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A DYNAMIC MODEL FOR PRODUCT STRATEGY SELECTION

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PREFACE

The Industrial Development Research Program studies the relationship of technology to economic growth and stability to determine a more effective use of science and technology to promote the growth of industry in the state of Michigan. The program is currently studying the importance of technology in the product and process development activities of Michigan firms in the machine tool, and electronic industries. Collected data identify existing product and process development capabilities and describe their use in product strategies adopted by firms. The development of a logical framework has allowed the systematic assessing and classifying of competitive situations faced by firms and possible product strategies. (Product strategy denotes possible product, process, or market alternatives available to a firm to improve its competitive situation.) Based on a firm's existing competitive situation, this static framework allows the selection of feasible product strategies. The analysis and comparison of the capabilities required to implement the selected product strategies by individual firms with the firm's existing capabilities will indicate deficient capabilities for the firm, and can lead, on an industry level, to the development of beneficial action programs for Michigan industries, especially when industry wide deficiencies appear.

The development of this static model and the Industrial Development Research Program's industry studies have certified the need of a dynamic model for making product strategy selections, especially where a significant change from an existing product line is required. This dissertation represents one approach toward the development of such a dynamic model. I have not tried to develop a completely validated model for industry use, but to determine, by the use of real data, whether the assumed analytical relationships actually describe the process of product strategy selection for the machine tool industry and to determine the significance of some of the variables as they affect this selection. I expect this development and analysis to facilitate the construction of other models that will be of greater use in predicting and controlling some of the situational forces.

I wish to express appreciation to the members of the doctoral committee, Professors Richard C. Wilson (Chairman), Kenneth E. Boulding, Merrill M. Flood, Wallace W. Gardner and Mr. Dean H. Wilson, whose encouragement, comments, and insights helped clarify many parts of the thesis.

I am also grateful to The University of Michigan's Institute of Science and Technology and its Industrial Development Research Program for the time, financial assistance, and data made available to me during the development and analysis activities of this research program. The Director of this Program, Frank R. Bacon, Jr., has provided numerous insights into the nature of research activity.

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Abstract

Product development activities are meaningful to a firm insofar as they contribute to the competitive effectiveness and profitability of the firm. Diversification, one type of product strategy, is not necessarily a cure-all for the economic problems of a firm. If, for example, the capabilities of a firm to implement a diversification strategy are not adequate, economic problems might be generated rather than solved. The basis for selection, then, of an appropriate product strategy to meet an existing competitive situation must take into account the expected long-run returns from the market a firm contemplates entering, relative to the expected long-run returns from the market it is currently serving. It must also account for the capabilities a firm has to implement this strategy, the resulting competitive situations it will face, and the long-run objectives of the firm.

The selection of product strategies by a firm is accomplished in this dissertation with a dynamic model which uses the mathematical techniques of Markov processes and dynamic programming. The model is applied to the Michigan machine tool industry; in this application a firm can select one of two possible product strategies to meet the specific competitive situation that it is currently facing and any one of six competitive situations that it could face in the future. The product strategies are (1) "continue to do what you are presently doing," and (2) "do something in addition to what you are presently doing." It is shown that "size of the firm" is a significant measure of the competitive situations facing the Michigan machine tool firms. The effect of the firm's capabilities on product strategy selection is represented by (a) the level of capabilities within a firm, and (b) the effective use of this level of capabilities, which represents management capability.

Indifference curves are plotted, giving total expected market share (the selected measure of return) as a function of the existing competitive situation, the planning horizon, and the capabilities of a firm. These curves represent a situation of indifference with respect to the optimal product strategy that a firm should select. Suboptimal strategies are also indicated on these graphs.

The extent to which the future (planning horizon) should be considered in making current product strategy selections is analyzed. If a firm can assume that the parameters of the model will remain constant for the second time period (second year) or longer, the optimal product strategy selected, for most conditions of firm capabilities, is different than that selected for a planning horizon of one year. Furthermore, the total expected market share is larger.

The general conclusions that can be drawn are: (1) a firm must have both a high level of capabilities and good management if it is to justify "doing something in addition to what it is presently doing"; (2) management capability is more important than the level of supporting capabilities in justifying the selection of the second product strategy; and (3) maximizing total expected market share in the short run (one-year planning horizons) is not optimal for many machine tool firms.

INTRODUCTION

Product development activities are important to a firm insofar as they contribute to the growth or survival of the firm in its environment. A firm's environment, broadly, is the sum of all factors outside the control of company management that influence a company's sales, profits, markets, products, and competition. Basically, the environment of a firm consists of two competitive markets: that in which it seeks resources to manufacture its products, and that in which it seeks customers to purchase its products. The significant aspects of this environment are competition and market demand. A firm would like to occupy a favorable competitive position (relative to other producers of similar products) while enjoying good profits. If a firm cannot compete effectively, it will not experience a good response from the market for its products and hence, over time, will not be profitable. Important to the attaining of a good competitive position and profitability is the development and marketing of new products. According to Dean, "The underlying purpose of product additions is to increase competitive effectiveness and make more money."[1]

Knowledge of the probable competitive situation faced by the firm and expected market demand will permit a firm to select those product development strategies that are consistent with the objectives and capabilities of the firm. Certain strategies are successful when applied to some competitive situations, but will probably fail when used in others. Diversification, for example, is considered these days to be a panacea for the economic ills of a firm. It appears, however, that frequently diversification is the opening of Pandora's box and the confrontation with economic problems that did not exist before. Ansoff sums it up in the following way:

> Does all this necessarily mean that diversification is the solution to all growth problems, that a firm should diversify regardless of its particular industry, or its position in that industry? There is considerable evidence to suggest a strongly negative answer, that indiscriminate and unplanned diversification can do much more harm than good.[2]

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[1]Joel Dean, Managerial Economics (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1951), p. 119.

[2]H. Igor Ansoff, "So You Want to Diversify," Presentation before Los Angeles Chamber of Commerce, DTFR-36, 1962.

Diversification, however, is only one of a large set of product strategies that can be used by a firm to meet its current competitive situation. Other forms of product, process, or market modifications can be exploited by a firm in an attempt to meet its competitive situation in a way that is consistent with its existing capabilities. The problem for a firm, then, is what product strategy will best fulfill these conditions so that it provides profits that are consistent with the firm's total objectives over time.

This thesis develops in Chapter III a dynamic analytic model which is an extension of Howard's dynamic model discussed in Chapter II; our model will attempt to give insight into the nature of the product strategy selection problem. The mathematical techniques of Markov processes and dynamic programming are used to provide the model with probabilistic elements and a time framework. These techniques are discussed in Chapter II. Specifically, the model will identify the conditions of expected market demand in a specified market that must exist for a firm, with given capabilities and facing a given competitive situation, that is contemplating using a certain product strategy to enter this market.

The model is applied to the Michigan machine tool industry in Chapter IV; the model permits a firm to select one of two possible product strategies to meet the specific competitive situation that it is currently facing and any one of the six competitive situations that it could face in the future. The effect of the firm's capabilities on product strategy selection is analyzed to determine the extent to which both the level of capabilities and the effective use of this level of capabilities will assist or prevent the firm from successfully implementing a product strategy that involves activities in product, process, or market modifications new to the firm.

Furthermore, the extent to which the future should be brought into the current selection of a product strategy is analyzed for the machine tool industry. Since a decision made this time period will affect future decisions, it is important to attempt to identify the conditions of expected market demand, the general economic environment, and firm capabilities for which a planning horizon of greater than one year is appropriate.

CHAPTER I
THE ECONOMIC SETTING

The purpose of this chapter is to present and discuss those economic factors of the problem described in the introduction that constitute the major variables in the model. Additional influencing factors (such as disutility of losses) will be discussed as they become meaningful in terms of the development of the model or the analysis of the results. The objective of this chapter is not to present a complete theoretical economic discussion of the significant factors in this model, but to point out the importance of considering them and the salient features they have relative to this model.

CONCEPT OF A PRODUCT STRATEGY

The term "product strategy" refers to those activities which must be carried out by a firm to develop and market new products or modify existing ones. These activities involve technical explorations, analysis of commercialization possibilities, consideration of financial arrangements and other steps that are necessary if a product is to be successfully modified or developed and marketed. More often than not, discussions of product strategies or product policies restrict the use of the term to product or market changes. If a new product is developed for an existing market or the existing products are shipped to new markets, or both, it is said we have examples of product strategies. Some authors use the term only to describe the development of a new product. These approaches, however, have the tendency to restrict the ways in which the underlying activities (engineering, market research, etc.) that result in new products can be used to improve the competitive effectiveness and/or profitability of a firm.

Since ultimately most firms are interested in improving their competitive situation and profitability, it would seem that the alternatives available to a firm to accomplish these objectives should reflect more directly the various activities that can be employed. For example, a price change can be considered to be a simple way of changing the economic characteristics of a product. Whether this product strategy proves to be successful or not obviously depends on the responses of the market and the firms' competitors. Significantly, however, this product strategy can be employed in a relatively short time; that is, the decision to make a price change and the communication of this decision to the market usually requires a relatively short time period. We will return to this point later.

The number of books and articles that deal with the use of product strategies is legion. Much of this literature discusses the problems and implications of product strategies in a qualitative way.[1] The important characteristics of product planning and development are treated and the typical results are check lists of questions to consider in making a decision, or groupings of characteristics which under certain stated conditions are deemed to be very good, good, average, poor, or very poor. Since there are great uncertainties in analyzing product development plans, it is difficult to get a grasp on any analytic relationships that would permit quantitative analysis. Hence the experience manifested in these articles and books is important.

Some attempts have been made to quantify product strategy decision making by proposing schemes for the assignment of weights to certain factors and then combining these weighted factors by another scheme.[2] Most of these techniques are restricted in use because they are applicable to specific situations under given conditions. Also, there is significant arbitrariness in the selection and combination of the weighted factors. More important, however, is the fact that they lack an explicit expression to account for the effect that a current decision will have on future decisions.

An interesting approach to product strategy decision making was made by Green.[3] He applied concepts of Bayesian statistics to answer two questions: (1) Should we make a decision now (with respect to instituting a product development program) or delay the decision until the next time period? (2) What particular strategy would be most appropriate?

Green's approach is significant for two reasons: (1) he recognizes the possibility of the firm's continuing to do what it is presently doing rather than instituting a new program; (2) he also cites the importance of the effect that a product strategy selected now will have on future decisions involving product strategy selection. The technique, however, does not explicitly

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[1]Alfred A. Kuehn and Ralph L. Day, "Strategy or Product Quality," Harvard Business Review, Vol. 40, No. 6, December 1962, pp. 100-110; Elizabeth Marting, Ed., Developing a Product Strategy, American Management Association, New York, 1959; Richard C. Christian, "Industrial Marketing—A Check List for New Industrial Products," Journal of Marketing, Vol. 24, No. 1, 1959, pp. 70-75; James F. Mahar and Dean C. Coddington, New Product Development—Reducing the Risk, SBA Research Report, Denver Research Institute, University of Denver, December 1961; Charles S. Roberts, "Product Selection-Witchcraft or Wisdom," IRE Transactions on Engineering Management, Vol. EM-6, No. 3, September 1959.

[2]Barry M. Richman, "A Rating Scale for Product Innovation," Business Horizon, Summer 1962, pp. 37-44; John T. O'Meara, Jr., "Selecting Profitable Products," Harvard Business Review, Jan-Feb 1961.

[3]Paul E. Green, "Bayesian Statistics and Product Decision," Business Horizons, Fall 1962, pp. 101-109.

relate the effect of current decisions on future decisions and requires a significant amount of subjective parameter estimation each time it is applied.

An attempt was made by Ansoff to structure the product strategy decision problem into a matrix of product-market characteristics.[4] His matrix represented different combinations of product and market changes. If no change occurred in either but company sales were made to increase, this was considered to be market penetration. If both product and market characteristics changed, it was considered to be diversification. Since his major interest was in diversification, he established abstract relationships, that, under given conditions of demand (a product-market selection), would permit him to study two desired results from employing this strategy. These results were: (1) improve the company growth pattern; (2) improve stability of company sales under random influences in the total company environment. Quantitative analysis of the selection of alternative diversification strategies over time is impossible because the alternative strategies (product-market combinations) are abstract representations with no indication of their effect on the firm over time. Furthermore, it is assumed that the firm has adequate capabilities to implement these alternative strategies.

One attempt at representing product strategies as n-tuples (discrete points in n-dimensional space) was made by Shubik. He represented product strategies as combinations of four factors: a product, advertising, quantity, and price. His objective was to discretely represent product strategies within the context of his game models. He also recognized the importance of the strategy of "do nothing" (i.e., do not innovate).[5]

Bacon and Sparrow devised a three-dimensional array of product, process and market characteristics.[6] They defined five discrete possible changes in a product, four in a process, and two in a market, and thus identified forty feasible product strategies which a firm might employ. These range from "no change in product, process or market characteristics" to "addition of a new product in a product line new to the firm, addition of a process forward (vertical integration towards the market) and development of a new market."

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[4] H. I. Ansoff, "A Model for Diversification," Management Science, Vol. 4, No. 64, July 1958, pp. 392-414.

[5] Martin Shubik, Strategy and Market Structure (New York: John Wiley and Sons, Inc., 1960), p. 177.

[6] Frank R. Bacon and Frederick T. Sparrow, Research on Product Development Capabilities of Michigan Firms, Report No. 66223-3-S, Industrial Development Research Program, Institute of Science and Technology, The University of Michigan, April 1962.

Bacon and Sparrow present a logical framework for qualitative analysis that considers the effect of the competitive situation facing a firm and the capabilities of a firm in the selection of an optimal product strategy. Their logical framework, however, is static and qualitative and hence does not permit quantitative analysis of product strategy selection over time. Furthermore, they have not treated the problem of measuring the characteristics that constitute the various product strategies in their model. Thus, one is not certain at what point a major product modification is a new product or still a product modification. Also, the problem of estimating parameters to permit analysis with their model is greatly compounded, with forty product strategies to consider.

The model developed in Chapter III of this thesis is applied in Chapter IV using two product strategies which are shown to be significant for the firms under consideration. Furthermore these two strategies are defined in a way that facilitates the estimation of the parameters of the model.

A significant point abstracted from the writings of the above authors is the meaningfulness and usefulness of discretely representing product strategy alternatives. Attempts to set forth a continuum of product strategies would generate the problem of determining the continuous relationships between alternative product strategies and their effects on the behavior of a firm and the problem of identifying a universal measure which would relate these relationships. These problems have been recognized and summarized well by Edith Penrose in discussing diversification:

> This points out once again the futility of attempting to measure the 'extent of' diversification as such, for there is no single all purpose measure . . . . Clearly, the type of diversification is different and for a study of the growth of firms the type of diversification and the reasons for it are of more relevance than the 'amount' of diversification, whatever that may mean.[7]

One aspect of product strategy selection that is not treated in the previous references is the expected time required for implementation of the selected product strategy. As mentioned earlier, the selection of the product strategy of "change the product price" requires relatively little time to implement. However, the product strategy of "addition of a new product in a product line new to the firm, addition of a process forward and development of a new market" would take considerably longer to implement. It would seem that one could evaluate all feasible product strategies in terms of the time required for implementation. One important aspect of

[7]Edith Penrose, The Theory of the Growth of the Firm (New York: Wiley, 1959), p. 109.

this type of evaluation is the amount of time a firm has to attempt a change in an unfavorable competitive situation that it faces before the firm is forced out of business. If, for example, a firm with limited capabilities tentatively concludes that product strategy "A" is the optimum one to employ, the time required for implementation may be greater than the time the firm has available before reaching a point of bankruptcy. Or the time required to increase the capabilities to handle product strategy "A" might result in a total time or total cost greater than that available to the firm.

The time required to implement a product strategy is a function of the selected product strategy, the capabilities a firm has to handle this product strategy, and certain random effects from the total environment of the firm. The time available to change an unfavorable competitive or profit situation depends basically on the rate at which the competitive position or profit picture becomes worse over time. For some firms, estimates of this time could come from simply computing the time before the rate of yearly loss reduces the effective asset position of a firm to zero.

The nature of product strategies, the selection of strategies over time, and the effects of time on their implementation have been stated by Clark as follows:

> The innovating firm has available a range of policies, in which immediate and long-run advantage and aggressive and defensive considerations may be variously combined. At one extreme, it may aim at maximum short-run profit and meet competition when it arises. Or if it succeeds in recompensing its original outlays while it still holds a competitive advantage, it may then use its advantage, or part of it, to increase volume and build up a stronger market position against the time when its original advantage will have lapsed. Or it may begin the building up of market position earlier, accepting more moderate returns and taking longer to recover its original outlays. And it will be trying to prolong or renew its advantage, installing fresh improvements and preparing to make others.[8]

Different product strategies in the model which is developed in Chapter III will be represented partially in terms of the number of time periods required for implementation.

THE NATURE OF COMPETITION

It was stated earlier that a firm is interested in selecting and implementing product strategies that will improve the competitive position and profitability of the firm. All firms are affected by some aspects of competition. The form, implications, and major determinants of

[8] John M. Clark, Competition as a Dynamic Process (Washington, D. C.: Brookings Institution, 1961), p. 192.

competition vary for industries and firms. Competition in the automotive industry (a small number of large firms) is much different than it is for the machine tool industry (a relatively large number of small firms). For one thing, it appears that the size of the firm carries important implications about the competition that is being faced by a firm. This is not to suggest that large firms do not face as much competitive pressure as small firms but that the large firms, in terms of their total capabilities, generally have more time available to implement product strategies to change an existing unfavorable competitive situation. Shubik considers firm size (measured in terms of total assets) as affording the large firm a greater number of feasible product strategies.[9] This larger set of strategies would include some that required a long time for implementation and eventual pay-off.

The potential effect and hence great importance of competition to small business firms is highlighted by three recent studies. The first study was conducted by the Denver Research Institute.[10] The Institute compiled extensive case histories of a large number of small firms. One of their significant findings concerning the problems of the small firms was the lack of knowledge and understanding of competitive position and expected market demand. The second study asked executives of small business firms in Michigan to identify the two or three most difficult problems facing them today.[11] The problem listed most frequently was competition and in particular that of competition with large national firms. The third study was a study by Dun and Bradstreet of the causes of business failure in 1961.[12] The two primary reasons given by manufacturing firms that failed were (1) inadequate sales and (2) competitive weaknesses.

The need exists, then, to develop a definition and classification scheme for competition that will facilitate the study and analysis of its effects on the behavior of a firm. The essence of competition has been captured in the following statement by Clark:

> Competition is an indispensible mainstay of a system in which the character of products and their development, the amount and ensuring efficiency of production, and the prices and profit margins charged are left to the operation of private enterprise.— Competition presupposes that businesses pursue their own self-interest, and it harnesses this force by their need of securing the customer's favor. By reasons of this discipline, business, which is profit minded, has to become production minded as a means of earning profits dependably.[13]

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[9]Shubik, p. 227.

[10]Mahar and Coddington.

[11]Winston Oberg, "Some Problems Faced by the Small Businessmen in Michigan," The Michigan Economic Record, Bureau of Business and Economic Research, Michigan State University, Vol. 4, No. 11, December 1962.

[12]The Failure Record Through 1961: A Comprehensive Study, Dun and Bradstreet, Inc., 1962.

[13]Clark, p. 9.

This definition identifies competition as a mechanism which relates the profits a firm receives (not necessarily a reflection of the objective of profit maximization) to the fulfillment of market demand. The development of a classification scheme to identify competitive situations that firms face should relate to the characteristics of the market for which a group of firms competes.

One classification scheme is that offered by classical economics where competitive situations are identified according to the classifications of perfect competition, monopolistic competition, oligopoly, and monopoly.[14] Most industries, if not all, will fall into the classifications of oligopoly or monopolistic competition; the distinction being based primarily on the number of competitors relative to the size of the market (few for oligopoly, many for monopolistic competition) and the degree of product differentiation (slight for oligopoly, significant for monopolistic competition). The important distinction between monopolistic competition and oligopoly is that a firm facing a competitive situation within the context of monopolistic competition determines policies independently of any effects which they may have upon the policies of its competitors, whereas a firm in oligopolistic competition determines policies that take into consideration the possible effects which these policies may have upon the actions of its competitors.

The machine tool industry, discussed in Chapter IV, is an example of a monopolistic competitive industry. This has been amply demonstrated by Himes.[15] Therefore, the model developed in this thesis and applied to the Michigan machine tool industry in Chapter IV assumes that firms attempt to select product strategies that are consistent with their capabilities, that will meet the competitive situations they face, and that are independent of the effects these product strategies may have on the firms' competitors. This is merely assuming a situation of monopolistic competition and it has already been indicated that this classification is appropriate for the machine tool industry.

However, there is still the problem of partitioning the various competitive situations that a firm can be in, within the framework of monopolistic competition. It would seem that the key to this problem should be based on the objective that is to be served and the industry that is to be analyzed. Thus, the partitioning scheme used in studying the degree of deviation from an "optimal" allocation of resources would probably be different from that used to study the relative effect of the business cycle on industry products. Or the scheme used to study an industry

[14] See the works by Boulding, Due and Clower, Leftwich, and Stigler, listed in the bibliography.

[15] Robert Stanley Himes, A Study of the Machine Tool Industry with Emphasis on the Problem of Stability, Unpublished Doctoral Thesis, The American University, 1962.

which caters to a localized special market would probably be different from that used to study an industry which attempted to reach a broad general market. This industry-market consideration appears to be a significant factor in determining an appropriate scheme for classifying the competitive situations that firms face within an industry. Even if one could identify ten, twenty, or thirty primary factors that were meaningful in any industrial competitive structure, those that were most significant would probably vary in number and kind, depending on the industry-market relationships.

For example, in Chapter IV, it will be shown that a significant factor which identifies the competitive situations of Michigan machine tool firms in terms of their industry-market relationships is the "size of the firm." It is assumed, then, that the "size of the firm" is a primary factor which explains almost completely the competitive situation of a firm and that other factors, which obviously exist, do not make significant contributions to a better identification of these competitive situations. (This factor is discussed further in Chapter IV.)

CAPABILITIES OF A FIRM

The selection of a product strategy to meet a competitive situation implies the existence of certain capabilities inside the firm to properly implement this strategy. A product strategy involving technological change requires, among other things, qualified engineers to develop and apply the technological changes. A product strategy involving a significant amount of basic research activities requires not only qualified scientists and engineers but also adequate financial capabilities to support the risk of little or no return on a sizeable investment. Product strategies involve not only capabilities of technical personnel and finance, but also certain capabilities in production, marketing, and management. If a firm were to construct a list of feasible product strategies that it could employ, and then indicate the estimated capabilities required in the various functional areas of a firm for the implementation of each strategy, this firm would note immediately the variability in type and amount of capabilities needed. Furthermore, the selection of a product strategy would then be facilitated by comparing the existing capabilities of a firm with those required for strategy implementation. For those strategies where the firm's capabilities are deficient, additional capabilities could conceivably be obtained. However, if the acquisition of capabilities required for certain strategies involves a larger financial investment or longer time period than the firm has available, these strategies would have to be eliminated from the set of the feasible strategies.

The importance of internal capabilities to handle adequately a product strategy has been summarized by Edith Penrose:

Once again, however, the search is necessarily circumscribed by the existing productive services available to the firm, of which the so-called 'intangible' services of managerial and technical skill may be far the most important. Bold ventures require entrepreneurial imagination, large ventures require managerial talent, entry into highly specialized fields requires some specialized ability, acquisition requires cash or at least sufficient standing in the capital market, or general reputation, to make it profitable for another firm to accept an exchange of shares. For firms with none of these, diversification into products which provide promising scope for the future will be difficult indeed.[16]

The preceding statement by Edith Penrose also focuses attention on another significant point concerning firm capabilities. This point pertains to management capabilities. Management capability differs somewhat from the other functional capabilities (such as engineering, production, finance and marketing) in that it must take these other functional capabilities and integrate them into a profitable manufacturing operation. The returns accruing to the firm will depend on the ability of management to carry out this integration process. In a sense, then, one can appraise firm capabilities from two points of view. The first is the assessing of the level of capabilities that exists in a firm (i.e., production capacity, financial resources, number of engineers), and the second is the consideration of the effective use of the given level of capabilities. The effective use of a given level of capabilities is a reflection, then, of management capability.

One can now consider the ultimate returns to a firm (measured in sales, profit, return on investment or market share) to be a reflection of the ability of the firm to capitalize on the potential that exists in the market. The market potential is a function of the firm's competitive situation (i.e., its industry-market relationship), and the exploitation of this potential is a function of the level of capabilities and the effective use of these capabilities within the firm. Ansoff seems to agree in stating:

It happens that business performance of a company is determined both by external characteristics of the product-market strategy and internal fit between the strategy and business resources. The first of these factors is what we have called Profit Potential of the product-market strategy, the second is the Business Fit of the strategy with respect to the diversifying company. Profit potential measures potential earnings as a function of the economic-political environment, characteristics of the demand, and nature of the competition under the assumption that the diversifying company is capable of offering effective competition in the new product-market areas.

Business fit tests the validity of this assumption. It is a measure of the company's ability to penetrate the new market. It is determined by the particular strengths and weaknesses which the company brings to the new venture, such as the capabilities and past experience in engineering, production, finance and merchandising.[17]

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[16]Edith Penrose, p. 142.

[17]Ansoff, p. 413.

The type and structure of management capability that is best for a firm depends on many factors—a fact well stated by Forrester:

> The desired dynamic characteristics of the management structure depend on the kind of markets, rate of technological change, and the other characteristics of the industry . Different organizational forms are seen to favor different classes of products. The management attitudes that work well in one situation falter in another because the life cycle of the product is longer or shorter, the ratios of times needed to develop a product in comparison with the time for putting it into production are different, or the market is more sensitive to certain of its characteristics and less sensitive to others.[18]

However, relative to the market being served and the characteristics of the industry, general conclusions concerning the effectiveness of management have been made. Significant results from two independent studies reach the same conclusion regarding the management of small business firms. These two studies show that only approximately ten percent of all small manufacturing firms have good, effective management.[19] A similar conclusion with respect to attempts to diversify by small firms was reached by Edith Penrose.[20] Thus, attempts to study the selection and implementation of product strategies must recognize the effect of management on the expected results, especially for small and medium-sized firms. The model in this thesis is one way of accounting for the effect that the level of capabilities and the effective use (management capability) of these capabilities within a firm will have on that firm's expected returns.

LONG-RUN ANALYSIS

Economic analysis of a firm is usually accomplished within a time framework of short-run or long-run considerations. The distinction between short-run and long-run analysis depends primarily on the extent to which certain assets of the firm are fixed relative to other assets. It is assumed that in the long run no assets are fixed. This means that the total structure of the firm can be changed, if necessary, to facilitate the implementation of certain strategies.[21]

The topic of this thesis involves a consideration of the effect that decisions made during this time period will have on decisions in future time periods. Short-run analysis usually applies to a time horizon of one time period, whereas long-run analysis applies to a time horizon

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[18]Jay W. Forrester, Industrial Dynamics (New York: Wiley and Sons, 1961), p. 329.

[19]Small Business Management Research Reports, p. 9; W. Arnold Hosmer, "The Small Manufacturing Enterprises," Harvard Business Review, November-December 1957.

[20]Edith Penrose, p. 150.

[21]See footnote 14 of this chapter and bibliography.

of many time periods. However, in the context of this thesis, the use of a time horizon of many time periods does not imply that the structure (such as assets) of the firm will change, although it has the opportunity to change. It is conceivable that a firm's environment and the strategies it has selected to operate in this environment result in a response (such as technological change) that is relatively stable (unchanged) over time. Hence a firm might not change its internal structure.

The importance of being prepared for future decision making is indicated by Clark in the following way:

> All these [new technical methods, new products, new selling tactics, or changed prices] may remain unchanged between active moves and may still embody the resultant of active and effective competitive forces. If so, this implies that preparedness is under way for further moves as occasion may present the need or the opportunity.[22]

Preparedness implies more than having or obtaining capabilities to handle the competitive situations as they arise. It also implies an attempt to employ a product strategy to handle the current competitive situation, consistent with the existing capabilities of a firm, that will increase the likelihood that the competitive situations arising from the use of this product strategy will permit using other product strategies that in the long run will best fulfill the objectives of the firm. Stated differently, this means that the firm should think of using a strategy which best fulfills its objectives in the long run rather than in the short run. Green, recognizing the importance of this, says:

> Thus the decision maker is assured that the best decision now (which happens to be delay one period) has been derived by considering the relationship of this decision to the future decisions that the decision maker visualizes.[23]

The extent to which the long run is important depends on many factors. In general, the future is unknown and hence fraught with many uncertainties. Expectations about the future are difficult to comprehend and even more difficult to estimate. However, general planning for the future is important if only to force a firm to focus on those factors that will probably affect its future activities. More specifically, under certain environmental conditions, it seems very reasonable to attempt to formulate explicit relationships to account for expected results of a firm's current decisions. For example, if technological change in an industry in terms of products and processes is very slow (as in the machine tool industry) and if the industry is economically mature, in the sense that firms have established quality products in the market which

[22]Clark, p. 18.

[23]Green, p. 109.

depend on technical capabilities in the firm (again, as in the machine tool industry)—then, certain parameters in the formulated explicit relationships (such as in production functions) are probably quite constant for a number of time periods into the future. Furthermore, it might then be reasonable to assume that the expected effects of competition and market response to the use of product strategies will not change significantly from one time period to the next.

Under the conditions stated above, the probability of going from competitive situation i to competitive situation j might not change significantly over the next few time periods. Thus, a firm should consider selecting a strategy which will be optimal over the next few time periods and not over the immediate forthcoming time period. Where technological change is rapid (as in the electronics industry) these assumptions might not be meaningful and a firm could be interested in selecting a strategy that is best for the next time period only. Then, the strategy which is best in the long run is the same as the strategy which is best in the short run. Or what is best for a firm in the long run is the summation of the best short-run strategies.

FIRM OBJECTIVES

In the introduction to this thesis, it was stated that a firm is interested in either growth or survival in its environment. This dichotomy is so inclusive as to be exhaustive for those firms that do not fail. If a firm does not fail, it survives. If it develops the capabilities to survive well, it might grow, and this growth, then, could possibly enhance its ability to continue to survive. Our interest in this thesis is in those firms who exist and are surviving.

A question that arises, then, is "What is the objective of the firm?" Much of economic analysis assumes that a firm attempts to maximize its profits. The existence of many other goals, however, serves to temper the objective of maximization of profits. As Clark notes,

> The assumption that a firm pursues maximum profits is an extreme simplification. Indeed, it is a simplification to assume that any unified objective governs all the operations of a firm, especially a large one. This covers up a multitude of divergencies. Theory has a tendency to dispose of these as being either differences of view on what kind of action will maximize profits on a given case, or differences between longer or shorter time perspectives in which profits may be viewed.[24]

Many objectives may be stated as being meaningful for one or more firms. Examples of these objectives are: to maximize share of the market, to minimize costs, to maximize profits, to maximize return on investment, to prevent entry into industry of new competitors, to maximize sales dollars, to grow, to survive, and other more intangible objectives such as fulfilling

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[24]Clark, p. 91.

community responsibilities, and developing a product of good quality. Obviously, this list is not exhaustive; however, enough objectives have been stated so that the following comments can be made.

Regardless of what objectives a firm indicates it is interested in fulfilling, it must realize some profit if it is to survive (this generalization excludes government subsidized activities). Furthermore, rapid technological changes have increased the need for product development activities, and this calls for greater expenditures, which means realizing more profits if these needed programs are to be sustained.

Most, if not all, firms could not possibly fulfill all the above objectives simultaneously. Certain incompatibilities exist in the attainment of some of them. The prevention of firms from entering the market implies a willingness on the part of the firm attempting to fulfill this objective to accept a lower profit rate. The same might hold true for firms that attempt to maximize their share of the market. Certainly, a firm that is vitally concerned with surviving will adopt strategies that more than likely will not be compatible with objectives such as maximizing market share or maximizing profits.

However, quite conceivably, more than one objective might be sought simultaneously. The problem that arises, then, is the determination of the relationships that properly identify the effects that the maximization of profits will have on the maximization of market share. In effect, the firm is attempting to fulfill a dual objective. Since a framework for relating these different objectives is lacking, the analysis of the optimal product strategies that a firm should select must be accomplished in terms of a stated objective. Conceivably, the analysis could be made for alternative objectives to point out differences (or similarities) that exist in the results. For example, in discussing the theory of the growth of the firm, Edith Penrose asserts:

> The assumption that the managers of firms wish to maximize long-run profits derived from investment in the enterprise itself has an interesting implication for the relation between the desire to grow and the desire to make profits. If profits are a condition of successful growth, but profits are sought primarily for the sake of the firm, that is, to reinvest in the firm rather than to reimburse owners for the use of their capital or their 'risk bearing,' then, from the point of view of investment policy, <u>growth and profits become equivalent as the criteria for the selection of investment programmes.</u>[25]

One final point deserves comment. It is possible to think of a so-called "firm objective" as being a constraint on the firm. The fulfillment of certain community responsibilities might

[25] Edith T. Penrose, p. 30.

simply reflect the desire on the part of the firm to avoid unionization. Hence, part of the profit accruing to the firm goes for higher wages, worker benefits and contributions to community projects. The objective of maximizing the firm's share of the market might be a constraint for a firm like General Motors. As the share of the market increases, a firm tends more and more toward a monopolistic situation and hence potential government intervention. In fact, the objective of profit maximization could be a restraint for a firm in the sense that too much profit might place the firm in a vulnerable position for the next union contract. A good summary statement concerning objectives is given by Clark:

> Profit maximization may be the most nearly dominant motive of the business firm, but it is part of a complex, the whole of which cannot be understood in terms of profit maximization alone.[26]

In Chapter IV of this thesis, the objective of maximizing market share is used in determining optimal product strategies for a machine tool firm. Justification for the use of this single objective is presented in that chapter. The potential results from using other objectives are discussed in Chapter V.

[26]Clark, p. 96.

CHAPTER II

MARKOV PROCESSES AND DYNAMIC PROGRAMMING

The model developed in Chapter III represents an extension of Ronald A. Howard's dynamic model presented in his book Dynamic Programming and Markov Processes.[1] Since this model represents an integration of Markov processes into a dynamic programming framework, it is felt that a brief discussion of each subject area is necessary. The objective in this chapter will be to present only the basic structure of each and the specific formulation of Howard's model.

THE NATURE OF MARKOV PROCESSES

The term "Markov process" describes a very large and important class of stochastic processes. A stochastic process is a process in which random phenomena arise over time in a manner controlled by probabilistic laws. If the time framework represents discrete time periods, the stochastic process is said to be a discrete parameter process. If the time framework represents continuous time, then the stochastic process is said to be a continuous parameter process. A stochastic process is characterized by the states which occur and by a measure which specifies the probability that at any given time the process will be in a particular state.

A Markov process is a special kind of stochastic process for which the probability of being in a given state at time t_2 may be derived from a knowledge of its state at any earlier time t_1 and does not depend on the history of the system before t_1. This process depends only on what happened during the last time interval, and is thus characterized by what is called the Markov property. The Markov property is essentially that "the probability law of the future development of the process, once it is in a given state depends only on the state and not on how the process arrived in that state."[2] Hence, given the "present," the "future" may be thought of as being independent of the "past."

A Markov chain is a special case of a Markov process in that its state space is discrete rather than continuous. The model in this thesis uses Markov chains.

The Markov chain can be best exhibited by a transition probability matrix. If we assume

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[1] Ronald A. Howard, Dynamic Programming and Markov Processes (New York: Wiley and Sons, 1960).

[2] Emanuel Parzen, Stochastic Processes (San Francisco: Holden-Day, 1962), p. 187.

that n states exist, then the following matrix would represent the probabilistic structure of the process:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix} \qquad (1)$$

Each ij-th element (p_{ij}) of P represents the probability that the process would make a transition from state i to state j during the next time period, given that the process is now in state i.

Several properties of P are important. The matrix P is an $n \times n$ (square) matrix in every case. The elements p_{ij} are non-negative and the sum of each row is unity. A matrix with these properties is said to be stochastic, and each row of a stochastic matrix can be regarded as a probability distribution.

The basic concepts of a Markov chain, then, are "state" of the process and state "transition." Since the subsequent development of the model in this thesis depends on certain properties of the states of a Markov chain (or Markov process), a classification scheme and its properties will be summarized here. The classification scheme presented is that of Feller.[3]

(1) Transient States. A state S_i is said to be transient if $f_i < 1$, where f_i represents the probability that, starting from S_i, the process returns to S_i. The probability of never returning, then, is positive and takes on the value $(1 - f_i)$. Thus, for a transient state S_i, f_{ij} is the probability that, starting from S_i, the process reaches S_j and $(1 - f_{ij})$ is the probability that, starting from S_i, the process will never reach S_j.

(2) Persistent States. A state S_i is persistent if $f_1 = 1$; that is, it is certain that, starting from S_i, the process will return to S_i in a finite number of time periods. A state S_i is persistent null, if $f_i = 1$, but the time required to return to S_i is infinite. A state is periodic if there exists some number k such that, starting from S_i, the process returns to S_i only after some integral multiple of k steps (i.e., k, 2k, 3k, . . . steps). A state is ergodic if it is persistent,

[3] William Feller, An Introduction to Probability Theory and Its Applications, Vol. I, 2nd Ed. (New York: Wiley, 1957), p. 353.

non-null, and non-periodic.[4] Thus, in an ergodic chain it is possible after a sufficiently large number of periods to go from any state S_i to any state S_j. An ergodic state S_i is said to be absorbing if it is certain that once S_i is reached it cannot be left; i.e., if

$$P_{ij} = \begin{cases} 0 & \text{If} \quad i \neq j \\ 1 & \text{If} \quad i = j \end{cases}$$

A set of ergodic states which contains no absorbing states is said to be irreducible. This means that it is possible to go from any state to any other state, and vice-versa.

This thesis and Howard's model are developed primarily in terms of irreducible Markov chains (or processes).

From the above classification scheme, many important theorems can be proved. These theorems pertain to the existence and uniqueness of certain properties of Markov chains and to operational techniques for the computation of numerical results. The statements, proofs, and illustrations of these basic theorems are thoroughly presented by Feller and Kemeny and Snell.[3,4]

The theorems and properties of Markov chains that are needed in this thesis will be stated at the appropriate time and references will be cited which prove and illustrate these theorems and their properties.

AN ECONOMIC INTERPRETATION OF THE MARKOV PROPERTY

The extent to which the past influences the future of a process depends on the process and its environment. Certain processes, such as mechanical processes, are strongly influenced by the past behavior of the process. For example, in the theory of plasticity, the whole past history influences its future. In many processes, however, the past has a negligible affect on the future of the process. This could mean that either it doesn't affect the process at all or it affects the process but not significantly.

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[4] See John G. Kemeny and J. Laurie Snell, Finite Markov Chains (Princeton, N. J.: Van Nostrand, 1960). Kemeny and Snell allow an ergodic state to be periodic. This really does not differ from Feller's classification scheme as shown in the following theorem which he proves on page 361.

Theorem. In an irreducible periodic Markov chain the states can be divided into t groups $G_0, \ldots G_{t-1}$ so that a one-step transition from a state G_i always leads to a state G_{i+1} (to G_0 if $i = t - 1$). If we consider the chain only at times t, 2t, 3t, . . . , then we get a new chain whose matrix of transition probabilities is P^t. In it each G_i forms an irreducible closed set.

The Markov property, discussed in the previous section, asserts that only one time period of history is important in accounting for the past. (To be technically correct, we should say a Markov process of first order. The present state of a second-order Markov process is a function of the last two time periods.) The question that naturally arises in the context of this thesis is: "Is this property of Markov processes economically meaningful?"

The economic discussion, so far, has centered around the selection of product strategies by a firm to meet its competitive situations. The selection of a product strategy is a decision that is made relative to the existing, and conceivably future competitive situation. Although many paths (routes) exist by which a firm could have arrived at its existing competitive situation, the important fact is that it is in this competitive situation. Outside of any illegal or perhaps highly questionable means employed by a firm to reach its current competitive situation, the past is probably not too significant in terms of the future operations of most firms. Immediately, questions can be raised concerning the importance of the quality of the product (built up over time, hence a result of the past), the name of the company (implying perhaps quality or good will), the technical skills that have accumulated as a result of strategies used in the past, and other factors that imply the passage of time. That these factors are important is not questioned. However, these factors reflect certain capabilities that now exist in a firm to handle a wider range of product strategies than those firms who lack these capabilities. These factors do not change the competitive situation which the firm now faces. The important decision is to select a strategy(ies) that, consistent with the current capabilities (which might reflect certain strategies used in the past) of a firm, will meet the firm's existing and future competitive situations. Thus, the Markov property implies that the competitive positions the firm faces the next time period and future time periods are a function of the product strategy employed to meet its existing competitive situation. One exception to the implication of this property involves the differing periods of time required to implement the various feasible product strategies. If, for example, a product strategy of developing a completely new and different product requires four time periods to implement, then in time period t_3 (assuming the process started at t_0), the importance of the decision made at time t_0 is still being felt. However, the development of the model in Chapter III will indicate the inclusion of this time factor into the Markov framework.

Many authors have studied the meaningfulness and use of the Markov process (with its accompanying Markovian property) in economic analysis.[5]

THE NATURE OF DYNAMIC PROGRAMMING[6]

The importance of accounting for the effect of a current decision made by a system on the future decisions that it will have to make was discussed in Chapter I. This means that we must attempt to structure a model that will reflect this phenomenon over time. In general, then, we are interested in multistage decision processes.

Our specific interest will be the kind of dynamic systems that have the following properties:

(1) The behavior over time can be interpreted in terms of the iteration of a point transformation. This means, simply, that if we look at the state of a system at time $t_1 + t_2$ (assuming that we started the process at t_0), we would note the same state as that we would have observed had we stopped the process at t_1, observed its state, and then with this state as our starting point permitted the system to operate for an additional time t_2.

(2) The transformation that is applied to the system at various points of time is dependent upon the time at which it is applied.

(3) The transformation that is applied will also be dependent upon the state of the system.

These properties of a multistage decision process can be represented symbolically by letting $[T(p, q)]$ be a family of transformations where q represents the decision variable and p the state of the system. In general the q that will be chosen will depend upon p, that is, $q = q(p)$. Since our interest is in discrete multistage decision processes, the development will be in that vein.

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[5]See for example Edgar A. Pessemier, Experimental Methods of Analysing Demand for Branded Consumer Goods With Applications to Problems in Marketing Strategy, Institute for Quantitative Research in Economics and Management, Graduate School of Industrial Administration, Purdue University, 1962; F. T. Sparrow, A Queuing Theory Model of Market Equilibrium, Unpublished Doctoral Thesis, The University of Michigan, 1963; Irma Adelman, "A Stochastic Analysis of the Size Distribution of Firms," Journal of the American Statistical Association, No. 53, December 1958, pp. 893-904; William H. Hannum, An Approach to the Problem of Analysing the Size Distribution of an Industry, Unpublished Doctoral Thesis, The University of Michigan, 1963; L. E. Preston and E. J. Bell, "The Statistical Analysis of Industry Structure: An Application to Food Industries," Journal of the American Statistical Association, No. 56, December 1961, pp. 925-932.

[6]The material in this section is abstracted from Richard Bellman, Dynamic Programming (Princeton University Press: 1957); Richard Bellman, Adaptive Control Processes—A Guided Tour (Princeton University Press: 1961).

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[7]Bellman, Adaptive Control Processes, p. 54.

We define the index n to be the number of stages (time periods) in our analysis. Then the value (reward, return) of our process over the n time periods is

$$f(p_1, p_2, \ldots, p_n; q_1, q_2, \ldots, q_n) \tag{2}$$

where

$$p_2 = T(p_1, q_1) \tag{3}$$

$$\begin{aligned} p_3 &= T(p_2, q_2) \\ &\vdots \end{aligned} \tag{4}$$

$$p_n = T(p_{n-1}, q_{n-1}) \tag{5}$$

Our objective, then, is to select a sequence of decisions $q_1, q_2, \ldots, q_n$ such that Equation 2 is maximized. We note that this means maximizing a function of n variables (Equation 2 could be rewritten to eliminate the p_i, since $q_i = q(p_i)$). Unless Equation 2 is a function of particularly simple form, the problem of solving n partial differential equations cannot be resolved analytically. Even when these are linear, partial differentiation may not be a feasible method of solution of the original maximization problem. Thus, we arrive typically at some type of search problem, to which search techniques should be applied.

The resolution of this problem results from some assumptions made concerning the form of Equation 2. The basic property that this function will possess is one of a Markovian nature. This property is described thus by Bellman:

> After any number of decisions, say k, we wish the effect of the remaining n-k stages of the decision process upon the total return to depend only upon the state of the system at the end of the k-th decision and the subsequent decisions.[7]

The model developed in Chapter III of this thesis involves the use of the Markov property in the transition matrix of probabilities and the time framework for product strategy selection. Thus, the discussion in the previous section of the meaningfulness of the Markov property, in general, to economic systems and specifically to the model in this thesis is relevant to the multi-stage decision process being presented in this section.

This assumption, then, permits us to rewrite Equation 2 as

$$q(p_1, q_1) + q(p_2, q_2) + \ldots + q(p_n, q_n) \tag{6}$$

[7] Bellman, Adaptive Control Processes, p. 54.

Assuming further that the maximum of Equation 6 exists, that q_i ranges over a finite set of values, and that q(p, q) is finite for all finite p and q, the development of the functional equation proceeds in the following way.[8]

Let $f_n(p_1)$ be the maximum return over the next n time periods starting in state p_1. Then

$$f_n(p_1) = \underset{q_i}{\text{Max}} \, [q(p_1, q_1) + q(p_2, q_2) + \ldots, + q(p_n, q_n)] \tag{7}$$

Equation 7 can be rewritten as

$$f_n(p_1) = \underset{q_1}{\text{Max}} \, \underset{q_2}{\text{Max}} \ldots \underset{q_n}{\text{Max}} \, [q(p_1, q_1) + q(p_2, q_2) + \ldots + q(p_n, q_n)] \tag{8}$$

The separability of Equation 8 permits us to write this relation in the form

$$f_n(p_1) = \underset{q_1}{\text{Max}} \left\{ q(p_1, q_1) + \underset{q_2}{\text{Max}} \, \underset{q_3}{\text{Max}} \ldots \underset{q_n}{\text{Max}} [q(p_2, q_2) + \ldots + q(p_n, q_n)] \right\} \tag{9}$$

We then note that a process with n-1 time periods remaining has the relation

$$f_{n-1}(p_2) = \underset{q_2}{\text{Max}} \, \underset{q_3}{\text{Max}} \ldots \underset{q_n}{\text{Max}} \, q(p_2, q_2) + \ldots + q(p_n, q_n) \tag{10}$$

By using Equation 10, we can simplify Equation 9 to

$$f_n(p_1) = \underset{q_1}{\text{Max}} \, [q(p_1, q_1) + f_{n-1}(p_2)] \tag{11}$$

Since $p_2 = T(p_1, q_1)$, Equation 11 may be written as

$$f_n(p_1) = \underset{q_1}{\text{Max}} \left\{ q(p_1, q_1) + f_{n-1}[T(p_1, q_1)] \right\} \tag{12}$$

for n = 2, 3, ...

For n = 1, we get

$$f_1(p_1) = \underset{q_1}{\text{Max}} \, q(p_1, q_1) \tag{13}$$

We have thus decomposed the problem of choosing a point in n-dimensional space into one of n choices of points in one-dimensional space.

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[8] Ibid., pp. 55-56.

Equation 12 provides the framework for decision making over time. With it, we attempt to determine that product strategy (q_1) which, implemented now, is optimal for the next n time periods and not necessarily optimal for the immediately forthcoming time period. The potential effect of the use of a product strategy this time period on the selection of future product strategies (where the sequence of n product strategies constitutes the decision vector over the n time periods) is explicitly accounted for in this relationship. It must be pointed out however, that this process is backward in application. The use of $f_1(p_1)$ implies that the process has one period remaining. Then, $f_2(p_2)$ implies that we determine the best strategy to employ with two periods remaining, under the condition that we know the best strategy to employ with one period remaining. This relationship builds up recursively to an n-state process. However, this does not imply complete determinism. Stochastic processes can be handled with this framework.

A short deductive approach to the development of the functional equation is based on Bellman's "Principle of Optimality" which states:

> An optimal policy has the property that whatever the intial state and the initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision.[9]

Using this principle, the recursive functional equation is derived in the following way. Suppose that we make an initial decision q_1. The result of this decision is to transform p_1 into $T(p_1, q_1)$ and to reduce an n-stage process to an (n-1)-stage process. The use of the principle of optimality permits us to assert that the contribution to the maximum return from the last (n-1) stages will be $f_{n-1}[T(p_1, q_1)]$. This is a reflection of the Markovian property discussed earlier in this section. Since q_1 will be selected to maximize total return, the functional relationship for an n-stage process is

$$f_n(p_1) = \max_{q_1} \left\{ q(p_1, q_1) + f_{n-1}[T(p_1, q_1)] \right\} \tag{14}$$

The combination of dynamic programming and Markov processes is the subject of the next section. However, one final point concerning dynamic programming should be made.

Equation 14, Bellman's functional equation, contains a certain duality with respect to its use in studying a multi-stage decision process. This duality arises from the relationship of the function $f_n(p_1)$, which measures the maximum return, and the policy q_1, which yields this maximum return. This means that the functional equation can be considered from two points of view: (1) approximation in function space; and (2) approximation in policy space. Approximation in

[9] Bellman, Dynamic Programming, p. 83.

function space results from iterating the functional equation over the time periods (stages) for a given policy. Approximation in policy space implies iterating the functional equation over the set of feasible policies for a given number of time periods. That approximation in policy space results in a monotone convergence to the optimal policy is proved by Bellman.[10] Furthermore, approximation in policy space offers certain advantages as indicated in the following statement by Bellman:

> Just as we can approximate in the space of functions $f_n(p_1)$, so we can approximate in the space of policies, q_1. Furthermore, in many ways, this is a more natural and simpler form of approximation. The advantage of this type of approximation analytically is that it always leads to monotone approximations. From the standpoint of applications, it is by far the more natural approximation since it is usually the one part of the problem about which a certain amount is known as a result of experience.[11]

The model developed in the next section of this chapter utilizes "approximation in policy space" to determine the policy that maximizes return for an infinite stage process. For finite stage processes of short duration, recourse is taken to "approximation in function space."

HOWARD'S DYNAMIC MODEL[12]

The dynamic model presented in this section incorporates concepts of Markov processes into the framework of dynamic programming. The stochastic elements that are introduced into this framework are the discrete probabilities of making transitions from one state of the process to another during the next time period.

Let an m-state Markov process earn a return of r_{ij}^k units when it makes a transition from state i to state j, during the next time period, by means of alternative k. We define by the index k, a finite set of alternatives that a process can use in making a transition from state i to state j. The different alternatives, then, represent different sets of probability transition and return matrices. The sets of probability transition and return matrices can be represented schematically in the following way:

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[10] Ibid., pp. 18-19.

[11] Ibid., p. 17.

[12] The material in this section is abstracted from Howard, Dynamic Programming and Markov Processes.

$$
\begin{array}{c|cccc|}
 & 1 & 2 & \cdots & m \\
\hline
1 & p_{11}^{1} & p_{12}^{1} & \cdots & p_{1m}^{1} \\
2 & p_{21}^{1} & p_{22}^{1} & \cdots & p_{2m}^{1} \\
\vdots & \vdots & \vdots & & \vdots \\
m & p_{m1}^{1} & p_{m2}^{1} & \cdots & p_{mm}^{1} \\
\hline
\end{array}
\qquad
\begin{array}{c|cccc|}
 & 1 & 2 & \cdots & m \\
\hline
1 & r_{11}^{1} & r_{12}^{1} & \cdots & r_{1m}^{1} \\
2 & r_{21}^{1} & r_{22}^{1} & \cdots & r_{2m}^{1} \\
\vdots & \vdots & \vdots & & \vdots \\
m & r_{m1}^{1} & r_{m2}^{1} & \cdots & r_{mm}^{1} \\
\hline
\end{array}
$$

$$
\begin{array}{c|cccc|}
 & 1 & 2 & \cdots & m \\
\hline
1 & p_{11}^{2} & p_{12}^{2} & \cdots & p_{1m}^{2} \\
2 & p_{21}^{2} & p_{22}^{2} & \cdots & p_{2m}^{2} \\
\vdots & \vdots & \vdots & & \vdots \\
m & p_{m1}^{2} & p_{m2}^{2} & \cdots & p_{mm}^{2} \\
\hline
\end{array}
\qquad
\begin{array}{c|cccc|}
 & 1 & 2 & \cdots & m \\
\hline
1 & r_{11}^{2} & r_{12}^{2} & \cdots & r_{1m}^{2} \\
2 & r_{21}^{2} & r_{22}^{2} & \cdots & r_{2m}^{2} \\
\vdots & \vdots & \vdots & & \vdots \\
m & r_{m1}^{2} & r_{m2}^{2} & \cdots & r_{mm}^{2} \\
\hline
\end{array}
$$

$$
\vdots \qquad\qquad\qquad\qquad \vdots
$$

$$
\begin{array}{c|cccc|}
 & 1 & 2 & \cdots & m \\
\hline
1 & p_{11}^{k} & p_{12}^{k} & \cdots & p_{1m}^{k} \\
2 & p_{21}^{k} & p_{22}^{k} & \cdots & p_{2m}^{k} \\
\vdots & \vdots & \vdots & & \vdots \\
m & p_{m1}^{k} & p_{m2}^{k} & \cdots & p_{mm}^{k} \\
\hline
\end{array}
\qquad
\begin{array}{c|cccc|}
 & 1 & 2 & \cdots & m \\
\hline
1 & r_{11}^{k} & r_{12}^{k} & \cdots & r_{1m}^{k} \\
2 & r_{21}^{k} & r_{22}^{k} & \cdots & r_{2m}^{k} \\
\vdots & \vdots & \vdots & & \vdots \\
m & r_{m1}^{k} & r_{m2}^{k} & \cdots & r_{mm}^{k} \\
\hline
\end{array}
$$

where

$$0 \leqq p_{ij}^{k} \leqq 1$$

$$\sum_{j=1}^{m} p_{ij}^{k} = 1 \qquad i = 1, 2, \ldots m$$

and r_{ij}^{k} takes on any real value for all i, j, and k.

Let $v_i(n)$ be the maximum total expected returns in n time periods starting from state i if an optimal policy is followed.

A policy has been determined when $d_i(n)$, which specifies which strategy to use for state i at stage n, has been specified for all i and n. The optimal policy is the one that maximizes total expected returns for each i and n.

It follows from Equation 14 that for any n

$$v_i(n) = \underset{k}{\mathrm{Max}} \sum_{j=1}^{k} p_{ij}^{k} \left[r_{ij}^{k} + v_j\,(n-1) \right] \qquad n = 0, 1, 2, \ldots \tag{15}$$

Equation 15 can be explained verbally in the following way:

Suppose that we make a transition from state i to state j during the next time period, using alternative k. The result is a return, r_{ij}^{k}, and a reduction of an n-stage process to an (n - 1)-stage process. The use of the principle of optimality permits us to assert that the contribution to the maximum return from the last (n - 1) stages will be $v_j(n - 1)$, since we are now in state j. However, the transition from state i to state j has a specified probability of occurring $\left(p_{ij}^{k}\right)$. Hence, multiplying the potential returns by the probability of receiving them and summing over the possible states the process could make a transition into from state i gives the total expected returns for the n-stage process using alternative k. Maximizing this expression over the set of k alternatives, then, gives the maximum total expected returns for an n-stage process starting in state i.

The use of Equation 15 will permit us to generate the maximum total expected returns for any n as a function of the state from which the process starts making its transitions. Thus, the decision vector $d_i(n)$ will give us the optimal strategy to use as a function of the state from which the process starts and the number of stages before termination of the process.

The iteration of Equation 15 over n represents "approximation in function space" according to Bellman, or "value iteration" according to Howard. For processes of short duration this iteration method is appropriate. For a given n, the optimal decision vector and the maximum total expected returns can be determined.

Suppose, however, that a process represented by Equation 15 is allowed to make transitions for a very, very long time. The total expected returns depend upon the total number of transitions that the system undergoes, so that this value grows without limit as the number of transitions increases. A useful quantity to employ, then, is the average return of the process per transition.

Before we state the analytic results which indicate how to maximize this quantity, a pertinent and important theorem concerning Markov processes is here paraphrased:

> Theorem: If P is the transition matrix for a finite, aperiodic, irreducible Markov chain, then the powers of P^n approach a stochastic matrix Π, each row of which is identical.[13] (That is, $P^n \rightarrow \Pi$ as $n \rightarrow \infty$.)

This means that we obtain a matrix thus:

$$\Pi = \begin{bmatrix} \pi_1 & \pi_2 & \cdots & \pi_m \\ \pi_1 & \pi_2 & \cdots & \pi_m \\ \vdots & \vdots & & \vdots \\ \pi_1 & \pi_2 & \cdots & \pi_m \end{bmatrix} \tag{16}$$

If we assume that the probability transition matrix in the process is finite, aperiodic, and irreducible (which means that it is possible to go from any state to any other state in a finite number of transitions), then the limiting state probabilities π_i are independent of the starting state and the average return per transition, g, is

$$g^k = \sum_{i=1}^{m} \pi_i^k q_i^k \tag{17}$$

[13] Kemeny and Snell, p. 70.

where

$$q_i^k = \sum_{j=1}^{m} p_{ij}^k r_{ij}^k$$

The asymptotic form of Equation 15 was found by Howard to be

$$v_i(n) = n\,g + v_i \qquad (18)$$

Then, using Equations 15, 17, and 18, Howard derives his policy-iteration method.[14] This method is represented and used operationally as follows:

Use p_{ij} and q_i for a given k to solve

$$g + v_i = q_i + \sum_{j=1}^{m} p_{ij} v_j \qquad i = 1, 2, \ldots m \qquad (19)$$

for all relative values v_i and g by setting $v_m = 0$. For each state i, find the alternative k' that maximizes

$$q_i^k + \sum_{j=1}^{m} p_{ij}^k v_j \qquad (20)$$

using the relative values v_i of the previous policy. Then k' becomes the new decision in the i-th state, $q_i^{k'}$ becomes q_i and $p_{ij}^{k'}$ becomes p_{ij}.

This iteration scheme is repeated until the optimal decision vector is determined.

The policy-iteration method just described has the following properties:[15]

(1) The solution of the sequential decision process is reduced to solving sets of linear simultaneous equations and subsequent comparisons.

(2) Each succeeding policy found in the iteration cycle has a higher average return per transition than the previous one.

(3) The iteration cycle will terminate on the policy that has the largest average return per transition attainable within the realm of the problem; it will usually find this policy in a small number of iterations.

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[14] Howard, pp. 32-37; pp. 42-43.

[15] Ibid., p. 39.

The use of Bellman's term "approximation in policy space" is misleading in the context of Howard's model, since Howard's policy-iteration method is an algorithm for determining the optimal decision vector and not an approximation to it. Convergence, in Howard's algorithm, then, occurs with respect to the optimal policy. This has several interesting consequences.

First, the set of feasible policies is discretely represented and finite. Hence, the optimal policy is obtained after a finite number of iterations and not "approached," as in "approximation in functional space."

Second, although the number of states into which and from which transitions are made may be large, Howard has found that convergence in policy space usually occurs in a small number of iterations if the number of alternatives is small relative to the number of states.

Third, it is quite conceivable that while convergence in function space is slow (i.e., requiring many iterations), convergence in policy space may be fast (i.e., requiring few iterations). Stated in other terms, this means that the transient behavior of a Markov process (e.g., the transition probability matrices in Howard's model) may require a large number of iterations to reach steady state conditions, but the policy that is optimal for these states may result after only a few iterations.[16] This consequence also has implications for sensitivity analysis, where one is interested in the extent to which parameters of the system can change without affecting the optimal policy. Thus, if market sales potential should decrease by, let us say, one-half, the optimal policy to obtain the maximum sales under these new market conditions might be the same even though the maximum total expected sales value would be different.

The policy-iteration algorithm of Howard is based on an infinite stage process. The optimal decision vector that is obtained gives the optimal strategy for each state of the system independent of the starting state. For certain economic processes where one is interested in equilibrium analysis, this assumption is meaningful. Even here, however, limitations may exist which restrict the use of Markov processes for economic analysis. For example, if the time interval required for convergence (and hence equilibrium) is greater than the time interval between expected changes in the parameters of the process, equilibrium is never reached and the optimal decision vector will be a function of the starting state of the process. This means that recourse must be taken to transient analysis, simulation, or attempts to include in the analytic framework some mechanism that explicitly accounts for expected changes in these parameters.

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[16] However, it would not be too difficult to construct situations where convergence in policy space would require a very large number of time periods even though the number of strategies is small relative to the number of states in the system.

However, the analysis of certain economic systems must consider the starting or existing state of the system. The use of transient analysis, then, permits one to study the optimal decision vector as a function of the existing state and the "planning horizon" (number of stages). "Approximation in function space" or value-iteration is used to generate the desired results. For example, the product strategy that a machine tool firm selects is very definitely a function of the competitive situation that it is currently in and the planning horizon for the firm. Therefore, product strategies that are selected independently of the existing competitive situation neglect very real and important information. Furthermore, it will be shown in Chapter IV that convergence of the probability transition matrices for the machine tool industry requires approximately 60-80 years. This interval is certainly greater than the time interval between expected significant changes in the probability values.

CHAPTER III

DEVELOPMENT OF THE MODEL

The objective of this chapter is to develop a general model for the analysis of product strategy selection that will be applied to the Michigan machine tool industry in Chapter IV. This model is an extension of Howard's dynamic model presented in Chapter II. Although certain aspects of the model in this chapter will not be used in the application in Chapter IV, the total structure of the model is presented to indicate its generality and scope.

THE VARIABLES OF THE MODEL

Competitive Situation. Let $CS = \{CS_1, CS_2, \ldots, CS_m\}$ be the exhaustive set of mutually exclusive competitive situations that a firm can be in. This set is conceived to be a set of competitive situations that would be appropriate for any firm operating in a specified competitive environment. Any element of this set, then, represents a particular combination of those factors that are judged to be most important in describing the specified competitive environment and that identify a unique state in which a firm can be found. For example, in Chapter IV it will be shown that the factor of "size of the firm" is the major determinant of the competitive situations that face Michigan machine tool firms. Thus, the exhaustive set of mutually exclusive competitive situations for these firms will be the set of "size interval" classes that identify differences in firm size.

Product Strategy. Let $PS = \{PS^1, PS^2, \ldots, PS^k\}$ be the exhaustive set of k mutually exclusive product stategies that a firm can employ when faced with any of the CS_i $(i = 1, 2, \ldots, m)$ competitive situations. Conceptually this set could be very large, as indicated in Chapter I. However, it will contain two product strategies for the machine tool firms discussed in Chapter IV. The first product strategy (PS^1) will be "continue to do what you are presently doing" and the second one (PS^2) will be "do something in addition to what you are presently doing." The exact meaning of these product strategies and their industry-market relationships are explained in detail in Chapter IV.

Probability Transition Matrix. Let $P^k = \left\{p_{ij}^k\right\}$ be a matrix of transition probability values for making a transition from any one competitive situation to any other according to a specified product strategy. Thus, p_{ij}^k is the probability that during the next time period a firm now in CS_i will make a transition to CS_j by employing PS^k. For k = 1 we have the following matrix:

	CS_1	CS_2		CS_m
CS_1	p_{11}^1	p_{12}^1	...	p_{1m}^1
CS_2	p_{21}^1	p_{22}^1	...	p_{2m}^1
⋮	⋮	⋮		⋮
CS_m	p_{m1}^1	p_{m2}^1	...	p_{mm}^1

where $0 \leq p_{ij}^1 \leq 1$

$$\sum_{j=1}^{m} p_{ij}^1 = 1 \qquad i = 1, 2, \ldots, m$$

If k = 1, 2, . . . , r, then r matrices similar to the one above would exist, one for each product strategy. It is conceivable that one or more product strategies would not be applicable to one or more of the competitive situations, in which case the appropriate p_{ij}^k would be equal to zero for all j for the specified i. Also, it may not be possible to make a transition from CS_i to CS_j during the next time period. Hence p_{ij}^k would be equal to zero for all k. However, it must be possible to make the transition from CS_i to CS_j after a finite number of transitions if the process is to be ergodic. For example, if the size of a firm is a significant factor in the identification of a firm's competitive position in its environment, and the probability transition matrix gives probabilities for making transitions from one size class to another, it might be impossible to make a transition from a very small firm to a very large firm in one time period. But this movement must be possible after a finite number of time periods.

The requirement of more than one time period to make a transition might also reflect the time required for implementing a selected product strategy. We will return to this point later in the chapter.

Return Matrix. Let $R^k = \{r_{ij}^k\}$ be a matrix of returns to a firm as it makes transitions from one competitive situation to another using a specified product strategy. That is, r_{ij}^k is the return a firm receives, if by using PS^k it makes a transition from CS_i to CS_j. For a given measure of return then, we have the following sets of associated probability transition and return matrices:

$$
\begin{array}{c|cccc|}
 & CS_1 & CS_2 & \cdots & CS_m \\
\hline
CS_1 & p^1_{11} & p^1_{12} & \cdots & p^1_{1m} \\
CS_2 & p^1_{21} & p^1_{22} & \cdots & p^1_{2m} \\
\vdots & \vdots & \vdots & & \vdots \\
CS_m & p^1_{m1} & p^1_{m2} & \cdots & p^1_{mm} \\
\hline
\end{array}
\qquad
\begin{array}{c|cccc|}
 & CS_1 & CS_2 & \cdots & CS_m \\
\hline
CS_1 & r^1_{11} & r^1_{12} & \cdots & r^1_{1m} \\
CS_2 & r^1_{21} & r^1_{22} & \cdots & r^1_{2m} \\
\vdots & \vdots & \vdots & & \vdots \\
CS_m & r^1_{m1} & r^1_{m2} & \cdots & r^1_{mm} \\
\hline
\end{array}
$$

$$
\vdots \qquad\qquad\qquad\qquad \vdots
$$

$$
\begin{array}{c|cccc|}
 & CS_1 & CS_2 & \cdots & CS_m \\
\hline
CS_1 & p^k_{11} & p^k_{12} & \cdots & p^k_{1m} \\
CS_2 & p^k_{21} & p^k_{22} & \cdots & p^k_{2m} \\
\vdots & \vdots & \vdots & & \vdots \\
CS_m & p^k_{m1} & p^k_{m2} & \cdots & p^k_{mm} \\
\hline
\end{array}
\qquad
\begin{array}{c|cccc|}
 & CS_1 & CS_2 & \cdots & CS_m \\
\hline
CS_1 & r^k_{11} & r^k_{12} & \cdots & r^k_{1m} \\
CS_2 & r^k_{21} & r^k_{22} & \cdots & r^k_{2m} \\
\vdots & \vdots & \vdots & & \vdots \\
CS_m & r^k_{m1} & r^k_{m2} & \cdots & r^k_{mm} \\
\hline
\end{array}
$$

It must be recognized, however, that the return a firm receives by using a specific product strategy is also a function of the capabilities a firm has to implement the selected product strategy. It could be assumed for example, that these returns represent what a firm will receive if it uses with maximum effectiveness its existing capabilities to implement the selected product strategy. Obviously, this statement implies the existence of capabilities within a firm to handle a selected product strategy. If a firm does not have adequate capabilities to implement a product strategy, its return could be zero. Thus, the model must account for the effects that the level of capabilities and the effective use of this level will have on potential returns.

Effective Use Of Firm's Existing Capabilities. Let $a = (a^1, a^2, \ldots, a^k)$ be a vector of weights which represents for a firm the effectiveness with which the firm uses its existing capabilities to handle each of the product strategies. Thus a^k is the effectiveness with which the firm uses its capabilities to implement PS^k. In Chapter I, it was indicated that the effective use of a firm's capabilities represented the activities of management, which is also a capability of the firm. Hence, the vector "a" could represent a measure of the effectiveness with which management can integrate the firm's capabilities to implement any one of the feasible product strategies.

If we assume that the maximum effective use of a firm's capabilities results in receiving the total potential return that exists, and that realized returns are directly proportional to the effectiveness measure, then

$$\text{Returns} = r_{ij}^{k} a^{k} \tag{21}$$

where $0 \leqq a^k \leqq 1$

Suppose a firm undertakes a new product development program. Although the new product may be developed successfully in a technical sense (implying the existence within the firm of adequate capabilities to develop this product), the market for the product will not be adeqately penetrated if the marketing activities are not properly used; the return to the firm may then be thought of as being proportional to the effectiveness of the market penetration. This effectiveness represents management's use of the firm's total capabilities to carry out the product development program.

Since we want Equation 21 to hold for any arbitrary r_{ij}^k (that is, r_{ij}^k can be positive or negative), we will have to restructure the equation to give us the desired results implied by the equation. Negative r_{ij}^k represent losses to a firm as a result of using PS^k to make the transition from CS_i to CS_j.

The assumption stated above, that resulted in Equation 21, was that r_{ij}^k represented the returns a firm would receive if it used its capabilities to implement PS^k with maximum effectiveness. As its effectiveness decreases, its potential positive returns will decrease. In a similar way we can think of negative r_{ij}^k representing the minimum loss to a firm, that is, the loss accruing to a firm that used its capabilities with maximum effectiveness to implement PS^k. As its effectiveness decreases, its potential negative returns (losses) will increase in a manner proportional to the decrease in effectiveness. The restructuring of Equation 21 to give us this desired result is

$$\bar{r}_{ij}^{k} = w_1 r_{ij}^{k} + w_2 r_{ij}^{k} (1 - a^k) \tag{22}$$

where

$$w_1 = \begin{cases} (2a^k - 1)\, w_2 & \text{If } r_{ij}^k \geqq 0 \\ f_1\left(a^k, r_{ij}^k\right) & \text{If } r_{ij}^k < 0 \end{cases}$$

$$w_2 = \begin{cases} f_2\left(a^k, r_{ij}^k\right) & \text{If } r_{ij}^k \geqq 0 \\ w_1 & \text{If } r_{ij}^k < 0 \end{cases}$$

If we assume $r_{ij}^k \geqq 0$, then

$$\bar{r}_{ij}^k = (2a^k - 1)\, f_2\left(a^k, r_{ij}^k\right) r_{ij}^k + f_2\left(a^k, r_{ij}^k\right) r_{ij}^k (1 - a^k) \tag{23}$$

Expanding Equation 23 gives us

$$\bar{r}_{ij}^k = 2a^k f_2\left(a^k, r_{ij}^k\right) r_{ij}^k - f_2\left(a^k, r_{ij}^k\right) r_{ij}^k + f_2\left(a^k, r_{ij}^k\right) r_{ij}^k - a^k f_2\left(a^k, r_{ij}^k\right) r_{ij}^k \tag{24}$$

Simplifying Equation 24 gives

$$\bar{r}_{ij}^k = a^k f_2\left(a^k, r_{ij}^k\right) r_{ij}^k \tag{25}$$

Equation 25 is similar to Equation 21 except for the inclusion of $f_2\left(a^k, r_{ij}^k\right)$. This factor could be thought of as "utility of positive return." "Utility of positive return" could represent some subjective estimate on the part of a particular firm of the desirability of a specific product strategy over and above the positive returns associated with the use of this product strategy. For example, a firm might wish to have the model reflect a greater desirability for selecting a product strategy involving basic research because, for this particular firm, the technical knowledge gained by doing basic research and the insights acquired concerning organization for research might be as important to the firm as the potential market returns resulting from successfully implementing this product strategy. However, for another firm this desirability may not exist. Equation 25, then, permits us to modify the potential returns so that the solution reflects this factor.

Assuming $r_{ij}^k < 0$, then

$$\bar{r}_{ij}^k = f_1\left(a^k, r_{ij}^k\right) r_{ij}^k + f_1\left(a^k, r_{ij}^k\right) r_{ij}^k (1 - a^k) \quad (26)$$

Simplifying Equation 26 gives

$$\bar{r}_{ij}^k = f_1\left(a^k, r_{ij}^k\right)\left[r_{ij}^k + r_{ij}^k (1 - a^k)\right] \quad (27)$$

Equation 27 has potential negative returns becoming more negative as the effective use of a firm's capabilities (a^k) decreases. The factor $f_1\left(a^k, r_{ij}^k\right)$ could represent "disutility of loss." For example, if a firm is small, then a potential loss of, let us say, $100,000 could force it into bankruptcy. This firm would want the model to reflect the great undesirability to the firm of selecting that product strategy which results in this loss. But a firm large enough to sustain this loss might want to consider using this strategy for other potential returns, such as increased technological understanding. Frequently this happens for one or more time periods to firms which use a product strategy involving a significant amount of basic research activities.

If we now substitute Equation 22 into 15 we get

$$v_i(n) = \underset{k}{\mathrm{Max}} \sum_{j=1}^{m} p_{ij}^k \left\{\left[w_1 r_{ij}^k + w_2 r_{ij}^k (1 - a^k)\right] + v_j(n-1)\right\} \quad i = 1, 2, \ldots, m \quad (28)$$

where

$$w_1 = \begin{cases} (2a^k - 1) w_2 & \text{If } r_{ij}^k \geqq 0 \\ f_1\left(a^k, r_{ij}^k\right) & \text{If } r_{ij}^k < 0 \end{cases}$$

$$w_2 = \begin{cases} f_2\left(a^k, r_{ij}^k\right) & \text{If } r_{ij}^k \geqq 0 \\ w_1 & \text{If } r_{ij}^k < 0 \end{cases}$$

This functional equation does not change the operational characteristics of Howard's algorithm because $\bar{r}_{ij}^k$ as defined in Equation 22 is independent of n, the number of stages. Hence, the algorithm would proceed as described in Chapter II with r_{ij}^k replaced by $\bar{r}_{ij}^k$.

Level of Firm's Existing Capabilities. However, at this point it should be recognized that the preceding development assumes that a firm's capabilities (in particular, the use of its capabilities) affect only the return matrix and not the probabilities of its movement from one competitive situation to another. As has been suggested before, this could be a measure of management capability, since management must integrate all the other specific capabilities into a profitable operating system. Thus, as management uses its capabilities more effectively its expected returns will increase. This implies two things: (1) that a firm using a specified product strategy has a high probability of making a transition into competitive situations that offer good return potentials; and (2) that the firm's present capabilities are sufficient to handle the specified product strategy. It seems reasonable to assume that the probability of making a transition from one competitive situation to another, using a specific product strategy, is dependent on the capabilities a firm has to implement this product strategy. As the capabilities a firm has to handle a specific product strategy increase, the probability that the firm can implement the product strategy increases, and thus the probability of making a transition from a competitive situation of low potential returns to a competitive situation of high potential returns should increase.

One operational way to incorporate this assumption into the model would be to identify a set of capability levels and for each level of capabilities (each element of the set) generate a probability transition matrix. The appropriate probability transition matrix for a firm whose capability level has been determined could be inserted into the model and the product strategies based on a given capability level could be selected. This procedure, however, involves a significant amount of subjective estimation based on an identifiable set of capability levels. The major objection to this procedure, however, is the impossibility of relating analytically the effect of capabilities on the probabilities of moving from one competitive situation to another. This means that one cannot structure the model to incorporate this concept in such a way that it would facilitate studying the effect of capabilities on firm behavior.

One way to handle this concept analytically is the following:

Define:

$\bar{p}_{ij}^k$ = The probability that a firm will make a transition from CS_i to CS_j during the next time period by using PS^k, given that it is now in CS_i <u>and</u> that with its present capabilities it <u>can</u> implement PS^k.

$\bar{\bar{p}}_{ij}^k$ = The probability that a firm will make a transition from CS_i to CS_j during the next time period by using PS^k, given that it is now in CS_i <u>and</u> that with its present capabilities it <u>cannot</u> implement PS^k.

b_i^k = The probability that a firm with its present capabilities can implement PS^k to make the transition from CS_i to any CS_j.

Then

$$p_{ij}^{k} = \bar{p}_{ij}^{k} b_i^k + \bar{\bar{p}}_{ij}^{k} \left(1 - b_i^k\right) \tag{29}$$

In matrix notation,

$$P^k = \bar{P}^k \otimes B^k + \bar{\bar{P}}^k \otimes (U - B^k) \tag{30}$$

where $0 \leqq b_i^k \leqq 1$

$$U = \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}$$

and

$$0 \leqq \bar{p}_{ij}^{k} \leqq 1 \qquad \sum_{j=1}^{m} \bar{p}_{ij}^{k} = 1 \qquad i = 1, 2, \ldots m$$

$$0 \leqq \bar{\bar{p}}_{ij}^{k} \leqq 1 \qquad \sum_{j=1}^{m} \bar{\bar{p}}_{ij}^{k} = 1 \qquad i = 1, 2, \ldots m$$

The operation $\otimes$ is defined to be the scalar product of the corresponding i, j cell values in the $\bar{P}^k$ and B^k matrices and the $\bar{\bar{P}}^k$ and $(U - B^k)$ matrices.

Equation 30 is a convex linear combination of $\bar{P}^k$ and $\bar{\bar{P}}^k$ and gives the desired properties of a probability transition matrix (that is, $0 \leqq p_{ij}^k \leqq 1$ and $\sum_{j=1}^{m} p_{ij}^k = 1$).[1] It shows the existence of a unique and possibly different b_i^k for each competitive situation in the probability transition matrix. This is the most general case and allows the firm's capabilities to affect specific movements in the set of competitive situations that is associated with a given product strategy. If there is justification for assuming that a firm's capabilities affect equally the movements from all competitive situations associated with a given strategy then Equation 30 becomes

$$P^k = \bar{\bar{P}}^k b^k + \bar{\bar{P}}^k (1 - b^k) \tag{31}$$

[1]See Appendix A for Proof.

The introduction of $\bar{P}^k$, $\bar{\bar{P}}^k$, and B^k into the model does not change the operational characteristics of Howard's algorithm because these matrices are independent of the number of time periods (stages) being considered. This means that the steady-state relationships for long-run analysis are applicable with the appropriate substitutions made for P^k and R^k. Since we are interested in transient analysis the appropriate functional equation is iterated over the number of time periods for which the system is being studied.

If we now substitute Equation 29 into 28, we get

$$v_i(n) = \underset{k}{\text{Max}} \sum_{j=1}^{m} \left[\bar{p}_{ij}^k b_{ij}^k + \bar{\bar{p}}_{ij}^k \left(1 - b_{ij}^k\right)\right]$$

$$\left[w_1 r_{ij}^k + w_2 r_{ij}^k (1 - a^k) + v_j(n - 1)\right] \qquad (32)$$

$$i = 1, 2, \ldots, m$$

This functional equation constitutes the most general model in this thesis. Capabilities are permitted to affect both the potential returns which result from making transitions from one competitive situation to another using a specified product strategy and the probabilities of making these transitions. The importance of the time required to implement product strategies has not yet been discussed; however, it does not affect Equation 32.

"DUMMY" COMPETITIVE SITUATIONS

In Chapter I, the importance of the time required to implement certain product strategies was discussed. It was indicated that this time factor might exclude certain strategies from the sets of feasible strategies for some firms, because the time required was longer than some firms could afford in attempting to change an existing unfavorable competitive situation. It was also pointed out that the time required to implement different product strategies varied from one strategy to the next. Longer time requirements might indicate the need for fewer firm capabilities—which probably suggests a capability-time substitution effect. Certain firms, however, are restrained in the extent to which they can increase their capabilities in order to reduce the time requirements; hence they must account for these varying lengths of time. We should recall that the structures of Howard's model and the model in this chapter imply that a different product strategy can be selected each time period, a fact which, in turn, implies an ability on the part of a firm to stop and start the implementation process of product strategies each time period. This means that we have a problem to resolve if the model is to reflect the fact that varying numbers of time periods are required for implementing the different feasible product strategies. This does not imply that firms should not have the opportunity to discontinue a product strategy that they selected the last time period; rather, a firm with a given level of capabilities might want its current strategy selection to account for the different implementation times of future strategy selections.

The solution to this problem involves the introduction of "dummy" competitive situations into the model. These "dummy" competitive situations represent states into which a firm must make a transition in the next time period if the product strategy being used requires more than one time period for complete implementation. In this way the transition that must be made calls for the use of the same product strategy that was used the last time period. Thus flexibility exists in deciding whether the returns associated with these "dummy" competitive situations represent a constant, increasing, or declining potential market situation for the firm. More than likely the returns to a firm would tend to decrease if the firm were in an unfavorable competitive situation when it decided to implement such a product strategy.

The use of the "dummy"competitive situations can be illustrated in the following way. Assume that two competitive situations exist (e.g., CS_1 and CS_2). Assume also that two product strategies (PS^1 and PS^2) are available and that the implementation time required for PS^2 is equal to three time periods whereas the implementation time required for PS^1 is equal to one time period. The P^1 and R^1 matrices would be similar to those described earlier in this chapter. The P^2 and R^2 matrices would appear as follows:

Let D_{ij} be the "dummy" competitive situation that is associated with the i-th real competitive situation for the j-th time period. Then

$$P^2 = \begin{array}{c|cccccc|} & CS_1 & D_{11} & D_{12} & CS_2 & D_{21} & D_{22} \\ \hline CS_1 & 0 & 1 & 0 & 0 & 0 & 0 \\ D_{11} & 0 & 0 & 1 & 0 & 0 & 0 \\ D_{12} & p_{11}^2 & 0 & 0 & p_{12}^2 & 0 & 0 \\ CS_2 & 0 & 0 & 0 & 0 & 1 & 0 \\ D_{21} & 0 & 0 & 0 & 0 & 0 & 1 \\ D_{22} & p_{21}^2 & 0 & 0 & p_{22}^2 & 0 & 0 \\ \hline \end{array} \qquad (33)$$

and

$$R^2 = \begin{array}{c|cccccc|} & CS_1 & D_{11} & D_{12} & CS_2 & D_{21} & D_{22} \\ \hline CS_1 & 0 & f_1\left(r_{11}^2\right) & 0 & 0 & 0 & 0 \\ D_{11} & 0 & 0 & f_1\left(r_{11}^2\right) & 0 & 0 & 0 \\ D_{12} & r_{11}^2 & 0 & 0 & r_{12}^2 & 0 & 0 \\ CS_2 & 0 & 0 & 0 & 0 & f_2\left(r_{22}^2\right) & 0 \\ D_{21} & 0 & 0 & 0 & 0 & 0 & f_2\left(r_{22}^2\right) \\ D_{22} & r_{21}^2 & 0 & 0 & r_{22}^2 & 0 & 0 \\ \hline \end{array} \qquad (34)$$

where $f_1\left(r_{11}^2\right)$ and $f_2\left(r_{22}^2\right)$ are decreasing, increasing, or constant functions of r_{ij}^2.

Since D_{11} is an impossible competitive situation for PS^1, PS^2 must be selected again. This scheme can be used to represent any number of time periods.

Note that although many zeros exist in P^2 it is possible to move from any one competitive situation to any other. However, several transitions may be required. We do not have any absorbing states in P^2, because i is different from j for those cells where $p_{ij}^2 = 1$. We do have an example of a periodic Markov chain. However, this does not destroy the required ergodic properties of the matrix. (This is clearly indicated by Kemeny and Snell; see footnote 4, Chapter II of the present work.) We still have an irreducible Markov chain, and thus Howard's steady-state relationships, which depend on theorems based on irreducible chains, are applicable for long-run analysis.

CHAPTER IV

AN APPLICATION TO THE MICHIGAN MACHINE TOOL INDUSTRY

In this chapter the dynamic model developed in Chapter III is applied to a segment of the Michigan machine tool industry. The application is intended to demonstrate the procedure and problems associated with applying the model to an industry and not to provide an extensive analysis of the industry. The segment of the machine tool industry to which the application is made is based on certain characteristics of the competitive structure within the industry. The most important characteristic, as will be demonstrated in the competitive structure section of this chapter, is "the size" of the firm. Since all the large machine tool firms are located outside of Michigan and these firms constitute the major form of competition for this segment of the Michigan machine tool industry, the sections on industry description and competitive structure that follow include aspects of the United States and Michigan machine tool industries.

DESCRIPTION OF THE INDUSTRY

The machine tool industry is the foundation of our modern machinery industry. Machine tools are used, directly or indirectly, in the manufacturing operations of all products. Consequently, the economic and technological progress and state of the art of the industry are important factors in broadening the industrial base and increasing the industrial output of the United States and of Michigan.

The definition of the machine tool industry that will be used in this thesis is based on the classification reported in the Standard Industrial Classification Manual.[1] This classification scheme has been adopted by the Bureau of the Census and the Department of Commerce for the reporting of industrial statistics. The manufacturing sector of the United States economy has been divided into twenty-one separate industries, numbered, for purposes of its own classification, 19 through 39. The Machinery Industry (except Electrical) is numbered 35, and is subdivided into nine 3-digit industries, one of which is Metalworking Machinery and Equipment, number 354. The Metalworking Machinery and Equipment industry is in turn subdivided into five 4-digit industries of which the machine tool industry is represented by Machine Tools—

[1]United States Bureau of the Budget, Standard Industrial Classification Manual (Washington: Government Printing Office, 1957).

Metal Cutting, number 3541, and Machine Tools—Metal Forming, number 3542. The relationship of these industries and product groups within the machine tool industry is represented schematically in Figure 1.[2]

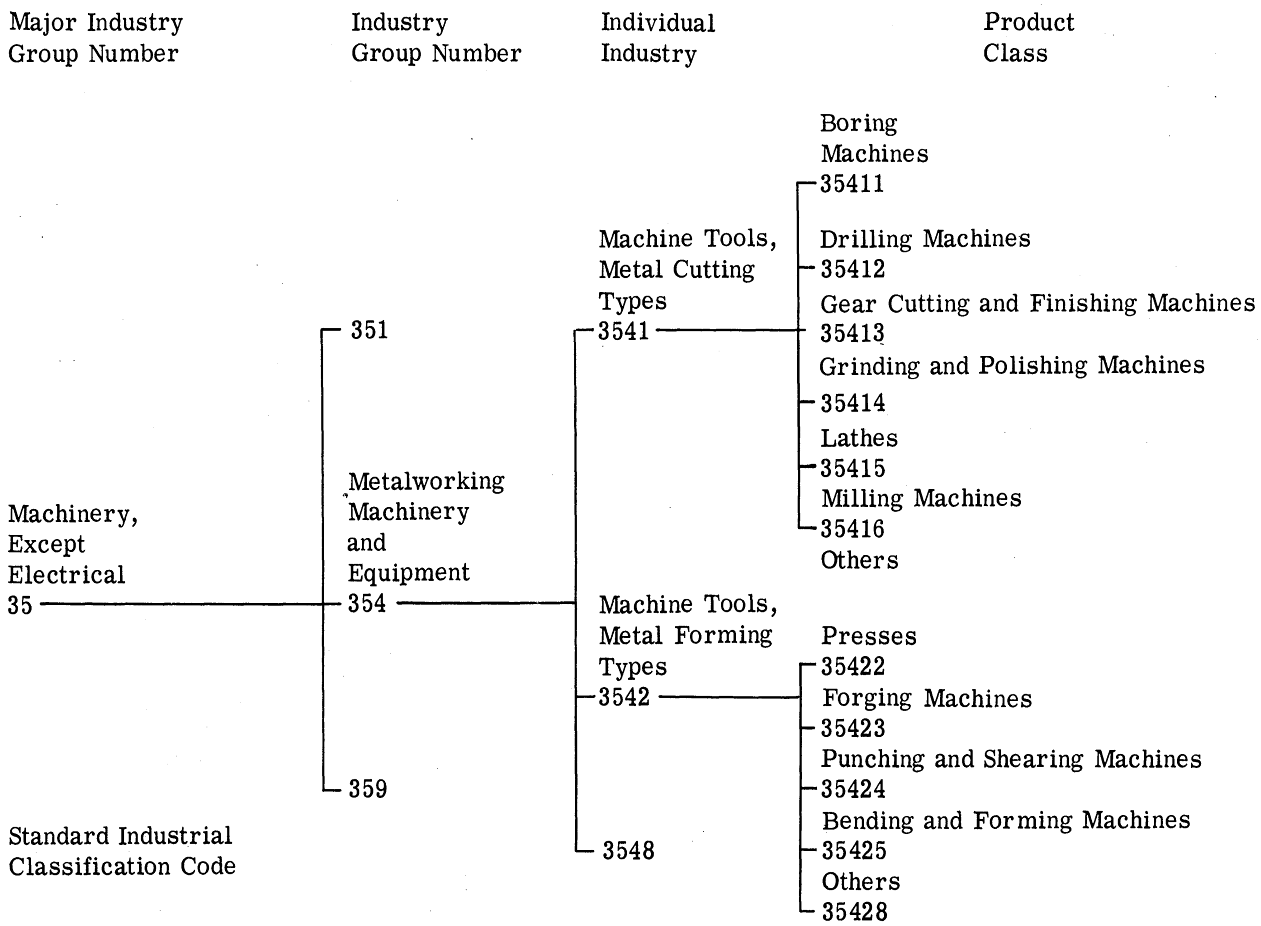

FIGURE 1. SIC STRUCTURE OF THE MACHINE TOOL INDUSTRY

Care must be exercised in drawing conclusions from statistical data which purport to represent given magnitudes of "the" machine tool industry. For example, current dollar shipments data are released by the trade association and published by various media as

[2]This figure is taken from Clark E. Chastain and Marvin G. DeVries, "The Machine-Tool Industry: Some Important Economic Trends," Procedures of the Michigan Machine Tool Conference, Report No. 66223-5-X, June 1962, Industrial Development Research Program, The University of Michigan, Institute of Science and Technology, Ann Arbor, Michigan.

representative of the machine tool industry, but these data always show less in dollar shipments than comparable census data because of the latter's greater coverage. For the year 1958, the value of shipments of machine tools by the industry approximated \$411 million, according to the National Machine Tool Builder's Association (NMTBA), whereas the 1958 census reports the value of shipments at \$529 million for the industry, and at \$593 million for all producers. Financial data, including various earnings ratios, are frequently referred to as representative of industry trends, but this information is not available publicly except for the largest firms, which are the only ones whose securities are publicly held. For this reason, the available sample is probably biased and reflects the fortunes only of the larger concerns. However, the analysis of small firms within Michigan was facilitated by the collection of a sizeable amount of information during the summer of 1962. This activity represented the information collection phase of the Industrial Development Research Program at The University of Michigan.[3]

Also, statistics on the "machine tool" industry are regularly published which include both Metal-Cutting (3541) and Metal-Forming (3542) types; but sometimes the only information available is for the three-digit group 354, Metalworking Machinery and Equipment. Other examples could be cited, but the point is that the source and method of collection of the data must be clearly indicated if "industry" statistics are to be meaningful.

The machine tool industry tends to locate near the industrial complex (the Metalworking Industry) for which it supplies equipment. This fact is indicated in Table I, which shows the geographical distribution of workers in the machine tool industry in the United States.

Michigan ranks third geographically in employment concentration of the industry. Hence, the Michigan machine tool industry plays an important role in the total output of the national industry. This is also seen in Figure 2, which gives a plot over time of total Michigan machine tool sales as a percent of the total national sales as reported by NMTBA. Note that Michigan's share of the national output has remained quite constant over the five-year period, varying slightly between 8.6% in 1957 and 9.8% in 1961. Note also, that there is a close correspondence between concentration of workers (9.78%) and share of national output of machine tools (8.6 to 9.8%) for the Michigan industry, as indicated in Table I and Figure 2.

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[3]For further information on this program see Frank R. Bacon, Jr. and Frederick T. Sparrow, Research on Product Development Capabilities of Michigan Firms, Report No. 66223-3-S, Institute of Science and Technology, The University of Michigan, April 1962.

TABLE I. GEOGRAPHICAL DISTRIBUTION OF WORKERS IN THE MACHINE TOOL AND METALWORKING INDUSTRIES*

State	Percent In Machine Tool Industry	Percent In Metalworking Industry
California	2.49	3.42
Connecticut	9.09	6.45
Illinois	12.16	10.24
Indiana	1.55	2.79
Massachusetts	5.93	8.02
Michigan	9.78	20.44
New Jersey	1.41	2.33
New York	6.03	4.74
Ohio	28.81	21.17
Pennsylvania	3.32	7.10
Vermont	4.26	2.14
Wisconsin	5.51	3.31
All Other States	9.64	7.84
	100.00	100.00

*Data are for the year 1960, and are restricted to firms employing 20 or more workers. Source: Iron Age, Basic Metalworking Data, Philadelphia, 1961.

The concentration of employment within the Michigan machine tool industry is shown in Figure 3. This figure divides the state of Michigan into six geographical areas and gives percent of total Michigan employment in Metal-Cutting (3541) and Metal-Forming (3542) for each area. We note the very high concentration of Metal-Cutting production in the Detroit area. This area also accounts for a significant proportion of the output of Metal-Forming production. This concentration within Michigan has significance for the competitive structure of the industry, as will be seen in the next section.

COMPETITIVE ASPECTS OF THE INDUSTRY

The information used in this section to derive the competitive structure of the Michigan machine tool industry is taken from questionnaires completed by thirty-four Michigan machine tool firms. This section draws on certain data from these questionnaires to depict and support certain competitive characteristics of the industry.[4]

[4]This questionnaire was designed so that the structured questions would elicit quantitative answers for analysis purposes in the areas of product development activities of Michigan firms, firm capabilities, competitive aspects of the industry, and the general effects of technological change on economic growth.

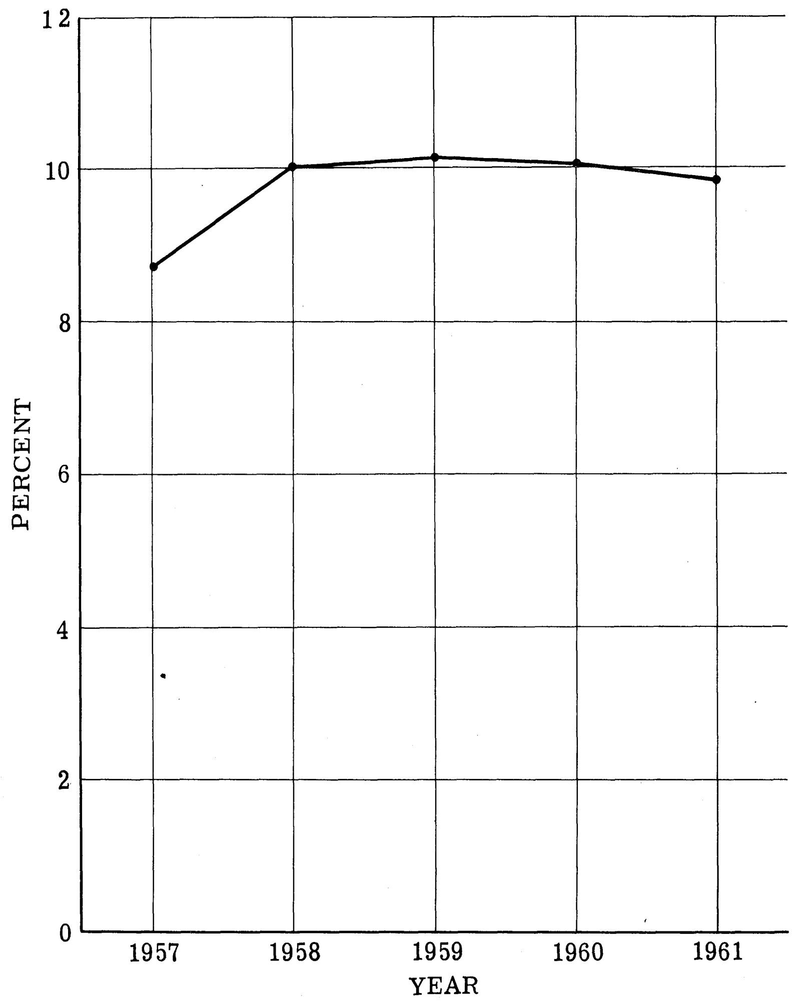

FIGURE 2. MICHIGAN MACHINE TOOL SALES AS A PERCENT OF UNITED STATES MACHINE TOOL SALES (AS REPORTED BY NMTBA)

The Michigan firms were asked to specify for each product line in 1961 the percent of sales that they considered to be standard or special products. A product is considered to be special if each order is manufactured partially or wholly to different individual customer specifications. A product is considered to be standard if it does not vary from customer to customer. The percent, of the total sales of a firm, that consisted of standard products was then computed for each firm. Figure 4 is a plot of the frequency with which the specified percentage intervals were indicated by firms as being the percent of total firm sales in 1961 that were standard products. One immediately notes the tri-modal distribution, with two modes occurring at the extremes of the distribution and the third mode occurring at approximately the 55-60 percentage interval. It is also interesting to note the gaps of percentage intervals with zero frequency and the high frequency occurring at the two extreme intervals.

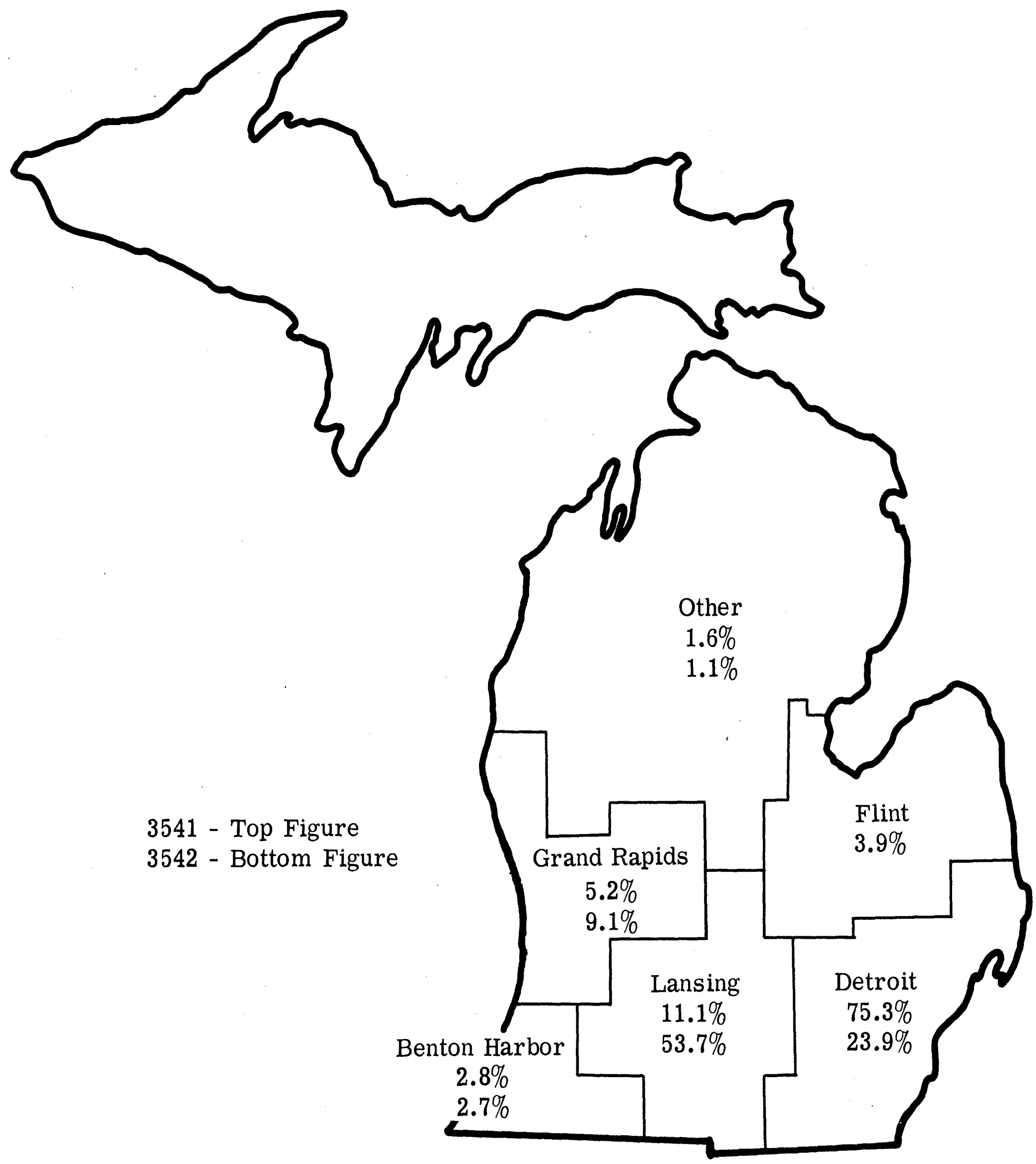

FIGURE 3. GEOGRAPHICAL CONCENTRATION OF MACHINE TOOL EMPLOYMENT IN THE MICHIGAN MACHINE TOOL INDUSTRY. From Chastain and DeVries, p. 12.

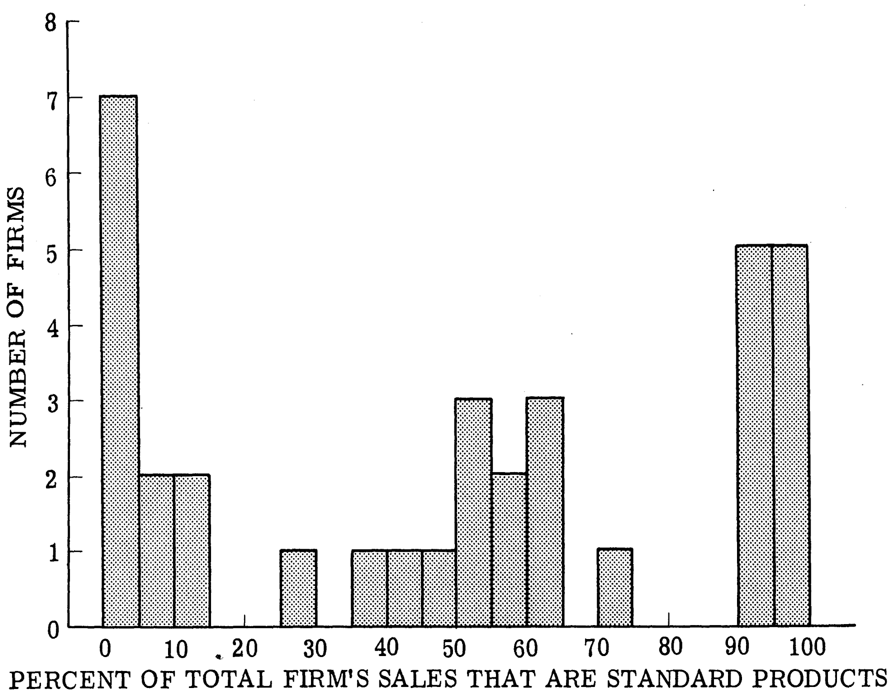

FIGURE 4. DISTRIBUTION OF MICHIGAN MACHINE TOOL FIRMS BY PERCENT OF FIRM'S SALES THAT ARE STANDARD PRODUCTS

This figure suggests a classifications scheme consisting of three groups of firms:

Group I —those firms who manufacture mostly standard products, hereafter referred to as "standard" firms.

Group II —those firms who manufacture mostly special products or who manufacture very few standard products, hereafter referred to as "special" firms.

Group III—those firms who manufacture approximately 50% standard and 50% special products, hereafter referred to as "mixed" firms.

An almost perfect division of the firms into three groups would exist if the frequency bars at the 25-30% and 70-75% intervals were removed. In order to decide into which group these two firms should be placed, we made a detailed analysis of the product lines of each firm. The firm represented at the 70-75% interval was placed in the mixed firm group because:

(a) All the product lines of this firm consisted of standard and special products.

(b) This firm is eighteen percentage points away from the standard group, which has a total spread of only ten percentage points.

(c) It was felt that reason "a" resulted in firm behavior typified most by the firms in the mixed group.

The firm represented at the 25-30% interval was placed in the special group because:

(a) One of this firm's major product lines consisted of 100% special products.

(b) This firm is 10 percentage points away from either the mixed or the special group, which has a total spread of fifteen percentage points.

(c) It was felt that reason "a" caused the firm to behave in a manner that is typified most by the firms in the special group.

The analysis of the competitive structure of the Michigan machine tool industry is greatly facilitated by the previously discussed classification scheme.[5] Our interest is in those characteristics of the competitive structure of the industry that facilitate the use of the model developed in Chapter III.

The size of a firm can be measured in many different ways, among which are employment and total assets. The measure of size that we will use is employment. The rationale for this decision is based on the following three points:

(1) The movement over time of employment and total assets for the machine tool industry is quite similar. The timing of the upward and downward movements are essentially the same, with differences occurring in the percent change.[6]

(2) It is often held that employment data provide a significant real measure of changes in firm size where technology has remained fairly constant over a period of time in a manufacturing industry.[7] One indication of the relative constancy of technology in the machine tool industry is reflected in the stock of machine tools. Approximately 60% of the stock in 1961 of British machine tools is 10 years old or older, as reported by Business Week.[8] A similar result was reported by a McGraw-Hill Survey of the American industries which discussed that in 1959 approximately 62% of the 2 1/4 millions of machine tools were 10 years old or older.[9] Another indication of the relative

[5]The complete competitive and market structure of the industry is contained in Chapter IX of the report, The Michigan Machine Tool Industry, which will be published in 1963 by the Industrial Development Research Program of the Institute of Science and Technology, The University of Michigan.

[6]Ibid., Chapter IX.

[7]See M. A. Adelman, "The Measurement of Industrial Concentration," Review of Economics and Statistics, Vol. 33, November 1951, pp. 269-296; also, for a discussion of various size measures, see G. Schroeder, The Growth of the Major Steel Companies, 1900-1950 (Baltimore: Johns Hopkins Press, 1952).

[8]"Britian's Over-Age Machine Tools," Business Week, January 6, 1962, pp. 42-43.

[9]The United States Industrial Outlook for 1960, McGraw-Hill, 1960; also see "Metalworking Manufacturing Progress," American Machinist, 1958.

constancy of technology is the amount of research and development effort in the industry. Compared with other manufacturing industries, the amount of effort expended is small.[10] Most of the developmental effort has resulted in small modifications of existing product designs to meet customer specification. Hence, there has been a lack of research into new technologies for metal removal processes.[11]

(3) The determination of estimates of the probabilities of making transitions from one size class to another was based on employment as the size measure. This work was done by Hannum and is discussed in the next section of this chapter.

A comparison of the size distribution of Michigan machine tool firms and United States machine tool firms is given in Table II.

TABLE II. SIZE DISTRIBUTION OF MACHINE TOOL FIRMS BY TOTAL EMPLOYMENT FOR 1961

	(Percent of firms in each group)		
Firms	Under 100	100-499	500 & Over
Michigan			
Standard	80.0	20.0	0.0
Special	41.6	58.4	0.0
Mixed	16.6	83.4	0.0
United States			
Industry*	58.4	29.9	11.7

*Plants employing 20 or more employees.

We observe that Michigan has no machine tool firms with an average employment greater than 500. However, 11.7% of the firms in the national industry have on the average 500 or more employees. Hence, these larger firms exist outside the state of Michigan. It is interesting to note that the Small Business Administration considers a firm small if its total employment is less than 500.[12] Thus the Michigan machine tool industry consists of small firms.

[10]Research and development dollars as a percent of value added in 1961 was 2.05% for the Michigan machine tool industry, 6.53% for the machinery (except electrical) industry and 6.65% for all United States manufacturing industries.

[11]See, for example, Himes; and William H. Brown, "Innovation in the Machine Tool Industry," Quarterly Journal of Economics, No. 71, 1957, pp. 406-425.

[12]Strengthening America's Small Businesses, Small Business Administration, 17th Semi-annual Report, 1961.

(Machine tool divisions of large firms in Michigan are treated as firms because the number of these divisions is very small.)

Ten major machine tool firms are mentioned and discussed in Himes.[13] These ten firms exist outside the state of Michigan and in 1961 accounted for 57.70% of the output of the national industry. Their output constituted 60.96%, 61.84%, and 56.93% of the output of the national industry in 1958, 1959, and 1960, respectively. The range of average total employment for these firms was from 739 to 9463 employees with an average total employment per firm of 2854 employees. Thus, it appears that the Michigan machine tool firms face competition with very large firms outside of Michigan.

The sales of the three groups of Michigan firms is presented in Figure 5 for a five-year period. Again, note the relative constancy over time of the sales of the groups as a percent of total Michigan machine tool sales. It appears that the market shares for the Michigan industry and the groups within the industry are quite constant over time, although the total of sales dollars fluctuates significantly.

The areas of destination of the output of Michigan machine tool firms and the major competitors of these firms must be considered before conclusions can be reached concerning the form of competition that is being faced by the Michigan firms.

The geographical distribution of the domestic sales of the Michigan machine tool firms in 1961 is given in Table III.

We note the significant percentage of the output of special firms that is shipped to destinations within Michigan. A further analysis of this data revealed that these shipments were made to the automotive industry. Furthermore, the shipments to areas outside of Michigan were also made primarily to the automotive industry.[14] Hence, it appears that the special firms in Michigan cater to a specific localized market. Standard firms, however, shipped a small percentage of their output to destinations within Michigan and, with the exception of the West North Central Area, shipped almost equal amounts to the other four areas. The distribution of the output of the mixed firms tended to fall between those of the standard and special firms. Thus, the standard firms and, to a lesser extent, the mixed firms sell to a broad national market. This is also the market to which the large national machine tool firms sell. Hence, the standard and mixed firms must contend with the size of their competition.

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[13]Himes, p. 45 and p. 247. See Appendix B of the present dissertation for a list of these firms and their employment for 1961.

[14]See The Michigan Machine Tool Industry, Chapters V and VII.

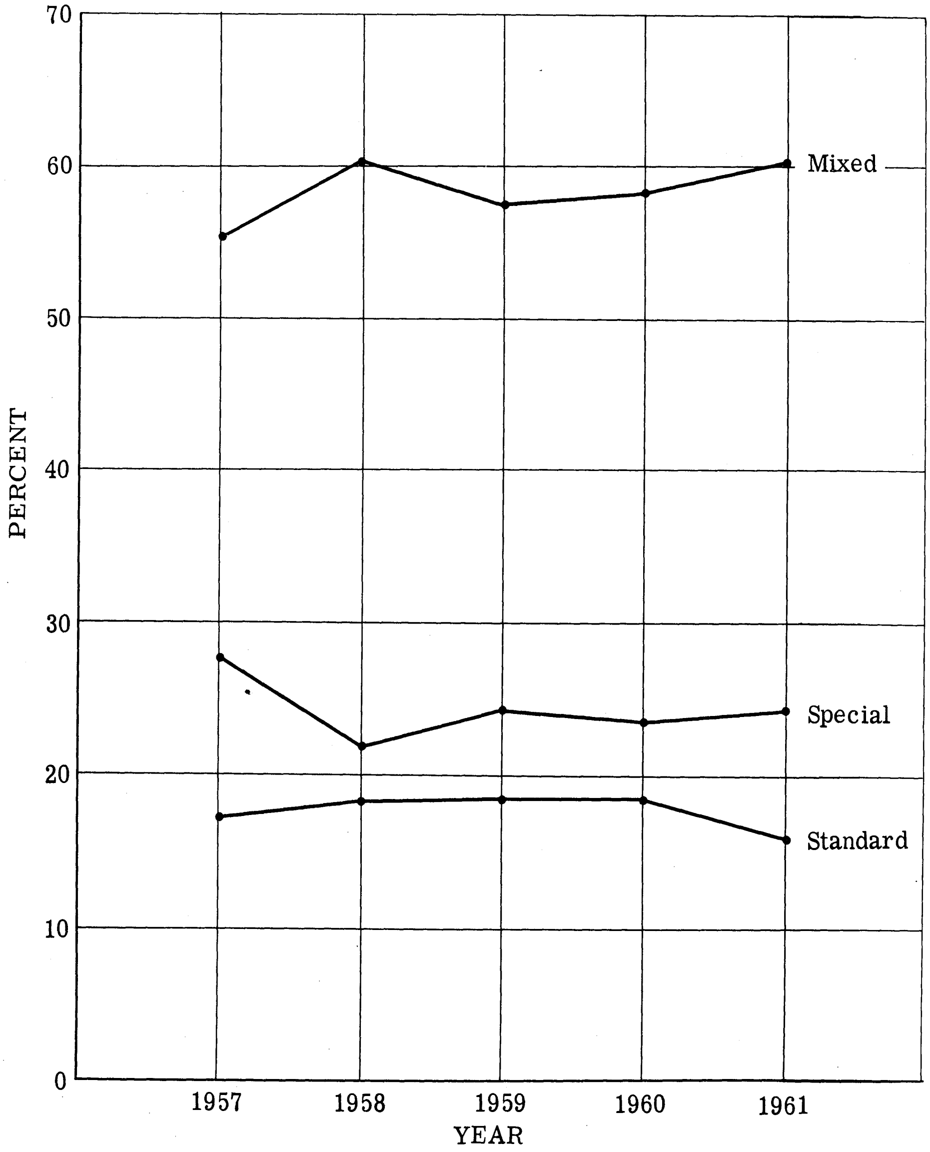

FIGURE 5. GROUP SALES AS A PERCENT OF MICHIGAN MACHINE TOOL SALES

A further indication of the fact that special firms attempt to serve a localized market is reflected in Figures 6, 7, and 8. These figures show the geographical locations of the three major competitors for each product line of the standard, special, and mixed firms. A comparison of these three figures reveals that the Michigan special firms compete mostly with each other in their localized market within Michigan, whereas the competition of standard firms is quite dispersed nationally. The dispersion of the competitors of mixed firms is somewhere

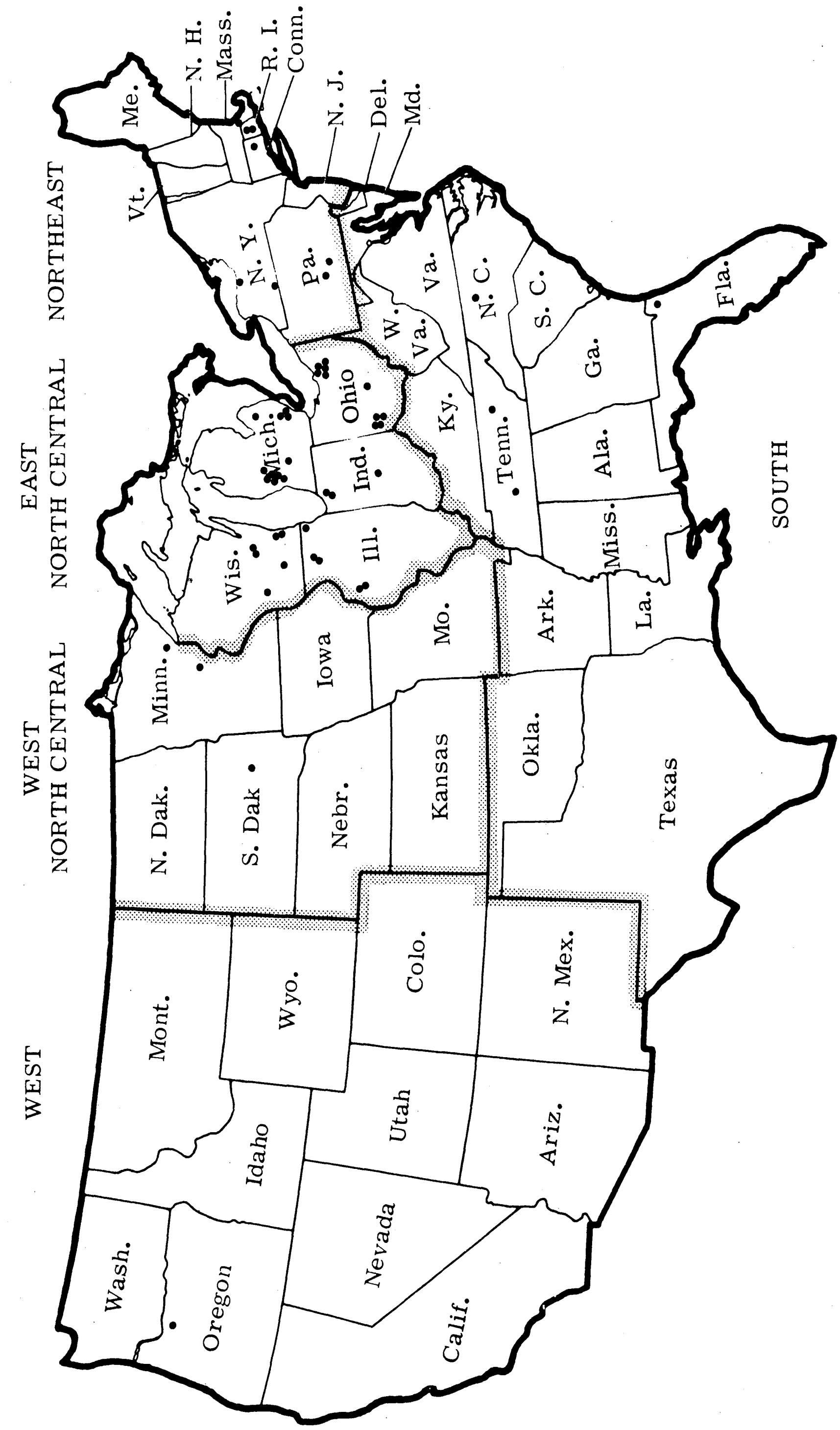

FIGURE 6. LOCATION OF THREE MAJOR COMPETITORS FOR EACH PRODUCT LINE OF THE STANDARD FIRMS

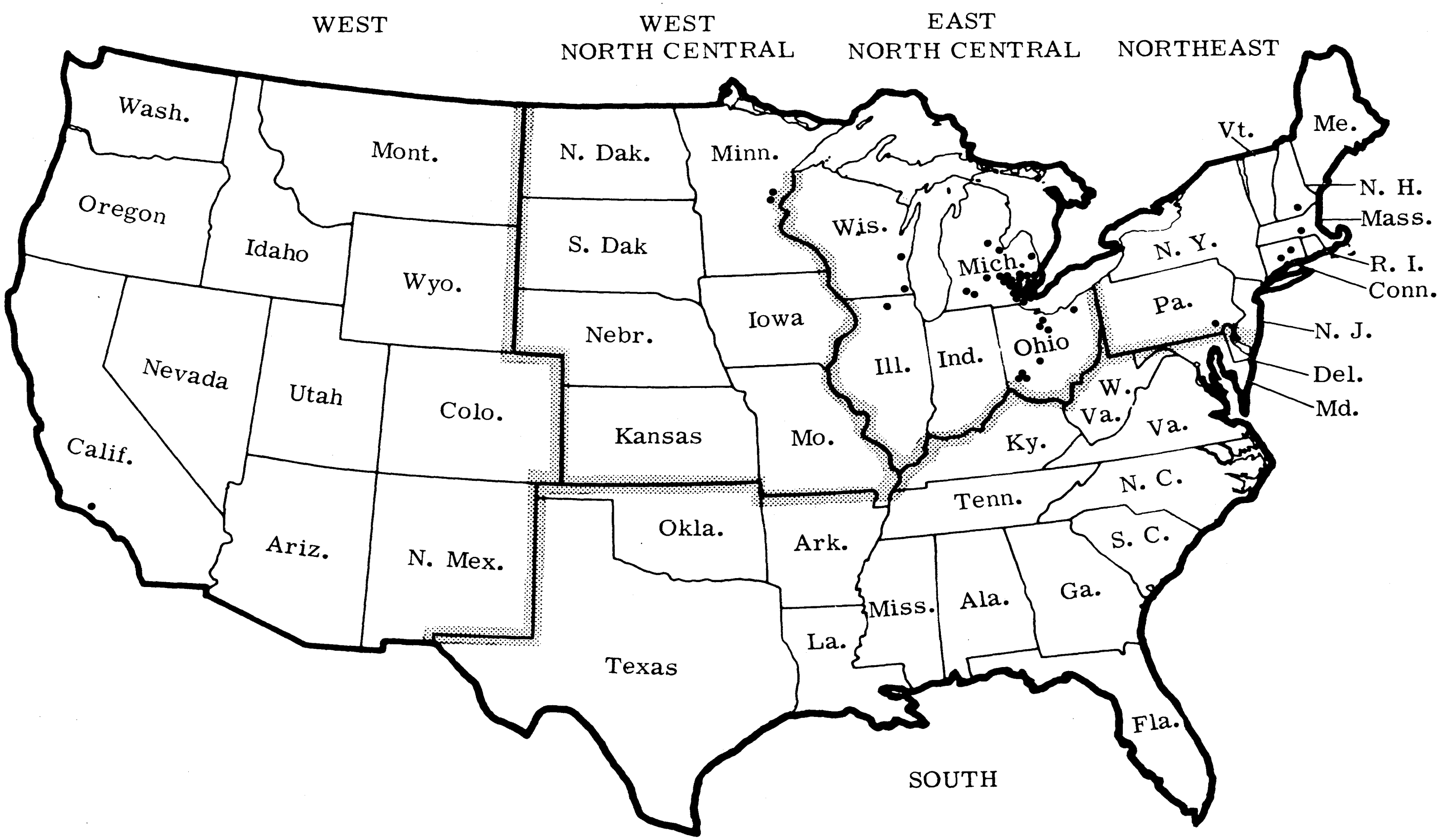

FIGURE 7. LOCATION OF THREE MAJOR COMPETITORS FOR EACH PRODUCT LINE OF THE SPECIAL FIRMS

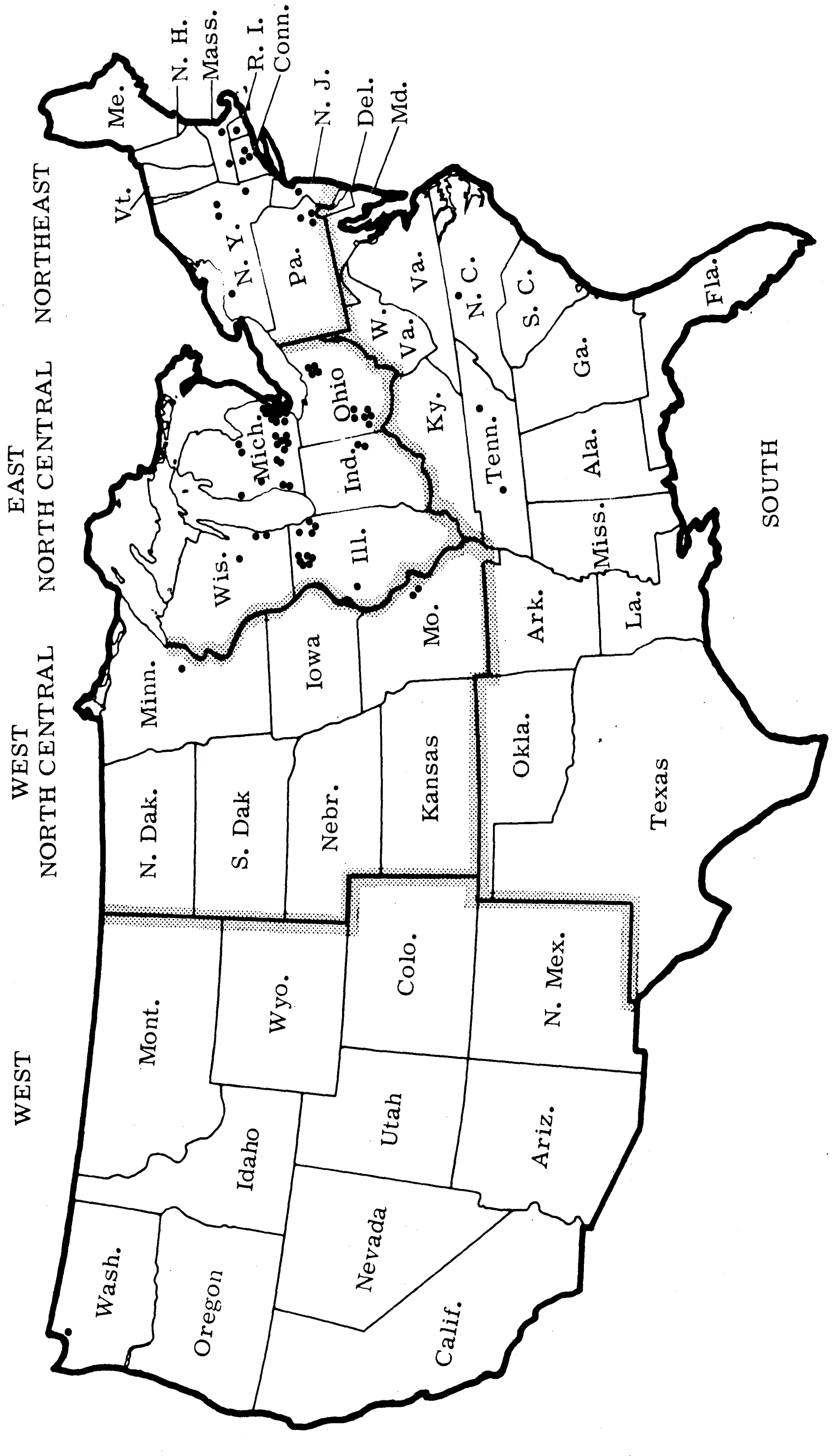

FIGURE 8. LOCATION OF THREE MAJOR COMPETITORS FOR EACH PRODUCT LINE OF THE MIXED FIRMS

between that of standard and special firms. This fact strengthens the argument that Michigan special firms do not compete with national firms in the national market, but compete with each other in a localized market.

TABLE III. GEOGRAPHICAL DISTRIBUTION OF DOMESTIC SALES OF THE MICHIGAN MACHINE TOOL FIRMS IN 1961

(Percent)

Geographical Area*	Standard Firms	Special Firms	Mixed Firms
Within Michigan	9.7	44.6	24.9
Remainder of East North Central	17.5	26.7	36.3
West North Central	5.4	4.1	7.5
Northeast	25.7	13.1	17.1
South	17.4	7.4	6.8
West	24.3	4.3	7.4
	100.0	100.0	100.0

*See Figure 6 for the boundaries of these areas.

A concluding piece of evidence is given in Table IV. This table gives the number of firms in each Michigan group that compete with ten of the major national machine tool firms listed in Appendix B.

TABLE IV. COMPETITION BETWEEN MICHIGAN MACHINE TOOL FIRMS AND TEN MAJOR NATIONAL MACHINE TOOL FIRMS

(Number of Firms)

Ten Major National Machine Tool Firms	Standard Firms	Special Firms	Mixed Firms
Cincinnati Milling	4	0	2
Brown and Sharpe	2	0	1
Bullard	0	0	0
Giddings & Lewis	1	0	1
Kearney & Trecker	0	0	0
Monarch	0	0	0
National Acme	0	0	0
New Britain	1	1	0
Sunstrand	0	0	0
Warner & Swasey	0	0	0

Eight of the twelve standard Michigan machine tool firms compete with these particular ten major national firms. Only one special firm competes with one of the national firms and this particular national firm has a division in Michigan which caters to and services the automotive industry. In addition, solicited written responses from twelve of the eighteen non-Michigan firms, listed in Appendix B, indicated that three of them were standard, eight mixed, and one special.

From the discussion on the preceding pages, the following conclusions can now be stated:

(1) Special firms in Michigan compete with each other for a local market.

(2) Standard and mixed firms distribute their output to a national market, in which they are competing with large national firms.

(3) The size of the firm does not appear to be a significant factor in describing the competitive situation of the special firms (see Table II).

(4) The size of the firm appears to be a significant factor in describing the competitive situation of the standard and mixed firms.

On the basis of the above discussion, it will be assumed for the remainder of this chapter that the competitive situation facing the Michigan standard and mixed firms is a function primarily of the size of the firm (as measured by average total employment). The other factors that obviously exist and are important in describing competitive situations will constitute the residual, or unexplained portion, of the competitive situation. At the present time, it can be assumed that this residual is reasonably small, which means that for the given conditions of market demand that exist for the machine tool industry, the size of the firm explains most of the competitive situation being faced by the Michigan standard and mixed machine tool firms. This is not intended to minimize the importance of other factors in describing competitive situations. For example, research and development is required for technological advancement and, ultimately, economic growth which, in turn, will create more favorable competitive situations for many firms. But, research and development activities result from certain product strategies that a firm is using to generate, hopefully, market conditions more favorable for the output of the firm. Also, the larger firms are in a better position to undertake these activities because the financial capabilities and/or time requirements generally exceed those available to the small firm. Thus the size of the firm can identify the position of a firm in its competitive environment relative to other firms, and also point to certain product strategies that might be unfeasible for the small firm because of its small size.

SELECTION OF THE SET OF PRODUCT STRATEGIES

In the next two sections the parameters of the model that is to be applied to the Michigan machine tool industry will be estimated. However, we must first establish the particular model that will constitute our framework of analysis.

It was indicated in Chapter I that the product strategy of diversification was not necessarily a cure-all for the economic problems of a firm. The capabilities of a firm to adequately implement a strategy of diversification are an important determinant of the desirability of this strategy to a firm. It is quite conceivable, then, that a strategy of "continuing to do what you are presently doing" could be optimal for a firm under certain conditions of capability and competitive situation. If a firm, for example, has been doing essentially the same thing for 10 to 15 years, there might be an unwillingness on the part of the firm to attempt something different. This could indicate a lack of capabilities to engage in new product development and could result in eventual economic ruin for the firm. However, if a firm has been performing well in the market, "continuing to do what it is presently doing" might be a reflection of the importance to product strategy selection of technological skills that have been acquired over time. For example, the special Michigan machine tool firms have developed tremendous technical knowhow and skills for solving the machine tool problems for the automotive industry. In any case, a firm generally compares the expected returns from developing a new product for the same or a new market with the expected returns from continuing to serve its existing markets with its existing products. The decision to develop a new product must take into account the fact that certain resources now being used to serve its existing markets with its existing products will be used to develop and market the new product. Thus attention will be focused on the effect that the capabilities of a firm have on its product strategy decisions. Therefore, it appears reasonable to consider one product strategy in the set of feasible product strategies for the Michigan standard and mixed firms to be the product strategy of "continuing to do what you are presently doing." We will call this product strategy PS^1.

As indicated in Chapter I, in an industry, such as the machine tool industry, where technological change is extremely slow and where the firms have tended on the average to follow PS^1 for the last 10 to 15 years, the use of this product strategy in our model will greatly facilitate estimating the probability transition values (p_{ij}^1) and the return values (r_{ij}^1).

We must now decide on the alternative feasible product strategies that a Michigan machine tool firm could use to meet its present and future competitive situations. In general, the larger the number of strategies we include in the model the greater will be our estimation problems. In fact, with only one additional product strategy, we find that the estimation problems are almost impossible, especially if we expect to associate that product strategy directly with a particular new product or a particular market. For example, the potential returns accruing from a market in which a machine tool firm has never been before (such as the market for electronic components) are almost impossible to estimate empirically, and the probabilities of making transitions from one competitive situation to another cannot be estimated because the potential competition and its effects on a machine tool firm cannot be determined. The primary reason for this is that machine tool firms have not attempted to enter the electronic components market. Furthermore, the probability transition and return values accruing to a firm from the introduction of a new machine tool into its existing markets would also be extremely difficult to estimate empirically. This means, then, that these probability transition and return values would have to be subjective estimates, reflecting the best guesses of people who are familiar with the economic characteristics of the machine tool and electronic components industries. Although this might be a feasible way to generate an additional product strategy for use in the model, it seems to this author that a more useful approach for purposes of analysis would be to consider PS^2 as an abstract product strategy that could be applicable for any new or different product or market. The analysis, then, would be an attempt to determine the potential returns that should exist in the particular market (new or existing) a firm is contemplating serving, if PS^2 is to be selected instead of PS^1, for the given conditions of this firm's capabilities and its competitive situation. The results of the model would be an indication of the expected market potential that must exist, if a firm wants to do something other than or in addition to what it is currently doing, as a function of the competitive situation a firm is currently in, the capabilities of a firm, the effective use of these capabilities, and the number of time periods which constitutes the planning time horizon.

This approach probably would not be feasible if the number of product strategies is greater than two. It would be almost impossible, for example, to determine which particular combined effect of $PS^2, \ldots, PS^k$ is being compared with PS^1. A presentation of all combinations would result in a combinative problem that is impractical both for purposes of analysis and interpretation for a large number of product strategies. Thus, we will restrict our attention to a model which considers an interaction of two product strategies, PS^1 and PS^2, where PS^1 is the product strategy "continue to do what you are presently doing" and PS^2 is the product strategy "do something in addition to what you are currently doing."

Obviously firms exist that employ a diversification program that simultaneously involves many products and many markets. The 2 product strategy model, then, is not appropriate in these cases for purposes of analysis. Conceptually a k product strategy model is appropriate and conceivably could yield certain analytical results that would give theoretical insights into this entire problem area. (This is discussed further in Chapter V.) However, a large number of medium and small firms exist for which the 2 product strategy model as previously discussed would be applicable. In particular, the Michigan standard and mixed machine tool firms are in a position where the analysis of "continuing to do what you are presently doing" and "attempting to do something in addition to what you are presently doing" is very meaningful. These small firms must contend with the "largeness" of their competitors, the significant yearly fluctuations in sales dollars, the relative lack of technological change in the industry (necessary for new products and processes) and, in general, a relative financial inability (because of their size) to engage in fundamental research important for technological change.[15] These factors suggest that a Michigan machine tool firm might want to develop a new product for their existing market, diversify into a different market, or even merge. But these firms probably do not have the total required capabilities to consider developing more than one new product or entering more than one new market simultaneously. In fact, the analysis with the 2 product strategy model may indicate that the existing capabilities of a firm might not be adequate to attempt developing one new product or entering one new market. Therefore, we will use a 2 product strategy model and will now proceed to estimate numerical values for P^1 and R^1. The numerical values given to P^2 and R^2 for purposes of analysis are presented later in this chapter.

ESTIMATION OF P^1 AND R^1

In the section on competitive aspects of the industry it was concluded that "size of the firm," as measured by total employment, was to be the major factor in identifying the competitive situations of the firms in the industry. Thus we are interested in estimating the probability that a firm will make a transition during the next time period from one size class to another using PS^1. The estimates are based on employment figures for the years 1946-1961. The source of this information is Poor's Register of Directors and Executives.[16] Although the information is a composite of the different product strategies used by the firms over time,

[15]This has prompted one analyst to conclude that all small and medium-sized machine tool firms must merge with each other to form an industry of approximately 50 large, efficient firms. See Seymour Melman, The Peace Race (New York: George Braziller, 1962), Chapter 6.

[16]Standard and Poor's Corporation, Poor's Register of Directors and Executives (New York: Standard and Poor's Corporation Annual Edition, 1948-1962).

it is reasonable to use this information for PS^1 because almost all of the machine tool firms have been doing essentially the same thing for the last 15 to 20 years. (This fact has been discussed extensively in this and the preceding chapters.)

The numerical estimates of the probabilities of making transitions from one size class to another were calculated by Hannum.[17] Before the results are presented, however, it is necessary to point out some limitations that exist with respect to the use of data from Poor's Register. Poor's Register lists all business firms in the United States and Canada which are aware of the register and acceptable for listing. Firms engaged in manufacturing, wholesale, or retail trade and insurance and financial institutions with at least forty employees are encouraged to apply for listing. The purpose of listing firms is, first, to identify the directors and executives of these firms and, second, to give employment and product information. Since this information is solicited on a voluntary basis, the coverage of firms by this service has increased somewhat over the fifteen year period 1946-1961. Also, the employment figures given represent average total employment for a firm for a year and tend to be grouped in sizes of 50, 75, 100, 125, etc. Therefore, the estimates of the probability transition values are not as reliable as they would be without these limitations. For our purposes, however, they will be adequate.

The technique used by Hannum to obtain p_{ij} values is based on work by Anderson and Goodman.[18] They show that if a Markov chain is first order and a set of observations over many time periods is available, the observations are a set of sufficient statistics for maximum likelihood estimates of the elements of the transition matrix P. They also show that it is possible to interpret the transition probabilities p_{ij} as multinomial probability numbers, and that the estimates of these p_{ij} behave according to the standard theory of multinomial distributions and to normal approximations to multinomial distributions.[19] This, then, permits the use of the chi-square (χ^2) distribution to test the hypotheses that: (1) a set of probability values p_{ij}^0 estimated from observations on a finite Markov chain are equal to a set of specified probability values p_{ij}; and that (2) the estimated transition probability values are constant over a number of periods.

[17]Hannum, Chapter IV.

[18]T. W. Anderson and Leo A. Goodman, "Statistical Inference About Markov Chains," The Annuals of Mathematical Statistics, Vol. 28, March 1957, pp. 92-98.

[19]See, for example, H. D. Brunk, An Introduction to Mathematical Statistics (New York: Ginn and Co., 1960).

The number and size of the class intervals used in the estimation procedure were based on the following factors:

(1) Each size class in the set used should have a positive probability of occurring at some point in the future.

(2) It is expected that large firms are able to change their size by greater absolute amounts than small firms.

(3) The number of class intervals is finite and should be small in order to make the analysis tractable.

Hannum used employment data from 346 firms for the years 1946-1961. He used five classification structures in order to try to discover the effect of various designs on the nature of the transition matrix. The structure that we will use consists of six class intervals with the range of employment for each class given in Table V.

TABLE V. EMPLOYMENT RANGE FOR MATRIX CLASSES

Class	Range
1	0-80
2	81-130
3	131-230
4	231-490
5	491-1525
6	Over 1525

Since the size of the firm as measured by employment constitutes the significant factor in identifying the competitive situation of a firm, the competitive situations facing firms are identified by the size classes shown in Table V. Thus CS_1 is equal to Class 1 and CS_2 is equal to Class 2, etc. The probability transition matrix was then computed and is given here:

$$P^1 = \begin{array}{c} \\ CS_1 \\ CS_2 \\ CS_3 \\ CS_4 \\ CS_5 \\ CS_6 \end{array} \begin{array}{cccccc} CS_1 & CS_2 & CS_3 & CS_4 & CS_5 & CS_6 \\ \hline .951 & .041 & .005 & .003 & 0 & 0 \\ .026 & .928 & .043 & .002 & 0 & 0 \\ .003 & .027 & .924 & .041 & .005 & 0 \\ .001 & 0 & .031 & .944 & .024 & 0 \\ 0 & 0 & .002 & .036 & .923 & .039 \\ 0 & 0 & 0 & 0 & .038 & .962 \end{array} \tag{35}$$

We note the high probability of a firm's staying in the competitive situation that it is in currently. Also, there is a small probability for a firm to move to the adjacent highest or lowest competitive situation and an extremely small probability, in a few instances, of moving to the second or third highest or lowest competitive situations. The existence of the zero values implies, for example, that a firm requires three or more time periods to make the transition from CS_1 to CS_6. This means that a firm cannot grow from a small firm to a large firm in less than three years. For the machine tool industry this seems reasonable.

The chi-square test was made on the hypothesis that the probability values in this transition matrix were good estimates of the true values and hence could be used to predict the size distribution of the industry in any specified year. The actual final-year distribution was compared with the expected distribution for the years 1946-1961, and a chi-square value was computed. From tables it was found that the probability of obtaining a chi-square value this great or greater was approximately equal to 0.80. This means that the probability transition matrix is only a reasonably good predictive tool for size distribution of an industry over time. Thus, the final results of the application of the model in this thesis to the Michigan machine tool industry, an application which uses this probability transition matrix, are only approximately reliable. However, since the primary purpose is to demonstrate the application of this model to an industry, the probability estimates in this matrix are adequate, and certainly better than an arbitrarily random selection of probability values.

The returns accruing to firms who make transitions according to P^1, given in Equation 35, could be measured in a number of different ways. Some of the alternatives are sales dollars, net income, market share, and return on investment. We note immediately that the alternative ways of representing returns can reflect different firm objectives, both in the short run and the long run. As we pointed out in Chapter I, the expected profits resulting from an objective of maximizing market share would probably be different from one of maximizing net income. The results would also depend on the time horizon considered in pursuing an objective.

The measure of return that will be used in this thesis is market share. This implies, then, because of the nature of the model, that a firm will be attempting to maximize market share over the long run. Obviously, this is not the objective of all or perhaps even most of the Michigan or United States machine tool firms. But, as mentioned before, the primary objective in this thesis is to demonstrate the procedure of applying this model to a particular industry, to indicate the types of results that can be expected, and subsequently to identify potential areas of future study for the use of this model. The ramifications and implications of using various measures of return for purposes of analysis with this model are discussed in Chapter V.

A significant reason for using market share as a measure of return is the fact that market share has tended to remain constant over time for specified groups and classes of firms, even though sales dollars have fluctuated widely in an almost random fashion. Figures 2 and 5 show the market shares over time of the total Michigan machine tool industry and the Michigan standard, special, and mixed firms. The market shares shown by these figures are quite constant over time. A further indication of this constancy is given in Figure 9. This figure gives a plot of the percent of total sales of all firms that were accounted for by the firms in each of the competitive situations at different points in time. Since the competitive situation of a firm is reflected by its size (as measured by employment), the percentage figures represent the contribution by firms in each size class to the total output of the industry which these firms constitute. The curves for CS_1, CS_2, and CS_3 are quite constant, whereas the curves CS_4, CS_5, and CS_6 show some fluctuations over time. (A partial explanation for this variation is given later in this section.) The importance of the constancy of this measure of return is in its use in the model. If sales dollars, for example, were used, predictions of future sales would be almost impossible because of the apparent random fluctuations in sales levels that occur over time.[20] However, by using market share, we can reasonably extrapolate these relatively constant values over some future time periods. Also, conceivably some form of sensitivity analysis could be used to determine the sensitivity of the optimal decision vector to changes in the market share figures. This would give an indication of the extent to which variations from the extrapolated values could exist without affecting the optimal decision vector.

Although market share values tend to be constant over time, one cannot predict exactly what any particular firm will receive at any point in time because this firm moves randomly from one CS_i ($i = 1, 2, \ldots, 6$) to another. At least, this is what the model (in terms of the Markov process) tells us should happen, and this is what we should be able to observe empirically. The picture of movement of any machine tool firm over time from one CS_i ($i = 1, 2, \ldots, 6$) to another, then, should be similar to Figure 10. This figure was constructed by using a random number table to generate the movement of firms over time according to the probabilities given in Equation 35. A plot was made for each CS_i ($i = 1, 2, \ldots, 6$) as the starting

[20]This is not quite true, since McGraw-Hill has given point estimates for United States and world consumption of machine tools in 1967 and 1970. See Metalworking Production, a McGraw-Hill weekly publication, Vol. 106, No. 30, July 25, 1962. However, random fluctuations about the trend lines indicated by these point estimates is certain to occur over time, and year-by-year predictions are impossible.

state of a sequence of movements over time. Fifteen transitions were recorded for each plot so that the theoretical plots could be compared with the empirical plots for the years 1946-1961.

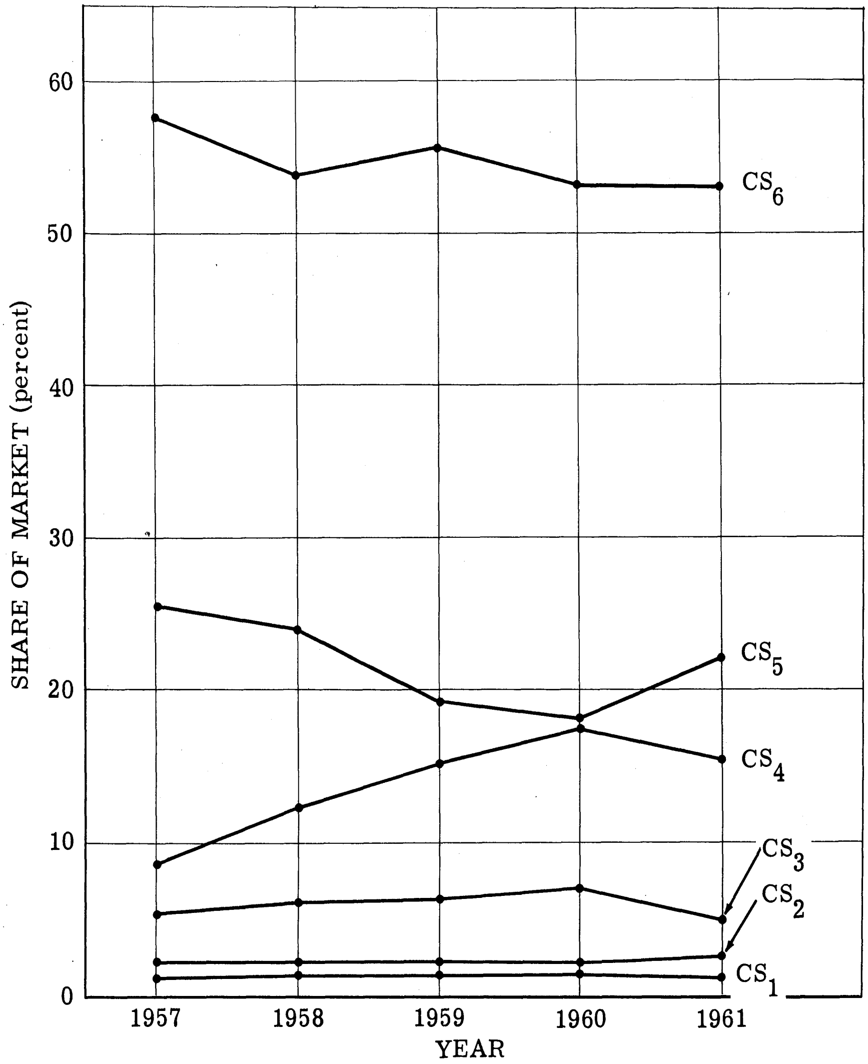

FIGURE 9. MARKET SHARE OF FIRMS IN EACH COMPETITIVE SITUATION

For the empirical plots, five machine tool firms were selected at random from the sample of forty-two firms whose data were used to estimate the market share values for R^1; their movements from one CS_i ($i = 1, 2, \ldots, 6$) to another were plotted over the 1946-1961 time period. Figure 11 shows these plots. Three points can be made about Figures 10 and 11.

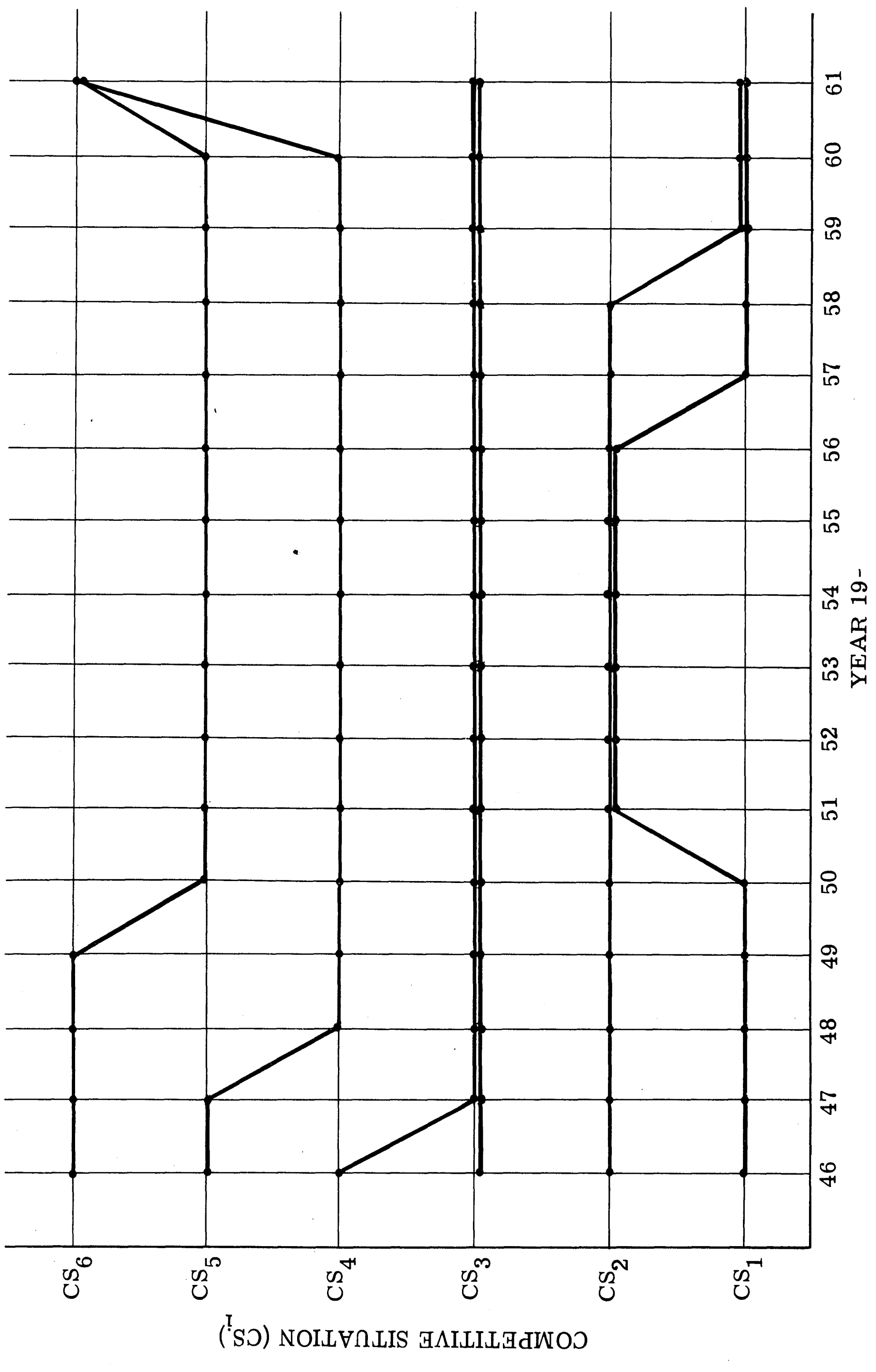

FIGURE 10. THEORETICAL MOVEMENTS OF MACHINE TOOL FIRMS FROM CS_i TO CS_j

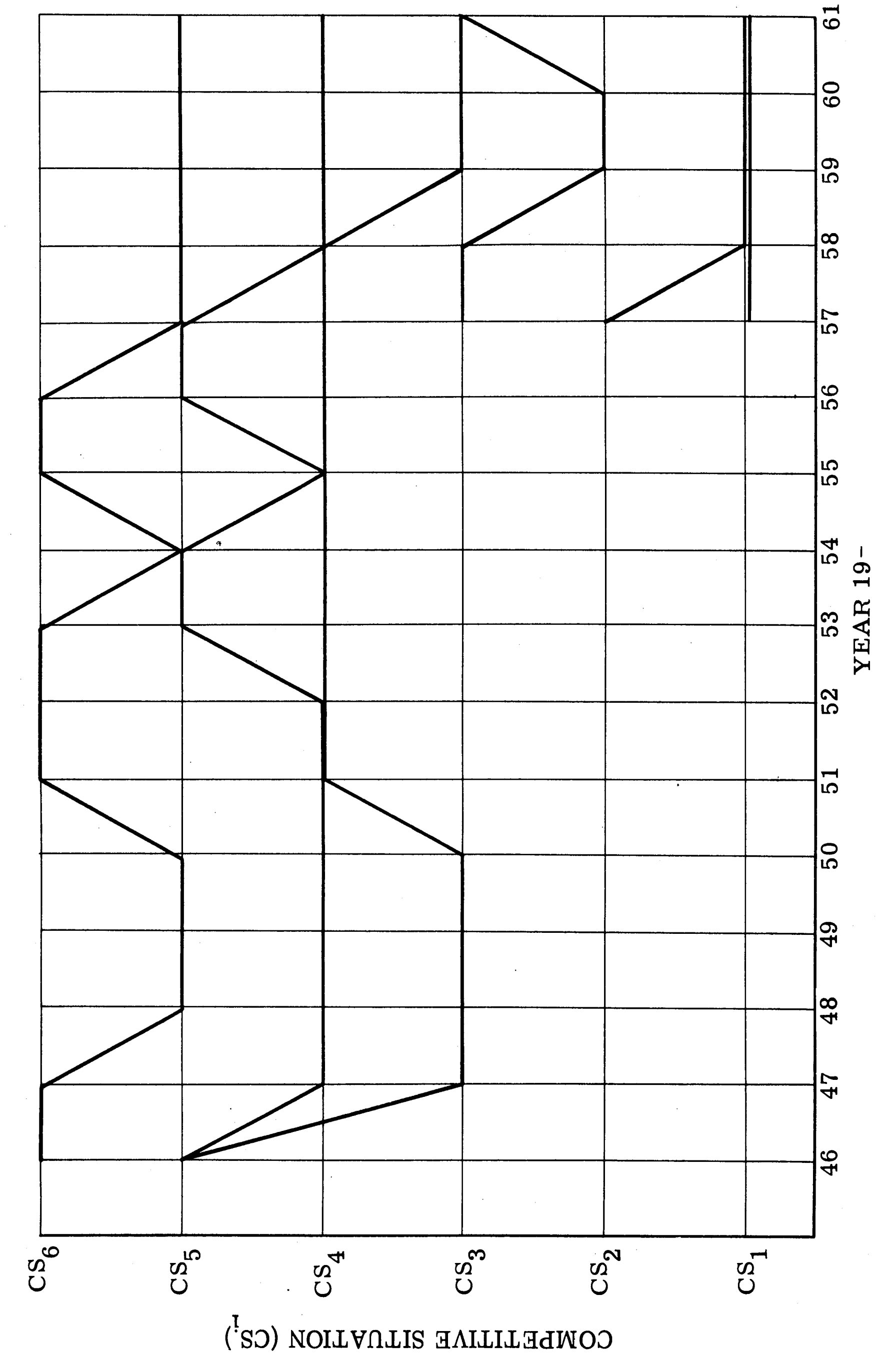

FIGURE 11. EMPIRICAL MOVEMENTS OF MACHINE TOOL FIRMS FROM CS_i TO CS_j

First, there is a definite tendency for firms to move between only two competitive situations over time. This tendency is observed in both the theoretical and empirical plots, and is a reflection of the high probability values associated with making transitions from CS_i to CS_i (i = 1, 2, . . . , 6). If the time interval for observation (theoretical or empirical) were significantly longer than 15 years, movements between more than two CS_i would probably be observed. It is also conceivable that the empirical plots suggest the existence of multiple ergodic chains in the process rather than one ergodic chain, as implied by Equation 35. However, the existence of multiple ergodic chains in a process implies that either a firm starts in a particular chain and stays in it, or that transient states must exist which make it possible for a firm to move from one chain to another. Steady-state analysis under these conditions implies that the starting state is important, but that after a firm makes the first transition it is caught in one of the chains in which it makes its future transitions. For transient analysis a small number of transitions could be made before entering one of the chains. Thus one might conclude that the empirical results represent the steady-state probabilities for firms in the machine tool industry. This assumption, however, implies that firms cannot leave these apparent chains and hence cannot grow or decline in size. Obviously this is unrealistic. The following discussion can partially explain this problem.

Equation 35 indicates a very high probability that firms will stay in the competitive situation that they are currently in. This means that the expected time for a firm to move from, for example, CS_1 to CS_6, is very large. Hannum has shown that this time is greater than 500 years (each time period is a year).[21] Hence, the time span in Figures 10 and 11 is not long enough to permit an observation of movements from CS_1 to CS_6. These figures also support the contention that the parameters of this model are likely to change during the total time required for convergence and steady-state conditions. Therefore, transient behavior must be studied and the results will be a function of the starting state and the number of time periods of the process.

It must also be recognized that only 42 firms are represented in R^1, from which group the five firms in Figure 11 were selected, whereas 346 firms are represented in P^1. Thus, it is possible that the firms which have made transitions over a larger number of CS_i (i = 1, 2, . . . , 6) are not included in the sample of 42 firms.

[21]Hannum, p. 111.

Second, the plots in Figure 11 do not represent completely random movements: all five firms are in the smallest CS_i of the two CS_i's that they move between for the years 1949 and 1959, which were low sales years for the national machine tool industry.

Third, information for the three smaller firms was available only for the years 1957-1961.

These limitations must be recognized since they reflect on the potential usefulness of the results of the application of this model.

The estimation of the market share values in R^1 was based on information collected from 42 machine tool firms. This sample includes 24 Michigan machine tool firms (12 standard and 12 mixed) and 18 non-Michigan machine tool firms. It was impossible at this time to collect information from more non-Michigan firms because other non-Michigan machine tool firms are not publicly held, and hence sales information is not available in Poor's Register and Moody's Industrials reporting services. The information used for the Michigan firms came from questionnaires that these firms completed during the summer of 1962. The range of employment for these 42 firms in 1961 was from 31 to 9463 employees. The number of firms making transitions over time was sufficient to permit an estimation of most of the R^1 values. However, no information was available for those transitions that had a very small probability of occurring (that is, $p_{ij}^1 \leq 0.005$). Therefore the market share values had to be estimated subjectively. This estimation does not introduce much of a bias in the expected results because (1) expected values are used and the p_{ij}^1 associated with these r_{ij}^1 are very small, and (2) certain trends in the other r_{ij}^1 estimated from the data were observed and hence suggested appropriate values.

The movement of each firm for each time period was noted and its sales dollars for that time period, expressed as a percent of total industry sales as reported by NMTBA, was recorded. The mean value (simple average) was then computed for each possible transition where data existed, and is given in Equation 36.

The dash marks in certain cells in the matrix in Equation 36 represent those r_{ij}^1 values that must be estimated subjectively since, as mentioned before, empirical data does not exist at the present time. Before these r_{ij}^1 values are estimated several interesting points about this matrix can be made.

First, we observe that transitions from a competitive situation to the next lower indexed competitive situation gives a market share that is less than the market share a firm would have received if it had stayed in the same competitive situation. This is reasonable from the point of view of economic theory.

$$R^1 = \begin{array}{c|cccccc|} & CS_1 & CS_2 & CS_3 & CS_4 & CS_5 & CS_6 \\ CS_1 & .118 & .116 & --- & --- & 0 & 0 \\ CS_2 & .140 & .240 & .119 & --- & 0 & 0 \\ CS_3 & --- & .214 & .568 & .325 & --- & 0 \\ CS_4 & --- & 0 & .508 & .768 & .579 & 0 \\ CS_5 & 0 & 0 & 0 & 1.062 & 1.969 & 2.846 \\ CS_6 & 0 & 0 & 0 & 0 & 3.161 & 5.008 \end{array} \qquad (36)$$

Second, we observe that, with the exception of the transition from CS_5 and CS_6, the upward transitions to the next highest indexed competitive situation result in a market share that is less than the market share a firm would have received if it had stayed in the same competitive situation. Since the higher indexed competitive situations represent greater market potential and presumably an improved competitive situation (see the section in this chapter on competitive aspects of the industry), this empirical result is a little puzzling. If we recall that the competitive situations represent size classes and that the size classes represent employment intervals, it is conceivable for firms to make greater percentage changes in employment within an interval than between two intervals. It is also conceivable that firms making a small percent of employment change between two intervals receive on the average a lower market share than firms making a larger percent of employment change up to but not exceeding the interval boundary. Another factor that might partially explain this phenomenon is the sample size. The number of market share values for transitions from CS_i to CS_i ($i = 1, 2, \ldots, 6$) is quite large, whereas the number of transitions from CS_i to CS_j ($i \neq j$) is relatively small. The small sample sizes could introduce a bias into the computed mean values.

Finally, we note that the market shares for firms making transitions from CS_4 to CS_3 and from CS_3 to CS_2 are smaller than those received by firms who stay in CS_3 and CS_2, respectively. At the present time the author has no explanation for this fact except to suggest that it might result from factors similar to those affecting the estimates of the r^1_{ij} ($j > i$) mentioned earlier.

The subjective estimation of the r^1_{ij} represented in Equation 36 by dash marks proceeded in the following way. The percentage increase in market values from r^1_{11} to r^1_{12} was applied successively to obtain the values for r^1_{13} and r^1_{14}. The results seem to be reasonable in terms of the other r^1_{ij} values. Because of the strange phenomenon occurring for $r^1_{i,\ i+1}$, except for r^1_{56}, it was decided to use the same values for $r^1_{i,\ i+2}$, and $r^1_{i,\ i+3}$, wherever they were required. Thus Equation 36 now becomes

$R^1 =$

	CS_1	CS_2	CS_3	CS_4	CS_5	CS_6
CS_1	.118	.116	.116	.116	0	0
CS_2	.140	.240	.119	.119	0	0
CS_3	.166	.214	.568	.325	.325	0
CS_4	.207	0	.508	.768	.579	0
CS_5	0	0	0	1.062	1.969	2.846
CS_6	0	0	0	0	2.161	5.008

(37)

One way to test the effect that the subjectively estimated r_{ij}^1 values will have on the optimal decision vector is to perform a sensitivity analysis on these values to determine the percent change that could occur in each value before the optimal decision vector would change. This would give an indication of the extent to which statistical accuracy is needed in the estimation of these values.

ESTIMATION OF P^2 AND R^2

It was indicated earlier in this chapter that the product strategy of "do something in addition to what you are currently doing" (PS^2) was to be represented abstractly, in the sense that it was not to be associated explicitly with a particular combination of a new or existing product and market. This means that the model will indicate the level of expected market share that should exist in the particular market (new or existing) a firm is contemplating serving with a new or modified product; the model will indicate that level as a function of the firm's capabilities to implement this product strategy, the competitive situation it is presently facing, and the selected future time horizon, which influences the current decision. Even this abstract thinking and representation of PS^2 does not permit meaningful estimates of P^2 and R^2 until assumptions are made.

First, it will be assumed that PS^2 for the machine tool firms represents the development of a new machine tool for their existing market. This new machine tool will represent a technological change from their existing machine tools and hence will involve research and development activities. The firm capabilities affecting its ultimate decision, then, will reflect both technically and financially its ability to engage in research and development. In view of the relative lack of both technological change within the machine tool industry and of research and development activities within the firms, this product strategy is a meaningful one to consider.

Second, it will be assumed that the machine tool firms have the capability to "continue doing what you are presently doing" (PS^1). This means that $b_i^1 = 1.0$ for all i, and hence the estimates of the probability transition values given in Equation 35 are P^1 or $\overline{P}^1$. Since $b_i^1 = 1.0$ for all i, Equation 29 becomes

$$p_{ij}^1 = \bar{p}_{ij}^1 (1) + \bar{\bar{p}}_{ij}^1 (1 - 1)$$

or

$$p_{ij}^1 = \bar{p}_{ij}^1 \tag{38}$$

Expressed in matrix form

$$P^1 = \overline{P}^1 \tag{39}$$

Third, it will be assumed that the numerical estimates for R^1 given in Equation 37 represent the market share values that machine tool firms will continue to receive, on the average, by employing PS^1. Although, as indicated earlier, this assumption involves a mixture of product strategies, no product strategy has been uniquely different from the others, and if all firms did continue to "do what they are currently doing," the firms would receive the indicated market share. Furthermore, at the present time it is impossible to determine which firms have poor management and which firms have good management. Therefore, the average market share values will represent what firms can expect to receive by employing PS^1 where these r_{ij}^1 values reflect the average impact of the management capability of the firm.

Fourth, it will be assumed that $\overline{P}^2 = P^1$. This means that the probabilities of making transitions from CS_i to CS_j by employing PS^2 under the condition that a firm has the capabilities to implement PS^2 are equal to the probabilities of making transitions from CS_i to CS_j by employing PS^1 with no conditions.

Fifth, it will be assumed that $\overline{\overline{P}}^2$ has the following numerical values:

$\overline{\overline{P}}^2 =$ (40)

	CS_1	CS_2	CS_3	CS_4	CS_5	CS_6
CS_1	1	0	0	0	0	0
CS_2	1	0	0	0	0	0
CS_3	0	1	0	0	0	0
CS_4	0	0	1	0	0	0
CS_5	0	0	0	1	0	0
CS_6	0	0	0	0	1	0

This means that with a probability value equal to one, a firm that attempts to employ PS^2 but does not have adequate capabilities to implement it, will make a transition to the next lowest size class during the next time period. This is not true of a firm in CS_1, which will stay in CS_1 the next time period. It is conceivable that a small firm could go out of business if it attempted to implement a product strategy for which it lacked adequate capabilities. In fact this could also occur to certain medium-sized firms. This suggests the use of CS_0 to represent the exit and entry of firms into the industry. (This idea is discussed further in Chapter V.) Some justification for $\bar{\bar{p}}_{11}^2 = 1$ is given later when Gibrat's Law is discussed. Using $\bar{P}^2$ as indicated above, P^2 is generated according to Equation 30. If we further assume that b_i^2 is the same for all i, then b^2 will serve as an independent variable in subsequent analysis.

Since our analysis will be of the type that indicates what the values of R^2 must be if PS^2 is to be selected instead of PS^1 under given conditions of firm capability and existing competitive situation, the specification of R^2 will be handled in a parametric fashion; that is, under different assumed values of R^2, the optimal strategies will be identified. Then, for given conditions of capability and competitive situation, the size of the expected market share resulting from the use of PS^2 can be determined.

However, with the existing size of the R^2 matrix, the selection of parameters would become intractable unless recourse was taken to a simplifying assumption. The simplifying assumption that is used is based on Gibrat's Law of Proportional Effect.[22]

Gibrat's Law states that the probability of a given proportionate change in size during a specified period is the same for all firms in a given industry—regardless of their size at the beginning of the period. For example, a firm with sales of $100 million is as likely to double its share in a given period as a firm with sales of $100 thousand. The fact that market share values have tended to be constant for the different size classes (see Figures 2, 5, and 9) is a manifestation of Gibrat's Law. Furthermore, since the objective of the model, as it is applied to the machine tool industry, is to select the product strategy that maximizes total expected market share, and since the model is operating on two product strategies, both applicable to the same market, then selecting a product strategy that maximizes market share is equivalent to selecting a product strategy that maximizes sales. In fact, if two different markets are

[22]Edwin Mansfield, "Entry, Gibrat's Law, Innovation, and the Growth of Firms," The American Economic Review, Vol. LII, No. 5, December 1962.

represented by the two product strategies, but both markets have the same expected sales potential, the above result still holds. A question that arises now is whether or not Gibrat's Law holds.

Mansfield has confronted this question by studying the steel, petroleum, and rubber tire industries.[23] In all cases, using a chi-square test for statistical significance, he found the following:

(1) Gibrat's Law did not hold if all the firms in a specified industry, including those that left the industry during the period, are included in the analysis. The primary reason for this exception is the lack of independence between the probability that a firm will die and its size. In every industry and time interval, the smaller firms were much more likely than the larger ones to leave the industry.

(2) Gibrat's Law did not hold for every firm other than those that leave the industry. Smaller firms tended to have higher and more variable growth rates than larger firms. This could suggest the existence of firms operating below some minimum efficient size in the industry.

(3) Gibrat's Law did hold if the subset of firms that was analyzed excluded those that left the industry and those that were less than the minimum efficient size in the industry. (The minimum efficient size is the size below which unit costs rise sharply and above which they vary only slightly.)[24]

Since the machine tool industry consists of firms that have been in business for a long period of time and hence firms that are fairly efficient (firms that are inefficient could not stay in business such a long period of time), it will be assumed that Gibrat's Law holds. This means that subsequent analysis will treat R^2 parametrically, that is, as scalar multiples of R^1 ($R^2 = 2R^1$, $R^2 = 3R^1$, etc.). Therefore, the results of the model will indicate what market share must exist if PS^2 is to be selected instead of PS^1 where, for a given firm, the potential effect of selecting PS^2 on this firm and its competitors (regardless of size) is based on Gibrat's Law.

In the fifth assumption, discussed previously, it was indicated that $\bar{\bar{p}}_{11}^{2} = 1$. This means that with certainty a firm will stay in CS_1 during the next time period if it is now in CS_1 and attempted to implement PS^2 without adequate capabilities. If PS^2 represents "doing something

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[23] Ibid.

[24] This concept is discussed and illustrated in J. Bain, Barriers to New Competition (Harvard University Press: 1956).

in addition to what you are presently doing," and if it represents doing something not too different from the current activities of the firm (PS^2 in this model), then a firm in CS_1 will probably not be forced out of business; with the assumption of Gibrat's Law for the machine tool industry this firm will stay in CS_1 because it is assumed that this firm is operating at or above the minimum efficiency size.

A final assumption concerns the values of b_i^2 (i = 1, 2, . . . , 6). It will be assumed that for a particular firm, b_i^2 is constant for all i. This implies that for a given level of firm capabilities, the effect on the probability transition values for all firms is the same regardless of the size of the firm. For example, if the probability, for both a large and small firm, is 0.5 that the firm's capabilities are adequate to implement PS^2, the effect in terms of modifying the probabilities of making transitions is the same for both firms.

The analysis will now proceed in the following way. Equation 32 will be used to select the optimal product strategy (PS^1 or PS^2) and simultaneously compute maximum total expected market share for the optimal product strategy as a function of n (the planning horizon), CS_i (the existing competitive situation of the firm), a^2 (the effectiveness with which the firm's capabilities are used to implement PS^2), and b^2 (the probability that the firm's existing total capabilities are adequate to implement PS^2). This analysis will be based on the estimated values of P^1 (Equation 35), R^1 (Equation 37), $\bar{P}^2$ (assumed, as above, to be equal to P^1), and $\bar{\bar{P}}^2$ (Equation 40).

RESULTS

The number of variables used and the range of each variable indicates that a significantly large amount of quantitative information could be obtained from the model in this chapter.[25] In order to keep the analysis tractable, we will present some of the results that include aspects of two problem areas that are of concern to most firms. The first problem area is the selection of an optimal product strategy for given conditions of firm capabilities, competitive situation, and planning horizon. The second problem area is the extent to which the future should be brought into the planning horizon which is used in the selection of an optimal product strategy for the next year.

In the first problem area we are concerned primarily with the effect that capabilities have on the selection of optimal product strategies. In particular, we would like to identify what the

[25] A computer program was written to facilitate analysis and is described in Appendix C.

total market share potential must be to justify the selection of PS^2 over PS^1 under given conditions of firm capabilities and a planning horizon. Since the optimal decision vector specifies the optimal product strategy for each competitive situation at any point in time, the graphs that can be plotted for each competitive situation are similar in shape but different in numerical values. Therefore, the essence of this information can be illustrated as in the graphs for CS_2 and CS_5 (Figures 12 and 13). These two competitive situations were selected because they represent a small and a large firm but not the smallest or the largest firms.

These figures show plots of maximum total expected returns ($v_i(5)$) for different probabilities of having adequate capabilities to implement PS^2 (b^2). Although the planning horizon used is five years, similar plots result from using other planning horizons. The value of a^2 (effective use of the existing level of capabilities) was fixed, whereas R^2 was treated parametrically, according to Gibrat's Law. For Figure 12, a^2 was set equal to 0.5, and for Figure 13, it was set equal to 0.8. On each figure the following points should be noted.

First, for each value of b^2 and R^2, $v_i(5)$ is indicated and the optimal product strategy is specified that, when implemented, will result in this maximum total expected market share. This is the appropriate product strategy, then, that a firm should select if it is in the indicated competitive situation and is basing its decision on a five-year planning horizon. As the level of capabilities (reflected by b^2) decreases and/or the effective use of this level decreases, PS^2 becomes a sub-optimal product strategy for a given market share expectation. In fact when R^2 is only twice R^1 (usually considered a significant increase from the point of view of businessmen), the plots show that a firm must have good capabilities in order to justify implementing PS^2. For a firm in CS_2, b^2 must be equal to 1 to justify using PS^2.

Second, the sub-optimal product strategies (in this case the other product strategy) are indicated with their associated total expected market share values for certain values of b_2. (The dashed curves represent sub-optimal product strategies.) In some cases (e.g., a low expected market share for PS^2), the sub-optimal product strategy gives an expected market share that is significantly lower than that obtained by using the optimal one. This effect, for a given level of capabilities, is a reflection of market share expectations and the effective use of the firm's level of capabilities. The difference between total expected market share values for the optimal and sub-optimal product strategies is an indication of the opportunity costs to the firm of those factors, not explicit in the model, that it feels are significant enough to justify its selection of the sub-optimal product strategy.

Third, and perhaps most important, these figures show the indifference curves for selecting optimal product strategies in a given competitive situation with given conditions of firm capability. That is, those points at which both product strategies are optimal represent, when

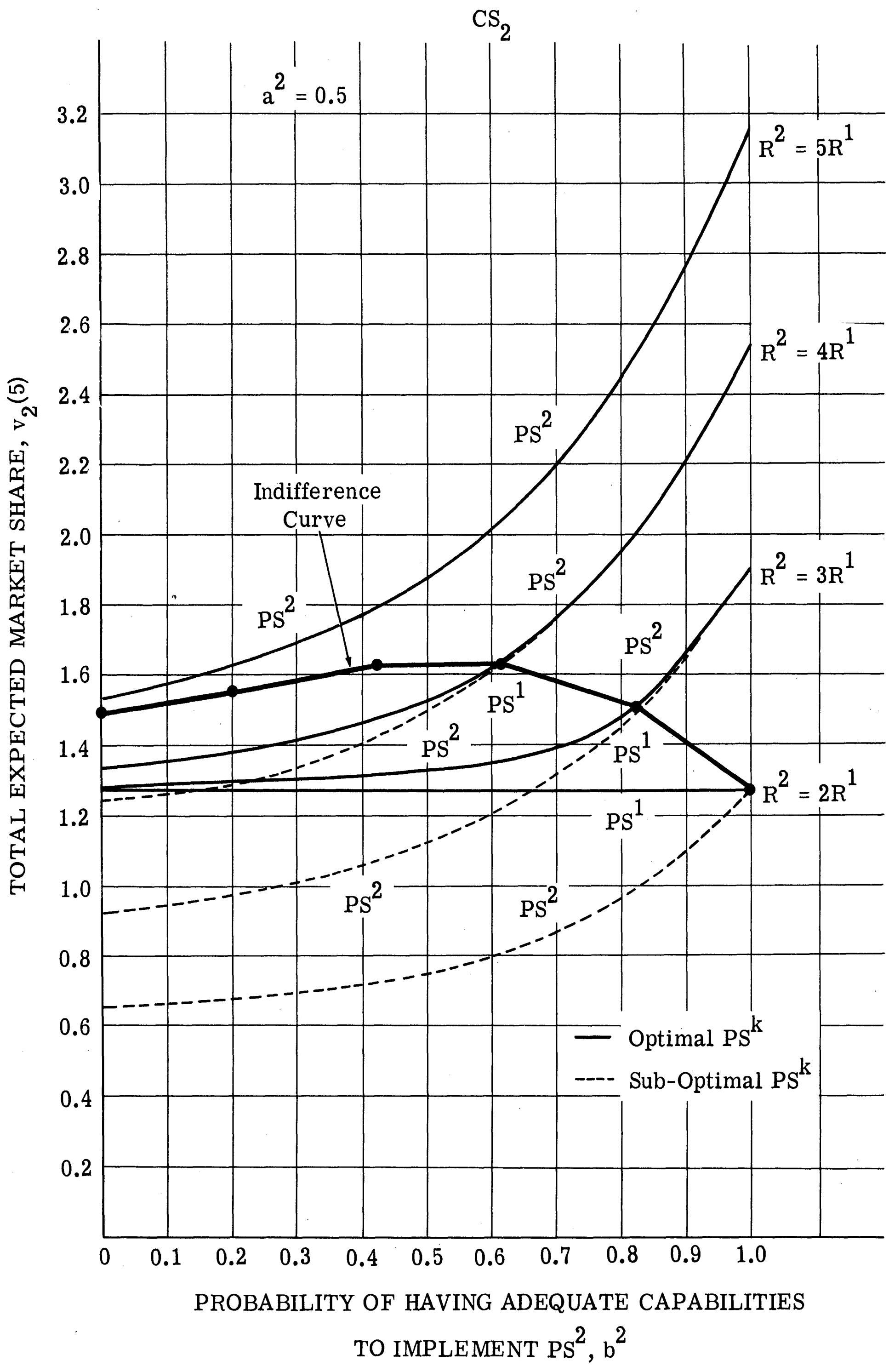

FIGURE 12. MARKET SHARE FOR CS_2 AS A FUNCTION OF b^2

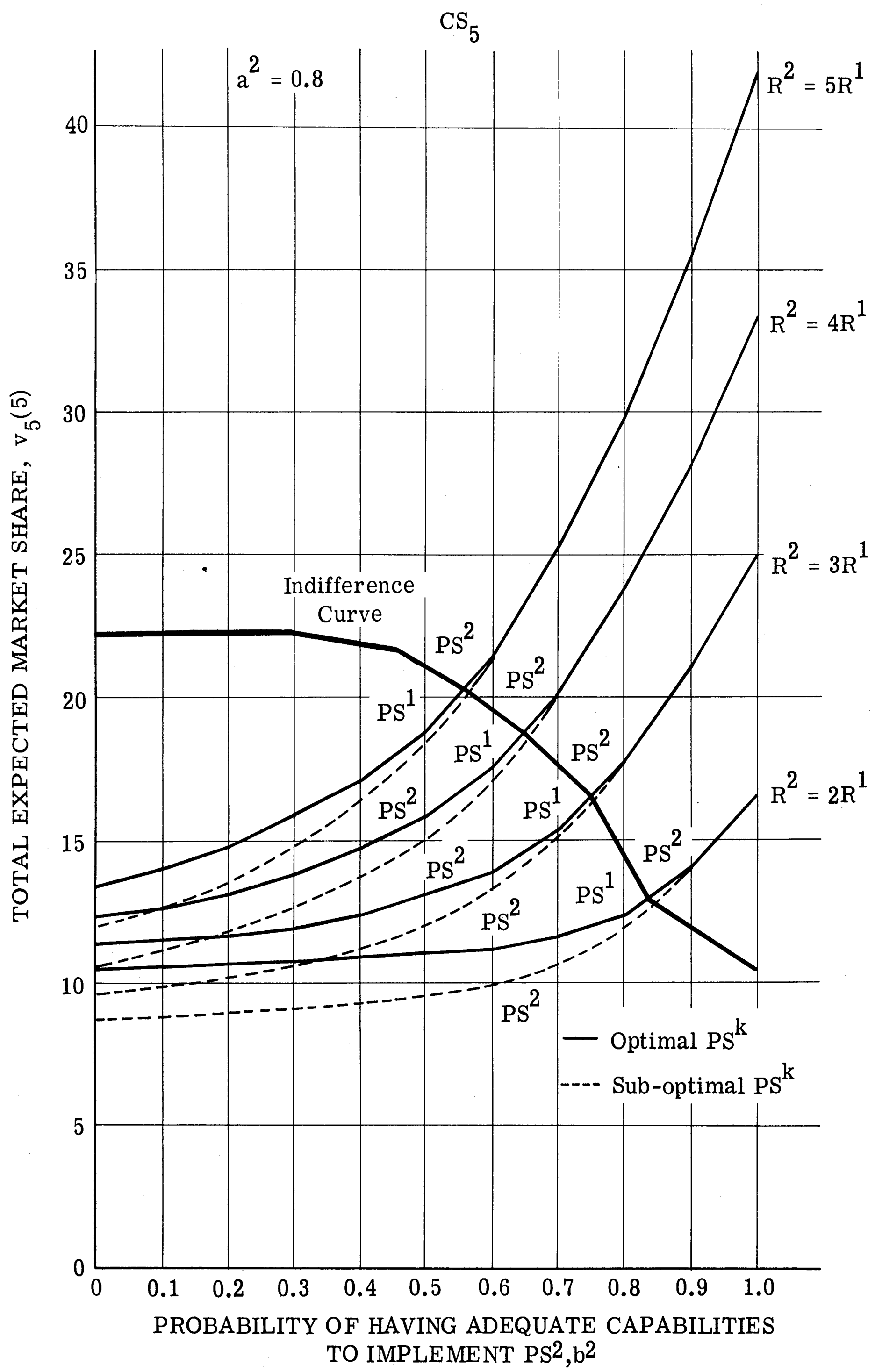

FIGURE 13. MARKET SHARE FOR CS_5 AS A FUNCTION OF b^2

plotted for all values of b^2, a situation (curved line) of indifference to the firm. The firm could select either product strategy and receive the same maximum total expected market share. The significant fact about these indifference curves is that for a given CS_i and planning horizon, the same curve holds for all values of a^2. For any value of b^2 the indifference curve indicates the $v_i(5)$ that will be received for all values of a^2 if PS^2 is selected instead of PS^1 as the optimal strategy to implement. However, a^2 plays the role of indicating what the market picture (in terms of market share) must look like for PS^2 in order to obtain the indicated $v_i(5)$. Thus, as a^2 takes on lower values, the total market share values (R^2) must increase. This means that for a given level of firm capabilities, the expected market share that must exist, if PS^2 is to be selected, is inversely related to the effectiveness of management to use its capabilities to penetrate the market adequately. The determination of the appropriate market share for any value of a^2 can be obtained by merely using the plot of the indifference curve and a set of plotted R^2 curves (where $R^2 = R^1$, $2R^1$, $3R^1$, etc.) for any CS_i. For example, Figure 12 gives a plot of the indifference curve and curves for various R^2 values for CS_2, where $a^2 = 0.5$. If the capability level (b^2) is equal to 0.82, the value of R^2 necessary to select PS^2 is $R^2 = 3R^1$ for $a^2 = 0.5$. One can now determine by using Equation 41 the value of R^2 for any value of a^2 for CS_2 with $b^2 = 0.82$.

$$R^2 = \frac{(0.5)(3R^1)}{a^2} \qquad 0 < a^2 \leq 1 \qquad b^2 = 0.82 \tag{41}$$

The values of $a^2 = 0.5$ and $R^2 = 3R^1$ in Equation 41 are merely based points from which to compute R^2 values for other values of a^2 for a given value of b^2. Any other a^2 value could serve as a base point provided its corresponding R^2 value can be obtained. The analysis would be similar for all CS_i ($i = 1, 2, \ldots, 6$).

Figures 12 and 13 clearly identify the importance to the firm of having good capabilities. The level of capabilities and the effective use of this level of capabilities (management capability) are both important if a firm contemplates doing something in addition to what it is currently doing. It will be shown in subsequent analysis that it is more important to have good management than to have a high level of capabilities which are not being used effectively.

In the second problem area, we are concerned with the extent to which the future should be brought to bear on a decision that is to be made for the next year. Since this model contains probability values for making transitions from one competitive situation to another and since these probability values are different for the alternative product strategies available to a firm, it is important to recognize the effect that a current decision will have on future decisions.

The optimal strategy in the short run may not be the optimal strategy—and in fact could be the worst strategy—in the long run.

Obviously the meaningfulness of including the future in making current decisions depends on many factors, among which are future technological changes, total market expectations, and general uncertainty about the total economic environment. Restated, for purposes of this model, the extent to which the future should be included in current decision making depends on the length of time over which the parameters are expected to remain relatively constant. If the parameters are expected to change significantly after a five-year period and not expected to change significantly <u>during</u> the next five years, it is reasonable to assume a planning horizon of five years for a firm. After this five-year period, the firm's environment would be different, and it would have to re-evaluate the assumptions of constancy of the new parameters. However, the firm would now be in a position to select an optimal product strategy for a five-year period rather than selecting one that is optimal for the next year, where this one-year strategy, selected each year of the five-year period, might not be optimal over the five-year period. This approach seems particularly meaningful for the machine tool industry, where technological change has been very slow and the firms have tended to engage in the same activities for the last ten to fifteen years.

As an example of the importance of accounting for the future, let us consider a machine tool firm in CS_2 that estimates its probability of implementing PS^2 with its existing capabilities to be 0.5. Let us assume also that its management capability has an effectiveness value of 0.5, and that the market share potential for PS^2 is three times as great as it is for PS^1 (that is, $R^2 = 3R^1$). The optimal decision, $d_i(n)$, under the above conditions for each competitive situation that a firm can be in at any time during the next five years is given in Table VI.

TABLE VI. THE OPTIMAL PRODUCT STRATEGY, $d_i(n)$, FOR EACH CS_i WHERE $b^2 = 0.5$, $a^2 = 0.5$, $R^2 = 3R^1$, AND $n = 1, 2, \ldots, 5$

	n = 1	2	3	4	5
d_1	2	2	2	2	2
d_2	2	1	1	1	1
d_3	2	1	1	1	1
d_4	2	1	1	1	1
d_5	2	1	1	1	1
d_6	2	1	1	1	1

This table indicates that if a firm based its selection of optimal product strategies on a one-year planning horizon, it would always select PS^2 regardless of the competitive situation in which it found itself. However, if it considered a planning horizon of two years or more, the optimal product strategy is PS^1 for all CS_i except CS_1.[26] Clearly, under these conditions a firm should not select an optimal product strategy based on a planning horizon of only one year. This short planning horizon does not permit the effect of this year's decision to manifest itself on future decisions. In fact, if this firm, currently in CS_2, selects PS^2 for the next five years (based on a one-year planning horizon) instead of PS^1 (based on a two- to five-year planning horizon), its total expected market share for the five-year period will be 1.12 instead of 1.33 (see Figure 12). This former value represents an amount 15% less than the firm could have received if it had used a longer planning horizon. The lower a firm's capabilities are, the greater will be the difference between the total expected market share for a planning horizon of greater than one year and a planning horizon of one year (see Figure 12). Obviously, this result depends on the assumption of relative constancy of the parameters for a period of time greater than one year (but not greater than five years in this case). If this assumption cannot be made, a one-year planning horizon must be used. The use of this horizon would imply, among other things, great uncertainty about the future and/or rapid technological change.

A question now arises concerning the sensitivity of the results in Table VI to variations in the values of b^2, a^2, and R^2. Some indication of this sensitivity is given in Table VII. This table shows the importance of using a time horizon greater than one year, as a function of b^2, a^2, and R^2. The basic assumption used is that the parameters of the model are constant for a five-year period. This assumption implies the use of a five-stage dynamic programming framework for selecting optimal product strategies. Since the framework and the analysis proceed in an iterative way, the optimal product strategies are obtained for planning horizons of one through five years. Thus a direct comparison can be made.

Table VII takes into account the importance of a planning horizon greater than one year but less than, or equal to, five years, and identifies three situations that can exist.

The first is a situation of indifference (I), which means that the same optimal product strategy would be selected regardless of the planning horizon. For $b^2 = 1.0$, $2R^1 \leqq R^2 \leqq 5R^1$ and all values of a^2, a situation of indifference exists. However, the results for $b^2 = 1.0$ are separated into two groups, the top group representing PS^1 as the optimal strategy, and the

[26]This is a reflection of $\overline{\overline{P}}^2$ in which $\overline{\overline{p}}_{11}^{\,2} = 1$.

TABLE VII. THE IMPORTANCE OF A PLANNING HORIZON OF GREATER THAN ONE YEAR AS A FUNCTION OF b^2, a^2, AND R^2 WHERE $R^2 = 2R^1, 3R^1, 4R^1, 5R^1$

a^2	b^2 = 1.0				0.8				0.6				0.4				0.2				0.1			
	$2R^1$	$3R^1$	$4R^1$	$5R^1$	$2R^1$	$3R^1$	$4R^1$	$5R^1$	$2R^1$	$3R^1$	$4R^1$	$5R^1$	$2R^1$	$3R^1$	$4R^1$	$5R^1$	$2R^1$	$3R^1$	$4R^1$	$5R^1$	$2R^1$	$3R^1$	$4R^1$	$5R^1$
0	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
0.1	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
0.2	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
0.3	I	I	I	I	I	I	B	B	I	I	F	B	I	I	F	F	I	I	F	F	I	I	F	F
0.4	I	I	I	I	I	B	B	I	I	F	B	B	I	F	B	B	I	F	F	B	I	F	F	F
0.5	I	I	I	I	I	B	I	I	I	B	B	B	I	F	B	B	I	F	B	B	I	F	F	F
0.6	I	I	I	I	B	B	I	I	F	B	B	B	F	B	B	B	F	F	B	B	F	F	F	B
0.7	I	I	I	I	B	I	I	I	B	B	B	B	F	B	B	B	F	B	B	B	F	F	B	B
0.8	I	I	I	I	B	I	I	I	B	B	B	I	B	B	B	B	F	B	B	B	F	F	B	B
0.9	I	I	I	I	B	I	I	I	B	B	B	I	B	B	B	B	F	B	B	B	F	B	B	B
1.0	I	I	I	I	I	I	I	I	B	B	I	I	B	B	B	B	B	B	B	B	F	B	B	B

I - A situation of indifference.

F - The importance is a function of the competitive situation.

B - A planning horizon of greater than one year is strictly better.

bottom group representing PS^2 as the optimal strategy. This result suggests that a firm with an extremely high or good level of capabilities has the ability to adapt quickly to changing market and competitive situations and to determine the best strategy regardless of the existing or new planning horizons. However, low levels of management capability, under these conditions, restrict the firm to the use of PS^1. Thus, even with a very high level of capabilities, a firm with poor management is ill-advised to select anything but PS^1 (continuing to do what it is presently doing). In fact, for all values of b^2, the top groups in Table VII represent the use of PS^1, regardless of the planning horizon.

The second possible situation is that in which the answer depends on the competitive situation that a firm is in and its expectations about future competitive situations. This means that one cannot make definite statements about the importance of all planning horizons greater than one year for firms in the situations implied by the associated values of b^2, a^2, and R^2. We note that for $b^2 = 0.1$, which value implies a very low level of capabilities within a firm, this situation of indeterminacy occurs frequently. This situation suggests the importance to a firm of attempting to increase its capabilities; with its low level of capabilities, it is not in a position to plan for the effect of the current product strategy on its future competitive situations. Thus, a firm (with an existing low level of capabilities) within the industry faces a future that is too uncertain from a planning point of view, even though expectations for the industry will not significantly change. However, if this firm has very good management capabilities and the market expectations for PS^2 are sufficiently large, it can account and plan for the future effects of using PS^2 even though its level of supporting capabilities (such as engineering, finance, marketing, etc.) are low. This again suggests the greater importance to a firm of management capability than high levels of supporting capabilities. Later discussion of the information in Table VII illustrates the importance of this point.

The third situation generated by variations in b^2, a^2, and R^2 is an indication (B) of the conditions for which the use of a planning horizon greater than one year (but equal to or less than five years) is strictly better (in terms of greater total expected market share) than using a planning horizon of one year.[27] For a firm with average capabilities, Table VII indicates that this is true for most of the market conditions. If one remembers that a situation of indifference (I) means that a planning horizon of greater than one year is at least as good as a planning horizon of one year, one can conclude, except where F exists, that a planning horizon of greater

[27] Whether a five-year planning horizon is better than a two-, three-, or four-year planning horizon is a question that is not dealt with in this thesis.

than one year is better than, or at least as good as, a planning horizon on one year. Table VII indicates this to be true for most of the a^2, b^2, and R^2 conditions. The exceptions occur for low levels of capabilities (i.e., where b^2 is small). Therefore, if the parameters of the model can be assumed to remain relatively constant for a short period of time, then for most of the conditions of the market and firm capabilities, a firm should select a planning horizon of greater than one year.

One final aspect, mentioned earlier, of the information in Table VII is the importance of the management capability relative to the level of supporting capabilities in a firm. One might be interested, for example, in comparing the effect in the market of a combination of a high level of supporting capabilities and poor management with a combination of a low level of supporting capabilities and good management. If one considers, for example, the combination of $b^2 = 1.0$ (a high level of supporting capabilities) and $a^2 = 0.2$ (poor management) with the combination of $b^2 = 0.2$ (a low level of supporting capabilities) and $a^2 = 1.0$ (good management), the following results are obtained:

(1) A planning horizon of greater than one year is strictly optimal for the firm with $b^2 = 0.2$ and $a^2 = 1.0$, whereas the situation of indifference with respect to the planning horizon exists for the firm with $b^2 = 1.0$ and $a^2 = 0.2$.
(2) For the range of market conditions given for PS^2, PS^1 is always optimal for the firm with $b^2 = 1.0$ and $a^2 = 0.2$, whereas for the firm with $b^2 = 0.2$ and $a^2 = 1.0$, the optimal decision vector for any planning horizon (n = 1, 2, 3, 4, 5) involves the use of PS^2.
(3) For all market conditions and planning horizons, the firm with $b^2 = 0.2$ and $a^2 = 1.0$ can expect a greater total market share than the firm with $b^2 = 1.0$ and $a^2 = 0.2$.

Therefore, this model indicates that good management with some supporting capabilities is more effective in penetrating the market than poor management with a high level of supporting capabilities.

This conclusion is important for the small Michigan machine tool firms, since two independent studies, described in Chapter I, reported that approximately ninety percent of the small firms studied had poor management. The results of this model, then, indicate the importance of this conclusion to the small machine tool firms by showing the potential effect in the market for firms who lack good management. It is conceivable that applications of the model to other industries would tend to show the same results.

One important aspect of a complete application of this model to the machine tool industry that has not been attempted in this thesis is the use of the applied model in a controlled experimental situation to make predictions about future behavior of a firm in its environment and to carry out the implementation of selected product strategies. If one could accomplish this phase of the total model validation process, the model could be tested in terms of its ability to make meaningful predictions about expected returns that result from implementing certain product strategies. This validation process, then, could produce for use by the machine tool firms the conditions of market potential, planning horizon, and capabilities for which the product strategy of "doing something in addition to what it is currently doing" is optimal. This phase of application or validation is quite difficult to implement, but is certainly an area for further research and investigation.

CHAPTER V

CONCLUSIONS CONCERNING THE MODEL AND SUGGESTIONS FOR FURTHER INVESTIGATION

The purpose of this final chapter is to discuss briefly the limitations of the model and its application, with a view toward identifying areas for further investigation. These areas will pertain both to possible extensions of this model and the development of other models that by themselves, or in conjunction with the model in this thesis, would facilitate an analysis of some of the problems of product strategy selection.

As indicated in the last section of Chapter IV, the application of this model to the machine tool industry involved an estimation of parameters for two product strategies that were assumed to be meaningful for firms in this industry. No attempt was made to validate this model; that is, assumptions and parameters were not tested for statistical significance in a controlled environmental situation. Therefore, although the analysis with this model appears to be very meaningful, it is not the result of a validated model. The accomplishment of this validation, however, would require a controlled experimental situation that is probably difficult to achieve for the machine tool industry. This does not mean that the total industry must be controlled and tested, but that at least some firms should be willing to cooperate over time in the selection and implementation of product strategies. Since the time periods are one-year intervals and since firms do not make transitions rapidly from one competitive situation to another, this validation procedure would require an extended period of time and a moderate dollar investment on the part of these firms. One implication of the above comments is that the model might be applied to and validated for an industry that has other characteristics that would tend to facilitate the validation procedure.

Chapter I discussed general objectives of a firm and Chapter IV utilized the specific single objective of maximizing market share. It was indicated that this objective is probably not the objective of most firms in a non-oligoplistic competitive situation. Furthermore, its use placed certain restrictions on the types of markets that could be associated with PS^2. The use of sales dollars as a measure of return would relieve the model of these restrictions—assuming the maximization of total expected sales dollars was the objective of the firm. This measure, however, was not feasible for the machine tool industry because of its severe fluctuations over time.

Many authors have attempted to consider multiple objectives, but as yet there is little that can be done to incorporate these concepts into most types of models for purposes of analysis.[1] Perhaps one approach possible with the model in this thesis would be to define a vector of objectives for a firm and to compute results for each component of this vector, assuming the associated measure of return can be quantitatively expressed. The results could then be presented in a way that would permit an analysis of differences in expectations for the alternative objectives. Conceivably, indifference curves could be plotted giving situations of indifference with respect to the selected objective. One major objection, however, is that this approach would not allow for interactions of the firm objectives as they affect the expected results in the market. Since the choice of objectives within a firm reflects management's motivation, the type of competitive structure confronting a firm would be important in determining the importance of working with multiple objectives. As Shubik has noted:

> The less the firm is able to influence its environment, the less needs to be known about the motivation of the management of the firm for most purposes of policy.[2]

Thus, it appears reasonable to consider single firm objectives for small firms in a monopolistic competitive situation, as we did for the machine tool industry.

The importance and effect of time was introduced and discussed in Chapters I and III, and partially analyzed in Chapter IV. The particular aspect of time that was analyzed involved a consideration of the influence on product strategy selection of various future planning horizons. The effect of varying lengths of time required for the implementation of alternative product strategies was discussed in Chapter III, but not analyzed.

It must be recognized that in one sense the time periods required are a function of the capabilities of a firm. It is possible to reduce the time required by expending more effort (dollars and man power). However, a minimum threshold of time compression does exist. Important for any specific firm is the time that would be required to implement alternative product strategies for its existing capabilities. It is in this context that the time required for implementation could be analyzed to determine its effect on product strategy selection. The mechanism to carry out this analysis is the "Dummy" competitive situation described and developed in Chapter III.

Some possible questions that might be analyzed are: (1) what effect do the market conditions of declining, constant, and increasing market potential, during the time of implementation, have

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[1] For an interesting discussion of this problem, see Martin Shubik, "Objective Functions and Models of Corporate Optimization," The Quarterly Journal of Economics, Vol. LXXV, No. 3, August 1961, pp. 345-375.

[2] Ibid., p. 374.

on the selection of product strategies? and (2) under what conditions of market trend, firm capability, and firm competitive situation is it feasible and/or optimal to discontinue the implementation of a product strategy in favor of another one even though the implementation phase is not complete? The latter question suggests the possibility to a firm of reaching a competitive situation for which the product strategy currently being implemented is no longer optimal. This condition could reflect the effect of changing market conditions or the acquisition of capabilities that permit the selection of a product strategy for which the total expected returns more than offset the losses resulting from a discontinuation of the current product strategy. Or, this discontinuation could prevent the firm from incurring greater losses resulting from a continuation of the current product strategy.

The model in this thesis incorporates the effect of firm capabilities on product strategy selection in two ways: (1) in the level of firm capabilities; and (2) in the effective use of this level of capabilities—which represents management capability. The level of capabilities was accounted for by b^k, which is the probability that a firm can implement PS^k with its existing level of capabilities. Since all the capabilities of a firm are important and affect product strategy selection, b^k represents a subjective estimate of the combined effect of all these capabilities. Obviously, then, this is one area requiring further investigation. Perhaps the most difficult problem here will be that of measurement. The particular measure, the range of values, and the relationships of the various capabilities would have to be determined. Once this is accomplished, different models can be developed and applied for purposes of analysis.[3]

The model also assumes that the existing level of capabilities stays constant over the length of the planning horizon. Since firm capabilites change over time, sometimes significantly in a short period of time, the model should account for this fact. The author attempted to explore this problem analytically for processes of long duration, and found that the asymptotic forms (without discounting) were non-linear and did not converge. (The author will make further attempts to determine, both by analysis and by simulation, the effects of changing firm capabilities on product strategy selection.)

The use of Gibrat's Law led to the assumption that the value of $\bar{\bar{p}}_{11}^{2}$ (the probability of making a transition from CS_1 to CS_1 using PS^2, given that the firm is currently in CS_1, and that with its existing capabilities it cannot implement PS^2) is equal to one. This implied that a firm would not go out of business as a result of attempting to implement PS^2 without adequate capabilities.

[3] The Industrial Development Research Program of The University of Michigan will study this problem during the year 1963-1964. This author expects to participate in these research activities.

Obviously, in any industry, for certain product strategies, a firm would have a positive probability of going out of business if it lacked adequate capabilities to implement these product strategies. Furthermore, if the trend of market potential were increasing and probably would continue to increase, new firms might enter the industry. Even in a monopolistic competitive situation, there would be some effect on the firms already in the industry. One means of studying these problems would be to define an additional "competitive situation" (CS_0) in the model. This is the "competitive situation" into which, and from which, firms could make transitions reflecting the entry and exit situations. It is also conceivable, that the measures of return $\left(r_{ij}^k\right)$ for all CS_i could be functions of the number of firms in the industry. Thus, problems of entry and exit, such as the level of firm capabilities required if the firm expects to be successful, could be studied as they affect both the firms in, and the firms entering, the industry.

Finally, more extensive sensitivity analysis could be performed on the parameters of the model. This study would give an indication of the extent to which these parameters could vary without affecting the optimal product strategies that were selected. Although the total expected market share values would change, the optimal strategy used to obtain these results might not change. This information would be important in identifying the accuracy required for parameter estimation and the extent to which additional randomness could manifest itself in the total economic environment without affecting the results.

APPENDIX A
THE PROOF THAT P^k AS DEFINED BY EQUATION 30 IS A STOCHASTIC MATRIX

A matrix P is said to be stochastic if $0 \leq p_{ij} \leq 1$ and $\sum_{j=1}^{m} p_{ij} = 1$, where i = 1, 2, . . . , m.

Equation 30 defines P^k as a convex linear combination of the stochastic matrices $\bar{P}^k$ and $\bar{\bar{P}}^k$. Therefore, P^k will be a stochastic matrix if it can be shown that $0 \leq p_{ij}^k \leq 1$ and $\sum_{j=1}^{m} p_{ij}^k = 1$, where i = 1, 2, . . . , m.

$$P^k = \bar{P}^k \otimes B^k + \bar{\bar{P}}^k \otimes (U - B^k) \qquad (30)$$

where

$$U = \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix} \qquad B^k = \begin{bmatrix} b_1^k \\ b_2^k \\ \vdots \\ b_m^k \end{bmatrix} \qquad 0 \leq b_i^k \leq 1$$

The operation $\otimes$ is defined to be the scalar product of the b_i^k values with each element in the corresponding i-th row of $\bar{P}^k$ and the $(1 - b_i^k)$ values with each element in the corresponding i-th row of $\bar{\bar{P}}^k$. Therefore, in proving Equation 30, we will work with Equation 29 which states

$$p_{ij}^k = \bar{p}_{ij}^k b_i^k + \bar{\bar{p}}_{ij}^k (1 - b_i^k) \qquad (29)$$

We first prove that $0 \leq p_{ij}^k \leq 1$.

Assuming that $\bar{p}_{ij}^k$ and $\bar{\bar{p}}_{ij}^k$ take on their maximum values of 1, then

$$p_{ij}^k = (1)b_i^k + (1)(1 - b_i^k)$$

and

$$p_{ij}^k = 1$$

The maximum value p_{ij}^k can assume, then, is 1.

Next, assuming that $\bar{p}_{ij}^k$ and $\bar{\bar{p}}_{ij}^k$ take on their minimum values of 0, then

$$p_{ij}^k = (0)b_i^k + (0)(1 - b_i^k)$$

and

$$p_{ij}^k = 0$$

The minimum value p_{ij}^k can assume, then, is 0. Therefore, with $0 \leqq b_i^k \leqq 1$, we have shown that

$$0 \leqq p_{ij}^k \leqq 1$$

We now prove that $\sum_{j=1}^{m} p_{ij}^k = 1$. Using Equation 29, we derive

$$\sum_{j=1}^{m} p_{ij}^k = \sum_{j=1}^{m} \bar{p}_{ij}^k b_i^k + \sum_{j=1}^{m} \bar{\bar{p}}_{ij}^k (1 - b_i^k)$$

Since b_i^k is independent of j we get

$$\sum_{j=1}^{m} p_{ij}^k = b_i^k \sum_{j=1}^{m} \bar{p}_{ij}^k + (1 - b_i^k) \sum_{j=1}^{m} \bar{\bar{p}}_{ij}^k$$

But $\sum_{j=1}^{m} \bar{p}_{ij}^k = 1$ and $\sum_{j=1}^{m} \bar{\bar{p}}_{ij}^k = 1$; therefore,

$$\sum_{j=1}^{m} p_{ij}^k = b_i^k(1) + (1 - b_i^k)(1)$$

and

$$\sum_{j=1}^{m} p_{ij}^k = 1$$

Thus P^k is a stochastic matrix.

APPENDIX B

EIGHTEEN NATIONAL MACHINE TOOL FIRMS AND THEIR EMPLOYMENT FOR 1961

FIRM	EMPLOYMENT
*Cincinnati Milling Machine	9463
*Sundstrand Machine Tool	4843
Van Norman Company	3026
*Warner and Swasey	3007
*Brown and Sharpe	2531
*National-Acme Company	1881
*Kearney and Trecker Company	1600
*Bullard Company	1600
*New Britain - Gridlay	1495
*Giddings and Lewis Machine Company	1377
Jones and Lamson	1028
Gisholt Machine Company	913
Landis Tool Company	756
*Monarch Machine Tool Company	739
Foote-Burt Company	400
Cleveland Automatic Machine Company	385
Lodge and Shipley Company	375
Seneca Falls Machine Company	194

*One of the set of ten major national machine tool firms discussed by Himes.

APPENDIX C

A DESCRIPTION OF THE COMPUTER PROGRAM USED FOR THE COMPUTATIONAL WORK IN CHAPTER IV

The computer program outlined in this appendix was written for the IBM 7090 Computer at The University of Michigan. Both the logical steps in the program analysis and the computer program statements are listed.

The logical steps in sequence are given here.

Step 1.

READ
- I - The Number of Row Competitive Situations[1]
- J - The Number of Column Competitive Situations
- K - The Number of Product Strategies
- PDS - The Number of Time Periods for Which the Process is to be Analyzed
- A1 - The Effective Use of a Firm's Existing Capabilities to Handle PS^1
- W1 - Numerical Value of Disutility of Losses[2]
- W2 - Numerical Value of Utility of Profits[2]
- P^k - The Probability Transition Values for All PS^k
- R^k - The Return Values for All PS^k
- S^k - Values of the Slopes of Linear Functions for All R^k[3]

Step 2.

Compute total expected returns for all CS_i and all PS^k as a function of PDS (or n), W1, W2, S^k, A^k, and B^k, where it is assumed that for any PDS, the value computed for CS_i represents CS_i as the starting state of the process.

Step 3.

Select that PS^k which is optimal for each CS_i and each PDS.

Step 4.

Print the value of maximum total expected returns for each CS_i, for the specific values of PDS, W1, W2, S^k, A^k, and B^k, and PS^k that gives this maximum value.

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[1]In most cases, I = J.
[2]These values were equal to one in this thesis.
[3]The R^k values did not change in this thesis, hence $S^k = 0$ for all R^k.

THE COMPUTER PROGRAM IN MAD LANGUAGE[4]

```
        DIMENSION FINVAL(60), V(60), Q(90), ADDRT(90),
       1P(650), R(650), EXPRT(90), D(60), S(650), RT(650)
        INTEGER I,N,M,B,J,K,H,F,L,E,G,T,U,PDS
BEGIN   READ FORMAT SPEC,I,J,K,PDS
        VECTOR VALUES SPEC = $413*$
        READ FORMAT INPUT,A1,W1,W2,P(1) . . . P(I*J*K),
       1R(1) . . . R(I*J*K), S(1) . . . S(I*J*K)
        VECTOR VALUES INPUT = $3F8.3/(8F10.3)*$
        PRINT FORMAT SKIP,I,J,K,A1,W1,W2,P(1) . . . P(I*J*K),
       1R(1) . . . R(I*J*K), S(1) . . . S(I*J*K)
        VECTOR VALUES SKIP = $1H1/316/3F12.3/(10F10.3)*$
        THROUGH FRANK, FOR A2=0, .1,A2.G.1
        PRINT FORMAT WORD, A2
        VECTOR VALUES WORD = $F6.2//*$
        N=0
        THROUGH LINNAE, FOR G=1,1,G.G.(I*J)
        WHENEVER R(G) .GE.0
        RT(G) = W2*R(G)*A1
        OTHERWISE
        RT(G) = (W1*R(G)) + (R(G)*(1-A1))
        END OF CONDITIONAL
LINNAE  CONTINUE
        THROUGH KATHY, FOR T=(I*J)+1,1,T.G.(I*J*K)
        WHENEVER R(T) .GE. 0
        RT(T) = W2*R(T)*A2
        OTHERWISE
        RT(T) = (W1*R(T)) + (R(T)*(1-A2))
        END OF CONDITIONAL
KATHY   CONTINUE
        THROUGH MARV, FOR H=1,1,H.G.I.
MARV    FINVAL(H) =0
START   N=N+1
        THROUGH CLARK, FOR F=1,1, F.G.I.
CLARK   V(F) = FINVAL(F)
        THROUGH PAT, FOR U=1,1, U.G.(I*J*K)
PAT     RT(U) = RT(U) + (S(U))*N
        M=0
        B=0
JOAN    M=M+1
        Q(B)=0
        ADDRT(B)= 0
        THROUGH EVIE, FOR L=1+B,1, L.G.J+B
        Q(L) = Q(L -1) + P(L)*RT(L)
```

[4]The letters MAD represent Michigan Algorithm Decoder. Manuals are available from The University of Michigan Computing Center, Ann Arbor, Michigan

```
EVIE      ADDRT(L) = ADDRT(L-1) + P(L)*V(L-B)
          EXPRT (M) = Q(J+B) + ADDRT(J+B)
          B=B+J
          WHENEVER M.L. I*K, TRANSFER TO JOAN
          THROUGH PERRY, FOR E=1,1,E.G. 1
          WHENEVER EXPRT(E) .GE. EXPRT (E+I)
          FINVAL(E) = EXPRT(E)
          D(E)=1
          OTHERWISE
          FINVAL (E) = EXPRT(E+I)
          D(E)=2
          END OF CONDITIONAL
PERRY     CONTINUE
          PRINT FORMAT OUTPUT,N, FINVAL(1) . . . FINVAL(I)
          VECTOR VALUES OUTPUT = $13/(10F11.3)*$
          PRINT FORMAT DECV, D(1) . . . D(I)
          VECTOR VALUES DECV = $(10F11.3)*$
          WHENEVER N.L.PDS, TRANSFER TO START
FRANK     CONTINUE
          TRANSFER TO BEGIN
          END OF PROGRAM
```

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