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SECOND SEMI-ANNUAL PROGRESS REPORT

to

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

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on Grant ~~NSG~~ 26 004 012

covering the period August 1, 1965 to January 31, 1966.

The studies described in this Second Progress Report, for the most part, were previously described in the First Progress Report of July 31, 1965. Developments in these studies are indicated herein. Several new studies are, however, described in some detail for the first time in this Report and somewhat greater emphasis is placed on these. Fuller descriptions of the continuing projects may be obtained by consulting the First Progress Report. Supporting financial and other data are also to be found in the earlier report.

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Overall Objective and Research Strategy.

It will be recalled that the overall project objective is the investigation of cost structures in research facilities with a view to establishing cost or efficiency criteria for the spatial allocation of funds for scientific research. In particular the studies in this program are directed toward analyzing the effects of clustering or agglomeration on the cost of performing certain kinds of research activities. This involves an improvement in the theory of agglomeration, extending the theory to include research, and the empirical documentation of variations produced in costs (if any) by the presence of other economic or research activity in the same local area.

In the first progress report the Research Strategy of the program was described. Briefly, it was to develop successively more sophisticated and specialized studies as the research period of the grant progressed. This strategy is reflected in the new studies described in this report.

I. Location Patterns of Research Activities.

A. Investigators: Professor John C. Murdock and Mr. Nicholas Filippello.

B. The study was described in detail and its functions relative to the total research program were set forth in the First Semi-Annual Report. The project sequence was in seven stages. The sixth step is presently being completed.

All primary and secondary data has been obtained and is being put on computer cards. The computer program has been written. The data

gathering process has been more time-consuming than was anticipated and this has made it necessary to extend the timetable for this project by about a month. The evaluation of the computer output and the synthesis of material should begin in about a month.

- C. In the First Progress Report a study entitled, Location Sequence of Research and Industry Study, was included as a direct extension of the Location Patterns Study. It became apparent that a number of economies could be effected if the two studies were carried out simultaneously and the decision was made to do the work all under the title of the Location Patterns Study.

II. Bibliographic Source Materials Collection.

- (1) Preparation of a comprehensive bibliography of the diverse interest areas upon which studies in Research and Development and Location may touch has been compiled. This has been carried out by Professor John C. Murdock and Miss Judith Graves.
- (2) The material has been evaluated and will be put in Key Word in Context Indexing and published.

III. Decentralized Decision-Making and Agglomeration Equilibriums in Research.

- A. Investigator: Professor John C. Murdock.
- B. Objective of Study: The external economies which a research center (agglomeration) may confer upon an individual research project or upon

a research laboratory from certain sets of conditions take a form that can be translated either into cost reductions in the performance of the research or into improvements in the prospects for (that is, the probability of) success of the research. The external diseconomies which a research agglomeration may imply for research projects or laboratories under certain other sets of conditions can be grouped either as cost increases or as reductions in the probability of success for the research.

The size of research agglomerations can be shown to affect substantially the availability of net external economies in the performance of research activities by laboratories. Defining the socially efficient size of a research agglomeration as that which maximizes the net economies per dollar of the research budgets of laboratories at a research center, the question is raised: Does a decentralized decision-making mechanism (such as that by which research location decisions are effected in the United States) bring about a spatial allocation of research activities which approximates the size for social efficiency? Or, by contrast, can it be shown that such a decision-making arrangement introduces biases which cause the size of the research agglomerations to diverge systematically from socially efficient levels and/or from other social optimums? This study will provide answers for these important questions.

C. **Research Design and Procedure:** This is a theoretical analysis.

The factual conditions upon which it rests have been established from literature on Research and Development, from interviews, and from preliminary information generated by the Location Patterns Study.

The framework of the study, however, is developed from the existing body of economic theory dealing with externalities and spatial agglomeration. It follows from such as, Ellis and Fellner, Meade, Scitovsky, Bator, and Baumol in the case of externalities and from, such as, Hoover, Hotelling, Lerner and Singer, Smithies, Greenhut, and Lösch in the case of agglomeration theory. The resulting theoretical framework is novel in that it combines these two streams of thought, requiring remarkably little modification of either in the bargain. Within this framework a model is constructed and the analysis carried out. The model requires certain stringent assumptions, a number of which are subsequently relaxed in degree as the analysis develops.

D. **Current Status of Study:** This work has been rough-completed. All the basic steps (review of the literature, development of the model structure, and the determination of theoretical implications have been completed and a rough-draft prepared. Certain minor kinks remain to be eliminated and the work must yet be polished. It is intended as a journal article.

IV. Economies of Scale in Research Agglomerations.

- A. Investigator: Professor Donald Murry.
- B. Objective: This analysis is attempting to test empirically the existence of economies of scale in spatial clusters (agglomerations) of research and development activities. This analysis utilizes economic analysis in order to help obviate the paucity of relevant data and in order to facilitate the empirical testing of relevant hypotheses.
- C. Significance: The rationale for undertaking this study is that, if successful, it will provide an efficiency criterion for the spatial allocation of scientific research resources.
- If the empirical tests are completely successful, a crude estimate of the shape of the cost function of research and development performance will be inferred. However, because of the burdens of scarce data, non-homogeneous outputs, and non-homogeneous inputs, the analysis probably will produce less precise results. These results would be statistically significant evidence of economies existing or not existing under certain circumstances.
- D. Research Design: The research design consists of approaching the existence of economies in spatial clusters of research and development activities in three stages.
- In the first stage the relevant, probable causes of economies in clusters

of research and development activities are investigated conceptually. These probable causes are indivisible inputs used jointly by various research and development activities in the cluster, and direct interdependence among research and development activities which employ indivisible inputs. This analysis considers the spatial stability of resources under these circumstances, and the effects of this phenomenon upon the optimum spatial allocation of resources as the level of research and development varies over time.

The second stage of the analysis employs and modifies the available secondary data in two separate tests of the hypothesis that the relevant economies exist. The first attempt employs a cross-sectional analysis. It will include testing the hypothesis that density of research is a significant variable. The second attempt is a test of the productivity of labor in different size clusters. This analysis consists of analyzing the comparative results of labor productivity to size of cluster, depending on whether size is classified by value of output or number of workers.<sup>1</sup>

The scope of the third stage is dependent upon the results of the second. It will consist of the analysis in depth of some certain research and development activities, and the effect of cluster size

1. Cf. Johnson, John, Statistical Cost Analysis, McGraw-Hill, New York, 1960, pp. 110-135.

upon the cost of these activities. Of course, it will utilize mostly primary data. Because the data at this stage of the analysis will be considerably improved over the former, attention will be paid to the occurrence of economies as a result of direct interdependence among research activities.

- E. **Current Status:** The first stage of the analysis is being completed. Preliminary drafts have been completed on portions of this analysis related to the effects of direct interdependence among research and development activities and the joint use of indivisible inputs by various research and development activities. The data are in the process of being modified and prepared for use in the second stage of the analysis. Preliminary arrangements are being made for the acquisition of data from certain research and development activities for stage three of the analysis.

V. Agglomeration Economies and the Location of Industrial Research.

- A. **Investigator:** John M. Brazzel.
- B. **Objective of Study:** The objective of this study is to investigate the role of agglomeration economies in location decisions by industrial research laboratories.
- C. **Research Procedure:** A theoretical and empirical analysis is being made of this role. In the theoretical phase, a survey of the



literature on the theory of agglomeration is being used to develop models that will submit to empirical tests in the second phase of the study. This survey will also be useful to the other studies in the overall project.

In the second phase of the study, several alternative data sources are being evaluated as to availability and usefulness of the data they offer. These data sources include information on:-

- (1) the location of various kinds of industrial research activities with respect to the number of laboratories in particular regions, the level and structure of employment, and other characteristics,
- (2) expenditures of industrial research laboratories categorized by type of research activity, nature of expenditure, and by region, and
- (3) the pattern of expenditures of individual laboratories.

Each of the data sources permits a somewhat different approach for determining the role of agglomeration economies, the first two being primarily cross-section analyses while the last represents a time analysis of a research firm's activities. Work on the three approaches is being carried out simultaneously. Data from these several sources is then to be investigated according to a priority which exploits first those data with the greatest apparent opportunity for fruitful conclusions about the role of agglomeration economies

in location decisions of industrial research laboratories. It is hoped that several approaches can be investigated during the time period of the grant.

- D. **Current Status:** This is a report on research activities since December 1, 1965, when this investigator rejoined the Project Staff. The theoretical phase of the study, which was begun during the summer while this investigator was a temporary member of the staff, has continued since this date. The empirical analysis is in its preparatory stages, models are being developed, and data are being collected and evaluated.

VI. A Theory of Production and Location for the Research Firm.

- A. **Investigator:** Carmen F. Menezes.
- B. **Objective of the Study:** A basic deficiency in the literature on research and development (R and D) has been the absence of a theory to explain the production and location decisions of the research firm. Should the firm undertake a particular research project?<sup>1/</sup>  
What combination of projects represents an optimal product-mix for the research firm? Which site is most suitable for its location? Questions such as these fall outside the scope of the conventional economic theory of the firm because of the special characteristics of research firms. There is a pressing need to extend the conventional

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<sup>1/</sup> The research laboratory of the industrial firm and the specialized research firm are both provisionally included under the term research firm.

analysis of the firm to apply to the research establishment.

This study represents an attempt to fill a basic gap in the R & D literature. Our objective is to formulate a theory to explain the size, product-mix and location of the research firm.

- C. **Research Design and Procedure:** It is expedient to develop the theory in stages. Following the approach generally used in economic analysis, we proceed to more complicated models only after the analytical properties of the simpler models have been carefully studied. To understand the research strategy employed here one has to be familiar with some special features of research firms. Accordingly we begin by focusing on these special features. Research firms are engaged in the production of new technology, which is eventually embodied in new products and more efficient production functions. A distinctive feature of research firms concerns the uncertainties they face. All firms face uncertainty to some extent. But the range and variety of sources of uncertainty that characterize the economic environment for the research firm are of a different order of magnitude from the uncertainties applicable to firms in general.
- Most firms know a good deal about their production functions. In contrast, the production of new technical information is usually a process of discovery. Expectations about the length of the gestation period for most projects are often in the form of vague hunches,

particularly for firms in the so-called "basic" research fields.

Prior information on the costs and payoffs for research projects are thus both vague and unreliable. Indeed it is not known for sure whether the research will yield the desired information.

Uncertainty clearly plays a crucial role in research and development decisions.

The behavior of the research firm depends greatly on the kind of uncertainty it faces. It is important to distinguish between two types of uncertainty. When the uncertainty can be arranged according to "degrees of belief and these "orderings of confidence" can be represented by a clearly defined subjective probability distribution, the uncertainty is called "risk". When degrees of belief cannot be expressed in terms of a unique probability distribution, because prior information is vague, scanty and unreliable, but the individual is not completely ignorant of relative likelihoods the uncertainty is called "ambiguity".

The distinction between "risk" and "ambiguity" provides an analytically significant framework for classifying research processes and hence research firms. It cannot be doubted that the amount, reliability, type and unanimity of prior knowledge -- all of which goes to make up one's confidence in expectations of relative likelihood -- depends on the nature of research activity. The more applied is the research the more likely it is that degrees of belief can be expressed as clearly defined probability distributions. The more basic the research the less

familiar is one with basic characteristics of the phenomena being discovered, and because prior information is scanty, unreliable and vague, the more likely it is that the situation corresponds to ambiguity.

There is now a considerable literature on decision-making under uncertainty. The conditions under which an individual will regard uncertainty as risk have been spelt out in a set of axioms. A well known theorem states that in the face of risky alternatives the decision-maker acts so as to maximize the mathematical expectation of the utility of net payoffs. How an individual behaves under ambiguity is not clear at present, although it is now possible to indicate when an individual will regard uncertainty as ambiguity. The strategy of our research will be to begin by formulating a theory of production for the research firm facing risk. The theory is thus applicable to firms in the applied research field. The theory will be concerned with delineating and relating the factors which determine the scale and product-mix of the firm. Particular emphasis will be placed on factors underlying the various probability distributions and the utility of net payoffs for firms in applied research. Next the theory will be extended to include location decisions. What is the relationship between uncertainties imbedded in applied research work and sites of location for the firm? A precise answer to this question must await further study, although it is perhaps

obvious that firms surely must favor sites that tend to minimize uncertainty. The impact of different sites of location on uncertainty is currently being investigated.

Other special features of research activities also have locational implications. One might notice that a significant feature of the research firm is that scientists are an important part of its plant while technical information is an important input as well as the output of the firm. During all phases of research there is usually a constant transfer of information between scientists working on a project, and between these scientists and other persons within and outside the firm. The cost of communication will depend on the location of various scientists, the frequency of communications and the mode of information-transfer. These characteristics in turn will vary with the kind of research being undertaken.

It can be shown that the location of scientists may have effects on production quite apart from the direct effects on transfer of information. Especially in the early phases of research, proximity of scientists raises productivity because of more effective information-retrieval. Problems are better defined and the likelihood of directing research into a blind alley is reduced when scientists are in close contact. The question of the exact relationship between location of scientists, transfer of information and productivity of

research effort needs to be carefully studied. Other factors which enter into a theory of location of the research firm concern the types of research firms that are orientated towards specialized facilities located at particular sites and the types of firms that are orientated towards the markets (perhaps the production site of the parent company). Only after the theory of production and location for the firm in applied research is fully developed do we expect to tackle research firms operating in an environment of ambiguity. The problems here are far more difficult. The most basic problem is to determine the decision-rule that explains the behavior of individuals in an atmosphere of ambiguity. Once such a decision-rule has been identified, the strategy will be the same as that outlined for the firm under risk. First a theory of production will be formulated for the firm engaged in basic research. The theory will then be extended to include location decisions.

- D. Current Status of Project: Currently we are working towards formulating a theory of production for the research firm operating under risk. A simple model has been constructed to explain the conditions under which the firm will undertake a particular project. The model is intended to provide part of the analytical background for the more complex models to come and is also somewhat revealing of the decision-making situation confronting firms that bid for government contracts. The model is outlined below.

Assume that the government invites a number of firms to submit proposals for a contract to develop a certain type of aircraft. The plane must meet a specified level of performance: speed between  $x$  and  $y$  miles per hour; cargo load factor of  $p$  to  $q$  tons; flight range between  $m$  and  $n$  miles; etc. The government will purchase  $X$  planes from the firm which wins the contract. All proposals must be submitted on or before a given date, called the "proposal submission" date. The firm which bids the lowest price gets the contract. (Actually there is some trade-off between performance and price in most government contracts, and the lowest bid price may not exceed a certain specified value). Research is required if the firm is to submit a proposal. Notice that when the firm has to decide whether it should prepare a proposal the cost of developing a proposal are not known for sure. Nor is the firm sure of what the manufacturing cost for the plane will be, so the firm cannot know for sure what its minimum bid price will be. What factors influence the firm's decision to submit a proposal? It knows that if it submits a proposal but does not win the award it loses the outlays spent on developing a proposal but it does gain new knowledge that might be useful in the future. If it does not submit a proposal it loses not only the chance to win the contract but may endanger its future market.



In the present context the firm's problem is a decision-situation in the theory of investment under risk. The problem is, of course, equivalent to that of an individual who has to decide whether he should participate in a lottery when he is not certain about the size of the prize, nor is he sure about the price of the ticket.

For the firm and individual much depends on how much they know about the relevant probability distributions.

For the research firm the probabilistic information needed for a decision includes the joint probability distribution over the length of the gestation period and total development outlays, the joint probability distribution for production costs per plane and the total development outlays for the plane, the probability distribution for the bid prices of its rivals. Given this information one can predict whether the firm will accept the invitation to submit the proposal, and if it does, the amount of resources it devotes to development of the proposal can also be predicted.

We are now working on the formal mathematics of this model. The determinants of the various probability distributions are being studied. The results from this model are expected to provide analytical insights into the more complex models of production and then location to be formulated.