18 | 50 |
| MIN | A.AS. | 83 | 83 | 78 | 88 | 67 | 81 | 67 |
| | S.S. | 49 | 79 | 50 | 67 | 29 | 59 | 75 |
| | S.P. | 33 | 36 | 19 | 33 | 14 | 27 | 0 |
| INV | A.AS. | 92 | 83 | 94 | 69 | 67 | 81 | 67 |
| | S.S. | 47 | 79 | 31 | 25 | 14 | 41 | 25 |
| | S.P. | 27 | 43 | 13 | 17 | 14 | 22 | 0 |
| RES | A.AS. | 92 | 100 | 94 | 75 | 83 | 90 | 33 |
| | S.S. | 40 | 57 | 31 | 42 | 57 | 45 | 0 |
| | S.P. | 16 | 36 | 0 | 17 | 43 | 20 | 0 |
| All TCs | A.AS. | 88 | 84 | 88 | 75 | 70 | 81 | 67 |
| | S.S. | 43 | 67 | 39 | 48 | 43 | 50 | 55 |
| | S.P. | 24 | 39 | 18 | 22 | 29 | 26 | 10 |

Source: Westphal (1989), Tables 12.2 and 14.2.

Notes: PRO denotes productive capability; MAJ, major change capability; MIN, minor change capability; INV, investment capability; RES, technological resources.

A.AS. = Coefficients of ALL and ONE Area regressions that have the same algrebraic sign as that in the ALL Pool regression, percent of maximum number possible.

S.S. = Coefficients — of ALL Pool regression, and of ALL & ONE Area regressions that have the same algebraic sign as that in the ALL Pool regression — that exceed their respective standard errors, percent of maximum number possible.

S.P. = Coefficients — of ALL Pool regression, and of ALL & ONE Area regressions that have the same algebraic sign as that in the ALL Pool regression — that significantly differ from zero at the 0.10 level, percent of maximum number possible.

Table 12
Sophistication of Technologies in Use by BIO Tech Firms

| Technology / Industry | AQC | FED | SED | DRY | FLO | ACD | ALC | PHR | All |
|---|---|---|---|---|---|---|---|---|---|
| **Engineering and related** | | | | | | | | | |
| Chemical engineering | | 3.00 | | 3.50 | | 3.25 | 2.75 | 3.60 | 3.24 |
| Chemical technology | | | | | | | | 3.00 | 3.00 |
| Chemical analysis | | 2.25 | | | | 3.25 | 2.00 | 3.50 | 2.50 |
| Control & measurement | 2.75 | 3.00 | 3.00 | 3.00 | | 3.25 | 2.50 | 3.50 | 3.03 |
| Controlled environment | 2.50 | | 3.50 | 3.00 | 3.50 | 3.67 | | 2.80 | 3.13 |
| Computer-aided production | | 5.00 | | | | | | 3.50 | 4.00 |
| Dehydration technology | | 2.50 | 2.00 | | | 3.67 | | 3.33 | 2.88 |
| Reactor technology | | | | | | 4.25 | 2.50 | 3.50 | 3.40 |
| Industrial engineering | | 3.50 | | 2.67 | | 3.00 | 2.75 | 3.60 | 3.15 |
| - - - - - - - - - - - - - - | - - | - - | - - | - - | - - | - - | - - | - - | - - |
| Average score | 2.63 | 3.05 | 2.83 | 3.67 | 3.50 | 3.46 | 2.50 | 3.28 | 3.08 |
| **Biological technologies** | | | | | | | | | |
| Biochemical | | | | | | 3.33 | 3.00 | 3.00 | 3.20 |
| Biochemical analysis | | | 3.00 | 3.00 | | 3.67 | | 3.00 | 3.12 |
| Enzyme | | | | | | 3.33 | 3.00 | 3.00 | 3.20 |
| rDNA (genetic engineering) | | | | | | | | | |
| Hybridoma / fusion | | | | | | | | | |
| Microbial | 2.00 | | | 2.50 | | 3.00 | 2.00 | 3.00 | 2.57 |
| Plant tissue culture | | | | | 4.00 | | | | 4.00 |
| Plant breeding | | | 5.00 | | 3.25 | | | 4.00 | 4.11 |
| - - - - - - - - - - - - - - | - - | - - | - - | - - | - - | - - | - - | - - | - - |
| Average score | 2.00 | | 4.00 | 2.75 | 3.63 | 3.31 | 2.33 | 3.07 | 3.15 |
| **Intermediate technologies** | | | | | | | | | |
| Fermentation | | | | 4.00 | | 4.25 | 2.50 | 3.50 | 3.45 |
| Biochemical engineering | | | | | | 3.00 | | 3.00 | 3.00 |
| Pollution control # | | 2.33 | | 2.25 | | 3.50 | 2.83 | 2.00 | 2.66 |
| - - - - - - - - - - - - - - | - - | - - | - - | - - | - - | - - | - - | - - | - - |
| Average score | | 2.33 | | 2.60 | | 3.78 | 2.70 | 3.00 | 2.94 |
| **Others** | | | | | | | | | |
| Consumer testing | | | | 2.67 | 3.00 | | | 3.00 | 2.90 |
| Clinical field testing | | 3.25 | 4.00 | | | | | 3.33 | 3.50 |
| - - - - - - - - - - - - - - | - - | - - | - - | - - | - - | - - | - - | - - | - - |
| Average score | | 3.25 | 4.00 | 2.67 | 3.00 | | | 3.22 | 3.25 |
| Overall average score | 2.49 | 2.94 | 3.42 | 2.87 | 3.44 | 3.48 | 2.53 | 3.21 | 3.09 |
| Standard deviation | 0.50 | 0.93 | 1.19 | 1.04 | 0.61 | 0.87 | 0.55 | 0.86 | 0.93 |

Source: Westphal (1989), Table 17.

Notes: The column order in which industries appear is the same as the row order in which they appear in Table 8. Blank cells denote technologies not in use by firms sampled; averages and standard deviations are with respect to technologies in use. Row and column averages correspond to weighted averages of cell values, with weights being the number of observations within each cell.

Table 13
Capability Scores Regressed against Sophistication Scores for BIO Tech

| Capability | TC Score | Constant | Slope | R**2 |
|---|---|---|---|---|
| AG-RES | ALL Pool | -1.72<br>(1.96) | 0.43<br>(0.65) | 0.08 |
| | ALL Bio | -0.77<br>(2.29) | 0.97<br>(0.76) | 0.25 |
| AG-INV | ALL Pool | 2.41<br>(1.31) | -0.77*<br>(0.43) | 0.38 |
| | ALL Bio | 5.87<br>(1.87) | -0.83<br>(0.62) | 0.26 |
| AG-PRO | ALL Pool | 1.40<br>(0.80) | -0.28<br>(0.27) | 0.18 |
| | ALL Bio | 5.50<br>(1.21) | -0.55<br>(0.40) | 0.27 |
| AG-MIN | ALL Pool | 0.42<br>(2.04) | -0.14<br>(0.68) | 0.01 |
| | ALL Bio | 4.19<br>(1.90) | -0.26<br>(0.63) | 0.03 |
| AG-MAJ | ALL Pool | 1.39<br>(2.09) | -0.76<br>(0.69) | 0.20 |
| | ALL Bio | 5.16<br>(2.02) | -1.02*<br>0.67 | 0.32 |

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Source: Westphal (1989), Table 18.

Notes: Capability scores are estimates of the constant terms in attribute regression specifications identified under the heading "TC Score;" sophistication scores are the "Overall average scores" given at the bottom of Table 12. For each regression: the eight BIO Tech industries comprise the sample; the first line gives the coefficient estimates (along with R**2); the second line, the corresponding standard errors.

* indicates value is significantly different from zero (t-test) at the 0.10 level.

Table 14
Parameter Estimates for Capability Regressions

| Sample | Constant | AG-MAJ | AG-MIN | AG-INV | AG-RES | R**2 | Signif. |
|---|---|---|---|---|---|---|---|
| | | -*-*-*-*- | AG-PRO | -*-*-*-*- | | | |
| All Firms | 0.64$$ | -0.14# | 0.10# | 0.12 | 0.37$$ | 0.35 | 0.01 |
| | (0.11) | (0.10) | (0.07) | (0.11) | (0.07) | | |
| Firms by SIZ | | | | | | | |
| Large | 1.05 | 0.02 | -0.01 | 0.0+ | 0.30$$ | 0.27 | 0.05 |
| | (0.13) | (0.11) | (0.07) | (0.12) | (0.07) | | |
| Medium & Small | 0.35$ | -0.0- | 0.09 | 0.31* | 0.20* | 0.37 | 0.01 |
| | (0.14) | (0.14) | (0.10) | (0.16) | (0.11) | | |
| Firms by OWN | | | | | | | |
| Thai | 0.37$$ | -0.14# | 0.19$ | 0.25* | 0.24$ | 0.40 | 0.05 |
| | (0.12) | (0.11) | (0.08) | (0.13) | (0.09) | | |
| Foreign | 1.12$$ | -0.0- | -0.05 | 0.03 | 0.20$ | 0.16 | -- |
| | (0.14) | (0.13) | (0.09) | (0.13) | (0.08) | | |
| Firms by MKT | | | | | | | |
| Domestic | 0.10 | -0.36* | 0.25* | 0.26# | 0.25$ | 0.41 | 0.05 |
| | (0.18) | (0.18) | (0.13) | (0.22) | (0.12) | | |
| Both | 0.62$$ | 0.12 | 0.42$$ | 0.11 | 0.15# | 0.51 | 0.05 |
| | (0.14) | (0.11) | (0.13) | (0.12) | (0.09) | | |
| Export | 1.08$$ | 0.15 | -0.39# | 0.37 | 0.38$$ | 0.40 | 0.25 |
| | (0.24) | (0.27) | (0.28) | (0.32) | (0.12) | | |
| Firms by PRO | | | | | | | |
| Yes | 0.90$$ | -0.07 | 0.07 | 0.01 | 0.29$$ | 0.20 | 0.25 |
| | (0.14) | (0.13) | (0.08) | (0.13) | (0.09) | | |
| No | 0.31$ | -0.10 | 0.16* | 0.30* | 0.17* | 0.34 | 0.05 |
| | (0.15) | (0.14) | (0.09) | (0.17) | (0.10) | | |
| | | -*-*-*-*- | AG-MAJ | -*-*-*-*- | | | |
| All Firms | -0.85$$ | -- | 0.16$$ | 0.23$ | 0.13$ | 0.30 | 0.05 |
| | (0.06) | | (0.06) | (0.10) | (0.06) | | |
| | | -*-*-*-*- | AG-MIN | -*-*-*-*- | | | |
| All Firms | 0.21$ | -- | -- | 0.65$$ | 0.29$$ | 0.34 | 0.05 |
| | (0.09) | | | (0.14) | (0.09) | | |
| Firms by MKT | | | | | | | |
| Domestic | 0.04 | -- | -- | 0.90$$ | 0.27# | 0.50 | 0.05 |
| | (0.15) | | | (0.24) | (0.16) | | |
| Both | 0.81$$ | -- | -- | 0.04 | 0.25$ | 0.15 | -- |
| | (0.12) | | | (0.18) | (0.12) | | |
| Export | -0.56$$ | -- | -- | 1.21$$ | 0.01 | 0.78 | 0.05 |
| | (0.10) | | | (0.15) | (0.11) | | |

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Notes: Signif.: significance level (F-test) for R**2.
$$, $, *, and # respectively indicate value significantly different from zero (t-test) at the 0.01, 0.05, 0.10, and 0.25 levels.
Separate regressions for characteristic sub-samples appear only if the null hypothesis of the relationship's homogenity across the sub-samples can be rejected at the 0.05 significance level [using covariance analysis F-test; see Johnston (1972), pp. 192 ff.].

Table 15.A
Technological Capabilities and Functional Correlations Compared

| Memo Items | ..ALL.. .Firms. | ..... Large | ..SIZ.. Medium | ..... Small | ..... Thai | OWN | ..... Foreign |
|---|---|---|---|---|---|---|---|
| PRO TC | .58$$ | .26$ GOOD !! | .07+ AVERAGE | -.32$ POOR !! | -.34+ -.23+ POOR !! | | .34+ .23+ GOOD !! |
| PRO FC | .35$$ HIGH MAJ | .27$ high ?? !! min | .48$ HIGH ?? | .11_ LOW ?? maj | .40$ HIGH !! MAJ | | .16_ LOW !! maj min |
| MAJ TC | -.08$$ | -.09# poor ?? | .09+ good | .0-_ AVERAGE | -.11+ -.17+ poor ?? | | .11+ .17+ MIXED |
| MAJ FC | .30$ HIGH | .36$ HIGH ?? | .34# high ?? | .57# high ?? inv | .32$ HIGH ?? | | .33# high ?? |
| MIN TC | -.04_ | .39$ GOOD !! | .01+ AVERAGE | -.40$ POOR !! | -.11+ -.07+ poor ?? | | .11+ .07+ MIXED |
| MIN FC | .34$ HIGH | .26# high ?? | .38# high ?? | .47# low ?? | .40$ HIGH ?? | | .26# low ?? |
| INV TC | .12_ | .18$ GOOD !! | .12+ good !! | -.29$ POOR !! | .31+ -.03+ MIXED | | -.31+ .03+ MIXED |
| RES TC | -.37$$ | .23# GOOD !! | .15+ good !! | -.39$ POOR !! | -.10+ -.39+ POOR | | .10+ .39+ GOOD |

Notes: See separate page following part B.



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Table 15.B
Technological Capabilities and Functional Correlations Compared

| Memo Items | ..ALL.. .Firms. | ..... Dom. | ..MKT.. Both | ..... Exp. | ..... Yes | PRO ..... No |
|---|---|---|---|---|---|---|
| PRO TC | .58$$ | -.06_ AVERAGE | .01_ AVERAGE | .04_ AVERAGE | .13$ good !! | -.13+ poor !! |
| PRO FC | .35$$ HIGH MAJ | .41$ HIGH MAJ* | .51$ HIGH | .40# low MIN | .20# low !! maj | .34$ HIGH !! maj |
| MAJ TC | -.08$$ | .15+ good !! | .10+ good !! | -.26$ POOR !! | .08# good ?? | -.08+ poor ?? |
| MAJ FC | .30$ HIGH | .50$ HIGH ?? | .11_ LOW ?? min | .54* high ?? res inv | .23* high ?? | .42$ HIGH ?? |
| MIN TC | -.04_ | .24+ GOOD !! | .09_ poor !! | -.13$ POOR !! | .06_ AVERAGE | -.06+ AVERAGE |
| MIN FC | .34$ HIGH | .50* high | .15_ LOW !! | .78$ HIGH | .38* high ?? | .38* high ?? |
| INV TC | .12_ | .0-+ AVERAGE | .0+_ AVERAGE | .0-_ AVERAGE | .04_ AVERAGE | -.04+ AVERAGE |
| RES TC | -.37$$ | .15+ good ?? | .22# GOOD | -.37$ POOR | .23$ GOOD !! | -.23+ POOR !! |

~~Source:~~ Notes: See separate page following part B.



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Notes to Table 15

Source: Westphal (1989), Table 21.

Column headings: SIZ denotes size; OWN, ownership; MKT, market orientation (Dom. means domestic); PRO, whether BoI promoted.

Row headings: PRO denotes productive capability; MAJ, major change capability; MIN, minor change capability; INV, investment capability; RES, technological resources.

TC denotes differential in technological capability; $$, $, and * are as indicated below (using t-test); # indicates value greater than or equal to standard error of the estimate; !! [??] indicates that estimate appears quite robust [of questionable robustness]. In OWN/Thai cells, the first value is for Elec tech; the second, for Bio and Mat tech.

FC denotes functional correlation (squared coefficient); $$, $, and * are as indicated below (using F-test); # indicates value significantly different from zero at the 0.25 level; !! [??] indicates that null hypothesis of relationship's homogeneity across characteristic sub-samples can be rejected at the 0.01 significance level [can not be rejected at the 0.05 level]. Bottom line of each cell indicates, using abbreviated acronyms, independent aggregate TCs having negative coefficients; upper case letters indicate coefficient is significantly different from zero at 0.25 level.

$$, $, and * respectively indicate value significantly different from zero at the 0.01, 0.05, and 0.10 levels. A + indicates level of significance is not determined. A _ means nothing; it is there simply for proper spacing.

See the text for additional details regarding the contents and interpretation of this table.