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DIFFUSION OF AN INNOVATION IN A SPATIAL ECONOMY: THE ADOPTION OF GENERAL PURPOSE DIGITAL COMPUTERS BY METROPOLITAN U.S. COMMERCIAL BANKS, 1959-1947

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Diffusion of an Innovation in a Spatial Economy: The Adoption of General Purpose Digital Computers by Metropolitan U.S. Commercial Banks, 1959-1974

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ABSTRACT

The purpose of this dissertation is to examine the effect of geographical space on the diffusion of innovations. Two issues are studied here. On the one hand, we examine the behavior of a profit-maximizing firm toward an innovation and interfirm differences in speed of response to an innovation in a spatial context. On the other hand, we also examine the pattern of innovation diffusion in a spatial economy.

In the first part of the theoretical exploration it is argued that spatial factor will affect a firm's attitude toward innovation adoption in the form of urban hierarchy and neighborhood effects. Information cost is inversely related to both the location rank of a firm and the number of neighboring firms which have adopted an innovation. The amount of information acquired by a firm to calculate the expected profit from adoption of innovation is also inversely related to information cost. Thus the probability to adopt an innovation by a firm is directly related to its location rank or the number of neighboring firms which have adopted the innovation, *ceteris paribus*. Therefore interfirm differences in speed of response to an innovation are due in part to the spatial factor through the effects of the firm's location rank and the number of neighboring adopters, in addition to firm size, growth rate, general profitability, profit trend, and the regulatory restraints on the adopter industry. Empirical estimation using the OLS method tested the theoretical model with data on adoption of computers by the banking industry showed

that firm size and urban rank effects are important factors in explaining interfirm differences in speed of response to innovation. Less clear are the effects of the other factors.

In the second part of the theoretical exploration we find that the probability that at least one firm will innovate at a place at any time increases monotonically with its size and follows a cumulative lognormal distribution. The temporal pattern of innovation diffusion in a spatial economy can be approximated by a cumulative normal distribution. Empirical estimation using the minimum normit chi-square method to linearize the diffusion function found the results supportive of the theoretical model.

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LIST OF SYMBOLS

Symbol	Definition	Page of First Appearance
CR_t	Cash return at time t from an investment. .	85
D_{i_r}	Spatial market demand for good i at a location of urban rank H_r	81
$ER^*_{t_i}$	Present value of the true expected return from innovation if the potential adopter adopts the innovation at time t_i when information about the innovation is perfect	85
$\hat{ER}_{t_i}$	Present value of the estimated expected return from innovation if adoption occurs at time t_i, based on a certain amount of information acquired by t_i	86
H_{r_k}	The urban hierarchy rank of firm k's location	91
$H^*_{r_k}$	The threshold urban rank of firm k beyond which adoption of an innovation will occur at time t_i	91
$Pr(a\|b)$	The conditional probability of occurrence of a given b	89
$Pr(U_x)$	The probability of occurrence of replacement of unit x of a certain type of equipment at any given time	101
$Pr(R)$	The probability that at any time at least one unit of a certain type of equipment must be replaced	101
$\bar{q}_{H_r}$	The optimal amount of information acquired by a firm of urban rank H_r between a certain period	90
$Q_I\|_{T = t_b - t_a}$	Amount of information acquired by a potential adopter in a certain time period from t_a to t_b	86

Symbol	Definition	Page of First Appearance
$R^{*}_{t_i}$	The cost of innovation, normally conceived as the purchasing cost of innovation equipment, but could be expanded to include other costs related to the adoption of an innovation like costs of retraining of personnel or restructuring of production facilities in a more complicated model	85
t_o	The date when first information about the innovation is learned by a potential adopter	85
$T = t_b - t_a$	The time period between time t_a and t_b . .	86
P_{t_i}	The population size of an urban place at time t_i	167
$P^{*}_{t_i}$	The threshold population size of an urban place beyond which at least one firm will adopt the innovation at time t_i	167
$Pr(t_j)$	The conditional probability that at urban place j there will be at least one firm which adopts the innovation at time t, given its population size	167
Q_{t_i}	The probability that an urban place chosen at random will have adopted an innovation at time t_i	167
$Pr(t_{i\ell})$	The probability of adoption of an innovation for urban places in a specific size ℓ at time $t = t_i$	181
$n_{i\ell}$	Number of total potential adopters of an innovation in size class ℓ at time t_i . . .	181
$m_{t_{i\ell}}$	Number of actual adopters of an innovation in size class ℓ at time t_i	181
$z_{i\ell}$	Normal equivalent deviate of $Pr(t_{i\ell})$ . . .	184

Sumbol	Definition	Page of First Appearance
$\hat{z}_{i\ell}$	Normal equivalent deviate of $m_{t_{i\ell}}/n_{i\ell}$; i.e., $\hat{z}_{i\ell} = -\frac{1}{\sigma^2_{t_{i\ell}}} \mu_{t_i} + \frac{1}{\sigma^2_{t_i}} (\frac{m_{t_{i\ell}}}{n_{i\ell}})$	184
z_t	Normal equivalent deviate of Q_t, where $t = t_0, \ldots, t_i$	187
$\Lambda(x; \mu_x, \sigma^2_x)$	The probability density function of x as a gamma distribution	168
$\Lambda\{x; \mu_x, \sigma^2_x\}$	The cumulative density function of x as a cumulative gamma distribution; i.e., $\Lambda\{x; \mu_x, \sigma^2_x\} = \Lambda(x \leq X; \mu_x, \sigma^2_x)$ . . .	169
$N\{x; \mu_x, \sigma^2_x\}$	The cumulative density function of x as a cumulative normal distribution	170
π	Expected profitability from adoption of a process innovation	13
π^*	Threshold profitably that is required by a firm to adopt a process innovation . .	15
π'	General profitability of a firm	17

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CHAPTER I

INTRODUCTION

1.1. Nature of the Problem

The importance of technological change for economic growth is by now well perceived by economists. For the U.S., several studies have shown that a major contributor to economic growth has been technological change.[1] Implicit in these findings is the notion of diffusion of new technology; while inventive and innovative activity (defined in the Schumpeterian sense) determine the "best practice" productivity level, i.e., the highest obtainable productivity level, it is diffusion activity which translates this "best practice" productivity level into an "actually achieved" productivity level. In other words, because innovations are not adopted by all potential adopters instantaneously, the speed and means by which new ideas and techniques are diffused will affect importantly an economy's productivity level and growth potential. If a higher rate of growth is one of the goals of an economy, the study of factors which affect the speed of diffusion of innovation can provide useful policy information, in addition to improving our understanding of this phenomenon.

Economic studies of the diffusion of innovations seems to be dated no earlier than 1957, when Griliches published his study on the diffusion of hybrid corn in the U.S.[2] Following Griliches' pioneering work were Mansfield's studies published in 1961 and 1963. In his 1961 study, Mansfield provided a rationale for the S-shaped temporal diffusion curve of innovations which has been observed in Griliches' work as well as in other social scientists' works.[3] Two more studies by Mansfield on innovation diffusion appeared in 1963. In one study, interfirm differences in the speed of response to an innovation were analyzed,[4] while in the second the issue was intrafirm differences in the speed of adoption.[5]

Mansfield implicitly classifies questions or issues related to innovation diffusion into two broad categories: the macro, interindustry-level issues, and the micro, intraindustry, interfirm-level issues. On the macro level, the main questions are interindustry differences in the speed of response to innovations and the development of an industrial temporal diffusion function for innovations. In other words, the important macro issues are the effect of market structure on the speed of diffusion of innovations and the development of a (statistical) function to approximate the time path of innovation diffusion function. On the micro level, the main question is interfirm differences in the speed of response to innovations.

By far the bulk of works on innovation diffusion since Mansfield are intraindustry, interfirm-level studies, which also include international comparisons of the diffusion speed of innovations in the same industry (of different countries).[6] The major concern in these studies is the measurement of the diffusion speed of innovation(s) as well as interfirm differences in speed of response to innovation(s). The logistic function proposed by Mansfield is widely imitated in these studies in measuring speed of diffusion. In the less-studied category of interindustry issues, discussions center on the development of alternative hypotheses for the functional form of the time path of innovation diffusion, although effects of market structure on diffusion speed are not neglected.[7] However, compared with the attention paid to those issues related to interindustry and interfirm differences in diffusion speed, the attention paid to factors which affect intrafirm diffusion of innovation is rather sparse.[8] But even less attention has been paid to another aspect of innovation diffusion, which has great theoretical as well as policy implications in diffusion study -- the spatial aspect of innovation diffusion. The effect of space on innovation diffusion never seems to be discussed in later studies, although Griliches mentioned spatial differences in speed of diffusion of an innovation. Given the fact that spatial factors could affect a firm's optimal level of price and output, we argue that spatial factors should also affect diffusion of innovations. The negligence of spatial factors in the economic literature is particularly glaring given that Griliches' paper appeared in 1957.

Several other factors have been neglected in recent diffusion studies. We live in a world of imperfect information, and many process inventions go through post-invention improvements after the original innovations.[9] It is doubtful that potential adopters will have full knowledge of the innovation when they are first exposed to knowledge of its existence. The extent to which additional information affects the adopters' response speed is an issue largely overlooked in the economic literature.[10] It has been found in sociologists' and geographers' studies of the diffusion of new consumer products and social institutions that additional information about the innovation will decrease the (psychological) resistence level of potential adopters, and hence increase the probability of adoption.[11] We argue here that additional information about a production process innovation will encourage firms to consider adopting the innovation, especially when post-invention improvements make the innovation more profitable. The negligence in the economic literature of the effect of additional information on response speed is a major deficiency in existing diffusion studies.

In addition, we also find that diffusion studies by economists are primarily concerned with the manufacturing sector of the economy. An important and growing part of many economies, the tertiary (service) industries, has thus far remained largely unexplored. We must recognize the importance of the service sector, and should not neglect its contribution to productivity increase, especially when we consider the fact that this sector contains such important parts of the infrastructure of an economy as the finance and banking industries. A study of innovation diffusion in the tertiary sector will improve our understanding of the speed of technological change and productivity improvements in this sector as well as for the economy as a whole.

Among the service industries, the banking industry has recently experienced a major change in its production technology. Traditionally, the capital equipment used in this industry consisted mainly of office equipment, and the production technique was labor-intensive. Documents of financial transactions were primarily processed by labor with limited assistance of capital (in the form of accounting machines). The appearance of electronic digital computers has significantly changed the nature of the production technology, as computers can replace not only the accounting machines but also most of the labor used in processing (business) data. As a result, a bank can replace its labor-intensive data processing with the capital-intensive method of electronic data processing by a digital computer. Given the banking industry's place in the infrastructure, this change in production technique will have effects reaching far beyond its own corner of the economy. A productivity increase in this industry due to technological improvement is a phenomenon which cannot be overlooked by economists interested in technological change.

The diffusion of this innovation in the banking industry deserves the attention of economists for several other reasons. First, the computer is one of the most important innovations in recent years.[12] An examination of the computer's diffusion will provide useful information about its effect on the productivity level of the economy. Second, the performance of regulated industries such as banking has been a traditional issue for students of industrial organization. A study of the innovation diffusion in this industry can provide useful information for industrial organization economists as well as regulation officials.

Summarizing, we find that several deficiencies exist in current diffusion studies. First, the spatial aspect of the diffusion theory requires further explorations. Second, the effect of (additional) information on responses to the innovation needs to be probed. Third, the tertiary sector remains largely untrodden territory for diffusion studies. This last deficiency, considering the fact that one such industry has recently experienced a major technological change, further shows the need for a study in this area. It is for these reasons that this present study is proposed.

1.2. Main Objectives

The main objectives of this study are twofold: to develop a theoretical model of innovation diffusion in a spatial context given that potential adopters have imperfect information; and to study the actual diffusion of an important innovation in one of the major tertiary industries.

The theoretical model will address several questions concerning both the individual firm in a spatial economy and the urban place which contains (many) firms. With several simplifying assumptions, we will first discuss a firm's response to innovation in a spatial economy given that information about the innovation is imperfect. The analysis will then be extended to consider a more complicated situation. Next, interfirm differences in the speed of response to innovation when the spatial factor is held constant will be discussed. In the third part of the theoretical exploration we will derive the temporal diffusion function for a spatial economy (composed of urban places).

The theoretical models will be "general" in the sense that the analysis can be applied to any firm in the tertiary sector industries. Thus, the theoretical model can be applied to empirical testing when data on diffusion of other innovations become available. In the current study, only one innovation diffusion phenomenon (in one adopting industry) will be examined.[13]

In addition to the main objectives, we also provide a review of the innovation history of the general purpose (electronic) digital computer. Because of its significance in revolutionizing the production technology for (business) data and management information handling, we feel that some attention should be paid to the many factors related to the computer's invention, innovation, and diffusion.

1.3. A Brief Outline

Chapter II is a review of the literature on diffusion studies. It provides a summary of what is already known about the diffusion of innovations, both in the economics literature and the literatures of other disciplines. It is hoped that this summary could point out to the readers those areas where there are gaps in our knowledge on diffusion. Some of these gaps will pertain to the objectives of the present study.

Chapter III examines the innovation to be studied here -- the electronic computer. A discussion of the technical feasibility of computers for the banking industry will also be included in this chapter.

Chapters IV and VI contain the theoretical core of this study. In Chapter IV, a model of the response to innovation by the individual firm in a spatial context will be presented, and further extensions will be discussed. The implications of the theoretical model will then be tested against empirical data in Chapter V and the results of econometric tests will be presented. In Chapter VI, a stochastic model will be used to derive the temporal diffusion function in a spatial economy. The implications of the theoretical model will again be tested against empirical evidence in the same chapter.

Chapter VII will summarize the results and discuss the implications derived from these results.

ENDNOTES

1. See e.g., Robert M. Solow, "Technical Change and the Aggregate Production Function," Review of Economics and Statistics, 39 (1957), 312-320; John W. Kendrick, Productivity Trends in the United States (New York: Princeton University Press, 1961).

2. Zvi Griliches, "Hybrid Corn: An Exploration in the Economics of Technological Change," Econometrica, 25 (1957), 501-522.

3. E. Mansfield, "Technical Change and the Rate of Imitation," Econometrica, 29 (1961), 741-766. In his 1955 and 1956 papers Dodd had noted the S-shaped temporal diffusion function of innovation and had already proposed the use of the logistic functions to approximate it. See S. C. Dodd, "Diffusion is Predictable: Testing Probability Models for Laws of Interaction," American Sociological Review, 20 (1955), 392-401; and "Testing Message Diffusion in Harmonic Logistic Curves," Psychometrika, 21 (1956), 191-205.

4. E. Mansfield, "The Speed of Response for Firms to New Techniques," Quarterly Journal of Electronics, 77 (1963), pp. 260-311.

5. E. Mansfield, "Intrafirm Rates of Diffusion of an Innovation," Review of Economics and Statistics, 45 (1963), 348-359.

6. See e.g., A. Sutherland, "The Diffusion of an Innovation in Cotton Spinning," Journal of Industrial Economics, 7, No. 2 (1959), 117-135; W. Woodruff, "An Inquiry into the Origin of Innovation and the Intercontinental Diffusion of Techniques of Production in the Rubber Industry," Economic Record, 38 (1962), 479-497; Gregory C. Chow, "Technological Change and the Demand for Computers," American Economic Review, 57 (1967), 1117-1130; J. S. Metcalfe, "Diffusion of Innovations in the Lancashire Textile Industry," Manchester School of Economics and Social Studies, 38 (1970), 145-162; B. Gold et al., "Diffusion of Major Technological Innovations in the U.S. Iron and Steel Manufacturing," Journal of Industrial Economics, 18, No. 3 (1970), 218-241; R. Hsia, "Technological Change in the Industrial Growth of Hong Kong," in Science and Technology in Economic Growth, ed. B. R. Williams (New York: John Wiley, 1973), pp. 335-359; L. Nabseth and G. F. Ray, eds., The Diffusion of New Industrial Process: An International Study (London: Cambridge University Press, 1974); I. Feller, "The Diffusion and Location of Technological Change in the American Cotton Textile Industry: 1890-1970," Technology and Culture, 15 (1974), 569-593; S. Globerman, "Technological Diffusion in the Canadian Tool and Die Industry," Review of Economics and Statistics, 57 (1975), 428-434; Paul

Stoneman, Technological Diffusion and the Computer Revolution: The U.K. Experience (London: Cambridge University Press, 1976); L. B. Russell, "Diffusion of Hospital Technologies: Some Econometric Evidence," Journal of Human Resources, 12 (1977), 482-502; Sharon Oster, "The Diffusion of Innovation among Steel Firms: The Basic Oxygen Furnace," Bell Journal of Economics, 13 (1982), 45-56; and Anita M. Benvagnati, "The Relationship between the Origin and Diffusion of Industrial Innovation," Economica, 49 (1982), 313-323.

8. Only Romeo has discussed this issue. See Romeo (1975).

9. As was found for the innovations studied by Davies (1979). This also applies to the current innovation studied here. For further discussions, see Chapter III.

10. The spread of (first) information about an innovation has been discussed by several researchers, but the discussion never extends to the spread of additional information and its effect on potential adopters' response speed. See, e.g., Nabseth and Ray (1974), pp. 22-57, 58-104. Information on post-invention improvements has been briefly discussed by Davies (1979), pp. 61-63.

11. See e.g., T. Hägerstrand, Innovation Diffusion as a Spatial Process, trans. Allen Pred (Chicago: University of Chicago Press, 1967), and Everett M. Rogers, Diffusion of Innovations (New York: Free Press, 1962).

12. The occurrence of computers has been labeled "The Information Revolution" by some economists, which shows the importance of this innovation. See Stoneman (1976), p. 1.

13. As a matter of fact, even data on this innovation prove difficult to be collected. See the discussion in Chapter V on data collection.

CHAPTER II

LITERATURE REVIEW

2.1. Introduction

In this chapter we will review the works related to innovation diffusion. The purpose of this review is to trace developments in the theory of diffusion, and to point out some of the deficiencies in the current body of research. The studies reviewed will be classified into two major groups: temporal diffusion studies and studies which discuss mainly the spatial aspect of the diffusion phenomenon (although the temporal aspect is also dealt with in these studies, it is in a much lesser role). Through this review the need for an integration of temporal and spatial diffusion theories will become clear.

2.2. Temporal Studies

Within this group, studies of diffusion have been conducted at two levels. At the macro level, the major interest is in developing an aggregate temporal diffusion function. At the micro level, the main interest is to compare the differences in firm adoption speed for the same innovation, and to contrast these results with other innovations. These two levels correspond to the two different levels of industrial organization theory: the macro level corresponds to the interindustry study of diffusion and the micro level corresponds to the intraindustry, interfirm study. Intercountry studies contain discussions on both levels. In Section 2.2.1 we will discuss interindustry studies, in 2.2.2 interfirm studies, in 2.2.3 intercountry studies, and in 2.2.4 related theoretical studies including the vintage capital model.

2.2.1. Interindustry Studies

2.2.1.1. The Theoretical Models. Studies of diffusion in different industries attempt to derive a theoretical model to explain this phenomenon, and thereby isolate the common characteristics which determine diffusion rates. The earliest study seems to be Mansfield's 1961 study of diffusion of 12 innovations in four different industries,[1] followed by Romeo's study of diffusion of numerically-controlled machines,[2] Hsia's study of diffusion of 26 innovations in three different industries,[3] and Davies' study of diffusion of 22 innovations in 12 industries.[4] Romeo and Hsia use Mansfield's theoretical model, so we will combine the discussion of their models with that of Mansfield.

To begin, define the proportion of "hold-outs" as the proportion of firms in an industry which did not adopt an innovation in time period t, but did adopt it in time period t + 1. Mansfield proposed that this proportion is a function of: (1) the number of existing adopters in that industry; (2) the (expected) profitability from adoption; (3) the required capital outlays for adoption; and (4) other unspecified variables.[5] These factors can be formally expressed as:

$$\lambda_{ijt} = \frac{m_{ijt+1} - m_{ijt}}{n_{ij} - m_{ijt}} = \frac{\Delta m}{n - m_t} \qquad (2.1)$$

where m_{ijt} is the number of adopters of innovation i in industry j at time t and n_{ij} is the number of potential adopters. The variable λ_{ijt} is the proportion of "hold-outs" in time period t, which is a function of the following factors:

$$\lambda_{ijt} = f_i(m_{ijt}/n_{ij}, \pi_{ij}, C_{ij}, \emptyset). \tag{2.2}$$

Several points follow from this function: first, λ is positively related to m_t/n, the proportion of firms adopting the innovation by time t. The greater this proportion, the greater the competitive pressure non-adopters will face. Also, a greater m_t/n implies more complete information about the innovation, which reduces the risk of adoption for non-adopters. Second, λ is positively related to π, the estimated profit from adoption. The higher the expected profit from adoption, the greater the incentive for firms to adopt the innovation. Third, λ is inversely related to the capital outlay required for adoption, C_{ij}, because of risk-averse management policies.

From this basic proposition, Mansfield derived a temporal diffusion function. Assuming a continuous, differentiable function, equation (2.2) can be expanded using a Taylor series. By further assuming that the coefficient of $(m_t/n)^2$ is zero and dropping all the third- and higher-order terms, equation (2.2) can be written as:

$$\frac{d\ m_t}{d\ t} = (n - m_t)(A + B\ m_t/n) \tag{2.3}$$

where $B = a_{i1} + a_{i2} + a_{i3}C$, and A is all the terms in a Taylor series which do not contain the term m_t/n, or in other words, the variable $\emptyset$ in equation (2.2). Finally, by imposing the condition that as $t \to -\infty$, $\lim m_t = 0$, i.e., as we go back in time, the number of adopters decreases to zero, equation (2.3) can be expressed in the following form:

$$\frac{m_t}{n} = \{1 + \exp\ (a-b\ t)\}^{-1} \qquad (2.4)$$

which is the logistic function derived in population growth theory.[6]

The assumptions adopted in deriving a population growth function (or epidemic diffusion function), which is essential to the development of the theory presented above, are not mentioned by Mansfield in his derivation of the temporal diffusion function. In deriving the epidemic diffusion function, it is assumed that the uninfected individuals have a constant and equal probability of adopting the disease from contacts with an infected individual, and that the number of contacts is proportional to the number of infected individuals in the population. These assumptions amount to the assertions that: (1) all of the non-adopters have an equal probability of adopting an innovation in any time period if they receive the same amount of information (i.e., equal amounts of contacts with the "infected" persons); and (2) this probability does not change over time. These assumptions imply that firms have identical estimates of the profitability and cost of innovation and these estimated values do not change over time.[7]

If information about the innovation is perfect and free during the relevant time period, these two assumptions might hold. But in reality, free and perfect information seems to be the exception rather than the rule. The theoretical basis for the logistic diffusion function is thus questionable. As a result, Davies developed an alternative model to approximate the temporal diffusion function.

Davies argued that the firm will adopt an innovation if the expected profit from innovation is higher than some threshold profitability, π^*. He proposed that the expected profit from innovation, π, is a function of firm size and other variables (basically of a technological nature rather than an economic nature).[8] If the factors which affect the distribution of expected profit are statistically independent of the factors affecting the distribution of threshold profitability among all firms, then π/π^*, according to the central limit theorem, will be lognormally distributed. Because firms use π/π^* as the critical value for adopting an innovation, and as π/π^* is lognormally distributed, it is argued that the adoption lag is also lognormally distributed. The cumulative lognormal distribution then approximates the temporal diffusion function.

2.2.1.2. Comments. Studies of interindustry diffusion should explore factors which cause differences in the speed of diffusion among industries, especially where these industries adopt the same innovation. The fitting of a temporal diffusion function serves only the purpose of measuring the diffusion speed. Unfortunately, existing studies of interindustry diffusion seem to take this means as an end in itself.[9] The more important issue of interindustry differences in diffusion speed receives but scanty attention.[10] Although this current study will not try to correct this deficiency due to difficulties in acquiring data for more than one industry, it is hoped that by pointing out this shortcoming future researchers might be steered in the right direction.

2.2.2. Interfirm Studies

2.2.2.1. The Theoretical Models. Studies in this area are concerned with differences between firms in the speed of adoption of an innovation. The pioneering work is Griliches' study of the diffusion of hybrid corn in the U.S.[11] His theory contains the following hypotheses: first, diffusion is a disequilibrium process in which an industry moves from one equilibrium position to another equilibrium position. Movement to a new equilibrium is affected by both demand and supply factors. On the demand side are the firms of the adopting industry. On the supply side are the suppliers of the new invention. Therefore, interfirm differences in adoption lag are the result of two factors: the acceptance rate of the innovation and the availability of the innovation. Acceptance depends on the firm's willingness to adopt the innovation, which is assumed to be positively affected by the expected profitability from adoption. Availability, on the other hand, depends on innovation suppliers' willingness to supply the invention to a specific (spatial) market. Therefore, interfirm differences in speed of adoption are explained by the differences in expected profit from innovation and the availability of the innovation. These hypotheses can be expressed as:

$$d_{ik} = f(S_i, \pi_{ikt}) \tag{2.5}$$

$$\pi_{ikt} = g(D_{kt}) \tag{2.6}$$

where the number of years firm k waits before it adopts innovation i, d_{ik}, is determined by availability factor S_i and the expected profit from adoption, π_{ikt}. Expected profit, in turn, depends on the demand faced by the firm, D_{kt}. Aggregating the adoption lag over all firms in the industry, equation (2.5) defines the intercept and slope of the diffusion function, while the demand factor defines the ceiling of the diffusion function, which is given in equation (2.6).

Griliches' model is relatively simple. Among factors which could affect adoption decision, only two were included in the model: expected profit from adoption and the availability of the innovation. While other important factors were neglected, Griliches' pioneering work has stimulated economists' study of innovation diffusion and provided a stimulus for further theoretical refinement. Griliches' use of a statistical function to approximate the diffusion path influenced Mansfield's effort, and he in turn provided a theory of the temporal diffusion function. Interfirm differences in adoption lag have also been probed by Mansfield in various studies to be discussed in this section. However, we find that several issues raised in Griliches' study are largely neglected by later investigators. For one thing, the role played by the innovation supplier is generally overlooked in later studies. For another, differences due to the spatial factor are totally neglected in economic studies.

In his 1963 study, Mansfield proposed that interfirm differences in adoption lag were explained by the following relationship:[12]

$$d_{ik} = f(\pi_{ik}, S_k, G_k, \pi'_k, A_k, L_k, T_k) \qquad (2.7)$$

where d_{ik}, as defined in equation (2.5), is the number of years firm k waits before it adopts innovation i, S_k the size of the firm, G_k the growth rate of the firm, π_{ik} the firm's expected profit from adoption, π'_k the firm's general profitability, A_k the age of the president of the firm, L_k the liquidity position of the firm, and T_k the profit trend of the firm. All variables except the age of the president were hypothesized to affect the length of adoption lag inversely. Given that the firm is a profit-seeker, additional profit from innovation provides an incentive for firms to adopt the innovation earlier. General profitability, π_k', will affect the length of adoption lag inversely because a strong profit position provides a larger pool of internally generated funds for investment, which reduces the capital barrier if the cost of innovation is high. The same reasoning applies to the firm's liquidity status, L_k, while a declining profit trend, T_k, creates a stronger incentive for adoption of new technology. The growth rate of the firm is an indicator for the firm's demand, which in turn affects the firm's profit status.

The proposition that firm size is inversely related to length of adoption lag is derived from the following rationales: (1) larger firms are more likely to encompass a wide range of operating conditions than smaller firms; and (2) larger firms have more frequent opportunities to replace old equipment than smaller firms. Both factors provide opportunities for larger firms to introduce new inventions. Larger firms are also believed to be better equipped to bear the risk and costs of innovation. In the empirical testing firm size was found to be an important factor.

Most of the later interfirm studies follow the same line of argument as does Mansfield's study. Thus, Romeo hypothesized that interfirm differences in diffusion speed could be explained by four factors: firm size, expected profitability from innovation, age of the firm's president (A), and educational level of the president (E):[13]

$$d_{ik} = f(S_k, \pi_{ik}, A_k, E_k) \qquad (2.8)$$

where S, π, and E were hypothesized to provide positive incentive for adoption and A was assumed to have a negative effect. The empirical testing showed that only S was significant, although other factors had the expected (negative) sign.

Globerman's diffusion study of numerically-controlled (NC) machines in the Canadian tool and die industry drops the profitability variables but adds another variable to the factors contained in Mansfield's model: the percentage of foreign ownership of a firm's equity.[14] A firm which is a subsidiary of a foreign company might have easier access to the parent company's technology, and will tend to introduce an innovation earlier than will a similar-sized firm that is locally-owned. In the empirical testing only S and A were found to be statistically significant.

A behavioral model was presented in the study by Gold et al.[15] They argued that the adoption decision depends on a firm's perception of the behavior of other firms' behavior. If other firms do not respond to a profitable invention, the firm in question will also tend to disregard the invention and the potential profit available from adoption. On the other hand, if firms feel that their current market share (or status) is threatened by other firms which have adopted the innovation, an incentive will be created for non-adopters to protect their market shares, especially when adoption has an important effect on a firm's survival. In behavioral models firms are assumed to pursue several goals, including profit. While profit is an important indicator for the firm's conduct, it is by no means the only indicator (or the most important indicator). Decision-making channels receive continuous inputs from product markets, factor markets, technological developments, and internal operating units. It might be misleading to infer the basis for a decision from eventual profits and other operating results, as the decision basis changes continuously over time, and the result does not necessarily reflect the current profit level. In essence, Gold et al. argued that interfirm differences in adoption lag might be due more to a "bandwagon effect" than to differences in expected profits, firm size and other characteristics. For example, if the number of adopters increases, then the operating environment for the remaining firms changes in an unfavorable way and threatens the goals of these firms. This stimulates their search for a solution, and increases the probability that remaining firms will adopt the innovation. It is differences in the perception of the business environment rather than the general characteristics of firms (firm size, profit expectations, etc.) which most explain the firm's adoption lag.[16]

2.2.2.2. Comments. In the previous section we asked why innovations diffuse faster in some industries and we found this question to be inadequately answered by existing diffusion studies. In this section, we ask a similar question and find that the existing studies provide a more ready answer. In explaining why some firms adopt certain innovation(s) faster than others, firm size was found to be an important factor. The effects of the following factors are less clear: growth rate of the firm, expected profit from adoption, profitability, liquidity position, profit trend, age and education of the chief executive officer, foreign ownership, and research and development activities conducted.[17] We also found that existing studies neglect an important factor addressed in Griliches' pioneering study, the spatial location of the firm. The present study will amend this deficiency by examining the diffusion of an innovation in a spatial context. Besides, although the effect of firm size on speed of adoption of innovation is generally found to be positive, there are arguments that such a relationship does not necessarily exist, at least for the case of "in-house" inventions and innovations.[18] This study will add evidence concerning the size effect on adoption decisions.

2.2.3. Intercountry Studies

2.2.3.1. The Theoretical Models. A variation on the interfirm study are intercountry studies which examine the diffusion of identical innovations in the same industry. Because the industrial structure might differ among countries, the intercountry studies also serve the purpose of examining the effects of industrial structure on diffusion. Tilton's study of diffusion of the semi-conductor is an example of such an approach.[19] He hypothesized that the diffusion of new technology is accelerated by a market structure that allows new firms to enter an industry and supplant the established industry leaders whenever the latter fail to employ techniques as quickly as economic conditions warrant, or simply speaking, that diffusion will be faster in a more (dynamically) competitive market. An empirical examination of the U.S. semi-conductor industry confirmed this hypothesis. Diffusion of semi-conductor technology (measured in terms of amounts of semi-conductors produced) advanced faster in the U.S. Furthermore, during the study period, entry of new firms occurred in greater numbers in the U.S., thus implying a more dynamically competitive industry. The entrants were also found to be the main force in adopting improved technology which was invented by outside sources. In Western Europe and Japan, the entry barrier was found to be higher than in the U.S., and the diffusion of semi-conductor technology was found to be mainly due to international subsidiaries of U.S. firms rather than to older, established national firms. Without the entry of U.S. international subsidiaries in these countries, diffusion would have advanced at a much slower rate.

Tilton hypothesized that the following factors have an effect on the adoption decisions: availability of technology (through licensing of patents), scale and learning economies, capital requirements, and demand growth. These factors amount to expected profitability from adoption and availability of supply. Firm size was not hypothesized to be an important factor as it was found that the minimum efficient scale of production was low and the capital requirement was also relatively moderate.[20] The major reason for new entry was hypothesized to be the expected profit from the innovation. Empirical tests were not conducted on the relationship between the existing firm's expected profit from innovation and the length of the adoption lag, thus giving no clue as to the relationship between these two variables.

In a study by Swan of international diffusion of synthetic rubber, the nature of the imitation lag was examined. Swan defined this lag as the interval between initial production in the innovating country and that in an imitating country.[21] The imitation lag was viewed as a sum of three components: (1) the foreign reaction lag, which is the time lag between innovation in the innovating country and import of the goods produced from the new technology; (2) the domestic reaction lag, which is the lag between the importing of the goods produced from new technology and domestic adoption of the new technology; and (3) the learning period, which is the time period needed for learning about the new technology. Adoption of an innovation will occur earlier if the following conditions are present: (1) the larger the value of imports from the innovating country; (2) the greater the domestic demand for the product; and (3) the longer the period of time technologically similar products have been produced domestically. All three conditions were hypothesized to shorten the lags discussed above. The greater value of imports increases the exposure of domestic customers and producers to new inventions, greater domestic demand provides a possibility for higher expected profit from adoption, and experiences of technologically similar products shorten the length of the learning period. Interfirm comparisons of differences on adoption lags were not discussed. The empirical testing used the logistic function to measure the diffusion speed, and these differences were found to be due to differences in demand faced by the adopting industry and competition from rubber imports.

An earlier examination of the international diffusion of the same innovation by Woodruff was based on a less satisfactory theory.[22]

He came to the conclusion that expected profit is an important factor in affecting the firm's adoption speed, but no empirical testing was conducted of this hypothesis. Government intervention was listed as another factor that affects the firm's decision. This might be explained on the grounds of a decrease in information costs about the innovation.[23] To the extent that government agencies promote information about new inventions, information costs will be decreased, and this will facilitate adoption.

In their study of international diffusion of the basic oxygen steelmaking process (BOF), Maddala and Knight proposed that international differences in adoption speed depend on the following factors: (1) differences in the relative proces of labor and capital between countries; (2) differential economies of scale; (3) differences in types of ore available; (4) differences in product flexibility between processes; (5) differences in scrap flexibility; and (6) differences in the age distribution of the existing capital and the rate of growth in the industry.[24] However, the findings showed that these factors are not necessarily the most important ones in explaining differences in diffusion speed of the BOF. Rather, Maddala and Knight found that industry structure plays a significant role in affecting diffusion speed. A more competitive industry structure will induce faster diffusion. At the firm level, expected profitability from the adoption hypothesis was again proposed, but empirical testing is lacking due to data inadequacy. An interesting finding, however, was observed. In the U.S., small firms were found to introduce the innovation faster than larger firms.

A large-scale study of eight innovations in six countries was conducted by a consortium of economic research institutes.[25] Rather than present the several theoretical models, a brief summary will suffice. First, profitability, π, was found to be a significant, if not the most important, factor affecting adoption speed. Second, the notion of technological applicability was mentioned in two studies through the form of a technological ceiling which restricts the applicability of new technology because of endowment constraints in natural resources. This represents a more behavioral-type approach, taking into consideration technological factors as well as economic factors. Third, Mansfield's proposition that the industrial diffusion function is a logistic function was tested in several studies with mixed results. Ray found that for the diffusion of floating glass, the logistic function did not fit the data well.[26] A linear function best represents the diffusion pattern. But this result was not repeated in other studies, in which the logistic function was found to fit well. Fourth, foreign ownership was found not to be very significant in affecting adoption speed. Fifth, the age of existing equipment, which is related to the vintage model proposed by Salter,[27] was briefly discussed in several studies. Sixth, the influence of industrial structure, though conceived as an important factor in the introductory chapter, was not given much attention in the individual studies. Seventh, a different theory was proposed regarding the effect of the profit trend. Contrary to Mansfield's argument that a declining profit trend will stimulate the firm to look for solutions, Hanansan argued that a deteriorating profit trend will deprive the firm of the ability to finance the adoption internally. He also argued that a deteriorating profit trend implies inferior managerial ability, and an inferior managerial ability might imply a risk-averse attitude toward inventions. Eighth, the notion of a "bandwagon effect," i.e., imitation among competitors, was briefly discussed in one study, but was not pursued further. Finally, the findings on firm size are in agreement with Mansfield's hypothesis that larger firms are early adopters, while smaller firms lag behind in adoption, though in some cases the constraint of technology (i.e., existence of scale diseconomies) does impede larger firms' adoption of new technology.

2.2.3.2. Comments. Several conclusions can be drawn from the studies reviewed here. In discussion of interindustry differences in speed of diffusion, the degree of competition (including competition from abroad) is found to be an important explanatory variable. More controversial is the influence of the growth in demand for the adopting industry. While Swan found it to be an important factor,[28] Maddala and Knight found that it did not play an important role in explaining the diffusion of the BOF.[29] As to the interfirm differences in speed of response to innovations, expected profit from adoption is found to be an important factor, thus confirming the hypothesis proposed by Mansfield.[30] Firm size effect has yielded mixed empirical results. Maddala and Knight reported that in the U.S. steel industry small firms responded to the BOF faster than larger firms.[31] The conflicting results for the effect of size on the speed of innovation lends further support to the value of this study. Finally, a vague recognition of information on response to innovations is observed in Woodruff's work. In his model, information cost executed influence through the form of government intervention in the market place. This effect is also mentioned by Nabseth in his summary report.[32] This point deserves exploration because expected profitability from adoption depends in part on the cost of innovation, which is in turn affected by the information available on technical and economic characteristics of the innovation. Since expected profitability from adoption has been found to be an important factor in determining a firm's response to innovations, a more detailed examination of the role of information costs will add to our understanding of the diffusion process.

2.2.4. Vintage Capital Model

2.2.4.1. The Theoretical Model. As mentioned above, in some studies the age of existing equipment was thought to have possible influence on innovation diffusion. This notion is supported by Salter's theoretical model of embodied technology, i.e., new technology can only be introduced as a whole set of new production techniques, rather than as a piece-meal addition to existing capital.[33] Consequently, technological change can only occur when a whole new production process replaces an existing production process. This theory is different from most of the theories discussed previously, which implicitly assume that technological change is a continuous revision of existing production techniques by the incremental addition of a new piece of capital equipment.

The basic argument in Salter's model is that production is conducted at the plant level and that the plant's technology is indivisible. Any plant represents the best production technology available when the plant was built, the "best practice" technique, and cannot be modified once it is built. New technology can only be introduced when a whole new plant which embodies the new technology is built. Because of the indivisibility of new technology, adoption of an innovation can only occur when the firm considers the building of a new plant or the replacement of an old plant. The firm is continuously evaluating the option of operating the existing plant or building a new plant, i.e., to adopt or not to adopt a new technology, by comparing the residual between revenue and cost under two options. The costs of the existing plant are composed of operating costs only, while the costs of the new plant are composed of both operating and capital costs. In other words, the only item of costs that is of concern for the existing plant are variable costs, while for the new plant it is the sum of variable costs and fixed (capital) costs. A newly-built plant always has lower operating costs than does an existing plant. Thus, when the operating costs of a new plant have decreased to such an extent that the difference between the operating cost of a new plant and that of an existing plant is great enough to cover the fixed cost, adoption of the new technology will occur and the new plant which embodies the new technology will be built to replace the existing plant. This argument can be presented in the following mathematical formulation.

Let R_2 be the revenue from the new plant; R_1 the revenue from the existing plant; V_2 and V_1 the operating costs of the new and the existing plant, respectively; I the initial cost of the new plant, i.e., capital costs plus operating costs; S the sum of the site value of the plant, working capital and the scrap value of the plant; and r the competitive interest rate, i.e., the normal rate of return. The entrepreneur will be indifferent between replacing the existing plant or continuing to operate it when the following condition holds:[34]

$$\int_o^n (R_2 - V_2)\ e^{-rt}dt - \int_o^n (R_1 - V_1)\ e^{-rt}dt = I - S. \qquad (2.9)$$

Rearranging the term we have

$$\int_o^n (R_2 - V_2)\ e^{-rt}dt - I = \int_o^n (R_1 - V_1)\ e^{-rt}dt - S. \qquad (2.10)$$

The firm will replace the existing plant whenever the following situation occurs:

$$\int_o^n (R_2 - V_2)\ e^{-rt}dt - I > \int_o^n (R_1 - V_1)\ e^{-rt}dt - S \qquad (2.11)$$

or

$$\int_o^n (R_2 - V_2)\ e^{-rt}dt - \int_o^n (R_1 - V_1)\ e^{-rt}dt > I - S. \qquad (2.12)$$

2.2.4.2. Comments. Gold et al. have proposed that the adoption decision made by a firm can be classified into three types: adoption which adds to existing production capacity, adoption which displaces existing facilities that are still functioning, and adoption which replaces facilities soon to be retired.[35] Salter's model is more related to the second type of adoption, while the models discussed previously seem to be more concerned with the first or the third type. Although there is a difference in perception of the environment faced by the firm, it seems that the Salterian model can include the first and the last types of adoption as special cases in which S of equation (2.9) is zero or is composed of scrap value only. For a firm, then, if an invention occurs, the firm can use the criterion suggested by equation (2.11) to decide whether or not to adopt the invention and when to adopt it (if the net present value of the investment is also affected by other firms' behavior). In the case when the invention goes through post-invention improvements, both the net present value of the investment and the investment cost can be affected and the firm might find it better to wait till a later date to adopt the invention. Thus Salter's model provides another clue to explain the fact that firms do not adopt an invention instantaneously at the time when the invention is commercially ready for adoption. This notion will be used by the current study in developing its theoretical model. Due to the fact that invention has gone through several post-invention improvements, firms will not have perfect information about the invention, and will search for more information in order to calculate the net present value of the investment. Differences in the extent and intensity of information search (and later behavior of other firms) will affect the firm's calculation of net present value, which in turn will affect the firm's attitude toward innovation adoption.

2.3. Temporal-Spatial Studies

In general, most studies under this heading concentrate on the spatial pattern of diffusion, rather than the temporal pattern. The epidemiology model is widely accepted as the theoretical basis for the study of temporal-spatial diffusion phenomenon. Two different versions of the spatial diffusion model have been developed. The first model stresses the importance of personal contacts in the information dissemination, and hence innovation diffusion. The existence of geographical space leads to a distance-decay information function, which in turn causes an ever-decreasing saturation adoption level for different locations. The second model, on the other hand, uses the notion of central place theory to argue that information dissemination is inversely related with city rank in terms of urban structure. Spatial diffusion of innovation is not wave-like, i.e., it does not disseminate from the innovation origin to other places in a closed wave, but rather in a leapfrog pattern which disseminates through the urban hierarchy. Finally, the discussion will extend to include effects of innovation suppliers' promotion activities on the spatial diffusion of innovation.

2.3.1. Epidemiology Model

The simplest model assumes an isotopic plane with a uniformly distributed population, i.e., the population density is identical for each unit of space. Starting from an initial period when a certain proportion of the population, p, is infected, let q denote the proportion of the population which is not infected. The probability that a non-infected person will be infected is the product of the probability that an infected person will meet a non-infected person, pq, and the conditional probability of a first-time infection during a unit period. Written in a differential equation form, we have:

$$\frac{dp}{dt} = kpq. \qquad (2.13)$$

Assuming a constant infection rate, i.e., k remains constant over time, the cumulative infection function is found by integrating equation (2.13) over time. This yields a symmetric S-shaped growth curve or the linear logistic function:

$$p_t = \frac{1}{1 + \frac{q_o}{p_o} e^{-kt}} \tag{2.14}$$

where p_o and q_o denote the proportion of infected and uninfected persons at time zero, and k is the slope of the temporal diffusion function, or speed of diffusion. Thus, the proportion of the population with the disease will increase at an increasing rate until a 50 percent infection is achieved. After that point infection will increase at a decreasing rate, until the ceiling of 100 percent is achieved asymptotically.[36]

A rationale for the symmetric property is provided by Casseti.[37] He argued that early adopters are the ones who have a lower degree of resistence to change. As diffusion spreads, average resistance of the residual users also increases, and will increase more rapidly than the proportion of adopters. Beyond a certain level (the 50 percent adoption level), repeated contacts between persons who have already adopted the disease or innovation occur so often that the decrease in information effectiveness is greater than the increase in the number of messages. The rate of diffusion slows down, resulting in a symmetric logistic function.

The epidemiology model relies upon an important assumption, namely that the infection rate (k) is constant over time. Without this assumption, the symmetric logistic function will not evolve. Empirically this implies that there is a constant relationship between the number of adoptions and number of contacts, i.e., there is a uniform flow of messages. For the diffusion of a disease, this might be a valid behavioral assumption: the more exposure a potential adopter has to a disease, the greater the probability that he will be infected, and such a relationship might be proportional. But this assumption seems to be less valid when applied to the diffusion of innovation, whether it be cultural or industrial. A potential adopter's resistance to the new invention will vary not only according to the amount of cumulative information he receives, but also according to changes in his peers' behavior -- thus giving rise to the "bandwagon" phenomenon. In terms of cultural innovation, peer group pressure is a very important factor in wearing down the potential adopter's resistance to a new invention.[38] In the case of an industrial innovation, changes in market competition due to other firms adopting the innovation represent such a kind of peer group pressure. Thus it is questionable that the assumption of a constant adoption rate over time will be valid for the diffusion of cultural and industrial innovations.

Secondly, the logistic function also relies upon another important behavior assumption, the assumption of a homogeneously mixed population. This assumption implies that in any region the proportion of infected to uninfected persons is exactly equal to the overall population:

$$\frac{p_i}{q_i} = \frac{p}{q} \tag{2.15}$$

where i denotes the location. If there is a time lag in the initial adoption at different locations, then the epidemiology model cannot be used to explain the spatial diffusion pattern of an innovation. More accurately, the epidemiology model does not derive a relationship between space and diffusion; it only assumes one. The derivation of the logistic temporal diffusion function can be conducted without regard to geographical space.[39] Consequently, although the logistic function is adopted in most temporal-spatial studies of diffusion, a strong theoretical basis for the use of the epidemiology model is still not available.

2.3.2. Innovation Wave Model

The "Innovation Wave" model is proposed by Hagerstrand.[40] The essence of the theory is that innovation is diffused from the innovation origin in a closed circle. The whole diffusion process will be like throwing a rock into the water: diffusion waves will be created from the point of contact (innovation origin) and spread out. Locations that are farther away from the origin will receive the impact later than locations that are closer to the origin. The diffusion wave is spatially-continuous: it will not jump from one point which lies closer to the innovation origin to another point which lies farther away from the innovation origin and leave points which lie between them intact.

According to this theory, each potential adopter has his social contacts from which information is received and to which the potential adopter dispatches information. Such contacts compose the "private information field" for this potential adopter. The private information field is found to be inversely related to space, i.e., if we denote the total amount of contacts for a potential adopter in a given period as 1, the probability of contacts will be highest for regions closest to the location of the potential adopter and becomes lower as the distance from the potential adopter increases. Averaging the individual's private information field, the "mean information field" is found. This field of contacts is also inversely related to distance from the potential adopter, as shown in Figure 2.1.

Assume a proportional relationship between the number of contacts (i.e., number of messages received) and willingness to adopt an innovation. Then there is a positive relationship between adoption and distance to innovation center: during any given period, the closer a location is to the innovation origin, the greater the probability of adoption for that location. Once the location adopts the innovation, it becomes the new innovation center and hence the new gravity of the mean information field. The mean information field is a "floating grid" which moves from the old innovation origin to new innovation origins over time. As the grid moves outward from the innovation origin, the intensity of messages about the innovation (measured in number of contacts received by a location from the innovation origin) increases, and so does the willingness to adopt the innovation. As the grid floats continuously over space, adoption spreads from the innovation origin in a ring of waves, as shown in Figure 2.2. In time period t_o, location d_o innovates. Messages about the innovation are disseminated from d_o to other locations. The closest locations receive the greatest number of messages and are ready to innovate in

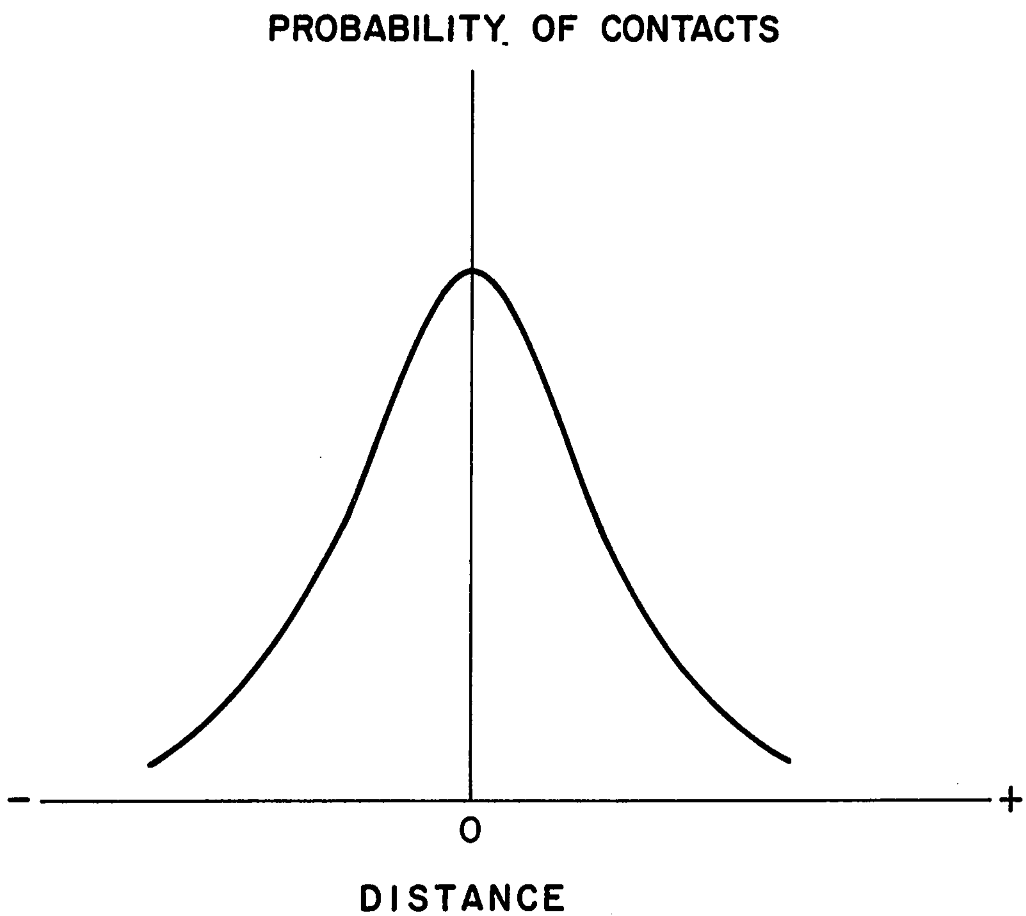


Figure 2.1. Probability Distribution of Mean Information Field in Space.

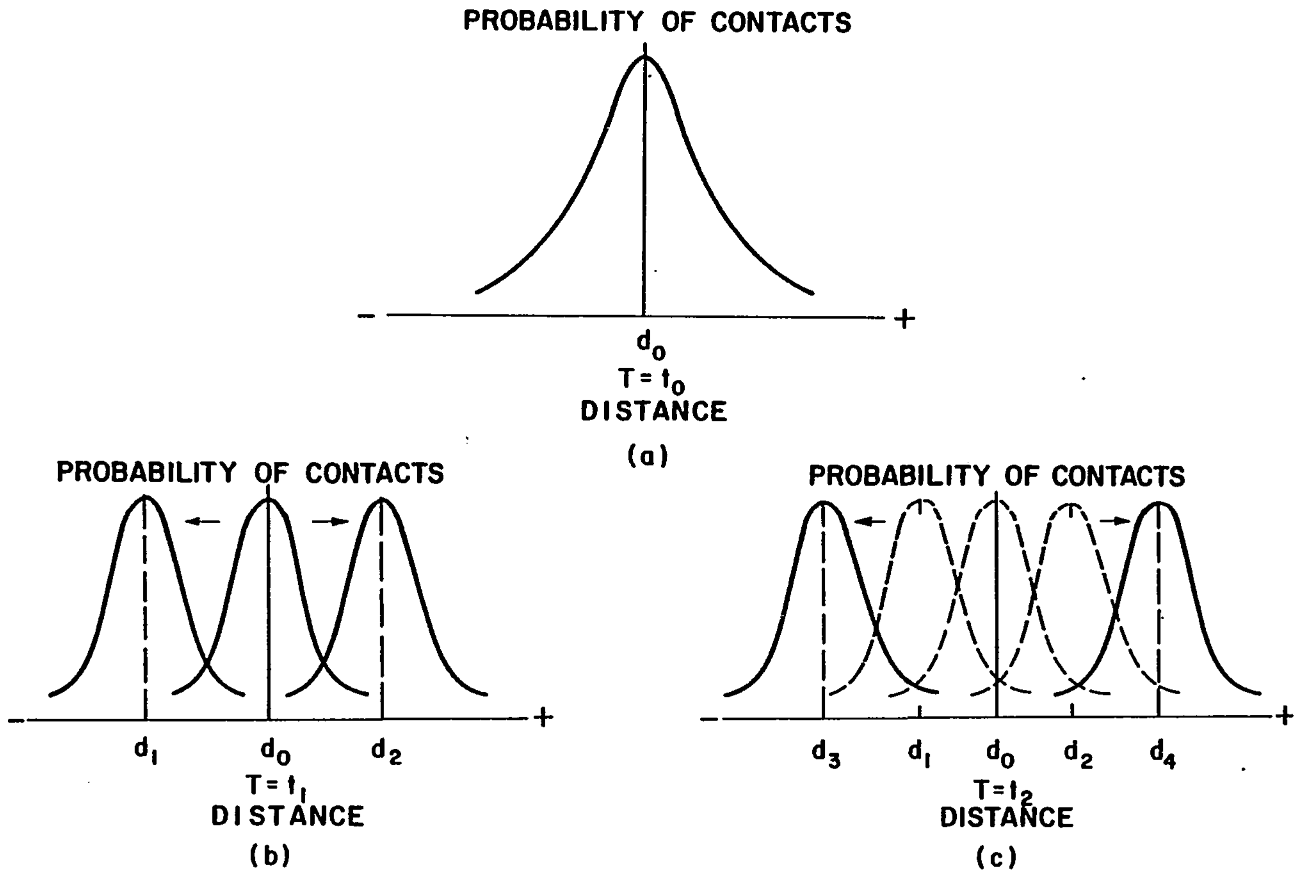


Figure 2.2. Change of the Probability Distribution of Mean Information Field Over Time in Space.

the next time period. Thus, in time period t_1, the closest locations, d_1 and d_2, innovate and become the new gravity of the mean information field. The locations next closest to d_o have received enough information and are ready to innovate. In time period t_2, locations d_3 and d_4 innovate and become the new gravity of the information field. The process goes on until the innovation wave encloses all of the locations in this region.

Various extensions of the innovation wave model have been proposed to analyze spatial diffusion of innovations under different (social) constraints, such as the constraint imposed by national boundaries.[41] But the essence of the model, that of the distance-decay information field and the accompanying spatially-continuous diffusion of innovation, is still preserved in these extensions.

In the original model the exact form of the mean information field over different places was not discussed. The mechanism of the innovation wave was worked out in detail by Morrill.[42] In his model, the mean information field has the following form:

$$p(x) = axe^{-bx} \qquad (2.16)$$

where x is the distance from the point of telling (or innovation origin) and a is a constant given by empirical properties of the information field (e.g., institutional or sociological factors affecting the probability distribution of the information field). In another study, Morrill proposed that this constant decreases as the distance from the innovation origin increases.[43] Thus, the whole set of probabilities of the information field is greater for locations closer to the innovation origin than for locations that are farther away from the innovation origin. The "floating grid" is filtered as it floats from the innovation origin to places farther away from it. As a result, places farther away will receive less information about the innovation and consequently have a smaller probability of innovating. Over time, the cumulative adoption level will reach a lower saturation level in more remote locations than locations that are closer to the innovation origin, as shown in Figure 2.3.

The existence of such a distance-cum-time decay information field, i.e., that the probability of personal contacts will not only vary inversely with distance but also with time, is the essence of Morrill's theory. In any given time period, the probability of contacts is inversely related to the distance from the nucleus. Over time, as the "grid" floats, the probability of contacts in every cell of the grid decreases, as shown in Figure 2.4, which results in the spatial-temporal diffusion pattern shown in Figure 2.5.

In the basic innovation wave model, the speed of the "floating grid" or mean information field seems to depend on the level of resistance of the potential adopter to the new invention. The lower the level of resistance, the easier it is for the potential adopter to become an actual adopter. Once adoption occurs, the location becomes a new innovation origin and enhances the information flow dispatched from the original innovation origin. That means that the shorter the time period between adoptions, the faster the rate of movement of the mean information field. However, the model does not provide an explanation of the distribution of the resistance level to the new invention among different locations. Thus, we cannot actually

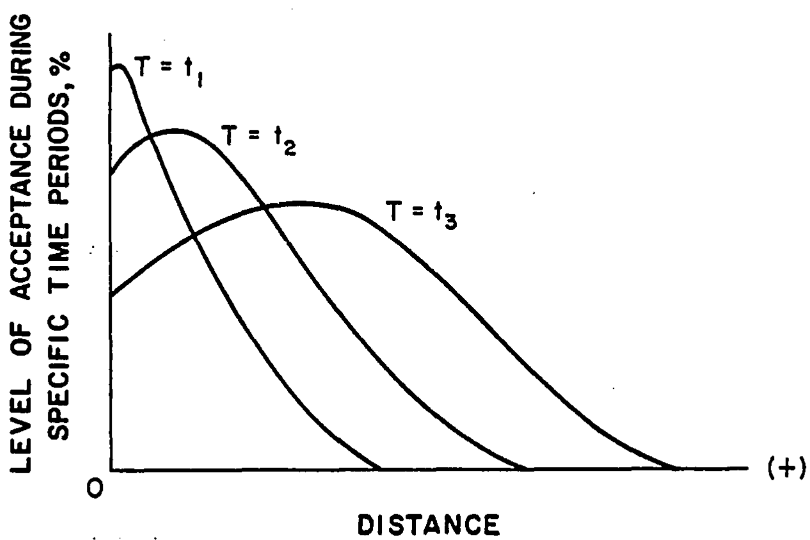


Figure 2.3. Probability Distribution of a Time-Decay Mean Information Field.

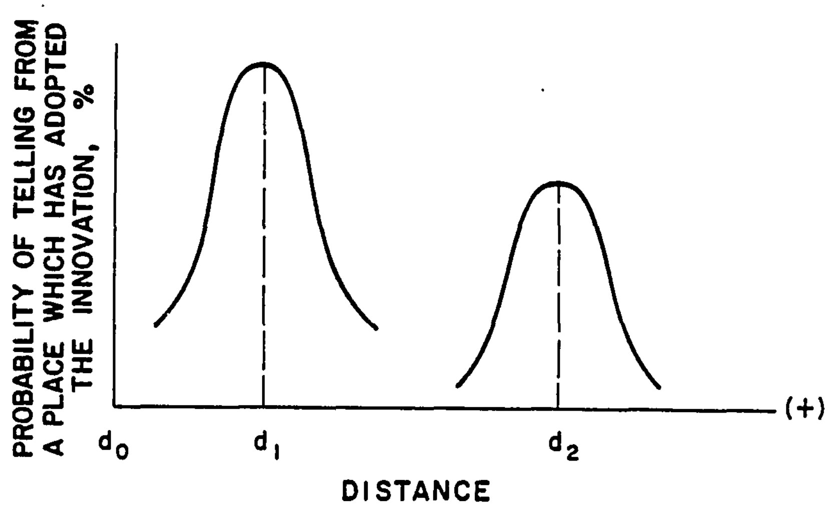


Figure 2.4. Probability of Contacts between Adopters and Non-Adopters of an Innovation.

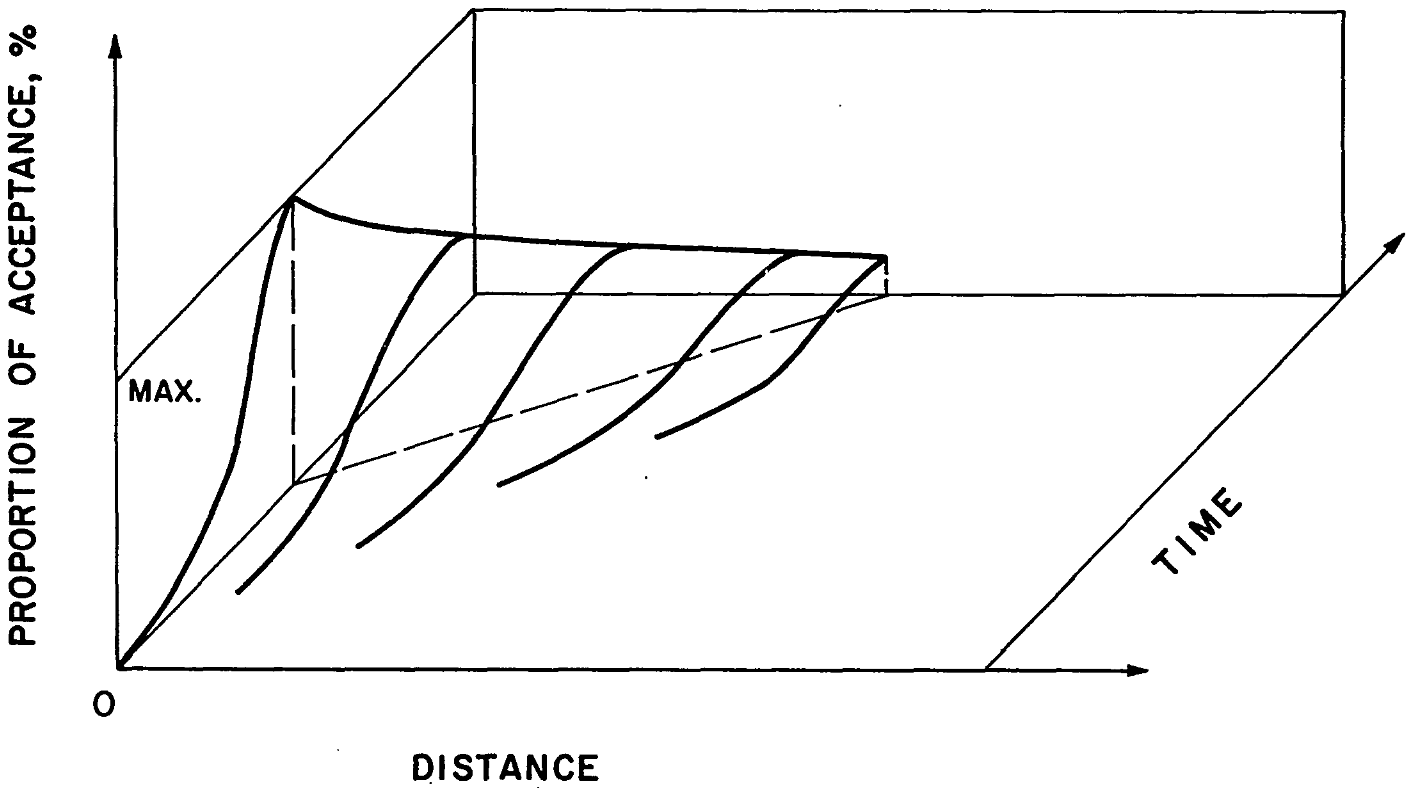


Figure 2.5. Diffusion of an Innovation in Space and Time.

predict which place will innovate earlier if two places are of equal distance from the innovation origin. Without an a priori theory of the level of resistance to the new invention in these two locations, such a prediction is impossible. The innovation wave theory only provides an explanation of the spatial pattern of diffusion. The link between the spatial diffusion pattern and the temporal rate of diffusion does not exist, even in Morrill's extended version of the innovation wave model.

2.3.3. Urban Hierarchy Diffusion Model

The urban hierarchy diffusion model hypothesizes that the information function is affected by the population of a location, or more precisely, its rank in the urban hierarchy. The information flow (I) from location i to location j is of the following form:

$$I_{ij} = kP_iP_j/d_{ij}^b \qquad (2.17)$$

where k is a constant, P the population of a location, and d the distance between two locations. Information flow between two locations is inversely related to the distance between them, but directly related to their populations. If two locations are of equal distance from the innovation origin, but one is on a higher order of urban hierarchy, then the higher-order location will have a greater information flow. Hence this location will have a greater probability of innovating if information exposure is positively related to adoption. In general, information is disseminated down through the urban hierarchy. Locations of much higher order in the hierarchy will receive the same amount of information much earlier than locations of lower order. For any location i, the cumulative number of messages received will be given by:

$$\sum_{j=1}^{i-1} (kP_iP_j/d_{ij}^b)(T - t_j) \qquad (2.18)$$

where $T - t_j$ measures the lapsed time period from the date location j innovates, t_j, to some later date, T.[44] If we denote the resistance level, i.e., the amount of information needed before a location innovates, as F, then the following condition denotes the necessary amount of information required for a location to innovate:

$$I_{ij} = \sum_{j=1}^{i-1} (kP_iP_j/d_{ij}^b)(t_i - t_j) > F \qquad (2.19)$$

where t_i is the date location i innovates.[45]

Up to now the urban hierarchy diffusion model only establishes the proposition that a location with a higher rank or greater population will tend to innovate earlier than locations of equal distance but of smaller population size. The general pattern of spatial diffusion is left to be established, that is, a broader theory would include a discussion of the general spatial-temporal diffusion pattern. Such a discussion is found in Hudson's work.[46]

Let λ denote the probability of a contact resulting in the acceptance of the innovation, and $p_{i,t}$ denote the probability that at time t the innovation has reached location i but not i+1. Then we can write:

$$p_{i,t} = (1 - \lambda)\ p_{i,t-1} + \lambda p_{i-1,t-1}. \qquad (2.20)$$

In order that the innovation should have reached i but not i+1 at time t, it must either have reached i before but not gone beyond, or it must have been transmitted from location i-1 in the previous period. Using the initial condition that $p_{o,o} = 1$ and $p_{i,o} = o$ for $i \neq 0$, a matrix which represents the number of locations of a given order that have received the message at time t can be written as:

$$A = [a_{ij}] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1m} \\ o & a_{22} & a_{23} & \cdots & a_{2m} \\ o & o & a_{33} & \cdots & a_{3m} \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ o & o & o & & a_{mm} \end{bmatrix} \qquad (2.21)$$

where i denotes the time period and j denotes the rank of the location. This matrix is found to have a column vectors which are binomially distributed:[47]

$$p_{i,t} = \binom{t}{i}\lambda^{i} (1 - \lambda)^{t-i}. \qquad (2.22)$$

If the message about an innovation is disseminated stochastically through an urban hierarchy, then the probability that the message will first reach a location at time t is a binomially-distributed random variable, with mean $E(i) = \lambda t$, and variance $Var(i) = \lambda(1 - \lambda)t$.

The probability of the innovation reaching location x at time t under a continuous diffusion process is normally-distributed with the following form:

$$p(x,t)dx = 1/\sqrt{2\pi\lambda(1 - \lambda)t} \cdot \exp \{-(x - \lambda)^2/[2\lambda(1 - \lambda)t]\}dx \qquad (2.23)$$

with the speed of diffusion given by the expected value of the distance reached at time $t = \lambda t$.[48]

The temporal implication of the hierarchical diffusion model is less clear. It has been noted that if innovation follows the urban hierarchy strictly, then because of the usual size distribution of locations (i.e., the higher the rank, the smaller the number of urban centers in that rank), the temporal diffusion function should be an exponential function. If we assume each location will start to disseminate the message the next time period once it innovates, this function has the following form:[49]

$$f(t) = k^t \tag{2.24}$$

where k is the number of lower-order locations to which the higher-order locations disseminate information. But whether this leads to a temporal diffusion function that is also exponential is unclear; we have to know the resistance level to adoption at each location. Unless we assume that locations of equal rank have the same level of resistance, any behavior implications as to which location will adopt earlier is only a guess. To solve this problem Pederson has suggested that there are "entrepreneurs" and the distribution of "entrepreneurs" over space is a Poisson distribution. A location in which there is at least one entrepreneur will innovate earlier than a similarly-ranked location in which no such entrepreneur resides if both locations have received the same amount of information.[50] This still does not solve the problem; first, the meaning of "entrepreneur" has to be defined. Second, this proposition leads to the conclusion that once a threshold level of information is reached, the decision to adopt an innovation at a location is randomly determined.

2.3.4. The Infrastructure-Market Analysis

The models we have discussed up to now deal with various issues related to the potential adopter, like firm size, expected profitability from adoption, amount of information received, aggressiveness of the management, degree of competition when the potential adopter is a profit-maximizing firm, and flow of information as well as level of psychological resistance to innovation when the potential adopter is an individual consumer. Thus, these studies focus their attention on the adoption perspective of the innovation diffusion phenomenon. This perspective composes the demand side of the innovation diffusion phenomenon. The other side of the coin, that of the supply side factors, is largely neglected in the studies we have reviewed up to now with the single exception of Griliches' work. He has discussed the issue of supply of innovation and its effect on the speed of diffusion. Thus, in addition to expected profit from adoption, the availability of the innovation also affects a firm's length of waiting time before it adopts the innovation, as shown in equation (2.5). But factors which affect the innovation suppliers' decision to promote the innovation and the mechanism through which innovations are made available to potential adopters were not discussed. This task was picked up by several recent researches by geographers which we will discuss in this section.

Availability of an innovation, i.e., supply of an innovation, is related to the "diffusion agency," the public or private sector entity through which an innovation is distributed or made available to the population at large.[51] In a spatial economy, locations of these diffusion agencies will affect information flow and hence the decision to adopt. In addition, marketing strategy used by innovation suppliers, like advertising or personal visits by representatives from the innovation suppliers, will also affect information cost and information flow. Thus, the "market and infrastructure factors," also have their effects on the pattern and speed of innovation diffusion.[52] In a spatial economy, when the innovation supplier decides to establish diffusion agencies, it will determine the location of a single diffusion agency by comparing the expected profit received from each location. Thus, writing

$$\overline{Z}_{it} = \sum_{k=t}^{t+h} \frac{Z_{ik} - I_{ik}}{(1 + r)^k} \qquad (2.25)$$

where $\overline{Z}_{it}$ is the net present value in time t of anticipated profit from place i over the planning horizon h, Z_{ik} the anticipated profit from place i in time k, I_{ik} the cost of establishing a diffusion agency in place i at time t, and r the discount rate. The innovation suppliers will rank places according to their $\overline{Z}_{it}$ and establishes the diffusion agency in accordance with this ranking.[53]

$\overline{Z}_{it}$ as well as Z_{ik} are affected by factors which enter into the cost and revenue calculations, among them the market potential, which is in turn determined by the degree of market penetration in place i.[54] Then differences in market penetration strategy will affect the diffusion pattern through their effects on $\overline{Z}_{it}$ and hence the decision to establish a diffusion agency at a spatial point. A sales maximization strategy will result in a higher rate of diffusion than one of cost minimization as the former strategy calls for a faster rate in the establishment of diffusion agencies.[55] Besides, if market potential varies directly with the market's total population, establishment of diffusion agencies will follow the urban hierarchy. Other things being equal, spatial diffusion will then follow the urban hierarchy. On the other hand, if the market potential is not closely related to the market's population and the transportation cost consists of a relatively large share of the delivered price, establishment of diffusion agencies will follow a contageous pattern. Then spatial diffusion of the innovation will also be contageous, other things being equal.[56] Thus, when the market and infrastructure factors enter the theoretical discussion, we find the outcome, the resulting diffusion pattern, differs as these factors differ. Different patterns of the establishment of a spatial diffusion agency network will cause differences in the rate as well as the pattern of spatial diffusion of innovations.

In addition to the case when there is a central propagator, e.g., an innovation supplier or a government agency, who coordinates the establishment of the diffusion agency network, the case when there is no central propagator to coordinate the establishment of the diffusion agency network is also discussed. In this case the pattern for the establishment of the diffusion agency network will be different. Entrepreneurs at each city will make their own judgments as to the profitability of marketing the innovation and decide whether to market the innovation based on this consideration. If locating at large cities can be conceived of as minimizing risk and uncertainty, then locating at a relatively small place implies a less risk-averse attitude by the entrepreneur.[57] If attitude toward risk of an entrepreneur is an indication of "innovativeness" of the entrepreneur, then we might expect the innovation to be marketed by these entrepreneurs first. Thus, other things being equal, there is a tendency for the establishment of the diffusion agency network to begin from medium-sized cities, as the more innovative entrepreneurs are more likely to be found in these cities.[58] The network will then spread to large cities and finally to cities even smaller than the medium-sized cities.[59] The spatial diffusion pattern of innovations will then also follow this trend. It will be more likely to start from medium-sized cities and spread to large cities and finally to smallest cities.

The literature reviewed in this section indicates that when promotion activities of innovation suppliers are considered, the spatial diffusion pattern will be affected as such activities affect the amount of information flow and hence the potential adopter's decision to adopt. This notion will be considered when we later examine the diffusion pattern and the innovation history of the studied innovation. If supplier promotion activities are found to exist for the studied innovation, the theoretical model should consider this effect.

2.3.5. Comments

The following comments about the spatial diffusion theory are appropriate. First, a strong link between information dissemination and the decision of the potential adopter is implied. Both the concept of an "information field" and a "gravity function" for information dissemination influence adoption decisions. However, with the exception of Davies' work, none of the economic diffusion studies have explored the role of information dissemination in innovation diffusion. Because industrial innovations entail post-invention improvements, firms regard additional information as an economic good. Thus, the role of information on adoption decisions is an issue which should not be neglected in theoretical and empirical studies. Unfortunately, although spatial innovation diffusion studies have pointed out the importance of information dissemination, these studies fail to provide an adequate theory linking information dissemination with the innovation decision. The mechanism which "wears down" the "resistance level" is not explained and is resolved by the existence of an "entrepreneur" in one study.[60] Additional study of this issue is obviously warranted.

Second, although the existence of a sigmoid-shaped temporal diffusion path is a common finding in spatial diffusion studies, these studies fail to develop a theory to explain this functional form. In the innovation wave model, the temporal diffusion function is conjectured to be a sigmoid curve without any theoretical explanation as to how such a result is derived. The urban hierarchy diffusion model does not fare any better in this regard. Hudson proposed that an innovation that is diffused through the urban hierarchy binomially can be approximated by an S-shaped function, without any further comment as to the derivation of such a function. The epidemiology model does generate an S-shaped function, but this model cannot be used to explain the spatial diffusion pattern because of its restrictive assumptions. As a matter of fact, the epidemiology model is more appropriately considered to be a temporal diffusion model than a spatial diffusion model.

This review suggests the following conclusions: existing spatial diffusion studies have yet to develop a theoretical model to explain the temporal diffusion pattern, and the explicit treatment of information dissemination is an important factor that deserves additional study.

2.4. Conclusions

The review presented in the previous two sections indicates several shortcomings in the existing literature. We find that studies of the diffusion of industrial innovations concentrate on innovations applicable to the manufacturing industries. Interindustry differences in speed of diffusion receive minor attention compared with the attention paid to the derivation of the temporal diffusion function. In the interfirm studies, the expected profit from adoption and firm size are found to be major determinants of the speed of response of a firm to innovation,[61] but our knowledge on the effects of other factors is more limited. For example, the effect of the technological characteristics of the innovation on the expected profitability calculation is not explored. The effect of space on the speed of response is almost totally neglected. In short, the mechanism of information dissemination in a spatial economy and its effect on the adoption decision is not discussed in economic literature.

The effect of space on innovation diffusion has been explored by cultural geographers and sociologists, and the notion of an "information function" is present in their studies. The flow of information and its effect on innovation diffusion has been explored, both from the potential adopter's perspective and the innovation supplier's perspective. Information flow is found to be affected by the size of the city where the potential adopter is located, as well as the distance from existing adopters on the one hand, and by the promotional activities conducted by innovation suppliers or other innovation propagators on the other hand. But the mechanism by which information is disseminated has not been fully explored, and the link between the temporal diffusion pattern and space has still to be established. Therefore, these models indicate a need for better integration between spatial diffusion theories and temporal diffusion theories.

In view of these deficiencies, the current study intends to fill in some of the gaps in our knowledge of innovation diffusion by exploring the behavior of the firm in a spatial context. The diffusion of an innovation in the tertiary sector will be examined. In Chapter III, the nature of this innovation will be discussed. Chapter IV will present a theoretical model to explain the behavior of the firm toward innovation in a spatial context. Empirical testings of this model will be discussed in Chapter V. Then, in Chapter VI the temporal diffusion function in a spatial economy will be derived.

ENDNOTES

1. Mansfield (1961).

2. Romeo (1975).

3. Hsia (1973).

4. Davies (1979).

5. Mansfield (1961), p. 745.

6. The methodology adopted by Mansfield is similar to that of population growth theory. See e.g., Alfred J. Lotka, Elements of Physical Biology (Baltimore: Williams & Wilkins Co. Ltd., 1924), p. 63.

7. Davies (1979), pp. 15-16.

8. Davies (1979), p. 74.

9. As is evidenced in the discussion on the derivation of temporal innovation diffusion functions by Mansfield (1961) and Davies (1979).

10. Romeo (1975) has discussed this issue and proposed five factors which could affect the speed of innovation diffusion: number of firms, average expected profit from adoption, distribution of firm size, demand faced by the industry, and average research and development expenditures as a percentage of industry sales. Davies (1979) examined the rate of industrial growth and size distribution in his discussion of interindustry differences in speed of diffusion.

11. Griliches (1957).

12. Mansfield (1963a), pp. 303-305.

13. Romeo (1975), pp. 316-317.

14. Globerman (1975), p. 430.

15. Gold et al. (1970), pp. 231-235.

16. A counter-argument might be that if firms differ in their estimation of expected profit from innovation, these differences might be at least partially due to the effect of changing business environments, i.e., changes in demand faced by the firm might be either because of changes in consumer behavior or changes in competing firms' conduct. To the extent that we cannot clearly distinguish one effect from the other, we have a problem with regard to the empirical testing of the behavior theory of the firm.

17. Mansfield (1963a) has tested the effects of growth rate, general profitability, profit trend, liquidity status, and age of the president of a firm on speed of response to innovation and found them to be statistically insignificant. The relationships were again tested by Romeo (1975) with the same results. Globerman has tested the effect of foreign ownership and research and development activities on a firm's speed of response to innovation and found them to be statistically insignificant.

18. C. Kennedy and A. P. Thirlwall, "Technical Progress: A Survey," Economic Journal, 82 (1972), 61.

19. John E. Tilton, The International Diffusion of Technology: The Case of Semiconductors (Washington, D.C.: Brookings Institution, 1971).

20. General Transistors, which for a while ranked second in the industry during the 1950s, entered the industry with only a $100,000 investment. See Tilton (1971), p. 88.

21. Peter Swan, "The International Diffusion of an Innovation," Journal of Industrial Economics, 22, No. 1 (1973), 61-69.

22. Woodruff (1962).

23. This is the point stressed by Feller in his article with Donald C. Menzel, "Diffusion Milieus as a Focus of Research on Innovation in the Public Sector," Policy Sciences, 8, No. 1 (1977), 49-68.

24. G. S. Maddala and P. T. Knight, "International Diffusion of Technical Change -- A Case Study for the Oxygen Steel Making Process," Economic Journal, 77 (1967), 531-558.

25. Nabseth and Ray (1974).

26. Nasbeth and Ray (1974), p. 207.

27. W. E. G. Salter, Productivity and Technical Change, 2nd ed. (London: Cambridge University Press, 1969).

28. Swan (1973), pp. 68-69.

29. Maddala and Knight (1967), p. 533.

30. This result is reported in Nabseth and Ray (1974).

31. Maddala and Knight (1967), p. 550.

32. Nabseth and Ray (1974), p. 301.

33. Salter (1969), p. 50.

34. Salter (1969), pp. 57-58, footnote #3.

35. Gold et al. (1970), p. 225.

36. For the mathematical derivation of the logistic function and its properties, see e.g., Raymond Pearl, Studies in Human Biology (Baltimore: Williams & Wilkins Co. Ltd., 1924), pp. 558-583; H. E. Soper, "Interpretation of Predicity in Disease Prevalence," Journal of Royal Statistical Society, 92 (1929), 37-42; Lotka (1924), pp. 64-76; M. S. Bartlett, "Some Evolutionary Stochastic Processes," Journal of Royal Statistical Society, Series B, 11 (1949), 211-229; N. T. J. Bailey, "A Simple Stochastic Epidemic," Biometrika, 46 (1959), 193-202; __________, Mathematical Theory of Epidemics (London: Charles Griffin & Co., 1957); H. W. Hanskey, "A General Expression for the Mean in a Simple Stochastic Epidemic," Biometrika, 41 (1954), 272-275; Dodd (1956); E. Mansfield and C. Hnasley, "The Logistic Process," Journal of Royal Statistical Society, Series B, 22 (1960), 332-337.

37. E. Casetti, "Why Do Diffusion Processes Conform to Logistic Trends?" Geographical Analysis, 1 (1969), 101-105.

38. See Herbert Menzel, "Innovation, Integration and Marginality: A Survey of Physicians," American Sociological Review, 25 (1960), 704-713.

39. Lawrence A. Brown, Diffusion Processes and Location (Philadelphia: Regional Science Institute, 1968), p. 79.

40. Torsten Hägerstrand (1967): __________, "Aspects of the Spatial Structure of Social Communications and the Diffusion of Information," Papers and Proceedings, Regional Science Association, 16 (1966), 27-42; __________, "A Monte Carlo Approach to Diffusion," European Journal of Sociology, 6 (1965), 43-67; __________, "Quantitative Techniques for the Analysis of the Spread of Information and Technology," in Education and Economic Development, eds. C. A. Anderson and M. J. Bowman (Chicago: Aldine, 1975), pp. 244-280.

41. See, e.g., R. S. Yuill, "A Simulation Study of Barrier Effects in Spatial Diffusion Study," O.N.R. Task No. 388-410, Contract No. 1228(33), 1965.

42. Richard L. Morrill, "Waves of Spatial Diffusion," Journal of Regional Science, 8 (1968), 1-18.

43. Richard L. Morrill, "The Negro Ghetto: Problems and Alternatives," Geographical Review, 55 (1965), 339-361.

44. Paul O. Pederson, "Innovation Diffusion Within and Between National Urban Systems," Geographical Analysis, 2 (1970), 217.

45. Pederson (1970), p. 217.

46. J. C. Hudson, "Diffusion in a Central Place System," Geographical Analysis, 1 (1969), 45-58.

47. Hudson (1969), p. 55; Martin J. Beckmann, "The Analysis of Spatial Diffusion Processes," Papers and Proceedings, Regional Science Association, 25 (1970), p. 110.

48. Beckmann (1970), p. 110.

49. Hudson (1970), p. 48.

50. Pederson (1970), p. 220.

51. Lawrence A. Brown, Innovation Diffusion: A New Perspective (New York: Methuen & Co., 1981), p. 50.

52. The importance of innovation suppliers' marketing activities has also been discussed by Feller and Menzel. This factor is one of the components of the "diffusion milieus." See Feller and Menzel (1977), p. 57.

53. Brown (1981), p. 57.

54. Brown (1981), p. 58.

55. Brown (1981), p. 61 and p. 72.

56. Brown (1981), p. 64, Table 3.4.

57. E. J. Malecki, "Firms and Innovation Diffusion: Examples from Banking," Environment and Planning, 9 (1977), 1295.

58. Malecki (1977), p. 1295.

59. Malecki (1977), p. 1299.

60. Pederson (1970), p. 220.

61. In the empirical estimations the expected profitability from adoption was often found to be statistically insignificant, although it had the proper sign. This might be due to the use of surrogate measures, as was mentioned in the respective studies.

CHAPTER III

THE SAMPLE INNOVATION -- NATURE, PROPERTIES AND IMPLICATIONS

3.1. Introduction -- Choice of Innovation for Study

A study of spatial innovation diffusion involves a restricted set of possibilities for study, because not all of the innovations provide a meaningful framework. An innovation which has a very small number of potential adopters in a whole country is a good example. All potential adopters might be located in a single urban center, thus eliminating an exploration of spatial diffusion, or they might be geographically concentrated, making the spatial diffusion pattern too vague to be meaningful. A small number of potential adopters might also cause problems in interpreting statistical results. It is in part for these reasons that the diffusion of the general-purpose digital computer in the U.S. commercial banking industry was chosen for study. The potential adopters are large in number (over 13,000) and scattered over the whole country, so the empirical testing of the proposed theory should provide a meaningful application. The computer is an important innovation, and the effect it has on the economy by revolutionizing the (economic) life of human beings is a good reason for its study.

In this chapter we will briefly describe the computer: its nature, properties, applications to the banking industry, and the implications of these characteristics for the theoretical model to be formulated in the next chapter. Section 3.2 will describe the technological characteristics of the computer; Section 3.3 will discuss the application of computer technology to the banking operation; and finally, in Section 3.4 the implication of these findings for the theoretical model will be examined.

3.2. Nature of the Innovation

We begin with a definition of computer:

> A computer is a very high speed calculating machine capable of performing all types of mathematical computations through the following five functions: input, control, storage, arithmetic, and output.[1]

or, alternatively,

> A device --
> a. capable of automatically accepting data, applying a sequence of processes to the data, delivering the results and restarting the cycle without operator intervention;
> b. having a stored program and capability of modifying its own program; and
> c. capable of being programmed to execute a reasonably wide variety of types of computation or other data handling processes, and enabling its users readily to replace one stored program by another in the ordinary course of their work.[2]

A computer, in general, is a system of interrelated machines with the central processing unit (CPU) as its core, as shown in Figure 3.1.

It is commonly accepted today that the first computer was the Electronic Numerical Integrator and Computer, known as ENIAC, built by John Mauchly and John Eckert in 1945.[3] Shortly after ENIAC was completed, Eckert and Mauchly left the University of Pennsylvania to launch a commercial project to produce computers for commercial use. The first such machine, the UNIVAC I (for Universal Automatic Com-

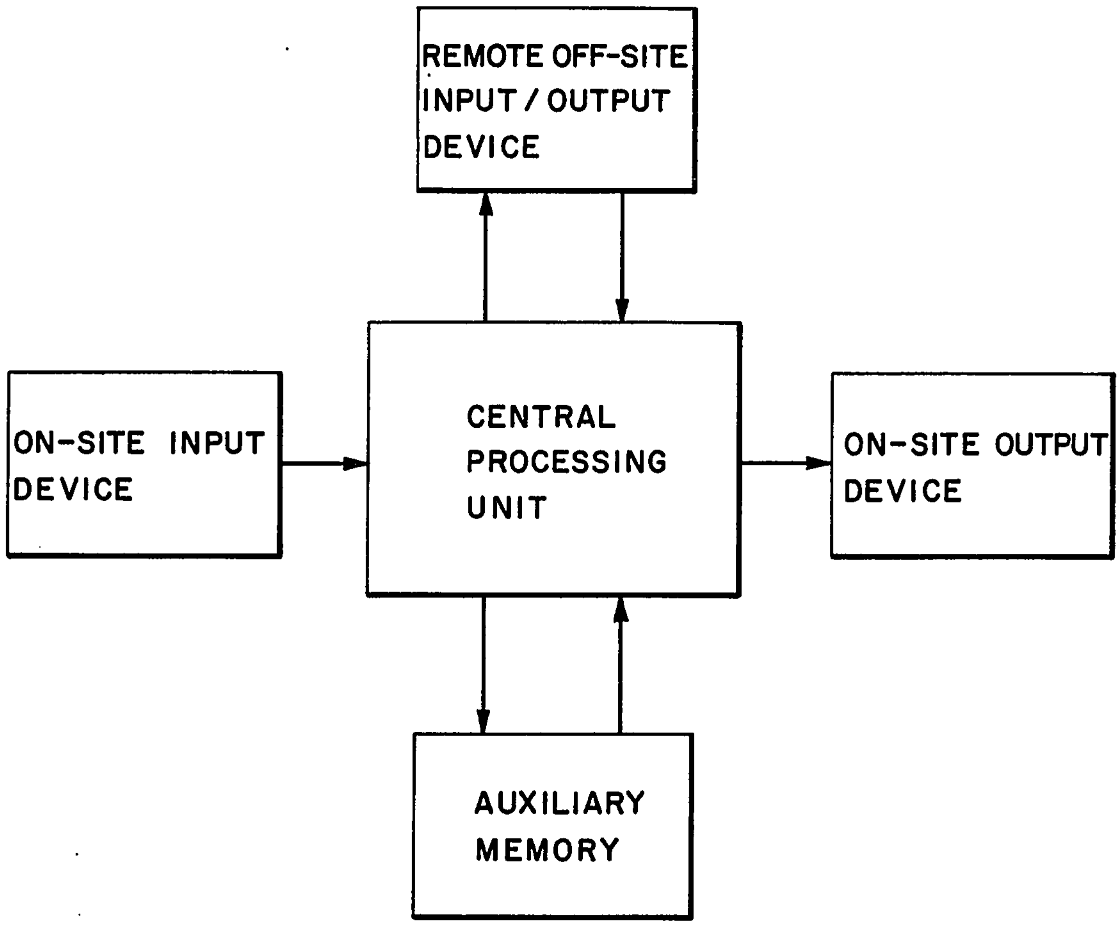


Figure 3.1. Composition of an Electronic Computer System.

puter I), was delivered in 1951 to the U.S. Bureau of the Census. Since then the technology in computer manufacturing has gone through four stages of change, and it is common today to label computer technology as being of four generations: system generation one occupies the period of the late fifties; system generation two covers the period 1960-1963; system generation three covers the period 1964-1970; and the current, or fourth, generation starts in 1971. In terms of computer technology, generation one used vacuum tubes in the electronic circuit part of the CPU, generation two used transistors, generation three used the integrated circuit (IC), and the current generation uses large-scale integration (LSI) in the CPU.

Performance of the CPU is measured in several ways. The following are the most commonly accepted measurement norms:

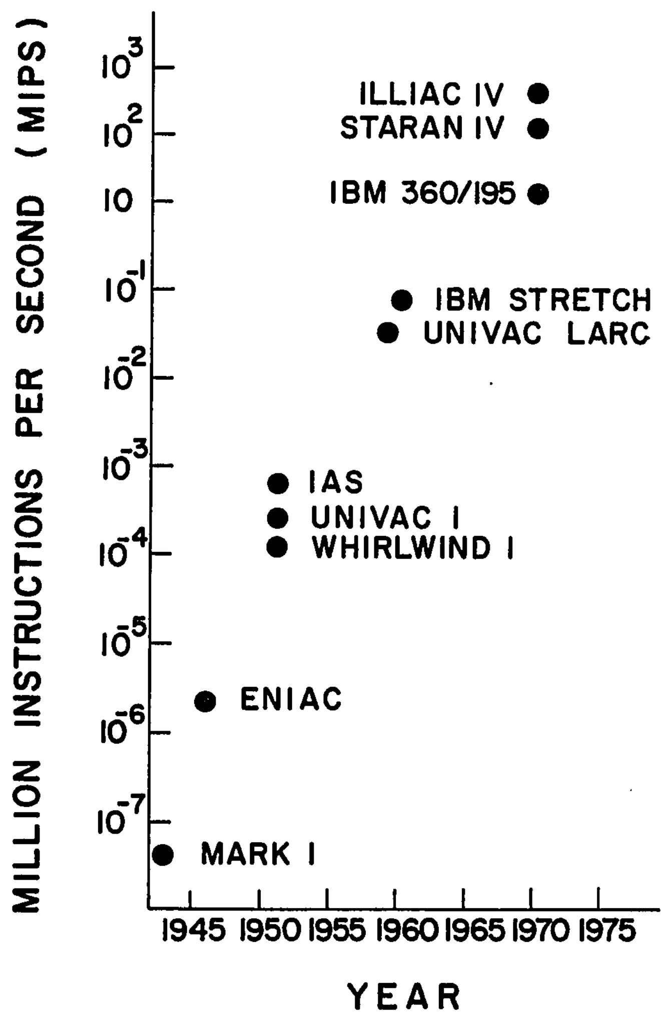
Cycle time -- the time required for a peripheral machine to access the contents of a single core location;

Add Time and Multiply Time -- the time required for the CPU to perform these arithmetic functions; and

Time Taken to Perform Specific Instruction Mixes -- the time required for the CPU to solve a given set of problems.

The change in materials used in constructing the CPU is reflected in the improvement in performance, as is shown in Figure 3.2 for the period of 1945 to 1975.

Any evaluation of CPU performance cannot be an exact science. Performance depends not only on the design of the machine, but also on the way instructions are sent to the CPU. In other words, the performance of a CPU (or more generally speaking, the whole computer



Adapted from John T. Soma, The Computer Industry: An Economic-Legal Analysis of the Technology and Growth. (Lexington, MA: Lexington Books, 1976), Figure 3.2, p. 26.

Figure 3.2. Improvements in Performance of Computers.

system) is the result of the "hardware," the machine, and the "software," the way the CPU is instructed to perform certain mathematical tasks. Consequently, the development of software also affects the performance of the CPU.

The so-called "software" is a language system that is understood by the CPU or, more precisely, "a complete and detailed set of instructions that cause the computer to perform a particular calculation on any values of numerical data presented to it, and to print (sic) the results of the calculation."[4] Software serves the function of the mind of a computer system. Without it a computer system is simply a pile of electronic machines that could not make a single calculation. Software is developed in three stages: machine-level language, which is a combination of binary digits,[5] assembly-level language, which uses certain combinations of alphabets that do not resemble our daily language, and, finally, compiler-level language, a language that resembles mathematical equations. According to the purposes they serve, software in general can be separated into two groups: "housekeeping" software and "applications" software. Housekeeping software serves the function of organizing the operation of the computer system, accepting user programs, and initiating action sequences in the CPU to perform arithmetic functions. The applications software, on the other hand, serves the function of interpreting a problem into a machine-readable language form so that the CPU can perform mathematical calculations. Both groups of software can be written in any level of language.[6] However, a machine-level language uses less actual add-and-multiply time, and a relatively large amount of programming time, that is, the time to convert a question into a machine-readable language by a human being. Compiler-level language, on the other hand, uses a relatively large amount of add-and-multiply time, but a relatively smaller amount of programming time. Assembly-level language is a compromise between these two languages. It uses more machine time than machine-level language, but less than that used by the compiler-level language. On the other hand, it needs less programming effort than the machine-level language but more of it than the compiler-level language.

Software programs and data can be stored in the CPU or in other forms of memories. Because a large part of the storage capacity of a CPU is occupied by the "housekeeping" software, the remaining available storage capacity normally does not provide enough space to store all the programs and data submitted to the computer. Use of other storage devices is necessary. However, storing programs on other devices increases the time and cost needed for the computer system to fetch the stored information. In general, the longer the access time for a stored memory to be fed into the computer system, the smaller the storage cost. The main memory, or the core memory, has the smallest access time but the highest storage cost, while punched cards have the longest access time but the smallest storage cost. Table 3.1 shows an estimate of storage costs for different types of memories.

Once a question has been correctly transformed into the appropriate language forms and fed into the computer system, the computer can execute a large amount of mathematical operations. Thus, computers are extremely useful for the following purposes: processing

Table 3.1. Storage Devices -- Performance Measures

Storage Media	Access Time (seconds)	Cost per Bit (dollars)
Core Memory	.0000001	.20
Extended Memory	.00001	.02
Magnetic Drum	.001	.002
Magnetic Disc	.01	.0002
Magnetic Tape	10.	.00002
Punched Paper Cards	100.	.000002

Source: U.S. Congress, Senate Hearings on the Industrial Reorganization Act, S1167, 1974, p. 4901, Figure 34.

large amounts of numerical data for mathematical tasks, and performing repeated calculations on a large amount of numerical values. In short, computers are found to be extremely helpful and useful when a large amount of data processing is required. In general, scientific calculations and business or accounting data processing are tasks best suited to computer technology. It is this property which makes computers so useful to the business sector as well as for scientific applications. Table 3.2 shows the application of computers, expressed in terms of percent of annual rental revenue for the period of 1958 to 1960, while Table 3.3 shows the main technological and economic characteristics of the computer.

Table 3.2. Application of Computers
(Percent of Annual Rental Revenue)

Application	Booz Allen and Hamilton Survey 1958	Booz Allen and Hamilton Survey 1960	Industry Source 1960
Engineering and Scientific	58%	36%	35%
Data Processing	40%	62%	63%
Process Control	2%	2%	2%
Total	100%	100%	100%

Source: Senate Hearing S1167, p. 5191.

Table 3.3. Computer Progress by Generation

	Early (First) Generation	Second Generation	Third Generation	Present (Fourth) Generation
Dates	1951-1958	1959-1964	1965-1970	1970-
Products	"Named" Machines	Business-Oriented	Families	Families
Electronics	Vacuum Tube	Transistor	Integrated Circuits	Large-Scale Integration
Main Memory	Delay Line/ Drum	Magnetic Core	Core/Plated Wire	Semi-conductor
Auxiliary Memory	Punched Cards/Tape	Drum/Tape/ Disc	Improved Disc/Tape	Advanced Disc/Tape
Users	Computation	Financial Data Processing	Information Processing	On-Line Information Processing
Acquisition	Purchase/ Rent	Purchase/ Rent	Purchase/ Rent/3rd Party Lease	Purchase/ Rent/3rd Party Lease

Source: Senate Hearing S1167, p. 4950.

3.3. Application of the Computer in the Commercial Banking Industry

3.3.1. Background -- Pre-Adoption Environment

Since World War II, the use of checks as a means of payment has been growing steadily at a rate of 6 percent per annum.[7] The number of checking accounts has also been increasing. For example, in the ten-year period from 1945 to 1955, the number of demand-deposit accounts in commercial banks has grown by 46.75 percent, while at the same time U.S. population growth was only 18.13 percent, resulting in an increase in the percentage of the U.S. population holding demand-deposit accounts with commercial banks from 25.3 percent to 31.5 percent.[8] These increases caused severe problems for demand-deposit accounting. The need for daily-updated records in demand-deposit accounts required banks to process accounts daily, and many banks found that processing costs increased sharply as they went to overnight or even three-shift processing.[9] Feeling the squeeze in operating revenues, banks began to look for methods which could decrease costs. The timely invention of electronic computers provided bank officials with an opportunity to use computers in processing checks.

3.3.2. Preparation for Adoption

In the early stages of computer technology, manufacturers were absorbed with the task of design and development of CPU hardware. Partly as a result, the adaptation of computers to the banking business was initiated by the banking industry. Bank of American cooperated with Stanford Research Institute to develop a system called the

Electric Recording Machine Accounting (ERMA) system in 1951. At approximately the same time, First National City Bank of New York launched a project with ITT to design a system which could process checks automatically.[10] Because of the differences in machine-readable inputs of these two systems, and also because checks are generally drawn on different banks (and consequently designed by different banks), a national standard in check design was necessary if automation was to progress further.[11] The problem prompted the American Bankers Association to organize a task force to set an industry standard for check processing. The Technical Subcommittee on Mechanization of Check Handling was formed on April 5, 1954 to standardize check design.[12] This committee, after five years of work, announced the standard for check design in April of 1959.[13] This announcement, together with the now available high-speed sorter-reader,[14] made the use of electronic computers in demand-deposit accounting technically feasible for the commercial banking industry. Bank of America became the industry's innovator when its demand-deposit accounts were automated by the use of a GE system in September of 1959.[15]

3.3.3. Evolution of Application

In the early stages of computer technology, computers were perceived as aids to calculation. Consequently, when system manufacturers promoted this new product, they stressed the usefulness of computers in replacing manual workers in handling accounting data. Computer applications were primarily in the fields of payroll accounting, inventory control, and payables and receivables accounting.[16] The role played by computers was that of an automated electronic clerk. Initially, the commercial banking industry had a similar perception of computers. Computers were used primarily as clerical aids in handling accounting data, especially in demand-deposit accounting (with the combined use of a high-speed check sorter-reader). Their application in banking operations also included such items as savings deposit accounting, trust accounting, and installment loans.[17] Users soon found that computers could play a more useful role than that of an electronic clerk. With the ability to recall memory correctly at an extremely high speed, the computer could serve as a memory bank, or, more accurately, as a data bank for any information. Banking management found that it could also benefit by using computers as aids in storing and generating business information at a relatively low cost. The use of computers as integrated management information systems evolved from this realization. Computer applications in the following areas are now common: credit analysis, portfolio management, and market research. A detailed listing of current applications of computers in the banking industry can be found in Appendix A.1.

3.3.3.1 Credit Analysis. The primary role of a lending officer is to judge the default risk on each loan application and to decide whether or not to approve the application. Prior to the use of computers, each lending officer had to base the decision on his own experience. With the use of computers, a new technique called "linear discriminant analysis" can be applied to the loan applications. Linear discriminant analysis is a statistical technique similar to multiple regression analysis. The bank studies records of previous loans to find certain characteristics of borrowers which are correlated with the payment records. Linear discriminant analysis is used to generate weights (similar to the coefficients for independent variables in regression analysis) for these characteristics. Once the weights are generated, a rating (or weighted mean) is prepared for each loan applicant and the bank sets a cutoff rating for loan applicants.[18] The use of a computer enables the lending officer to judge his decision (of whether or not to approve a loan application) against a larger sample of previous loans, and hence decreases the probability of making wrong decisions. Without computers, such comparisons would be very costly and time-consuming, especially for larger banks whose loan accounts run into the tens of thousands.

3.3.3.2 Portfolio Management. Various programs have been developed by system manufacturers as well as by banks to perform many kinds of tasks, from simple arithmetical calculations on stock market data to simulation and prediction of stock yields and the selection of an optimal portfolio. The computer can also be programmed to provide reports on asset yieldings by type, detailed breakdowns on asset composition, and other analyses for trust officers.

3.3.3.3 Market Research. With data processing wholly automated, a bank can conduct a thorough study of the sources and uses of its funds, thus identifying the bank's market area and the potential for growth in each geographic area. Moreover, data from the Census can now be used to the bank's advantage in identifying areas where potential exists for expansion. The bank can then enter the market by establishing a new branch or through a merger with banks which were already in existence but have failed to realize the growth potential of their markets.

In addition to expanding the role of computers in internal operations, commercial banks also found that, with the installation of computers, new services could be provided to attract customers. Accounting services, billing and collection services, and many specialized services were added to the list of services provided by the bank. New services provided by commercial banks include all of the functions performed by the accounting department of a business, from payroll accounting to cash management and capital budgeting. By extending the uses of the computer from internal operation to external data processing and provision of management information, the bank can replace the accounting department of a business. It was this extension of the bank's role from that of intermediary in arranging loanable funds to the role of business' and household sectors' accounting departments which creates the potential for a "checkless" society.

3.4. Implications

The facts presented in the previous two sections indicate the following: (1) the computer has gone through several major post-invention improvements since it was first introduced in 1951; (2) application of the computer in the banking industry has also gone through several stages; and (3) the computer industry offers a variety of products (both in terms of hardward and software) for potential adopters. All of these points have a bearing on the theoretical arguments to be presented in the next chapter. First, the occurrence of major post-invention improvements in the computer indicates that expected profit from adoption will change over the course of the post-invention improvements, and this change is expected to affect a firm's attitude toward adoption. Second, with four major technological improvements occurring in a span of twenty years and given the differentiated products offered by the computer manufacturers, it seems questionable that potential adopters will have perfect economic or technological information. Potential adopters may have to search for more information in order to make a decision whether or not to adopt the innovation. Information search activity should be incorporated into the theoretical model of a firm's adoption decision. Indeed, diffusion of an innovation may be generated by lack of information.[19] This search for information was not helped by innovation suppliers to the extent that promotion activities conducted by innovation suppliers can facilitate the dissemination of information about the innovation. If the innovation suppliers had conducted promotional activities, information costs would be lowered for those potential adopters located at places where promotional activities had been conducted, and this in turn would affect their decision to adopt the innovation. The early innovation history indicates that it was the potential adopters, in this case the commercial banks, which initiated the quest of the applicability of this new invention to commercial banking.[20] Later when the applicability of this new invention to commercial banking had been acknowledged by banks, it was again the commercial banks which initiated the quest for extended application of this innovation from demand deposit accounting to other areas of banking.[21] Computer system manufacturers, the innovation suppliers, were more absorbed with the task of improving the performance of computers through better engineering design and better integrated utility software, the so-called "housekeeping" software, as we have mentioned in section 3.3.2. Thus, even if innovation suppliers do conduct promotional activities, the effect of such activities on the flow and cost of information is questionable. Although potential adopters can learn information on the engineering aspect of the innovation more easily if a diffusion agency of the innovation supplier is close by and hence lower the information cost on this part of information, the more important part of information, the application software and hence the applicability of the innovation, is in general not learned from diffusion agencies of innovation suppliers but rather from existing adopters through the channel of the so-called "users' group" which exchanges information on application software.[22] Thus the "market and infrastructure" factors discussed in Chapter II do not play a significant role in affecting (actual) innovation diffusion for this innovation. The pattern of the establishment of diffusion agencies does not have a strong effect on the cost structure of information faced by potential adopters, in this case the commercial banks, if computer system manufacturers do promote the use of this innovation through their diffusion agencies. Therefore in Chapter IV we will center our focus on the adoption perspective on the innovation diffusion phenomenon, acknowledging the fact that in theory the market and infrastructure factors can affect the adoption cost faced by potential adopters and hence adoption decisions. Third, although it has been argued that size advantage has a positive effect on a firm's adoption decision,[23] some characteristics of the computer provide counter-arguments: small firms can adopt computers without fearing the existence of excess capacity generated from adoption. Small firms will not face the problem of under-utilization of scale economies. The excess computing time can be sold to other businesses, and this was the case even before time-sharing became available. The nature of the computer also enables businesses to process their data on a batch job basis at an off-site computer owned by other firms.[24] A priori any adopter can utilize this capacity to its maximum, with the resultant impacts on expected profitability from adoption and the firm's attitude toward adoption. These considerations should also enter the theoretical model.

With these facts in mind, Chapter IV presents a theoretical model to explain the firm's adoption of an innovation in a spatial context.

ENDNOTES

1. Thomas R. Parkin, Statements before the Senate Hearings on Industrial Reorganization Act, Part 7, S1167 (hereafter referred to as S1167), p. 4884.

2. Department of Employment, United Kingdom, Computers in Offices 1972, Manpower Studies No. 12, Appendix 1.

3. Another experimental model, the Harvard Mark I, was built earlier. Since the technology was found to lead to a dead end, however, this calculator was not considered to be the origin of today's computer technology.

4. R. Woodridge and J. F. Radcliff, Algol Programming (London: English Universities Press, 1963), p. 1.

5. Computer languages are based on a binary (digit) system: 0 and 1. In computer science jargon, this binary is called bits (for binary digits). Thus, one bit is simply one binary digit (a 0 or a 1).

6. A good example is shown in S1167, p. 4909.

7. Dennis W. Richardson, Electric Money: Evolution of an Electronic Fund Transfer System (Cambridge, MA: MIT Press, 1971), p. 46, Table 4.2.

8. Richardson (1971), p. 46, Table 4.3.

9. Boris Yavitz, Automation in Commercial Banking: Its Process and Impact (New York: Free Press, 1967), p. 17.

10. Yavitz (1967), p. 21. It is not clear when the actual dates were for these projects to be launched.

11. The Bank of America system was a "direct" system: accounting information would be printed directly on the check and read by the computer. The City Bank system was "indirect": for each check to be processed electronically, a voucher or "slip" would be manually prepared which would contain all the accounting information to be read by the computer. Thus these two systems differed in the fundamental question of check design and input feedings. If such differences were not resolved, full automation in demand-deposit accounting in the commercial banking industry implied that each bank had to have two different systems in operation, apparently not a very efficient way to operate the demand-deposit accounting.

12. Yavitz (1967), p. 23.

13. Yavitz (1967), p. 25. For a more detailed discussion, see Robert S. Aldom et al., Automation in Banking (New Brunswick, NJ: Rutgers University Press, 1963).

14. These machines are developed by (computer) system manufacturers with the technical characteristics suggested by the American Bankers' Association.

15. Computers and Automation, October 1959, p. 14.

16. Stoneman (1976), pp. 58-59, Tables 4.3 and 4.4.

17. "ABA National Automation Survey," Banking, 57 (October 1964), pp. 37-56; Banking, 57 (November 1964), pp. 106-109.

18. For a more detailed discussion on this topic, see, e.g., Edward C. Bryant, Statistical Analysis, 2nd ed. (New York: McGraw-Hill, 1966), pp. 239-241.

19. As another piece of evidence to support this proposition, the history of the early stages of adoption of the computer also indicates that the commercial banking industry did not fully perceive the usefulness of this innovation (and perhaps neither did the innovation suppliers). See, e.g., Yavitz (1967), pp. 15-17.

20. Yavitz (1967), pp. 21-27.

21. As can be found from the announcements by banks about the new services offered with the use of computers. These new applications of the innovation were developed by the adopters themselves. Such developments in the application of the innovation is documented in several professional journals. See, e.g., Computers and Automation, EDP Industry Report, and Banking. One of such new applications is the Electronic Funds Transfer System (EFTS). The development history of this new application is a typical case for the extended applications of computers in commercial banking. For a more detailed look at the development history of EFTS, see, e.g., Mark G. Bender, EFTS, Electronic Funds Transfer Systems: Elements and Impact (Port Washington, NY: Kennikat Press, 1975), especially pp. 10-36.

22. Computers and Automation publishes an annual roster of users' groups which appears in the June issue. An examination of these rosters indicates that these groups were formed by computer users, not by system manufacturers.

23. See, e.g., E. Mansfield, "Size of Firms, Market Structure, and Innovation," Journal of Political Economy, 71 (1963), 556-558.

24. In addition, there are many different models supplied by system manufacturers which vary in capacity, thus further narrowing the size disadvantages faced by small firms. For a detailed description of the technical characteristics of all the computer models, see, e.g., "Characteristics of Digital Computers," Computers and Automation, July 1973, pp. 84-109.

CHAPTER IV

A DETERMINISTIC MODEL OF INTERFIRM DIFFERENCES IN THE SPEED OF RESPONSE TO INNOVATIONS IN A SPATIAL ECONOMY

4.1. Introduction

A few words about the methodological approach are necessary before we begin the discussion. In this chapter we will analyze a "general" model which could be applied to any new process invention in a tertiary industry. The reasons for adopting a general rather than a special model are: (1) by adopting a more generalized model, we leave room for extending the study to include more than one adopting industry if sufficient data become available; (2) this approach makes possible a comparison with other models which also deal with diffusion of one innovation in several industries; and (3) such a comparison may provide an opportunity of further advancement of the model.

We start the discussion at the level of the individual firm. Section 4.2 presents a model of the firm's adoption decision in a spatial context, and in Section 4.3 interfirm differences in speed of response to innovation are discussed. Empirical testing of the theoretical model will be conducted in Chapter V.

4.2. A Theory of Response to Innovation by a Firm in a Spatial Context

4.2.1. Derivation of Spatial Market Demand

When buyers and sellers are not located at the same place, buying goods also implies a shopping trip. Define the spatial demand for the goods as the relationship between quantity purchased and the delivered or full price of the goods, as shown by the dd' schedule in Figure 4.1(a). We can relate this spatial demand to the distance travelled by dividing the transportation cost by the freight rate. A functional relationship between the spatial demand and the "shopping range" of the buyer can then be defined: given the freight rate, a mill price (or FOB price) defines a maximum distance the buyer is willing to travel to buy these goods, as shown in Figure 4.1(b) by OR_1 and OR_3 for prices OP_1 and OP_3, respectively.

In Figure 4.1(a), dd' is the individual buyer's demand curve. If we let the price include both the mill price and the buyer's transportation cost, then dd' is also the individual's spatial demand schedule. For example, if the mill price is OP_1 but the seller is located OR_2 miles away from the buyer, then with the cost of travelling OR_2 miles given by P_1P_2, this individual will spend a total of OP_2 per unit and buy OQ_2 units. Assume for simplicity that the per unit opportunity cost of travel is constant; then for each mill price there is a corresponding shopping range. If the mill price is OP_1, the shopping range will be OR_1. If the mill price is OP_3, then the shopping range will be OR_3, and so on.

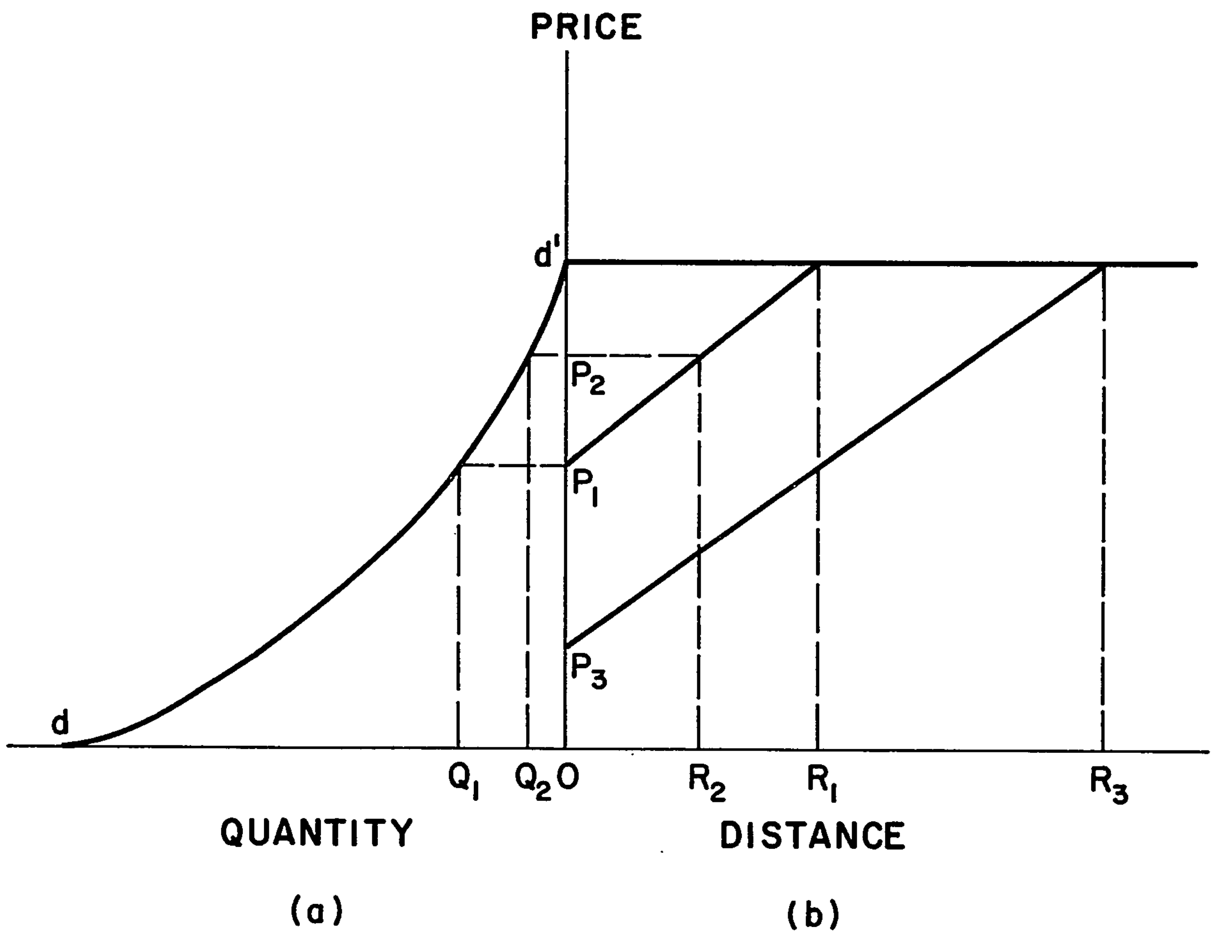


Figure 4.1. Determination of Shopping Range and Market Area.

From the seller's viewpoint, the shopping range of the buyer is the "market range" of the seller. For a firm located at a specific point in space,[1] the spatial market demand the firm faces is the horizontal summation of the individual demands whose shopping ranges include the seller.[2] When urban places differ in population density as well as (per capita) income level, the spatial demand faced by firms at different locations will also differ. Provided that the goods are normal goods, sellers located at places of higher per capita income or denser population will face a greater spatial market demand than firms which are located at places of lower per capita income or sparser population.[3]

4.2.2. Classification of Urban Places

Let the "threshold demand" of a good be that demand which will yield a long-run equilibrium so that each firm can produce at minimum efficient scale (MES).[4] Because of variations in production methods and technology, various goods and services will have a different MES and different corresponding threshold demands. All goods can be ranked in terms of their (total) production cost at MES so a hierarchical ranking of goods will be formed.[5] Corresponding to this hierarchical ranking of goods, a hierarchical ranking of threshold demands can also be formed.[6] An urban place will have different spatial market demands for various goods -- some might be greater than the threshold demand of the respective goods concerned, some smaller. If (at an urban place) the spatial market demand for a good is smaller than the threshold demand, then a seller will not exist at this place in the long run. If we rank all the urban places according to the highest-ranked threshold demand each urban place can sustain, a hierarchy of urban places can be defined as follows:[7]

For an urban hierarchy of r ranks, H_r, where $H_a < H_b < \ldots < H_r$,

$$H_r = f(D_r) \qquad f' > 0 \tag{4.1}$$

$$D_r = g(\overline{Y}, G, P, X) \qquad g_{\overline{Y}}, g_G, g_p, g_X > 0. \tag{4.2}$$

Then for any normal good i, the spatial demand D_{i_r} has the following relationship with H_r:

$$D_{i_r} = h(H_r) \qquad h' > 0 \tag{4.3}$$

Equation (4.1) defines an urban hierarchy of r ranks, H_r, and this hierarchy is defined by the highest sustainable threshold demand, D_r. The threshold demand, in turn, is a function of per capita income, $\overline{Y}$; population density, which is the population of an urban place P divided by its geographical size, G; and all the other unspecified socioeconomic factors which could affect the preference functions of the residents, X. Each of these factors is assumed to have a positive effect on the hierarchy ranking of an urban place, as is indicated by the partial derivatives. For any (normal) good i, spatial market demand D_{i_r} is an increasing function of urban rank r, as shown in equation (4.3). Diagrammatically let L_a and L_b represent two locations of rank H_a and H_b, respectively; then the spatial market demand for i at L_b, D_{i_b}, will be greater than that of L_a, D_{i_a}, as shown in Figure 4.2.

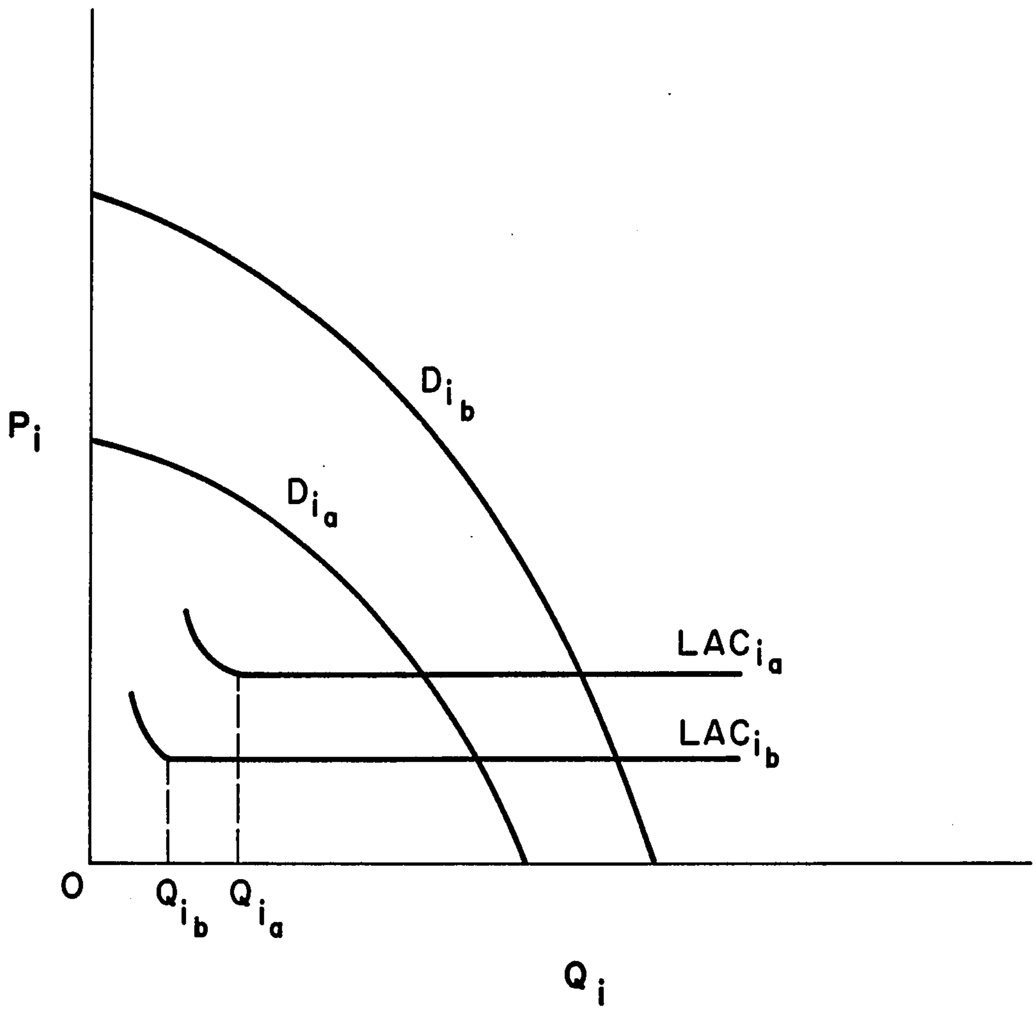


Figure 4.2. Relationship between Location Rank and Production Cost of a Firm.

4.2.3. Firm Location Rank and Production Cost

In the urban hierarchy formed above, will production costs of firms differ when the location ranks of firms differ? Let us take Stigler's notion of a firm, i.e., the firm is an entity which engages in a series of distinct operations.[8] Each operation has its own cost function and the cost function of the final product is the sum of costs of all operations. Technical relationships between operations might cause the firm to be in the increasing cost range of the (long-run) average cost curve on some operations, while at the same time in the decreasing cost range of the average cost curve on other operations. Consider those operations whose scale economies have not been fully utilized by the firm. If industry demand is great enough for a firm to specialize in one of the operations, then other firms could abandon that operation.[9] Since the specialty firm can take full advantage of scale economies, average cost will be lower for all of the firms which abandon this process.[10] However, if market demand does not exceed the threshold level, thereby precluding the existence of specialty firms, other firms will have to conduct these operations at higher costs. The abandoning of operations to specialty firm(s) will not only lower the average cost of the final output, but also the minimum efficient scale.[11]

We have pointed out that in an urban hierarchy, places of higher rank will have a greater spatial demand for a good. This implies a greater long-run equilibrium quantity. Consequently, as the urban rank of a firm's location changes, specialty firms will evolve as other firms abandon some operations. The abandonment process continues as long as the industry's demand expands or, in our theoretical framework, as the firm's location rank increases.[12] It follows that in the urban hierarchical spatial economy defined by equations (4.1) to (4.3), the degree of specialization in the production of goods will increase as the urban rank increases. Long-run average cost for a good will then differ between firms of different location ranks: higher-ranked firms will have lower average costs, as shown in Figure 4.2. For spatial market demand D_{i_a} at location L_a, firms will have a long-run average cost represented by LAC_{i_a} and the MES is at output level Q_{i_a}. For firms facing spatial market demand D_{i_b}, long-run average cost is LAC_{i_b} and MES is at a smaller output level Q_{i_b}, other things being equal.[13]

Information is an economic good. Firms purchase information as an input into their production functions, and the same reasoning leads to operation of specialty firms. Production cost of information, like that of any other good, will also differ for firms of different location ranks. At higher-ranked places, the information cost for firms will be lower. As shown below, this causes differences in a firm's response to an innovation.

4.2.4. An Information Theory Approach to a Firm's Adoption Decision in a Spatial Context -- A Simple Model

We start our analysis with several simplifying assumptions. Denote $ER^*_{t_i}$ as the present value of expected return a firm receives from adopting an innovation at time t_i with perfect information:

$$ER^*_{t_i} = \sum_{t=t_i}^{t_n} \frac{CR_t}{(1 + s)^t} \qquad t_i < t_n \tag{4.4}$$

where s is the discount rate and CR_t the cash return received at time t. Also denote $R^*_{t_i}$ as the innovation cost at time t_i; i.e., the purchasing cost of new equipment which embodies the new technology. We now assume the following:

Assumption 1: The present value of expected return calculated with perfect information remains constant over time:

$$ER^*_{t_o} = ER^*_{t_a} = \ldots = ER^*_{t_n} \qquad \text{where } t_o < t_a < \ldots < t_n. \tag{4.5}$$

Assumption 2: The purchasing cost of an innovation also remains constant over time:

$$R^*_{t_o} = R^*_{t_a} = \ldots = R^*_{t_n}. \tag{4.6}$$

Assumption 3: The financial market is competitive so that the discount rate used by the firm, s, is the competitive market rate of interest.

Assumption 4: Adoption is profitable for the firm from the beginning:[14]

$$ER^*_{t_o} - R^*_{t_o} > 0. \tag{4.7}$$

Thus, with perfect information, the potential adopter would have learned the profitability of adoption on the same date information about the existence of the innovation is first available, which is denoted as time t_o. In reality, firms do not adopt innovations instantaneously. The time lag between t_o and the actual adoption date, t_i, then has to be explained.

A firm will make an investment if the net present value of the investment is greater than or equal to zero. Denote the present value of the expected return with imperfect information as $\hat{ER}$; then the investment will be made if the following condition is satisfied:[15]

$$\hat{ER} - R^* \geqq 0. \qquad (4.8)$$

We will call this condition the adoption criterion, and we know that $\hat{ER}$ will be affected by the information about the innovation, among other factors. Knowledge of the technical as well as economic characteristics of the innovation will decrease the firm's investment risk. If $ER^*_{t_i}$ is the true expected return at t_i when the information is perfect, the difference between $ER^*_{t_i}$ and $\hat{ER}_{t_i}$ then measures the risk premium deducted from $ER^*_{t_i}$ due to imperfect information. Information search will increase $\hat{ER}$ through a reduction in risk premium. Search activity could increase $\hat{ER}$ at an increasing or nondecreasing rate, but it seems more possible that diminishing returns apply here, as suggested by Stigler.[16] An increased amount of information will yield diminishing returns as measured by the expected reduction in the difference between ER^* and $\hat{ER}$. Thus we could write $ER^*_{t_i} - \hat{ER}_{t_i}$ as an inverse function of information search, or in a more convenient form, let $\hat{ER}$ be an increasing function of information, which is denoted by Q_I:[17]

$$\hat{ER}_{t_i} = f(Q_I)\Big|_{T = t_i - t_o} \qquad f' > 0 \qquad f'' < 0 \qquad (4.9)$$

i.e., the estimated expected return from the adoption of an innovation at time t_i is a function of information acquired within the period from the date the innovation is known to the potential adopter, t_o, to the date t_i. This period is denoted as $T = t_i - t_o$. Equation (4.9) can be represented by Figure 4.3(a). A stochastic approach is adopted, i.e., at each level of information, a distribution of $\hat{ER}$ exists, and the $\hat{ER}$ curve in Figure 4.3(a) is the locus of the sampling means from the distribution of all possible values of $\hat{ER}$. If we translate the decrease in the risk premium into a monetary sum, then a marginal return to information, MR, can be derived. Such a curve is displaced in Figure 4.3(b).

From Figure 4.3(a) we can see that for a given R^*, the greater $\hat{ER}$ is, the greater the difference between $\hat{ER}$ and R^*. In other words, the greater $\hat{ER}$ is, the greater the probability that a firm will adopt an innovation for a given R^*. The estimated expected return, $\hat{ER}$, is positively related to information search. Other things being equal, the more information acquired, the greater the probability of adoption at time t_i. In probabilistic form, denoting the attribute of adoption at t_i by a (0,1) variable a_{t_i}, then we can write:

$$a_{t_i} = 1 \quad \text{if } \hat{ER}_{t_i} - R^*_{t_i} \geqq 0$$
$$= 0 \quad \text{otherwise.} \qquad (4.10)$$

If we denote the minimum level of information which can generate a level of $\hat{ER}$ that satisfies the condition given by equation (4.8) as $q_{\hat{ER}}$, then the firm will adopt the innovation at t_i if $q_j = q_{\hat{ER}}$ where q_j denotes the amount of information acquired. Denoting the condi-

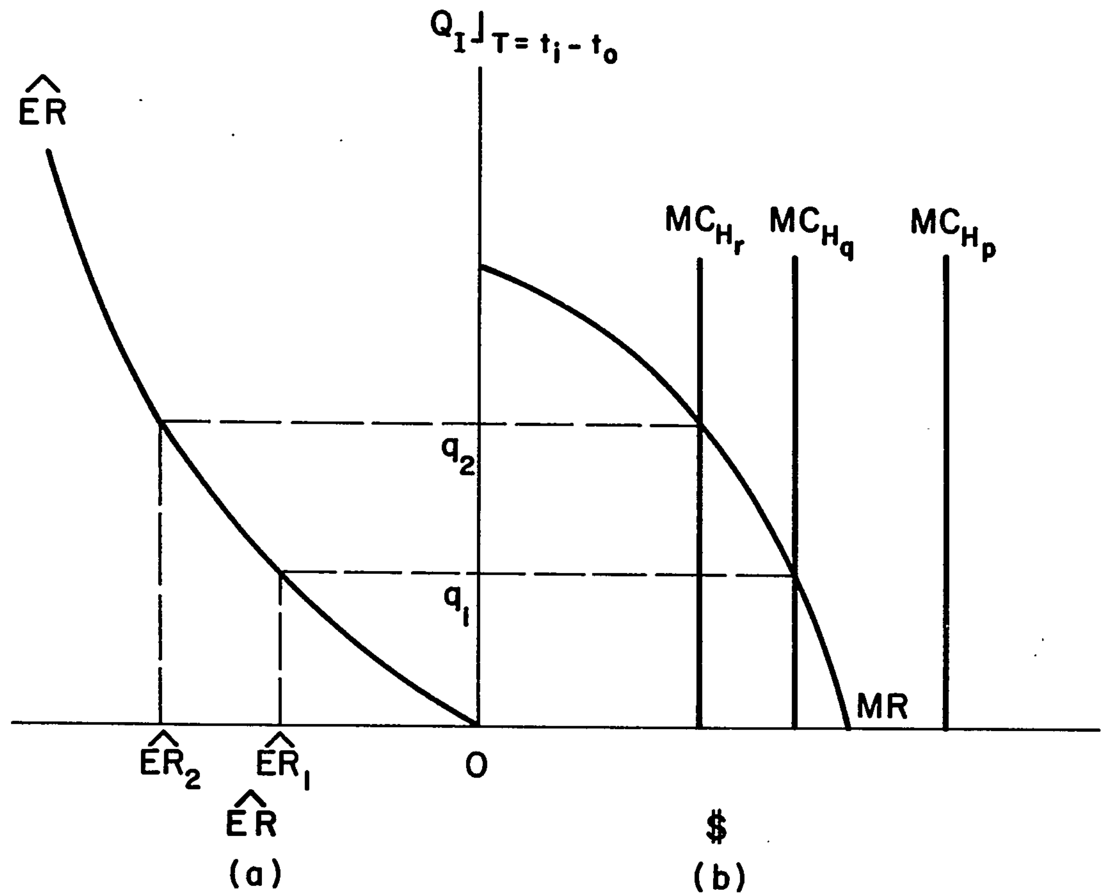


Figure 4.3. Relationship between Adoption Cost and Expected Return for Firms of Different Location Rank.

tional probability of adoption with a given level of information as $Pr(a_{t_i} | Q_I = q_j)$, then

$$Pr(a_{t_i} = 1 | Q_I = q_j) = 0 \quad \text{if } q_j = 0 \tag{4.11}$$

$$Pr(a_{t_i} = 1 | Q_I = q_j) = 1 \quad \text{if } q_j = q_{\hat{\hat{ER}}},\ q_{\hat{\hat{ER}}} > 0. \tag{4.12}$$

Thus

$$Pr(a_{t_i} = 1 | Q_I = q_j) = f(q_j) \quad f' > 0. \tag{4.13}$$

Given the development to this point, the questions we are interested in are: How will the firm determine the optimal level of q_j, denoted as $\overline{q}_j$? In a spatial economy, will q_j differ when the firm's location rank differs? In other words, will firms search for different amounts of information depending on their location ranks or other spatial factors? In the following we will consider the effect of location rank first.

It has been noted by Stigler that the optimal information search is the level where the additional cost of search equals the expected marginal return.[18] If a firm's optimal search level does not change as location rank changes, then the probability that the firm adopts an innovation will be unaffected by the location rank. We have pointed out that the production cost of a firm will be inversely affected by a firm's urban rank: the higher the urban rank, the lower the cost functions. The search costs for a firm will be affected for similar reasons: at lower-ranked places, information search has to be conducted by the firm itself, if the spatial market demand for information search does not exceed the threshold demand. As the urban rank increases, the spatial market demand for information search increases and specialty firms will evolve. Customer firms' information costs will be lowered, and the marginal as well as average cost of information search of the potential adopters will be replaced by a horizontal line which lies below the original average cost curve.[19] As market demand expands, which is tantamount to an increase in urban rank, further specialization can occur and production cost of information can be lowered even further.[20] Thus, for three different urban ranks, H_p, H_q, and H_r, the marginal search cost curves can be represented by MC_{H_p}, MC_{H_q}, and MC_{H_r} in Figure 4.3(b). It is clear from the diagram that if a firm is located at a higher-ranked place, the optimal level of information will be greater. This in turn yields a higher $\hat{ER}$ for the firm, thus increasing the probability of adoption of an innovation. In the diagram, a firm with urban rank H_r will acquire q_2 amount of information, which generates an expected return of $\hat{ER}_2$ in Figure 4.3(a). If the urban rank is H_q, only q_1 amount of information will be acquired, which in turn yields $\hat{ER}_1$ in Figure 4.3(a). Other things being equal, the adoption probability will increase with an increase in the firm's urban rank. Denoting the optimal amount of information at a location of urban rank H_r as $\bar{q}_{H_r}$, then the above discussion yields the following hypothesis:

Hypothesis 1: The probability that a firm adopts an innovation at time t_i increases with the increase in its urban rank, other things being equal.

$$\Pr(a_{t_i} = 1 | Q_I = \bar{q}_{H_r}) = f(H_r) \qquad f' > 0 \qquad (4.14)$$

The limiting case of equation (4.14) is when the conditional probability of adoption equals to one, as is expressed in equation (4.12). Denoting the urban rank where $\bar{q}_j = q_{\hat{ER}}$ as the threshold urban rank, $H^*_{r_k}$, then the adoption criterion of equation (4.10) can be alternatively expressed as follows:

$$a_{t_i} = 1 \qquad \text{if } H_{r_k} \geqq H^*_{r_k}$$
$$= 0 \qquad \text{otherwise.} \qquad (4.15)$$

Thus in a certain period $t_i - t_o$, if a firm's location rank is greater than the threshold rank, adoption of an innovation will occur, other things being equal. The question we are interested in now is: Will this threshold rank change over time?

In the following analysis, we assume that the period of consideration is shortened to t_h, and all other factors which might affect ER^* do not change. Also assume that the distribution of $\hat{ER}$ does not change, so that the shape of the $\hat{ER}$ curve in Figure 4.3(a) remains the same. The time period measured in Figure 4.3(a) is now shortened from $t_i - t_o$ to $t_h - t_o$. The corresponding marginal return curve in Figure 4.3(b) is also unchanged, except that the time period measured is again shortened. Following Alchian, this means that search intensity has to be increased in order to produce the same amount of information in a shorter time period.[21] The increased rate of production implies a higher total cost for each level of output.[22] Thus the total cost of information shifts upward, as shown in Figure 4.4, where TC_2 represents the total cost when search is more intensive. At any level of information acquired, the total cost and marginal cost will be higher.[23]

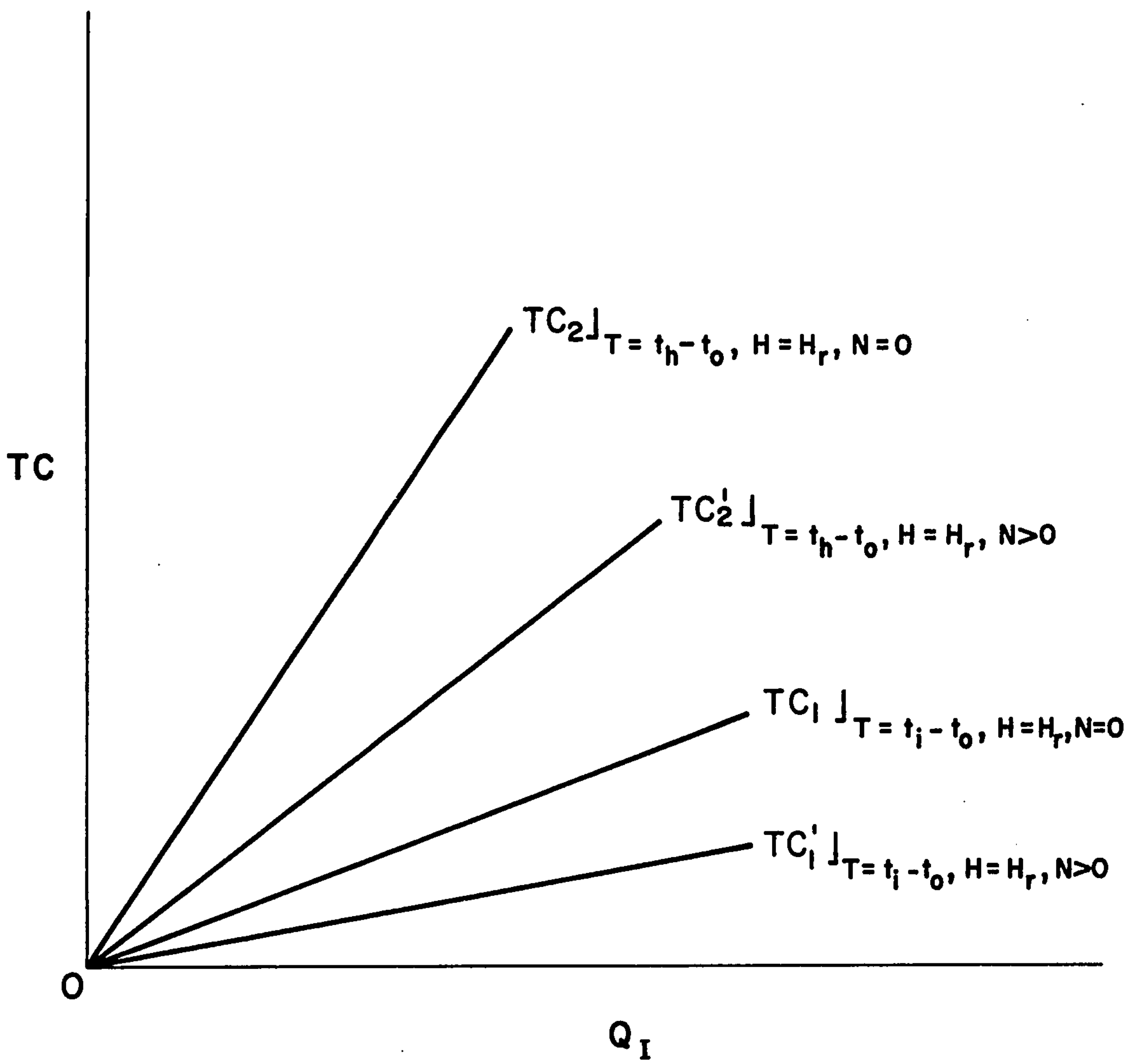


Figure 4.4. Relationship between Search Intensity, Number of Adoptions, and Cost of Information.

The increase in total as well as marginal cost due to increased search intensity implies that for each urban rank the marginal cost function will be higher than when the search intensity (which is directly related to total search time when the volume of information acquired is held constant) is lower. Thus in Figure 4.3(b) if we now let T be shortened from $t_i - t_o$ to $t_h - t_o$, then all the MC curves will shift up. With an increase in (marginal) search cost, the optimal level of search will be smaller. For example, the optimal level of information acquired decreases from q_2 to a smaller amount, e.g., q_1, for firms which have an urban rank of H_r as the total production time of information is shortened. This results in a smaller $\hat{ER}$, as is represented by a decrease from $\hat{ER}_2$ to $\hat{ER}_1$. Since the threshold level for adoption is still $\hat{ER}_2$, which requires q_2 amount of information to generate, we find that as the information production time is shortened, the threshold urban rank for adoption is increased. In this example, it is increased from H_r to a higher level. Thus, in our simple model, a firm's threshold urban rank is inversely related with the time of adoption. In other words, if we measure the adoption lag as the time between the date the innovation is first available and the time when adoption occurs for firm k, then the adoption lag will be inversely related to its location rank:

Hypothesis 2: Other things being equal, a firm's adoption lag will be inversely related to its location rank.

$$(t_i - t_o)_k = f(H_{r_k}) \qquad f' < 0 \qquad (4.16)$$

In this section, several restrictive assumptions about the environment faced by a firm are made in order to obtain theoretical simplicity. Now that we have constructed the basic model, we will relax these assumptions to explore the behavior of a firm in a more complex environment. This will be the task of the next section.

4.2.5. Spatial Competition and the Firm's Speed of Response to an Innovation

If ER^* does not change over time, an individual firm's decision to adopt an innovation relies on the comparison between the marginal search cost and the marginal return from search. And as the cost of information is affected by urban rank, the adoption decision is in turn affected by urban rank, other things being equal. However, when we expand our discussion to include activities of other firms, we find there are other factors which can affect the adoption decision of a firm. When a firm's competitors adopt an innovation, their costs will, in general, be lowered, and this should enable them to compete at lower prices and to expand their market shares.[24] This expansion will affect the market shares of other firms, which in turn will affect their true return, $ER^*_{t_i}$. Unless disadoption occurs, i.e., adopters abandon an innovation at a later time, we can expect cumulative adoption of an innovation to be a non-decreasing function of time. This implies that a firm's ER^* will be adversely affected by time: the later the firm adopts, the lower is ER^*_t. Thus, delayed adoption of an innovation imposes costs on non-adopters in the form of decreases in ER^*_t.[25] Therefore we can now replace Assumption 1 with the following equation:

$$ER^*_t = f(t) \qquad f' < 0 \qquad f'' \gtrless 0. \tag{4.17}$$

On the other hand, delayed adoption also has its benefits. Costs are incurred during adoption of an innovation, just like any other investment, including costs due to restructuring of management, retraining of personnel, decreased output due to new layout of production facilities, and so on.[26] As noted by Alchian, the later a production program is started, the lower the total cost function.[27] Thus late adopters incur lower adoption costs. Purchasing costs of new inventions can also decrease over time. It has been found that many inventions have experienced reductions in production costs due to the "learning by doing" effect, and the decrease in production costs is reflected in the price charged by invention suppliers.[28] With these decreases in adoption costs, Assumption 2 can now be replaced by a new function:

$$R_t^* = g(t) \qquad g' < 0 \qquad g'' \lesseqgtr 0. \tag{4.18}$$

Now that both ER^* and R^* will decrease over time, what will happen to the results we reached in the previous analysis? Suppose that adoption was unprofitable at time t_o, i.e., $ER_{t_o}^* - R_{t_o}^* < 0$. If the adoption cost decreases at a rate faster than the expected return, then eventually the following situation will occur:

$$ER_{t_i}^* - R_{t_i}^* \geqq 0 \tag{4.19}$$

and adoption will take place at t_i. Therefore, if the adoption cost decreases faster than decreases in ER^*, then there is an optimum waiting period. Diagrammatically, the analysis is shown in Figure 4.5. If R^* decreases at a faster rate than ER^*, then the firm should wait t_1 periods before it adopts the innovation.[29] The next question

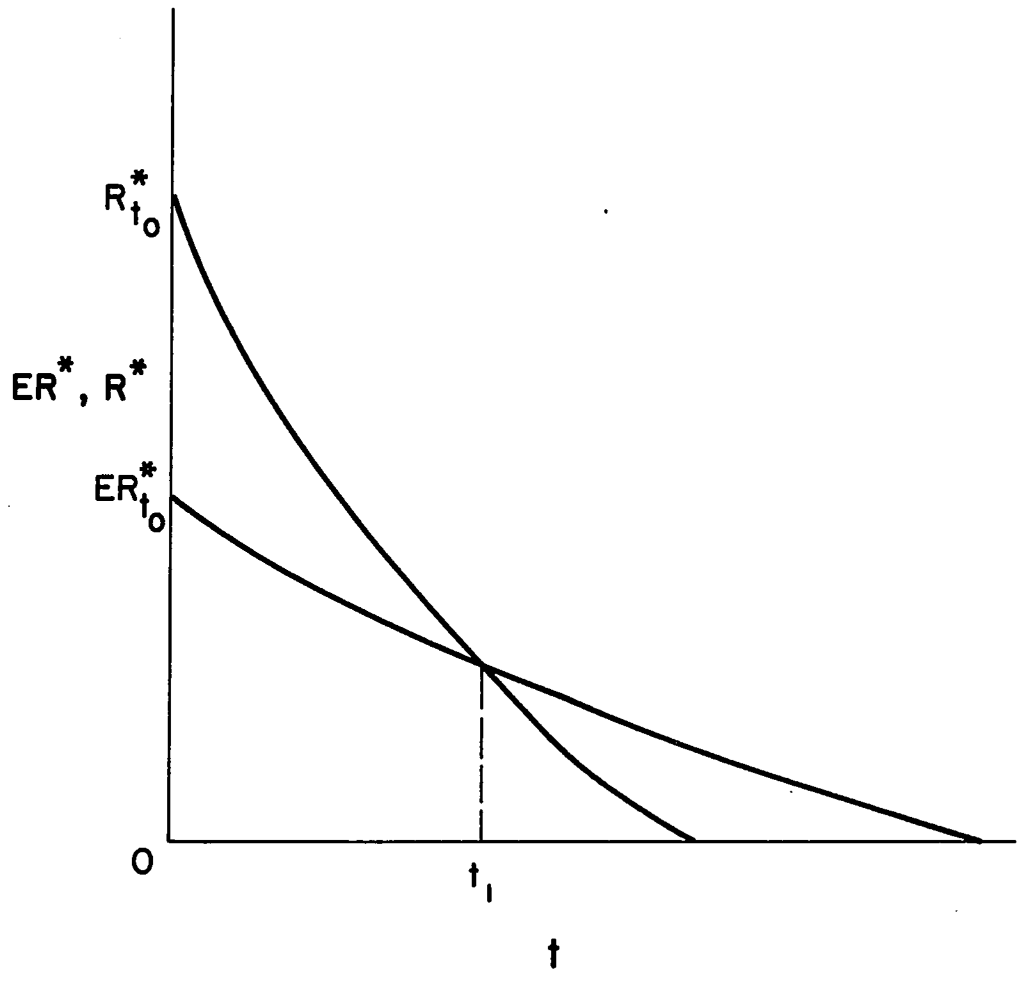


Figure 4.5. Determination of Optimum Waiting Period.

we can raise is: Under this new framework, will the optimum waiting period be affected by the spatial factors?

As we have already noted, locations of higher urban rank can sustain more firms of minimum efficient scale because the spatial market demand is greater, and also because MES is smaller for higher-ranked firms. Both factors contribute to a greater potential for more firms to exist in higher-ranked places. Thus, the (spatial) market tends to become more atomized as the urban rank increases. In other words, the market becomes more competitive. It has been argued that a more competitive firm will have a greater incentive to adopt an innovation, other things being equal.[30] Competition will also induce firms to decrease X-inefficiencies which arise from the lack of competition pressure.[31] Therefore, we expect firms in a more competitive environment to respond to the innovation faster. That is, adoption will be more likely to occur earlier.[32] Thus, there is an inverse relationship between a firm's urban rank and the adoption lag. The time lag between the date when innovation occurs and the date when the firm adopts the innovation will be shorter, the higher the firm's location rank.

Hypothesis 2': A firm's optimum waiting period before adopting an innovation is inversely related to its location rank, other things being equal.

$$(t_i - t_o)_k = f(H_{r_k}) \qquad f' < 0. \qquad (4.20)$$

This result is the same result we reached before under more restrictive assumptions, but with greater recognition of the full set of conditions under which the hypothesis might or might not hold.

Although the spatial factor can affect a firm's speed of response to an innovation through the effect of urban hierarchy rank, it can also exert its influence through the form of the "neighborhood" effect. Information cost is lower for firms locating at higher-ranked places because of the existence of specialty firms, thus increasing the probability of adoption of the firm. But for firms locating at lower-ranked places, the cost disadvantage will be less if firms at nearby places adopt the innovation. The search area (for information) can be narrowed, which will decrease the cost of information.[33] Thus, with firms at nearby places adopting the innovation, the original cost disadvantage for firms locating at lower-ranked places can be lessened. This implies an increase in the probability of adoption by the firm, which in turn will affect the adoption lag of a firm. In terms of Figure 4.4, TC_1 will shift down if there are firms at nearby places which have adopted the innovation. If it shifts down to, e.g., TC_1', then MC curves in Figure 4.3(b) will also shift down. If the period of consideration is shortened from $T = t_i - t_o$ to $T = t_h - t_o$, TC_1' will shift to TC_2', which lies below TC_2. We therefore find that if there are firms at nearby places which have adopted an innovation, then the probability of adoption for the firm will increase:

Hypothesis 2": Other things being equal, a firm's probability of adopting an innovation will be positively related to the number of firms adopting the innovation at nearby places.

$$Pr(a_{t_i} = 1 | Q_I = \bar{q}_{H_r}) = f(N) \qquad f' > 0 \qquad (4.21)$$

where N denotes the number of firms at nearby places which have adopted an innovation.

In summary, we find that a firm's probability of adopting an innovation is a function of two factors: the urban hierarchy rank of the firm's location, and the number of adopters at nearby places. Which factor has a greater effect on the adoption probability of firms has to be determined by the extent of cost disadvantages incurred to the firm due to urban hierarchy rank: If the cost disadvantage incurred due to urban rank of the location is too great for the "neighborhood" effect to overcome, diffusion will follow the urban hierarchy. On the other hand, if the (information) cost disadvantage caused by urban rank is small, then such cost disadvantage may be overcome by the neighborhood effect, and a wave-pattern diffusion will result. Combining Hypothesis 2' and 2", we have the following hypothesis:

Hypothesis 2"': A firm's optimum waiting period before adopting an innovation is inversely related both to its location rank and the number of adopters at nearby places, other things being equal.

$$(t_i - t_o)_k = f(H_{r_k}, N) \qquad f_H, f_N < 0. \qquad (4.22)$$

4.3. Intrarank, Interfirm Differences in Speed of Response to Innovation

Having discussed the differences in speed of response to an innovation due to spatial factors, we now turn to the interfirm differences in speed of response to an innovation. In this section we will hold spatial factors constant in order to compare interfirm differences in speed of response due to other factors.

Different firms, because of differences in management attitude toward risk and new investment, might have different views about the profitability of an innovation. Management attitude, in turn, might be affected by economic characteristics of the firm: size, profitability, liquidity, and growth rate. In addition, industry structure might also cause differences in attitude toward an innovation. On a macro scale, disturbances which are external to the industry, like the business cycle and changes in industry demand, can also influence management decisions. In the following discussion, we will concentrate on those factors which cause intraindustry, interfirm differences in speed of response to an innovation.

4.3.1. Firm Size

Several effects of firm size have been proposed. Mansfield argues that large firms tend to be early adopters because they generally have a more diversified line of production equipment and make more replacements.[34] If the innovation replaces a specific type of equipment, only large firms might adopt the new technology during the initial stages of diffusion. Only when the innovation has been adapted to suit equipment used by small firms could they then become potential adopters. If the original innovation is a success, the innovation supplier might find itself fully occupied with the task of fulfilling orders from larger customers and is not likely to divert its attention to the problem of adapting the innovation to small firms.

Expansion of production capacity to produce the original innovation to match customer demands might be a more urgent problem for the innovation supplier.

Mansfield also suggests that because larger firms operate at a greater production capacity, they will have more units of any particular type of equipment. If at any time each unit has the same probability of (repair and) replacement, then the probability that at least one unit has to be replaced will be greater for larger firms. We could use a simple analysis to illustrate this point. Denote the probability of replacement of unit U_x as $Pr(U_x)$. Then if the occurrence of the event (i.e., the need of replacement) is statistically independent, the probability that at any time at least one unit has to be replaced, $Pr(R)$, can be expressed as follows:

$$Pr(R) = \sum_{x=1}^{n} Pr(U_x). \qquad (4.23)$$

$Pr(R)$ increases with the increase in the numbers of equipment units. Since larger firms have more units, the probability of replacement will be greater. Other things being equal, this implies that the probability of introducing the innovation earlier will be greater for larger firms.

Firm size advantage also applies to the use of the computer in banking for similar reasons. The idling time of the computer, or the so-called "down-time," increases the production cost (for each computer job) and decreases adoption profitability. Larger banks have large amounts of financial transactions or other data which can be processed by computers, and can use the computer more intensively, thus cutting down the amount of "down-time." They consequently view the adoption more favorably.[35] Small firms, until "time-sharing" systems were developed and third-party leasing became available, were at a cost disadvantage. In terms of the theoretical framework, even if there is no difference in the purchasing cost of a computer system, a less intensive use of computer time will cause the waiting period for smaller firms to be longer than that of larger firms.[36]

4.3.2. Growth Rate of the Firm

The effect of the growth of a firm on the adoption decision is clear. For a growing firm, new capacities are added, which require new equipment. The acquisition of new equipment, in turn, provides opportunities for search for information on technologically new equipment. Thus, growing firms are more likely to obtain information about the innovation earlier. Even if information is not actively acquired by potential adopters, but instead passively received from the innovation supplier(s), growing firms will be more interested in conducting further information acquisition activities because they do not have to consider sunk costs of existing equipment.[37] A stagnating firm, in contrast to the growing firm, is restricted in the degree of freedom in decision making because the stagnating firm has to consider the sunk costs of existing equipment when deciding whether to adopt an innovation. We might call this factor the dynamic influence on the adoption decision. Thus, we expect the growth rate of a firm to exert a negative effect on the length of time a firm waits before adoption.[38]

4.3.3. Profitability of the Firm

The availability of investment funds is an important issue for adoption decision. In a world of imperfect information, external financial capital is not a perfect substitute for internally-generated investment funds. External capital suppliers might require a higher expected profitability (i.e., a higher risk premium) and, if the investment costs are high, might not want to support the full amount of investment. The availability of investment funds from internally-generated sources then might decide whether an innovation will be adopted. A more profitable firm will be able to generate more investment funds internally and might also lower the risk premium asked by external capital suppliers. Finally, if profitability captures some aspects of management efficiency, i.e., the higher level of profitability is due not to a generally more favorable industrial environment but rather to more efficient management, then we might also conjecture that the manager will be able to estimate $\hat{ER}$ more accurately. In sum, we expect profitability to have a negative effect on the length of time a firm waits before adoption.

4.3.4. Profit Trend of the Firm

It has been argued that a deteriorating profit trend will induce firms to search for solutions to improve the profit level.[39] The rationale for this argument is found in the behavioral theory of the firm.[40] According to this theory, the firm will not engage in information search unless its goals (sales target, output target, growth target, profit target, etc.) cannot be fulfilled. A deteriorating profit trend suggests that the profit target is not being fulfilled, and a search for solutions will be conducted. The greater the deterioration in profits (or, in more general terms, the greater the difference between targets and actual performance), the more intensive the resulting search activity. We have already pointed out in the previous analysis that a more intensive search will yield the same amount of information in a shorter time period, though the cost of information will also be higher. Provided the adoption is profitable, an intensified search will shorten the length of time a firm waits before adopting the innovation. Thus, we expect the effect of profit trend on adoption lag to be negative. There are, however, some qualifications. First, a deteriorating profit trend might imply an inefficient management, which in turn will decrease the probability of adoption. Secondly, a deteriorating profit trend might also cause a problem in investment capital availability. Therefore the effect of deteriorating profitability trend on adoption lag might be weak, and it is possible that these latter two forces could cause a sign reversal.

We have to point out here that it has been proposed that firm size is not independent from profit and profit is also related to growth. Baumol has argued that there is a positive relationship between profitability and size.[41] There are always some things which only large firms can undertake, but a large firm could always undertake any activity that a small firm does if it wishes. Therefore large firms should be at least as profitable as the small firms, and will probably be more profitable. If there are also firm-level economies of scale, then average cost will fall with an increase in firm size, leading to an increasing profit/size ratio, _ceteris paribus_.

As to the relationship between profitability and growth, it has also been argued to be positive.[42] Higher profits provide a greater availability of investment funds both in the form of retained earnings and external (financial) capital, and empirical studies have indicated the existence of such relationships.[43] Taking into consideration these relations, we might expect some of the independent variables to show a weak effect on the adoption lag as the effects of these variables are partially absorbed by other variables.

In addition to these considerations which apply to tertiary industries in general, there is also a set of considerations which apply to the banking industry: regulatory restrictions. The banking industry is a regulated industry. Regulation covers not only financial structure and product (i.e., the type of service offered), but also industry structure. Three types of banking structure are found in this country: unlimited state-wide branch banking, limited branch banking, and unit banking. The ability to establish new branches has been suggested to be a factor which promotes competition.[44] The threat of potential entry for existing banks is greater under branch banking than unit banking. It has been argued that regulatory authorities tend to be more cautious in granting new bank charters than branch permits, especially if the latter requests come from well-established, low-default-risk banks.[45] In addition, the MES for a branch (in terms of population) seems to be smaller than that of a unit bank, especially in urban areas, making the entry barrier lower for potential entrants.[46] Thus, banks in the branch-banking law states face greater competitive pressures than those in the unit-banking states. Since it has been suggested that competition hastens the adoption of new innovations,[47] we expect regulatory restrictions on branch banking to have an effect on the speed of adoption. For banks in states where branch banking is allowed, the speed of adoption will be faster than banks in states where branch banking is prohibited, other things being equal.

Issues have been raised concerning the effect of regulation on (adoption of an) innovation. It is argued that firms of regulated industry might try to "innovate" in order to circumvent regulations, i.e., the so-called "regulatee avoidance."[48] Adoption of general purpose digital computers might be (partially) explained on the ground of regulatee avoidance, i.e., commercial banks adopt computers not only because of their technical superiority but also because of their providing the banks an opportunity to circumvent existing regulations and hence to increase (general) profit potentials further. But upon closer examination we find this consideration less applicable to the phenomenon discussed in this study. In the commercial banking industry the innovation which is related to computers and could circumvent existing regulations is the electronic fund transfer (EFT).[49] But EFT requires a special type of banking equipment, the automatic teller machine (ATM), to be installed by the bank before EFT can function. The first ATM was delivered in 1969, and six years later only 10 percent of national banks had installed ATM.[50] Thus by 1974 no more than 500 banks among the 14,000 plus commercial banks had installed ATM, and most were large banks with deposit figures over $100 million.[51] But the median deposit figure for the sample used in this study is only \$82 million, and the mode is \$15 million.[52] Thus it seems less possible that banks in our sample adopted computers based mainly on the consideration of regulation avoidance. The profitability consideration is more appropriate, i.e., banks adopt computers in order to improve their profit status.

Summarizing, with regard to factors which might cause interfirm differences in speed of response to innovations, we propose the following hypothesis:

Hypothesis 3: Holding the spatial factors constant, the length of time a firm waits before it adopts an innovation is inversely related to the size S, growth rate g, profitability π', profit trend π^t, and regulatory restrictions on branch banking B. Thus, for any firm k:

$$(t_i - t_o)_k \Big|_{H = H_r,\ N = a} = f(S_k,\ g_k,\ \pi'_k,\ \pi^t_k,\ B_k). \qquad (4.24)$$

Including the effects of spatial factors discussed previously, the model we wish to test empirically can be summarized as follows: In a spatial economy, the time a firm waits before it adopts an innovation is inversely affected by its urban rank H_r, the number of firms at nearby places which have adopted the innovation N, size S, growth rate g, profit π', trend of profit change π^t, and the industry structure. In the commercial banking industry, the industry structure is measured by the regulatory restrictions on branch banking. The adoption speed is inversely related to the restrictiveness of the banking structure B: the more restrictive state regulations are, the longer a bank waits before it decides to adopt an innovation. Writing in a functional form, we have:

$$(t_i - t_o)_k = f(H_{r_k}, N, S_k, g_k, \pi'_k, \pi^t_k, B_k). \qquad (4.25)$$

ENDNOTES

1. Since we are dealing with a central goods producer, this spatial point could be conceived of as an urban place.

2. Under more restrictive assumptions, it can be shown that the spatial market demand a firm faces is derived as follows:

$$D_i = S\int_0^{2\pi} [\int_0^R f(P_i + mt)\ m\cdot dm]\, d\Theta$$

where D_i denotes the spatial market quantity for good i at price p_i, S is the population density which is assumed to be constant over all urban places, m is the distance between seller and buyer, R the shopping range, and t the freight rate. Repeating the calculation for different mill prices, a spatial market demand for the firm can be found. See August Lösch, The Economics of Location, tr. William H. Woglom (New York: John Wiley & Sons, 1952), pp. 105-107.

3. In this kind of spatial economy, the market area of a firm varies inversely with population density and per capita income. See Edgar M. Hoover, Regional Economics, 2nd ed. (New York: Alfred A. Knopf, 1975), pp. 128-134.

4. Minimum efficient scale (MES) is defined as the first point on the long-run average cost function where scale economies are fully utilized. In other words, it is the minimum capacity to fully utilize scale economies. In terms of Figure 4.2, Q_{i_a} and Q_{i_b} are the respective MES for LAC_{i_a} and LAC_{i_b}.

5. In order to form such a ranking, we have to assume all factor prices are held constant, i.e., this ranking is a "snapshot" of the economy at a specific point of time.

6. A study which has explored the threshold demand in terms of minimum population level shows the minimum population level differs for various goods, implying the ranking of goods in terms of threshold population level is possible. See Stanley D. Brunn, "Changes in the Service Structure of Rural Trade Centers," Rural Sociology, 33 (1968), 242. The existence of the threshold demand is also briefly discussed in Hoover (1975), p. 23.

7. Berry has defined a Christaller-type urban hierarchy in terms of population. See B. J. L. Berry, "Hierarchical Diffusion: The Basis of Developmental Filtering and Spread in a System of Growth Centers," in Nilev M. Hansen, ed., Growth Centers in Regional Development (New York: Free Press, 1972), pp. 108-138.

In such type of hierarchy, each place has an exact mathematical relationship with the place of next (higher or) lower rank. The urban hierarchy formed here is less restrictive in the underlying assumptions.

8. George J. Stigler, "The Division of Labor is Limited by the Extent of the Market," Journal of Political Economy, 59 (1951), 185-193.

9. We can call this phenomenon "backward disintegration." By "backward integration" we mean the absorption of firms which formerly produced the goods that are used by the absorbing firm(s) as inputs. Thus, through backward disintegration a firm abandons part of the production process to the specialty firm and purchases the output from the specialty firm instead of producing it.

10. Stigler (1951), p. 188. Hoover also discussed this phenomenon. See Hoover (1975), p. 78.

11. Stigler (1951), p. 188.

12. As a matter of fact, Stigler pointed out that firms could not only abandon those operations which still have scale economies to be utilized to the specialty firms, but also those operations which the firm is operating in the diseconomies of scale range. This again will lower the firm's final output cost.

13. It could also be conjectured that the labor supply will be more elastic in higher-ranking urban places, thus lowering the (equilibrium) wage rate. This will also contribute to a lower long-run average cost and probably smaller MES. This kind of phenomenon is called "economies of a large labor market" by Townroe and Roberts. See P. M. Townroe and N. J. Roberts, Local External Economies for British Manufacturing Industry (Westmead, U.K.: Gower, 1980), p. 10. In addition, Hoover has also discussed the possibility of a lower LAC due to location rank difference. See E. M. Hoover, The Location of Economic Activity (New York: McGraw-Hill, 1948), p. 120.

14. This assumption eliminates the possibility of adoption by firms of all those new inventions which are unprofitable to innovate. In the framework of the Salterian model, we are dealing only with those innovations which satisfy the condition of equation (2.12).

15. For simplicity we will call ER the estimated expected return, and ER^* true expected return in later discussions.

16. George J. Stigler, "The Economics of Information," Journal of Political Economy, 69 (1961), 213-225.

17. Consider Q_I as a distribution of information. Then (expected) information content, or "entropy" of an information distribution, is defined in terms of either a bit (for binary digit) or a nit (for natural logarithm). For a more detailed discussion on the information content of each message, see Henri Theil, Economics and Information Theory (Amsterdam: North-Holland, 1967), Chaps. I-II.

18. Stigler (1961), p. 216.

19. Stigler (1951), pp. 187-188.

20. Stigler (1951), p. 188.

21. Arman Alchian, "Costs and Outputs," in The Allocation of Economic Resources, ed. Moses Abramovitz (Stanford: Stanford University Press, 1959), p. 24, Proposition 1.

22. Alchian (1959), p. 24, Proposition 1.

23. Alchian (1959), p. 24, Proposition 2.

24. This is only a possibility. Competitors do not have to lower their prices and expand their markets. But when the number of competitors increases, the probability that this kind of activity will occur will increase due to the increase in competition, and competitive pressure, as argued later, is related to urban rank of a firm's location.

25. The discussion here is akin to the so-called "fast second" theory: a dominant firm in a market might not be a vigorous innovator. But if a (small) firm innovates, the dominant firm will respond fast lest it lose the market share to the innovator. The slower the dominant firm responds to its competitor, the greater the loss in profit and market share. For a more detailed discussion of the "fast second" theory, see Frederic M. Scherer, Industrial Market Structure and Economic Performance, 2nd ed. (Chicago: Rand McNally, 1980), pp. 328-338.

26. This cost is called the "adjustment cost." See S. J. Nickell, The Investment Decisions of Firms (London: Cambridge University Press, 1978), p. 25.

27. Alchian (1959), p. 31.

28. Davies (1979), p. 49.

29. Actually there is also another reason for potential adopters to wait rather than to adopt the innovation the first time they have learned about the innovation. Innovations can go through post-invention improvements. These improvements will bring

faster obsolescence to previous (machine) models. In terms of the theoretical model developed in this chapter, ER^* will decrease if innovations have gone through post-invention improvements due to speeded obsolescence. Thus, if a potential adopter decides to adopt an innovation the first time it has learned about the innovation as it finds $\hat{ER}_{t_o} - R^*_{t_o} \geq 0$, it might have to abandon the adoption later due to decreases in ER^* which reverse the condition, i.e., $\hat{ER}_{t_i} - R^*_{t_i} < 0$ for $t_i > t_o$. To avoid the occurrence of this situation, potential adopters might decide to wait "till the dust settles," that is to say, until the rate of decrease in $\hat{ER}$ is stabilized and the potential adopter could make a more accurate estimation on $\hat{ER}$. This possibility has been discussed by Rosenberg. See Nathan Rosenberg, "On Technological Expectations," Economic Journal, 86 (1976), 523-535.

30. William Fellner, "The Influence of Market Structure on Technological Progress," Quarterly Journal of Economics, 65 (November 1951), 560-567.

31. Harvey Leibenstein, "Allocation Efficiency vs. X-Efficiency," American Economic Review, 45 (1966), 392-415.

32. It could also be conjectured that as the number of firms increases, the cumulative number of firms which have adopted an innovation at any time also increases. This will affect nonadopters' ER^*. Fearing a further decrease in ER^*, nonadopters will have a greater incentive to adopt the innovation than otherwise.

33. Stigler (1961), p. 219.

34. Mansfield (1963a), p. 292.

35. Actually in the early stages of computer diffusion in the commercial banking industry, only the largest banks could fully utilize the full capacity of a computer. Smaller banks had to add more applications in addition to demand-deposit accounting if they wanted to fully utilize the computer. These new applications implied additional programming costs and consequently a lower $ER^*_t - R^*_t$. See Yavitz (1967), p. 63ff.

36. The importance of cutting down the "down-time" had a strong influence on a firm's decision whether or not to adopt a computer-related innovation, the computer-controlled paper machine and computer typesetting. See Davies (1979), p. 48.

37. Here we use the Salterian notion of "sunk costs." Salter's treatment of this concept has been discussed before (see Chapter II, Section 2.4).

38. We might also call the growth rate of an industry the dynamic influence on the adoption decision of firms. Expanding industries will adopt innovations faster. But since we are not concerned with interindustry differences in the speed of response to innovations, this issue will not be pursued any further.

39. Ruth Mack, The Flow of Business Funds and Consumer Purchasing Power (New York: Columbia University Press, 1941), p. 289.

40. R. Cyert and J. March, A Behavioral Theory of the Firm (Englewood Cliffs, NJ: Prentice-Hall, 1963).

41. W. J. Baumol, Business Behavior, Value and Growth, revised ed. (London: Macmillan, 1967), pp. 42-44.

42. Geoffrey Whittington, "The Profitability and Size of United Kingdom Companies, 1960-1964," Journal of Industrial Economics, 28 No. 1 (June 1980), 335-336.

43. See, e.g., A. Singh and G. Whittington, Growth, Profitability, and Valuation (London: Cambridge University Press, 1968), especially pp. 188-190.

44. Jack M. Guttentag and Edward S. Herman, Banking Structure and Performance (New York: New York University Press, 1967), p. 76ff.

45. Guttentag and Herman (1967), p. 77.

46. Guttentag and Herman (1967), p. 153, Table 39.

47. Scherer (1980), pp. 425-427.

48. Edward J. Kane, "Accelerating Inflation, Technological Innovation, and the Decreasing Effectiveness of Banking Regulation," Journal of Finance, 36 (May 1981), 355.

49. Kane (1981), p. 360, Table 1.

50. Lewis Mandell, "Diffusion of EFTs among National Banks," Journal of Money, Credit and Banking, 9 (May 1977), 342.

51. Mandell (1977), p. 345, Table 2.

52. See Appendix A.3.

CHAPTER V

EMPIRICAL ESTIMATION AND RESULTS

5.1. Introduction

This chapter presents the results of empirical estimates of the theoretical model developed in the previous chapter. The values of the urban hierarchy factor are generated by factor analysis. After the values are generated they are fitted to the empirical models and estimated with the ordinary least square (OLS) method. The effect of the neighborhood factor is measured by the use of several dummy variables. Section 5.2 discusses the empirical measurement of the variables. Section 5.3 describes the characteristics of the data base. Empirical estimation results are presented in Section 5.4. A brief summary of these results is presented in the final section.

5.2. Estimation of Variables

5.2.1. Construction of the Urban Hierarchy Variable -- A Factor Analysis Approach

Equations (4.1) through (4.3) represent an urban hierarchy based on a ranking of threshold demands for commodities. Such a hierarchy is based on urban economic characteristics related to the formulation of threshold demands. Provided that these commodities are normal goods, economic theory suggests that the following factors are important for the threshold demand: income and the number of residents (i.e., buyers) in a given spatial market. These factors represent the aggregate demand of a spatial market. It is less clear what weight should be assigned to each variable in order to generate an index for aggregate demand. This problem can be avoided by the use of factor analysis. By factorizing these variables, factor scores can be generated that represent an index of aggregate demand. An urban place can then be ranked according to its score on the factor (or factors) that most closely represent(s) the concept of aggregate demand.

The fundamental hypothesis of factor analysis is that values of observed variables are the result of interactions among some underlying forces (which are smaller in number than the observed variables). Therefore, by examining the covariation of observed variables, we can detect the effect of these underlying forces (i.e., source variables) on the observed variables.[1] For example, a student's scholastic performance might be determined by his verbal and quantitative abilities. If twenty tests are taken by each student in a group of 100, the 100 x 20 data matrix $\underline{M}$ is the result of the interaction of two source variables, or factors:

$$\underline{M} = \underline{AB} + \underline{E} \qquad (5.1)$$

where $\underline{M}$ is a 100 x 20 data matrix which contains scores on twenty tests by 100 students, $\underline{A}$ is a 100 x 2 matrix which contains coefficients representing each student's verbal and quantitative abilities, $\underline{B}$ is a 2 x 20 matrix which measures the interaction (i.e., relative influence) of these two factors on each test, and $\underline{E}$ is a 100 x 20 error term matrix.

A factor analysis can be used to determine the coefficients in matrices A and B by examining the covariance matrix generated from matrix M.[2] Matrix A is called the factor-score matrix and B the factor-loading matrix. In the current study, this is applied in constructing the value of the urban hierarchy variable for each urban place. The matrix M is an m x n data matrix, where m is the number of urban places and n the number of observed variables which are the economic characteristics of urban places that are related to threshold demand. The matrix A is an m x q score matrix which contains coefficients that represent the degree of strength each urban place has on the q factors. The matrix B is a q x n factor-loading matrix which shows the relative influence of the q factors on each economic characteristic. After matrix A is generated, the factor pattern will be used to represent aggregate demand.

In previous studies of city classification, a "socioeconomic status" or "affluence" factor has been generated from the following characteristics (in terms of the jargon of factor analysis, the affluence factor typically "loads on" these characteristics): median income, percentage of incomes exceeding $10,000, percentage of incomes below $3,000, percentage of the population with a high-school education, median number of school years, (pecuniary) value of owner-occupied housing units, median rent, percentage of housing units that are sound, percentage of housing units that are owner-occupied, median number of rooms per housing unit, percentage of the labor force that is white-collar, and unemployment rate.[3] The variables listed in equation (4.2) correspond to the characteristics loaded by this "socioeconomic status" factor. Therefore, in the data matrix M the following variables will be used in generating factor scores for the urban hierarchy variable:

Income Characteristics: Several measures are available for income, among them mean income, median income, and per capita income. While there might be a theoretical preference for the use of a per capita income measure, other measures also provide useful information about the income distribution of an urban place. It may be better to include all three measures in the analysis. In addition, housing investment is an important part of household wealth and is frequently used to proxy permanent income. Also, the exclusion of rental income will understate the true income level of an urban place.[4] Therefore, median rent and percentage of owner-occupied housing will also be included in the data matrix to capture a more comprehensive measure of income.

Size Characteristics: Population, population density, and population growth are three variables closely related to the size of an urban place. Since all three measures provide information on the size of an urban place, the inclusion of all three variables in factor analysis might provide a more comprehensive treatment of the variable. Therefore, all three variables will be included in the data matrix.

Other Socioeconomic Characteristics: As a measure of income potential, the following variables might also be relevant: median number of school years, percentage of high-school graduates, percentage of the labor force in manufacturing industries, percentage of the labor force in white-collar occupations, unemployment rate, and median age of the population.

Thus, these fourteen variables will be included in the data matrix from which values of the urban hierarchy variable will be generated through factor analysis.

5.2.2. Measurement of Other Variables

5.2.2.1. Adoption Lag. The date when the first operational computer system was installed by a commercial bank will be designated as the origin against which adoption time lags will be measured. As mentioned in Section 3.3.2 of Chapter III, the first operational computer system was installed at the Bank of America in September of 1959.[5] Therefore, this date will be the origin and has a value of 1. Adoption lags will be measured in terms of months.

5.2.2.2. Size. Several size measures have been suggested in previous studies. Mansfield and Davies use physical production capacity as a measure of size, while Romeo uses number of employees. For the commercial banking industry, the traditional measures of firm size are total deposits and total loans.[6] As the deposit measure seems to be more common, this measure will be used in the current study. The deposit figure for the year prior to installation of the innovation is used, and this figure will be adjusted with the GNP price deflator (with base year of 1972) so that all deposit figures are real-dollar figures.[7]

5.2.2.3. Growth Rate. This variable is measured by the percentage increase in real deposits over a five-year period. The five-year period used is that six years before the installation occurred to the year before installation occurred. Both deposit figures will be inflation-adjusted real-dollar figures.

5.2.2.4. Profitability. Profit is measured by dividing net-operating earnings by owner equity. A five-year average covering the same period as the growth rate measure will be used. If such a measure is unavailable, a substitute measure in obtained by dividing dividends by the par value of common stocks.

5.2.2.5. Profit Trend. The profit measure mentioned above will be regressed against time to obtain a trend value of profits. The regression model is profit = ae^{bt}, or log profit = log a + bt. The slope of this regression function, which is the coefficient b, will be used as a measure of the profit trend variable.

5.2.2.6. Banking Structure. The differences in regulatory restrictions on banking structure will be measured by a dummy variable. The variable will have a value of 1 if branch banking is allowed by state regulation; otherwise it will have a value of 0.

5.2.2.7. Neighborhood Effect. As banks located in the same federal reserve district will face similar regulation environments, each federal reserve district is a unique economic region and can form an economic "neighborhood." Therefore we will define the neighborhood according to federal reserve districts (FRD). Eleven dummies will be constructed, with FRD1, the Boston FRD, as the base. In addition, in order to better represent the differences in economic (as well as regulatory) environments and hence to provide a more comprehensive picture of the neighborhood effect, two more dummies will be added to represent differences in FRD size according to average reserve holdings of each federal reserve bank for the period 1959 to 1974. (The figures have been adjusted with GNP deflators with 1972 as the base.) If the average real reserve holdings of the federal reserve bank are $3 billion or higher, then it will be put in class 1. The second class will include those federal reserve banks with reserve holdings between $1 and $3 billion, and the last class will include those federal reserve banks that had reserve holdings lower than $1 billion. The first class will be the base for this set of dummies. Finally, as another test of the relative effect of urban hierarchy versus neighborhood, a dummy representing the status of large banks located in the same city with a federal reserve bank and had adopted the computer by 1964 is introduced. In all, 14 dummies will be used to proxy the neighborhood effect.

5.3. Characteristics of the Data Base

5.3.1. Data on Urban Hierarchy

All the variables mentioned in Section 5.2.1 in the formulation of the data matrix are contained in U.S. Census publications. Median rent and the percentage of owner-occupied housing figures are available from the U.S. Housing Census, and values on all of the remaining variables are from the U.S. Population Census.[8] In theory, an urban hierarchy rank should be constructed from the data contemporaneous with adoption decisions, but in reality such practice proves to be difficult because censuses are conducted only every ten years. During the interim years no data are available for the construction of the urban hierarchy rank. Therefore only 1970 Census data will be used, and factor scores generated from these data will be used for all periods during the innovations diffusion. Thus, the empirical test assumes that the urban hierarchy rank of a place remains constant during the period 1959-1974.[9]

In the 1970 Census there were 2,470 places with populations of 10,000 or more. Since this study is not a study of U.S. urban hierarchy construction per se, an urban hierarchy composed of 2,470 cities will be too time-consuming a task for our purposes. A screening of the data on computer installations reveals that 131 banks were located in cities with populations greater than or equal to 30,000; seven banks were located in cities with populations between 20,000 and 30,000; and 14 banks were located in cities with populations between 10,000 and 20,000. Thus, the majority of observations are from urban places with populations of no less than 30,000. The 1970 Census contains 759 cities with populations of no less than 30,000 (of which 735 have complete information on values of the 14 variables); 440 cities with populations between 20,000 and 30,000; and 1,271 cities with populations between 10,000 and 20,000. Judging by these figures, the additional time spent in coding data in order to construct a larger urban hierarchy would not be well spent. In addition, almost all of the banks which are located in places with populations of less than 30,000 do not have complete financial statements, making the measurement of several variables impossible.[10] Based on these considerations, it was decided that the urban hierarchy would include only places with populations of 30,000 or more. Thus, 735 cities will be used in the construction of the urban hierarchy, generating a 735 x 14 data matrix on which factor analysis will be conducted.

5.3.2. Data on Computer Installation

Data on the installation of general purpose digital computers for the period 1959 to 1974 have been published by Computers and Automation and EDP Weekly. A total of 157 installations in the commercial banking industry were reported for this period, which composes only a small portion of actual installations.[11] Of the 157 observations, 357 represent intrafirm diffusion; i.e., these installations were either additional installations or replacements for existing computers. Eleven banks were deleted because of inadequate data on other independent variables. Therefore, the usable data base contains 113 reported installations. An extensive search was conducted for other data sources to augment the information obtained from these two journals. Unfortunately, no other such publications are available for public use. One business source indicates that such data were available at a fee charge, but it was learned that the data collected by this source are still incomplete.[12] As such, it seemed that the cost was not justified for this study. The basic statistics for the installation data appear in Appendix A.2.

There are many difficulties with the data on installation of computers and the related issue of the definition of the adoption.

First, the largest system supplier, IBM, is extremely cautious about providing information on installation of its computers lest it should be used as evidence in the antitrust suit brought by the Justice Department.[13] Many other system manufacturers also follow IBM's practice. Second, rather than one bank's purchasing (or renting) a computer by itself, many banks set up joint ventures with other banks or nonbank businesses. Data on this type of adoption also proved difficult to obtain. In addition, there are also banks that use the computer facilities of service bureaus or other businesses which sell surplus computer time. This method became very popular after the successful development of time-sharing techniques. While there might be a theoretical argument for including this type of adoption, information is only available in a survey conducted by the American Bankers Association, and the survey data are unavailable to the public.[14] Thus, although any bank that introduces automation into its banking operation could be considered an adopter, in practice we have to limit ourselves to the category in which adopters do actually install in-house computers, and even in this category data are not readily available.[15]

The data base covers the period 1959 to 1974, a time span of 25 years. Although the diffusion is still to be completed, this time span seems to cover a reasonable length of time to allow conclusions to be drawn from the empirical testing. As to the sample size, it has been estimated that by 1974 about 20 percent of the more than 14,000 commercial banks had installed in-house general purpose digital computers.[16] Therefore, the data on computer installations collected for this study cover only about 4 percent of the actual installation figures. Although the coverage rate is still relatively small, this study can provide some useful information about the diffusion of general purpose digital computers in the commercial banking industry. An examination of the data shows that most of the reported installations are by relatively small banks.[17] Thus, the sample appears to be biased in favor of small banks. This implies that the size and urban rank variables may not be accurately represented in the sample. To the extent that this is true, significant results for the size and urban rank variables will tend to validate the theoretical model on the effects of these two factors.

5.3.3. Data on Commercial and Federal Reserve Bank Financial Statistics

All the basic financial statistics of commercial banks are available in Moody's Bank and Financial Manual. Total deposits figures are found in the balance sheet for each bank. The growth rate was calculated according to the method discussed in Section 5.2.2. Owner's equity was defined as the sum of capital stock, surplus, and undivided profits (or undistributed dividends). Net operating earnings are found in the income statement of each bank if such a statement is published in the Manual. The profit rate was found by dividing net operating earnings by owner's equity. When the income statement of a bank was not available, an alternative profit rate measure was found by dividing dividends by the par value of common stock. Both dividends and the par value of common stock are available in the Manual. Banking structure was determined by the status of state banking regulations on branch banking at the end of 1974. The basic statistical properties of the data set are presented in Appendix A.3.

Reserve holdings of federal reserve banks are published in the Annual Report of Board of Governors. The Federal Reserve District territorial composition is contained in Description of Federal Reserve Districts published by the Federal Reserve System in September, 1977.

5.4. Empirical Estimation and Results

5.4.1. Generation of Urban Rank Values

Equation (4.25) is the basic equation in the empirical model. Before we estimate this equation, values of the urban rank variable H_{r_k} have to be constructed. The first step, therefore, is the generation of the factor score matrix which can be used in determining the value of the urban rank variable, H_{r_k}.

Preliminary screening of the data matrix $\underline{M}$ indicated that the population variable is lognormally distributed, which implies that a logarithmic transformation is required to normalize this variable.[18] By the same token, population density might also require a logarithmic transformation. In previous city classification studies other variables have been transformed by taking square root values or logarithmic values, but the reason for such transformations is not fully disclosed.[19] Rather than routinely following these studies, the normality of each of the variables is examined.[20] If the distribution is found to be skewed, then a transformation was introduced to decrease the degree of skewness.[21] The results of this examination are shown in Appendix A.4.

Principal Axis Factor Analysis was performed on the transformed data matrix. Only factors with eigenvalues greater than or equal to 1 were extracted.[22] Both promax oblique and varimax orthogonal rotations were performed to get the final path model, although there might be a theoretical preference for using oblique rotation.[23] The promax-rotated factor pattern is shown in Table 5.1 and the varimax-rotated factor pattern is shown in Table 5.2.

A comparison of these two tables indicates that factor pattern does not vary much with the rotation method. In both tables, factor 1 loads on the income characteristics: median income, mean income, per capita income, and median rent, and explains more than 38 percent of the variation. The second factor loads on employment and education characteristics, and accounts for 30 percent of the variation. The third factor loads on size characteristics and accounts for 16 percent of the variation. The last factor loads on age and population growth, which have been described as the "life cycle" or "age" of an urban place in other studies. Since both oblique and orthogonal rotation generate the same factor pattern, there seems to be no empirical preference for using one rotation method rather than the other. Because the oblique rotation places fewer theoretical restrictions on the relationship between observed variables, the factor scores generated from this method will be used.

The next question concerns the choice of the representative factor. As the relationship between income and demand is clearly indicated by economic theory, factor 1 is the best choice for our model. But the effect of population characteristics (i.e., population and

Table 5.1

Factor Pattern of Promax Oblique Rotation

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Transformations
Median income	0.96462	-0.18627	-0.14700	0.08694	None
Mean income	0.94444	-0.00889	-0.10953	-0.02191	None
Per capita income	0.73255	0.30277	0.14592	-0.29398	None
Median rent	0.80300	0.26938	0.21150	0.18298	None
Median school year	0.21002	0.76526	-0.13398	0.08796	None
Percent high school graduates	0.30844	0.77113	-0.08740	0.17243	None
Percent labor force in manufacturing	0.43945	-0.90650	-0.06525	0.01624	None
Percent labor force in white-collar jobs	0.32509	0.80244	0.01545	-0.09285	None
Median age	0.17336	-0.07315	0.10877	-0.76354	None
Population growth	0.32342	0.06903	0.12911	0.67531	None
Population	-0.06815	0.02904	0.58303	0.15433	Log
Population density	0.36814	-0.21191	0.76776	-0.09499	Log
Percent owner-occupied housing	0.39927	-0.11576	-0.66399	0.19075	None
Unemployment rate	-0.30799	-0.12085	0.43917	0.46804	None
Variance explained by each factor	4.586406	3.593031	1.977518	1.626049	
% of variance explained by each factor	38.93	30.50	16.78	13.80	

Table 5.2

Factor Pattern of Varimax Orthogonal Rotation

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Transformations
Median income	0.92378	-0.01974	-0.24607	0.08064	None
Mean income	0.93202	0.14888	-0.19752	-0.02678	None
Per capita income	0.76767	0.40862	0.10329	-0.31956	None
Median rent	0.80684	0.39551	0.09721	0.14008	None
Median school year	0.31598	0.79750	-0.18744	0.12524	None
Percent high school graduates	0.40717	0.81983	-0.16276	0.19989	None
Percent labor force in manufacturing	0.30665	-0.82234	-0.08297	-0.01144	None
Percent labor force in white-collar jobs	0.43505	0.84456	-0.02768	-0.07715	None
Median age	0.18972	-0.06397	0.19645	-0.77756	None
Population growth	0.28947	0.13201	0.00182	0.64396	None
Population	-0.09886	0.00288	0.56046	0.06901	Log
Population density	0.29785	-0.17514	0.74109	-0.22192	Log
Percent owner-occupied housing	0.39973	-0.02437	-0.71726	0.27438	None
Unemployment rate	-0.36259	-0.17341	0.40368	0.40143	None
Variance explained by each factor	4.020827	3.126472	1.768313	1.500410	
% of variance explained by each factor	38.60	30.03	16.97	14.40	

population density) on the formation of spatial demand is also clearly indicated by economic theory. Therefore, the scores on this factor are also useful in describing an urban hierarchy. Two possible models can be derived from this discussion: one with the scores of factor 1 for each adopter, and the other with the scores of both factors 1 and 3 for each adopter. Both models will be estimated. In addition, a third model using scores of factor 3 will also be included in empirical estimations.

5.4.2. Testing the Theoretical Model

The first step in estimating the model is to determine the appropriate functional form for equation (4.25). In previous studies the most commonly used estimation equation is a log linear function which was first used by Mansfield.[24] The basis for this functional form is not strong as Mansfield did not provide a theoretical argument for the second derivative properties of the general profitability, profit trend, education level, and growth rate variables.[25] Other interfirm diffusion studies do not fare any better in this regard. For example, the choice of functional form in Davies' study is based on a comparison of the goodness of fit rather than on theoretical considerations.[26] In this study, the method suggested by Box and Cox is used to choose a functional form.[27] This method standardizes the dependent variable by its geometric mean, and then regresses this transformed dependent variable on independent variables of various functional forms. The residual sums of squares are compared and the regression function which yields the minimum residual sum of squares is adopted as the appropriate functional form.[28] Given this criterion, the simple linear OLS regression function was chosen. We therefore propose to estimate:

$$Y_k = \alpha_o + \alpha_1 S_k + \alpha_2 g_k + \alpha_3 \pi_k' + \alpha_4 \pi_k^t + \alpha_5 B_k + \alpha_6 H_{r_k} + \alpha_7 N_k + \varepsilon_k \qquad (5.2)$$

where Y_k is the length of time bank k waits before it installs a general purpose digital computer, measured in months; S_k the size of the bank, measured in real total deposits; g_k the real growth rate; π_k' the (general) profit rate; π_k^t the profit trend; B_k a dummy indicating the status of state regulations on branch banking at the end of 1974; H_{r_k} the urban hierarchy rank of the bank's location; and N_k the (economics) neighborhood to which the bank belongs.

In equation (5.2) π_k' is measured in two different ways: as net operating earnings divided by owners' equity and as dividends divided by the par value of common stock. Therefore a dummy was inserted to detect any differences between these two measures. In addition, the neighborhood effect is proxied by 14 dummies, as previously discussed. The estimating equation thus becomes:

$$Y_k = \alpha_o + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \beta_8 D_8 + \beta_9 D_9 + \beta_{10} D_{10} + \beta_{11} D_{11} + \beta_{12} D_{12} + \beta_{13} D_{13} + \beta_{14} D_{14} + \alpha_1 S_k + \alpha_2 g_k + \alpha_3 \pi_k' + \alpha_3' (\pi_k' \cdot D) + \alpha_4 \pi_k^t + \alpha_5 B_k + \alpha_6 H_{r_k} + \varepsilon_k . \qquad (5.3)$$

The estimation result is presented in Table 5.3 for three different versions of equation (5.3). The first version used (factor) scores of factor 1 generated in Table 5.2 as the value of the urban hierarchy value. Finally the last version used scores of both factors to proxy the urban hierarchy factor.

Table 5.3

Estimation of Interfirm Differences in Speed of Response to Innovation

	Intercept	Size S	Growth Rate g	Average Profit π'	Average Profit Dummy	Profit Trend π_t	Banking Structure B	Urban Hierarchy Factor 1	Urban Hierarchy Factor 3
Equation (5.3)									
Version 1	158.63	-2.20×10^{-6}	1.43×10^{-3}	1.48*	27.61**	32.15	0.74	-1.61	
		(2.50×10^{-6})	(5.31×10^{-2})	(0.77)	(8.03)	(29.99)	(9.76)	(5.89)	
Version 2	158.52	-1.88×10^{-6}	-6.13×10^{-3}	1.49**	22.23**	20.73	-4.37		-10.03**
		(2.42×10^{-6})	(5.14×10^{-2})	(0.73)	(8.03)	(29.32)	(9.54)		(3.95)
Version 3	158.54	-1.76×10^{-6}	-7.19×10^{-3}	1.40*	22.27**	19.49	-5.47	-3.29	-10.28**
		(2.43×10^{-6})	(5.16×10^{-2})	(0.75)	(8.06)	(29.51)	(9.78)	(5.75)	(3.99)
Equation (5.4)									
Version 1	71.02	-6.84×10^{-6}**	-2.37×10^{-2}	0.91	31.72**	32.06	-6.87	-1.14	
		(2.01×10^{-6})	(5.36×10^{-2})	(0.78)	(7.98)	(30.57)	(7.43)	(5.16)	
Version 2	81.94	-3.25×10^{-6}	-2.84×10^{-2}	1.05	19.52**	16.35	-7.52		-12.49**
		(2.08×10^{-6})	(4.99×10^{-2})	(0.71)	(8.01)	(28.79)	(6.92)		(3.14)
Version 3	81.97	-3.05×10^{-6}	-3.06×10^{-2}	0.96	19.66**	15.98	-7.89	-3.51	-12.77**
		(2.10×10^{-6})	(5.02×10^{-2})	(0.73)	(8.04)	(28.86)	(6.95)	(4.86)	(3.18)
Equation (5.5)	158.62	-2.26×10^{-6}	1.85×10^{-3}	1.52**	27.53**	32.61	1.21		
		(2.48×10^{-6})	(5.28×10^{-2})	(0.75)	(7.98)	(29.79)	(9.56)		

Notes: 1. Numerical values in parentheses are standard errors of regression coefficients.
2. ** indicates significance at the 5% level; * indicates significance at the 10% level by the 2-tailed t test.
3. All F values are significant at the 5% level.

Table 5.3 (continued)

	Federal Reserve District Dummies										
	1 (New York)	2 (Phila-delphia)	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minne-apolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
Equation (5.3)											
Version 1	-102.31*	-60.52	-53.07	-42.24	-45.24	-85.53	28.74	-29.33	-59.75	-27.69	-110.83**
	(59.49)	(40.46)	(38.07)	(38.65)	(37.10)	(54.83)	(18.68)	(38.65)	(38.49)	(38.11)	(55.04)
Version 2	-80.44	-60.57	-54.72	-44.20	-43.79	-82.01	17.23	-44.99	-67.42*	-35.31	-93.99*
	(58.16)	(39.12)	(36.79)	(37.36)	(35.76)	(52.91)	(18.29)	(37.58)	(37.33)	(36.95)	(53.63)
Version 3	-78.68	-60.33	-54.17	-44.93	-45.42	-79.85	14.56	-48.59	-68.30*	-36.38	-92.90*
	(58.45)	(39.27)	(36.94)	(37.52)	(36.00)	(53.24)	(18.94)	(38.24)	(37.49)	(37.14)	(53.86)
Equation (5.4)											
Version 1											
Version 2											
Version 3											
Equation (5.5)	-102.89*	-60.63	-53.36	-41.91	-44.43	-86.53	29.89	-27.78	-59.42	-27.26	-111.15**
	(59.16)	(40.26)	(37.86)	(38.43)	(36.79)	(54.43)	(18.11)	(38.04)	(38.28)	(37.89)	(54.75)

Table 5.3 (continued)

	Federal Reserve Bank Size Dummies					
	1 ($1-3 billion)	2 (Less than $1 billion)	Early Adapter Dummy	F	R^2	$\bar{R}^2$
Equation (5.3)						
Version 1	-47.76	-119.06**	-42.20**	3.998	0.479	0.359
	(39.99)	(55.42)	(19.11)			
Version 2	-34.87	-103.05*	-19.66	4.581	0.514	0.402
	(38.99)	(53.94)	(20.45)			
Version 3	-34.49	-101.38*	-19.48	4.355	0.516	0.397
	(39.14)	(54.21)	(20.52)			
Equation (5.4)						
Version 1				7.112	0.321	0.276
Version 2				10.423	0.410	0.371
Version 3				9.144	0.413	0.368
Equation (5.5)	-47.78	-119.67**	-42.01	4.237	0.479	0.366
	(39.79)	(55.09)	(18.99)			

In addition to the basic estimation equation of (5.3), two more equations were also estimated. One equation excluded the neighborhood effect and the other excluded the urban hierarchy effect. Thus, these two estimating equations are written as follows:

$$Y_k = \alpha_o + \alpha_1 S_k + \alpha_2 g_k + \alpha_3 \pi_k' + \alpha_3'(\pi_k' \cdot D) + \alpha_4 \pi_k^t + \alpha_5 B_k + \alpha_6 H_{r_k} + \varepsilon_k \qquad (5.4)$$

$$Y_k = \alpha_o + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \beta_8 D_8 + \beta_9 D_9 + \beta_{10} D_{10} + \beta_{11} D_{11} + \beta_{12} D_{12} + \beta_{13} D_{13} + \beta_{14} D_{14} + \alpha_1 S_k + \alpha_2 G_k + \alpha_3 \pi_k' + \alpha_3'(\pi_k' \cdot D) + \alpha_4 \pi_k^t + \alpha_5 B_k + \varepsilon_k. \qquad (5.5)$$

Results of these estimates are also presented in Table 5.3. Comparison estimates by previous studies are summarized in Table 5.4.

Detection of multicolinearity was performed using the method suggested by Belsey et al.[29] The $\underline{X}'\underline{X}$ matrix is scaled so that all of the ones are on the diagonal. Eigenvalues and eigenvectors are extracted. Condition indexes, which are the square roots of the ratio of the largest eigenvalue to each individual eigenvalue, for the singular values are calculated. The proportion of variance in the regression coefficient of each independent variable that is associated with a singular value is also calculated. Multicolinearity may exist when more than 50% of the variance of two or more coefficients is associated with a singular value which has a condition index of 15 or higher.[30] Tables 5.5 to 5.7 show the decomposition of variance of regression coefficients for the three different versions of

Table 5.4

Summary of Empirical Estimation Results of Previous Studies

	Size	Growth Rate	Average Profit	Profit Trend	R^2	$\bar{R}^2$
Mansfield's study	$-^{**}$	$-$	+	+		
Romeo's study	$-^{**}$					0.315
Globerman's study	$-^{**}$					0.265
Hakanson's study†	$-^{‡}$				0.189~0.601§	
Smith's study†	$-^{§§}$				0.179~0.456§	

Notes: 1. Signs indicate the sign of the regression coefficient.
2. ** indicates significance at the 5% level by the 2-tailed t test.

† From Nabseth and Ray (1974).

‡ Significant at the 5% level when run with profitability from adoption variable, insignificant in other estimations.

§ R^2 varies for different countries.

§§ Most are significant at the 10% level. Some are significant at the 5% level.

Table 5.5

Variance-Decomposition Proportions and Condition Indexes, Version 1 of Equation (5.3)

Associated Singular Value	Eigenvalue	Condition Index	Proportion of Variation Associated with Each Singular Value							
			Intercept	Size S	Growth Rate g	Average Profit π'	Average Profit Dummy	Profit Trend π^t	Banking Structure B	Urban Hierarchy Factor 1
μ_1	5.590000	1.000	0.0001	0.0012	0.0071	0.0033	0.0054	0.0018	0.0037	0.0057
μ_2	2.175000	1.603	0.0000	0.0568	0.0025	0.0000	0.0036	0.0016	0.0015	0.0029
μ_3	1.726000	1.800	0.0000	0.0073	0.0056	0.0004	0.0007	0.0033	0.0002	0.0001
μ_4	1.498000	1.931	0.0000	0.0011	0.0009	0.0006	0.0061	0.0301	0.0018	0.0664
μ_5	1.204000	2.155	0.0000	0.0032	0.0031	0.0008	0.0073	0.0982	0.0112	0.0045
μ_6	1.135000	2.220	0.0000	0.0006	0.0114	0.0005	0.0000	0.0908	0.0049	0.0067
μ_7	1.080000	2.275	0.0000	0.0078	0.0596	0.0001	0.0007	0.0071	0.0001	0.0011
μ_8	1.033000	2.326	0.0000	0.0088	0.0062	0.0004	0.0015	0.0087	0.0003	0.0000
μ_9	1.009000	2.353	0.0000	0.0000	0.0006	0.0000	0.0000	0.0053	0.0004	0.0025
μ_{10}	1.004000	2.360	0.0000	0.0001	0.0003	0.0003	0.0003	0.0001	0.0000	0.0001
μ_{11}	1.001000	2.363	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
μ_{12}	0.795556	2.651	0.0000	0.0035	0.0077	0.0019	0.0006	0.6036	0.0042	0.0038
μ_{13}	0.666500	2.896	0.0000	0.0307	0.4457	0.0007	0.0003	0.0186	0.0081	0.0051
μ_{14}	0.571972	3.126	0.0000	0.1802	0.1571	0.0014	0.0027	0.0129	0.0051	0.0912
μ_{15}	0.409681	3.694	0.0001	0.0075	0.1290	0.0005	0.0136	0.0068	0.0070	0.6339
μ_{16}	0.387494	3.798	0.0000	0.0005	0.1172	0.0014	0.0236	0.0046	0.1511	0.0556
μ_{17}	0.272019	4.533	0.0001	0.6565	0.0168	0.0008	0.0782	0.0002	0.0017	0.0267
μ_{18}	0.225455	4.979	0.0005	0.0141	0.0119	0.0022	0.5890	0.0011	0.0966	0.0299
μ_{19}	0.130812	6.537	0.0002	0.0107	0.0011	0.4339	0.2387	0.0121	0.3824	0.0020
μ_{20}	0.066978	9.135	0.0104	0.0005	0.0147	0.5507	0.0144	0.0725	0.3980	0.0607
μ_{21}	0.016995	18.136	0.0004	0.0049	0.0002	0.0001	0.0006	0.0129	0.0150	0.0008
μ_{22}	0.002082	51.815	0.9882	0.0039	0.0012	0.0001	0.0127	0.0080	0.0067	0.0002

Table 5.5 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value										
	Federal Reserve District Dummies										
	1 (New York)	2 (Phila-delphia	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minne-apolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
μ_1	0.0001	0.0002	0.0003	0.0004	0.0003	0.0001	0.0011	0.0002	0.0003	0.0002	0.0001
μ_2	0.0070	0.0011	0.0004	0.0004	0.0007	0.0000	0.0010	0.0000	0.0011	0.0009	0.0006
μ_3	0.0010	0.0021	0.0014	0.0011	0.0011	0.0001	0.0818	0.0221	0.0003	0.0008	0.0000
μ_4	0.0001	0.0017	0.0007	0.0006	0.0023	0.0039	0.0149	0.0079	0.0003	0.0006	0.0003
μ_5	0.0018	0.0031	0.0132	0.0118	0.0000	0.0003	0.0069	0.0248	0.0148	0.0076	0.0002
μ_6	0.0038	0.0017	0.0032	0.0011	0.0024	0.0000	0.0198	0.0644	0.0041	0.0006	0.0141
μ_7	0.0009	0.0337	0.0003	0.0058	0.0004	0.0006	0.0008	0.0889	0.0162	0.0069	0.0030
μ_8	0.0035	0.0496	0.0214	0.0104	0.0007	0.0003	0.0010	0.0091	0.0070	0.0104	0.0002
μ_9	0.0008	0.0054	0.0274	0.0043	0.0116	0.0006	0.0112	0.1589	0.0125	0.0037	0.0006
μ_{10}	0.0003	0.0000	0.0010	0.0306	0.0266	0.0001	0.0001	0.0001	0.0008	0.0264	0.0007
μ_{11}	0.0076	0.0114	0.0001	0.0371	0.0002	0.0002	0.0191	0.2126	0.0003	0.0048	0.0068
μ_{12}	0.0005	0.0013	0.0137	0.0030	0.0006	0.0001	0.0073	0.1435	0.0005	0.0011	0.0019
μ_{13}	0.0115	0.0059	0.0004	0.0034	0.0000	0.0009	0.0858	0.0011	0.0109	0.0012	0.0000
μ_{14}	0.0509	0.0015	0.0012	0.0039	0.0032	0.0000	0.0041	0.0026	0.0017	0.0003	0.0014
μ_{15}	0.0039	0.0016	0.0035	0.0053	0.0064	0.0046	0.0000	0.0012	0.0027	0.0001	0.0006
μ_{16}	0.0083	0.0145	0.0026	0.0067	0.0012	0.0000	0.3587	0.0719	0.0046	0.0008	0.0051
μ_{17}	0.0017	0.0233	0.0013	0.0006	0.0016	0.0001	0.0002	0.0105	0.0003	0.0005	0.0054
μ_{18}	0.0025	0.0002	0.0003	0.0025	0.0012	0.0023	0.1362	0.0726	0.0104	0.0084	0.0004
μ_{19}	0.0050	0.0080	0.0105	0.0002	0.0008	0.0000	0.0862	0.0257	0.0060	0.0028	0.0009
μ_{20}	0.0344	0.0297	0.0243	0.0375	0.0012	0.0112	0.1609	0.0810	0.0015	0.0003	0.0214
μ_{21}	0.0004	0.2506	0.4950	0.4777	0.5368	0.0001	0.0017	0.0007	0.5162	0.5255	0.0000
μ_{22}	0.8544	0.5534	0.3777	0.3557	0.4008	0.9745	0.0010	0.0000	0.3876	0.3961	0.9362

Table 5.5 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value: Federal Reserve Bank Size Dummies 1 ($1-3 billion)	2 (Less than $1 billion)	Early Adapter Dummy
μ_1	0.0003	0.0001	0.0011
μ_2	0.0004	0.0001	0.0484
μ_3	0.0009	0.0042	0.0023
μ_4	0.0005	0.0003	0.0042
μ_5	0.0000	0.0001	0.0011
μ_6	0.0001	0.0001	0.0119
μ_7	0.0001	0.0000	0.0033
μ_8	0.0000	0.0000	0.0012
μ_9	0.0000	0.0000	0.0000
μ_{10}	0.0000	0.0000	0.0001
μ_{11}	0.0000	0.0000	0.0000
μ_{12}	0.0001	0.0000	0.0002
μ_{13}	0.0003	0.0005	0.0116
μ_{14}	0.0004	0.0004	0.0247
μ_{15}	0.0010	0.0035	0.0112
μ_{16}	0.0002	0.0118	0.0045
μ_{17}	0.0005	0.0001	0.5365
μ_{18}	0.0014	0.0011	0.1593
μ_{19}	0.0000	0.0024	0.0885
μ_{20}	0.0022	0.0384	0.0411
μ_{21}	0.4199	0.0000	0.0169
μ_{22}	0.5716	0.9368	0.0318

Table 5.6

Variance-Decomposition Proportions and Condition Indexes, Version 2 of Equation (5.3)

			Proportion of Variation Associated with Each Singular Value							
Associated Singular Value	Eigenvalue	Condition Index	Intercept	Size S	Growth Rate g	Average Profit π'	Average Profit Dummy	Profit Trend π^t	Banking Structure B	Urban Hierarchy Factor 3
μ_1	5.389000	1.000	0.0001	0.0020	0.0074	0.0037	0.0052	0.0018	0.0040	0.0015
μ_2	2.658000	1.424	0.0000	0.0343	0.0042	0.0002	0.0051	0.0032	0.0002	0.0281
μ_3	1.740000	1.760	0.0000	0.0015	0.0039	0.0004	0.0002	0.0033	0.0000	0.0010
μ_4	1.334000	2.010	0.0000	0.0007	0.0016	0.0001	0.0004	0.0508	0.0068	0.0049
μ_5	1.187000	2.130	0.0000	0.0042	0.0005	0.0012	0.0074	0.0987	0.0049	0.0001
μ_6	1.113000	2.200	0.0000	0.0006	0.0200	0.0002	0.0002	0.0817	0.0068	0.0015
μ_7	1.076000	2.238	0.0000	0.0058	0.0512	0.0001	0.0009	0.0005	0.0001	0.0006
μ_8	1.034000	2.283	0.0000	0.0058	0.0063	0.0005	0.0018	0.0123	0.0005	0.0003
μ_9	1.012000	2.307	0.0000	0.0034	0.0005	0.0001	0.0000	0.0003	0.0000	0.0029
μ_{10}	1.004000	2.316	0.0000	0.0000	0.0003	0.0002	0.0004	0.0007	0.0002	0.0000
μ_{11}	1.000000	2.321	0.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{12}	0.792042	2.608	0.0000	0.0056	0.0123	0.0021	0.0007	0.5612	0.0036	0.0001
μ_{13}	0.664318	2.848	0.0000	0.0433	0.4135	0.0006	0.0002	0.0184	0.0083	0.0001
μ_{14}	0.548569	3.134	0.0000	0.1242	0.2256	0.0016	0.0061	0.0139	0.0067	0.0098
μ_{15}	0.447059	3.472	0.0000	0.2456	0.0774	0.0021	0.0074	0.0294	0.0026	0.2307
μ_{16}	0.359613	3.871	0.0000	0.2489	0.1356	0.0001	0.0000	0.0000	0.0739	0.1153
μ_{17}	0.233841	4.800	0.0003	0.0146	0.0199	0.0010	0.6249	0.0033	0.1097	0.0323
μ_{18}	0.199230	5.201	0.0001	0.2483	0.0000	0.0009	0.0172	0.0066	0.0109	0.3271
μ_{19}	0.122654	6.628	0.0000	0.0018	0.0006	0.5876	0.2397	0.0090	0.2698	0.1003
μ_{20}	0.064275	9.156	0.0117	0.0000	0.0181	0.3973	0.0674	0.0883	0.4613	0.1233
μ_{21}	0.016721	17.952	0.0007	0.0053	0.0000	0.0001	0.0003	0.0080	0.0240	0.0187
μ_{22}	0.002079	50.908	0.9869	0.0041	0.0011	0.0000	0.0143	0.0088	0.0055	0.0015

Table 5.6 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value — Federal Reserve District Dummies: 1 (New York)	2 (Phila-delphia	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minne-apolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
μ_1	0.0002	0.0003	0.0003	0.0003	0.0003	0.0001	0.0011	0.0002	0.0003	0.0002	0.0001
μ_2	0.0042	0.0007	0.0004	0.0003	0.0001	0.0001	0.0000	0.0002	0.0007	0.0005	0.0003
μ_3	0.0002	0.0014	0.0016	0.0012	0.0015	0.0001	0.0799	0.0213	0.0006	0.0011	0.0000
μ_4	0.0000	0.0010	0.0008	0.0001	0.0029	0.0035	0.0162	0.0132	0.0047	0.0042	0.0022
μ_5	0.0008	0.0076	0.0167	0.0093	0.0000	0.0011	0.0217	0.0292	0.0080	0.0035	0.0009
μ_6	0.0076	0.0005	0.0000	0.0016	0.0047	0.0004	0.0069	0.0877	0.0100	0.0003	0.0094
μ_7	0.0000	0.0322	0.0000	0.0067	0.0000	0.0013	0.0007	0.0565	0.0121	0.0079	0.0055
μ_8	0.0032	0.0494	0.0181	0.0146	0.0021	0.0001	0.0017	0.0017	0.0082	0.0096	0.0000
μ_9	0.0005	0.0003	0.0063	0.0173	0.0313	0.0004	0.0080	0.1437	0.0008	0.0061	0.0001
μ_{10}	0.0004	0.0008	0.0190	0.0170	0.0006	0.0000	0.0150	0.1602	0.0089	0.0256	0.0008
μ_{11}	0.0071	0.0159	0.0052	0.0406	0.0061	0.0002	0.0063	0.0713	0.0032	0.0035	0.0064
μ_{12}	0.0006	0.0015	0.0148	0.0018	0.0017	0.0004	0.0058	0.1423	0.0003	0.0011	0.0021
μ_{13}	0.0141	0.0057	0.0002	0.0049	0.0003	0.0006	0.0879	0.0021	0.0103	0.0010	0.0000
μ_{14}	0.0581	0.0044	0.0032	0.0004	0.0000	0.0010	0.0291	0.0003	0.0024	0.0003	0.0031
μ_{15}	0.0054	0.0148	0.0002	0.0002	0.0019	0.0001	0.1387	0.0117	0.0046	0.0005	0.0005
μ_{16}	0.0002	0.0000	0.0063	0.0038	0.0001	0.0012	0.1613	0.0653	0.0025	0.0003	0.0052
μ_{17}	0.0005	0.0080	0.0002	0.0049	0.0013	0.0024	0.0727	0.0612	0.0093	0.0085	0.0000
μ_{18}	0.0025	0.0203	0.0002	0.0000	0.0017	0.0012	0.0346	0.0045	0.0002	0.0000	0.0027
μ_{19}	0.0029	0.0019	0.0076	0.0002	0.0019	0.0007	0.1018	0.0275	0.0070	0.0025	0.0009
μ_{20}	0.0456	0.0322	0.0308	0.0460	0.0080	0.0075	0.2043	0.0974	0.0015	0.0001	0.0302
μ_{21}	0.0013	0.2491	0.4924	0.4745	0.5297	0.0002	0.0059	0.0026	0.5238	0.5338	0.0001
μ_{22}	0.8446	0.5522	0.3758	0.3543	0.4039	0.9774	0.0005	0.0000	0.3807	0.3893	0.9294

Table 5.6 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value: Federal Reserve Bank Size Dummies 1 ($1-3 billion)	Federal Reserve Bank Size Dummies 2 (Less than $1 billion)	Early Adapter Dummy
μ_1	0.0002	0.0001	0.0015
μ_2	0.0002	0.0000	0.0263
μ_3	0.0011	0.0041	0.0001
μ_4	0.0012	0.0005	0.0010
μ_5	0.0001	0.0005	0.0001
μ_6	0.0000	0.0000	0.0090
μ_7	0.0000	0.0000	0.0059
μ_8	0.0000	0.0000	0.0011
μ_9	0.0000	0.0000	0.0001
μ_{10}	0.0000	0.0000	0.0001
μ_{11}	0.0000	0.0000	0.0000
μ_{12}	0.0000	0.0001	0.0002
μ_{13}	0.0004	0.0004	0.0111
μ_{14}	0.0000	0.0002	0.0215
μ_{15}	0.0000	0.0047	0.0010
μ_{16}	0.0001	0.0093	0.0201
μ_{17}	0.0010	0.0012	0.0001
μ_{18}	0.0000	0.0001	0.8768
μ_{19}	0.0003	0.0012	0.0003
μ_{20}	0.0025	0.0460	0.0000
μ_{21}	0.4236	0.0002	0.0031
μ_{22}	0.5693	0.9314	0.0208

Table 5.7

Variance-Decomposition Proportions and Condition Indexes, Version 3 of Equation (5.3)

Associated Singular Value	Eigenvalue	Condition Index	Proportion of Variation Associated with Each Singular Value								
			Intercept	Size S	Growth Rate g	Average Profit π'	Average Profit Dummy	Profit Trend π_t	Banking Structure B	Urban Hierarchy Factor 1	Urban Hierarchy Factor 3
μ_1	5.688000	1.000	0.0001	0.0016	0.0065	0.0031	0.0046	0.0015	0.0034	0.0054	0.0013
μ_2	2.668000	1.460	0.0000	0.0348	0.0036	0.0001	0.0045	0.0027	0.0003	0.0009	0.0275
μ_3	1.744000	1.806	0.0000	0.0013	0.0045	0.0005	0.0005	0.0018	0.0000	0.0017	0.0014
μ_4	1.540000	1.922	0.0000	0.0016	0.0001	0.0005	0.0034	0.0287	0.0027	0.0627	0.0039
μ_5	1.204000	2.174	0.0000	0.0028	0.0032	0.0008	0.0070	0.0953	0.0105	0.0047	0.0000
μ_6	1.136000	2.238	0.0000	0.0002	0.0102	0.0005	0.0000	0.0829	0.0045	0.0056	0.0003
μ_7	1.080000	2.295	0.0000	0.0066	0.0604	0.0001	0.0005	0.0082	0.0001	0.0008	0.0001
μ_8	1.034000	2.345	0.0000	0.0059	0.0058	0.0005	0.0017	0.0103	0.0004	0.0001	0.0004
μ_9	1.014000	2.369	0.0000	0.0028	0.0000	0.0000	0.0001	0.0028	0.0002	0.0007	0.0020
μ_{10}	1.007000	2.377	0.0000	0.0005	0.0011	0.0002	0.0002	0.0025	0.0003	0.0009	0.0003
μ_{11}	1.002000	2.383	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000
μ_{12}	0.796224	2.673	0.0000	0.0051	0.0068	0.0019	0.0006	0.5798	0.0037	0.0045	0.0004
μ_{13}	0.666872	2.920	0.0000	0.0338	0.4500	0.0007	0.0003	0.0162	0.0071	0.0060	0.0005
μ_{14}	0.577718	3.138	0.0000	0.1164	0.1369	0.0011	0.0028	0.0055	0.0060	0.0938	0.0119
μ_{15}	0.447108	3.567	0.0000	0.2386	0.0704	0.0020	0.0082	0.0282	0.0023	0.0007	0.2285
μ_{16}	0.409487	3.727	0.0001	0.0033	0.1059	0.0003	0.0163	0.0047	0.0044	0.6475	0.0008
μ_{17}	0.356465	3.995	0.0000	0.2648	0.0967	0.0000	0.0022	0.0002	0.0706	0.0496	0.1182
μ_{18}	0.229030	4.983	0.0005	0.0228	0.0168	0.0018	0.6079	0.0034	0.1034	0.0399	0.0277
μ_{19}	0.199227	5.343	0.0001	0.2455	0.0000	0.0008	0.0179	0.0065	0.0103	0.0000	0.3226
μ_{20}	0.122303	6.820	0.0000	0.0012	0.0007	0.5507	0.2519	0.0082	0.2641	0.0036	0.1013
μ_{21}	0.060522	9.694	0.0118	0.0003	0.0192	0.4338	0.0549	0.0946	0.4741	0.0680	0.1291
μ_{22}	0.016686	18.463	0.0008	0.0059	0.0000	0.0004	0.0003	0.0071	0.0268	0.0022	0.0202
μ_{23}	0.002079	52.310	0.9866	0.0043	0.0010	0.0001	0.0142	0.0090	0.0048	0.0003	0.0016

Table 5.7 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value — Federal Reserve District Dummies: 1 (New York)	2 (Phila-delphia)	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minne-apolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
μ_1	0.0002	0.0003	0.0003	0.0003	0.0003	0.0000	0.0010	0.0002	0.0003	0.0002	0.0001
μ_2	0.0042	0.0007	0.0003	0.0003	0.0002	0.0000	0.0000	0.0002	0.0006	0.0004	0.0003
μ_3	0.0002	0.0015	0.0014	0.0013	0.0019	0.0002	0.0690	0.0185	0.0006	0.0012	0.0000
μ_4	0.0002	0.0004	0.0007	0.0004	0.0025	0.0034	0.0203	0.0098	0.0004	0.0006	0.0005
μ_5	0.0016	0.0033	0.0132	0.0119	0.0000	0.0003	0.0065	0.0236	0.0146	0.0074	0.0001
μ_6	0.0042	0.0024	0.0030	0.0009	0.0027	0.0000	0.0180	0.0553	0.0041	0.0007	0.0138
μ_7	0.0008	0.0350	0.0003	0.0051	0.0003	0.0005	0.0009	0.0918	0.0159	0.0068	0.0028
μ_8	0.0028	0.0493	0.0197	0.0144	0.0020	0.0002	0.0015	0.0026	0.0076	0.0091	0.0001
μ_9	0.0000	0.0001	0.0139	0.0067	0.0282	0.0007	0.0087	0.1678	0.0034	0.0016	0.0006
μ_{10}	0.0008	0.0054	0.0162	0.0426	0.0026	0.0001	0.0025	0.0258	0.0094	0.0224	0.0001
μ_{11}	0.0082	0.0114	0.0001	0.0188	0.0044	0.0003	0.0153	0.1717	0.0002	0.0118	0.0075
μ_{12}	0.0003	0.0015	0.0140	0.0033	0.0008	0.0001	0.0058	0.1351	0.0004	0.0010	0.0020
μ_{13}	0.0098	0.0055	0.0003	0.0031	0.0000	0.0009	0.0820	0.0008	0.0106	0.0013	0.0000
μ_{14}	0.0575	0.0030	0.0014	0.0044	0.0021	0.0000	0.0080	0.0030	0.0010	0.0004	0.0016
μ_{15}	0.0059	0.0154	0.0002	0.0003	0.0022	0.0001	0.1337	0.0115	0.0044	0.0005	0.0006
μ_{16}	0.0051	0.0029	0.0032	0.0061	0.0071	0.0047	0.0029	0.0002	0.0020	0.0000	0.0009
μ_{17}	0.0008	0.0004	0.0049	0.0074	0.0002	0.0004	0.1667	0.0641	0.0019	0.0003	0.0066
μ_{18}	0.0009	0.0064	0.0002	0.0023	0.0029	0.0017	0.0865	0.0680	0.0104	0.0091	0.0000
μ_{19}	0.0025	0.0203	0.0002	0.0000	0.0016	0.0012	0.0331	0.0045	0.0002	0.0000	0.0027
μ_{20}	0.0034	0.0022	0.0078	0.0001	0.0025	0.0007	0.0921	0.0256	0.0066	0.0023	0.0012
μ_{21}	0.0454	0.0325	0.0338	0.0425	0.0052	0.0096	0.2375	0.1163	0.0013	0.0002	0.0293
μ_{22}	0.0014	0.2480	0.4891	0.4747	0.5311	0.0001	0.0077	0.0035	0.5252	0.5356	0.0002
μ_{23}	0.8437	0.5522	0.3759	0.3530	0.3994	0.9746	0.0003	0.0000	0.3789	0.3870	0.9292

Table 5.7 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value: Federal Reserve Bank Size Dummies: 1 ($1-3 billion)	2 (Less than $1 billion)	Early Adapter Dummy
μ_1	0.0002	0.0001	0.0012
μ_2	0.0002	0.0000	0.0266
μ_3	0.0012	0.0039	0.0001
μ_4	0.0004	0.0006	0.0000
μ_5	0.0000	0.0001	0.0007
μ_6	0.0001	0.0001	0.0117
μ_7	0.0001	0.0000	0.0030
μ_8	0.0000	0.0000	0.0013
μ_9	0.0000	0.0000	0.0000
μ_{10}	0.0000	0.0000	0.0000
μ_{11}	0.0000	0.0000	0.0000
μ_{12}	0.0001	0.0000	0.0004
μ_{13}	0.0003	0.0005	0.0098
μ_{14}	0.0004	0.0007	0.0167
μ_{15}	0.0000	0.0046	0.0013
μ_{16}	0.0011	0.0024	0.0110
μ_{17}	0.0003	0.0074	0.0152
μ_{18}	0.0017	0.0009	0.0000
μ_{19}	0.0000	0.0001	0.8768
μ_{20}	0.0002	0.0014	0.0003
μ_{21}	0.0015	0.0467	0.0001
μ_{22}	0.4229	0.0003	0.0030
μ_{23}	0.5695	0.9302	0.0207

equation (5.3). In all three tables two condition indexes exceed 15. One is associated with dummies indicating New York, Philadelphia, Chicago, San Francisco FRDs and the dummies representing FR bank size. The other is associated with Atlanta, Kansas City, Dallas, and to a lesser extent Cleveland and Richmond FRDs. (The latter two have variances closer to 50%.) To detect if colinearity exists, four auxiliary regressions were run on these two groups of variables. The dependent variables were chosen on the ground of maximum involvement in the near dependency found in each group.[31] Thus one pair of auxiliary regressions have dummies representing Chicago FRD and Dallas FRD as the dependent variables, while another pair of regressions have Chicago FRD and Atlanta FRD as the dependent variables. Results of the auxiliary regressions are summarized in Table 5.8.

From Table 5.8 we find that strong near dependency exists in the first regression of each pair in which the dummy representing Chicago FRD is the dependent variable. There is a close to one-to-one relationship between New York FRD, Chicago FRD, and San Francisco FRD in the first auxiliary regression. This might be interpreted as an "urban hierarchy" effect since these FRDs are not geographically linked and all three FRDs had similar economic characteristics. All three Federal Reserve Banks are in the same size category. The Federal Reserve Bank size measures appear to be redundant. Therefore an alternative estimation of equation (5.2) in which the last three dummies of equation (5.3) were excluded was conducted and the results are summarized in Table 5.9. The variance-decomposition indicates one border-line situation of colinearity, as shown in Tables 5.10 to

Table 5.8

Auxiliary Regressions for Equation (5.3)

	Coefficients of Dummies Representing Federal Reserve Districts of								Federal Reserve Bank Size		
	New York	Phila-delphia	Cleveland	Richmond	Atlanta	Denver	Dallas	San Francisco	Average Real Reserve between \$1 and \$3 billion	Average Real Reserve less than \$1 billion	R^2
Chicago FRD	-0.974^{**}	-0.248^{**}	-0.066^{*}	-0.066	-0.066^{*}	-0.066^{*}		-0.974^{**}	-0.908^{**}	-0.974^{**}	0.9625
	(0.045)	(0.043)	(0.038)	(0.042)	(0.033)	(0.037)		(0.031)	(0.028)	(0.025)	
Dallas FRD	-0.024	-0.684^{**}	-0.849^{**}	-0.849^{**}	-0.849^{**}	-0.849^{**}		-0.024	0.825^{**}	-0.024	0.8199
	(0.065)	(0.061)	(0.055)	(0.061)	(0.049)	(0.054)		(0.044)	(0.041)	(0.036)	
Chicago FRD	-0.973	-0.237^{**}	-0.053^{**}	-0.053		-0.053	-0.053	-0.974^{**}	-0.921^{**}	-0.974^{**}	0.9650
	(0.045)	(0.042)	(0.037)	(0.041)		(0.035)	(0.036)	(0.031)	(0.027)	(0.025)	
Atlanta FRD	-0.024	-0.709^{**}	-0.880^{**}	-0.880^{**}		-0.880^{**}	-0.880^{**}	-0.024	-0.855^{**}	-0.024	0.8641
	(0.066)	(0.061)	(0.054)	(0.060)		(0.050)	(0.052)	(0.045)	(0.039)	(0.036)	

Notes: 1. Numerical values in parentheses are standard errors of regression coefficients.
2. ** indicates significance at the 5% level by the 2-tailed t test; * indicates significance at the 10% level by the 2-tailed t test.
3. All F values (unreported here) are significant at the 5% level.

Table 5.9

Alternative Estimation of Equation (5.3)

	Intercept	Size S	Growth g	Average Profit π'	Average Profit Dummy	Profit Trend π^t	Banking Structure B	Urban Hierarchy Factor 1	Urban Hierarchy Factor 3
Version 1	42.41	-5.56×10^{-6}**	0.007	1.21	29.95**	23.47	3.08	-1.74	
		(2.19×10^{-6})	(0.055)	(0.80)	(8.11)	(30.97)	(10.12)	(6.16)	
Version 2	67.32	-2.96×10^{-6}	-0.010	1.29	20.48**	8.64	-5.50		-12.91**
		(2.17×10^{-6})	(0.052)	(0.74)	(8.00)	(29.25)	(9.66)		(3.52)
Version 3	69.19	-2.80×10^{-6}	-0.011	1.17	20.57**	7.33	-6.87	-4.16	-13.20**
		(2.19×10^{-6})	(0.052)	(0.75)	(8.02)	(29.38)	(9.87)	(5.81)	(3.55)

Notes: 1. Numerical values in parentheses are standard errors of regression coefficients.
2. ** indicates significance at the 5% level by the 2-tailed t test.
3. All F values are significant at the 5% level.

Table 5.9 (continued)

	Federal Reserve District Dummies										
	1 (New York)	2 (Phila-delphia)	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minne-apolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
Version 1	-3.37	2.96	15.21	27.40	23.37	29.95**	21.70	-31.77	9.76	41.56**	6.91
	(22.71)	(19.82)	(17.25)	(18.68)	(16.52)	(14.11)	(19.23)	(40.18)	(18.71)	(18.77)	(16.14)
Version 2	14.39	3.11	7.62	18.47	18.63	12.60	7.52	-55.20	-6.69	24.80	4.90
	(21.79)	(18.47)	(16.26)	(17.42)	(14.81)	(13.89)	(18.05)	(37.85)	(17.88)	(17.91)	(15.09)
Version 3	14.65	1.88	6.82	16.03	15.07	13.39	4.33	-59.54	-9.28	21.99	4.28
	(21.85)	(18.60)	(16.34)	(17.79)	(15.66)	(13.97)	(18.64)	(38.43)	(18.29)	(18.38)	(15.16)

Table 5.9 (continued)

	F	R^2	$\bar{R}^2$
Version 1	3.630	0.410	0.297
Version 2	4.887	0.483	0.385
Version 3	4.633	0.486	0.381

5.12. An auxiliary regression of Chicago FRD dummy on San Francisco FRD dummy has an $\bar{R}^2$ of only 0.05, thus excluding the possibility of colinearity.[32]

From Tables 5.3 and 5.9, we find that size, growth, banking structure, and urban hierarchy factors have the expected signs, although only the urban hierarchy factor (measured by scores of factor 3 from Table 5.2) is statistically significant at the 5% level. Profit, though significant at the 10% level in Table 5.3, is insignificant in Table 5.9. The neighborhood effect, though insignificant, is negative in Table 5.3, but changes sign in Table 5.9. As a further test of urban hierarchy effect, the adoption lag of each firm is regressed on the population (log transformed) of the firm's location.[33] The result appears in equation (5.6) and the residual plotting is shown in Figure 5.1. From the diagram we can find the urban hierarchy effect is clearly indicated in the early stages of diffusion. The pattern becomes less clear in later periods.

$$\begin{aligned} Y_k &= 386.27 - 25.33 \ln P \qquad (5.6) \\ &= 3.34 \\ F &= 57.38 \\ \bar{R}^2 &= 0.377 \quad \text{F value significant at 5\% level.} \end{aligned}$$

We have mentioned in Chapter IV that size and profit have been proposed to be related, as have profit and growth. Although multicolinearity analysis conducted in Tables 5.5 to 5.7 and 5.10 to 5.12 do not show any indication of colinearity among these variables, we still perform a test by dropping these variables from the regression. Results show that exclusion of some variables did not improve the re-

Table 5.10

Variance-Decomposition of Regression Coefficients

Associated Singular Value	Eigenvalue	Condition Index	Intercept	Size S	Growth Rate g	Average Profit π'	Average Profit Dummy	Profit Trend π^t	Banking Structure B	Urban Hierarchy Factor 1
			Proportion of Variation Associated with Each Singular Value							
μ_1	4.832000	1.000	0.0014	0.0021	0.0099	0.0045	0.0082	0.0027	0.0052	0.0069
μ_2	1.565000	1.757	0.0000	0.1617	0.0096	0.0000	0.0083	0.0023	0.0063	0.0059
μ_3	1.376000	1.874	0.0001	0.0032	0.0000	0.0000	0.0037	0.0492	0.0002	0.1076
μ_4	1.216000	1.993	0.0001	0.0113	0.0018	0.0013	0.0059	0.1376	0.0076	0.0092
μ_5	1.097000	2.098	0.0002	0.0136	0.0618	0.0004	0.0003	0.0507	0.0031	0.0000
μ_6	1.034000	2.162	0.0000	0.0047	0.0135	0.0004	0.0023	0.0183	0.0013	0.0014
μ_7	1.010000	2.187	0.0000	0.0000	0.0009	0.0004	0.0011	0.0024	0.0004	0.0000
μ_8	1.002000	2.196	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000
μ_9	1.000000	2.198	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{10}	1.000000	2.198	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{11}	1.000000	2.198	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{12}	0.786032	2.479	0.0000	0.0124	0.0018	0.0017	0.0011	0.6233	0.0055	0.0012
μ_{13}	0.621212	2.789	0.0003	0.0276	0.7345	0.0019	0.0011	0.0154	0.0013	0.0241
μ_{14}	0.525149	3.033	0.0000	0.6271	0.0470	0.0004	0.0011	0.0084	0.0087	0.0292
μ_{15}	0.378586	3.572	0.0007	0.0264	0.0350	0.0005	0.0669	0.0009	0.0012	0.6613
μ_{16}	0.239638	4.490	0.0061	0.0393	0.0013	0.0016	0.4887	0.0013	0.2215	0.1152
μ_{17}	0.173771	5.273	0.0055	0.0658	0.0338	0.0124	0.3730	0.0098	0.3187	0.0004
μ_{18}	0.118633	6.382	0.0014	0.0003	0.0067	0.7212	0.0359	0.0629	0.0577	0.0150
μ_{19}	0.024538	14.032	0.9841	0.0047	0.0424	0.2531	0.0024	0.0148	0.3612	0.0227

Table 5.10 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value — Federal Reserve District Dummies: 1 (New York)	2 (Phila-delphia)	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minne-apolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
μ_1	0.0011	0.0012	0.0021	0.0023	0.0020	0.0018	0.0013	0.0002	0.0016	0.0011	0.0021
μ_2	0.0998	0.0058	0.0000	0.0003	0.0038	0.0003	0.0037	0.0014	0.0134	0.0071	0.0384
μ_3	0.0010	0.0036	0.0107	0.0088	0.0235	0.0658	0.0139	0.0138	0.0017	0.0015	0.0018
μ_4	0.0139	0.0245	0.0809	0.0652	0.0037	0.0073	0.0027	0.0579	0.0345	0.0143	0.0010
μ_5	0.0638	0.0577	0.0016	0.0021	0.0060	0.0097	0.0027	0.1506	0.1002	0.0013	0.0151
μ_6	0.0528	0.0476	0.0505	0.0592	0.0286	0.0014	0.0033	0.0003	0.0439	0.1123	0.0326
μ_7	0.0123	0.0717	0.0669	0.0305	0.0336	0.0031	0.1241	0.0469	0.0313	0.0405	0.0475
μ_8	0.0086	0.1186	0.0150	0.2091	0.0581	0.0004	0.0000	0.2237	0.0035	0.0008	0.0035
μ_9	0.0735	0.0021	0.0324	0.0149	0.0768	0.0129	0.0093	0.0268	0.0004	0.0686	0.1545
μ_{10}	0.0000	0.0322	0.0413	0.0630	0.0002	0.0002	0.2816	0.0127	0.0105	0.0690	0.0000
μ_{11}	0.0114	0.2239	0.0832	0.0415	0.0389	0.0062	0.0021	0.0931	0.0346	0.0000	0.0521
μ_{12}	0.0025	0.0043	0.0882	0.0147	0.0010	0.0003	0.0019	0.1664	0.0011	0.0005	0.0274
μ_{13}	0.0089	0.0049	0.0021	0.0102	0.0001	0.0079	0.0060	0.0137	0.0982	0.0003	0.0018
μ_{14}	0.3406	0.0021	0.0188	0.0239	0.0183	0.0007	0.0029	0.0021	0.0000	0.0043	0.0616
μ_{15}	0.0185	0.0330	0.0004	0.0878	0.0774	0.0987	0.0438	0.0033	0.0080	0.0025	0.0203
μ_{16}	0.0278	0.0720	0.0128	0.0180	0.0153	0.0021	0.0146	0.0351	0.0780	0.0579	0.0507
μ_{17}	0.1276	0.0846	0.2628	0.1252	0.0955	0.1171	0.0124	0.0049	0.0148	0.0189	0.2134
μ_{18}	0.0489	0.0420	0.0315	0.1079	0.0361	0.1453	0.1094	0.0199	0.1232	0.0712	0.0666
μ_{19}	0.0869	0.1682	0.1987	0.1154	0.4813	0.5190	0.3644	0.1273	0.4013	0.5279	0.2096

Table 5.11

Variance-Decomposition of Regression Coefficients

Associated Singular Value	Eigenvalue	Condition Index	Proportion of Variation Associated with Each Singular Value							
			Intercept	Size S	Growth Rate g	Average Profit π'	Average Profit Dummy	Profit Trend π^t	Banking Structure B	Urban Hierarchy Factor 3
μ_1	4.641000	1.000	0.0013	0.0030	0.0104	0.0051	0.0077	0.0028	0.0056	0.0019
μ_2	2.054000	1.503	0.0000	0.0746	0.0066	0.0002	0.0080	0.0076	0.0010	0.0649
μ_3	1.240000	1.935	0.0000	0.0009	0.0063	0.0011	0.0038	0.1682	0.0094	0.0014
μ_4	1.100000	2.054	0.0001	0.0042	0.0655	0.0005	0.0003	0.0571	0.0032	0.0009
μ_5	1.054000	2.098	0.0000	0.0150	0.0156	0.0001	0.0032	0.0228	0.0023	0.0008
μ_6	1.030000	2.122	0.0000	0.0098	0.0012	0.0001	0.0004	0.0026	0.0004	0.0086
μ_7	1.011000	2.143	0.0000	0.0000	0.0006	0.0005	0.0011	0.0017	0.0004	0.0000
μ_8	1.001000	2.154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_9	1.000000	2.154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{10}	1.000000	2.154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{11}	1.000000	2.154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{12}	0.784458	2.432	0.0000	0.0126	0.0051	0.0018	0.0009	0.5907	0.0047	0.0001
μ_{13}	0.609602	2.759	0.0005	0.0402	0.6633	0.0023	0.0018	0.0190	0.0028	0.0036
μ_{14}	0.519598	2.989	0.0000	0.4138	0.1351	0.0010	0.0058	0.0072	0.0109	0.0177
μ_{15}	0.408848	3.369	0.0004	0.3999	0.0031	0.0017	0.0151	0.0258	0.0062	0.5938
μ_{16}	0.245970	4.344	0.0022	0.0005	0.0012	0.0003	0.4235	0.0001	0.2697	0.0368
μ_{17}	0.162882	5.338	0.0041	0.0138	0.0333	0.0007	0.4079	0.0265	0.2030	0.0780
μ_{18}	0.115622	6.336	0.0025	0.0087	0.0032	0.7990	0.0859	0.0429	0.0795	0.0476
μ_{19}	0.021711	14.621	0.9886	0.0031	0.0496	0.1855	0.0347	0.0249	0.4011	0.1437

Table 5.11 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value										
	Federal Reserve District Dummies										
	1 (New York)	2 (Phila-delphia)	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minne-apolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
μ_1	0.0018	0.0014	0.0022	0.0021	0.0020	0.0020	0.0012	0.0002	0.0015	0.0010	0.0026
μ_2	0.0517	0.0045	0.0014	0.0007	0.0000	0.0038	0.0007	0.0006	0.0047	0.0024	0.0130
μ_3	0.0026	0.0125	0.0854	0.0310	0.0022	0.0015	0.0136	0.0633	0.0457	0.0184	0.0001
μ_4	0.0439	0.0399	0.0026	0.0032	0.0011	0.0127	0.0036	0.1664	0.0934	0.0011	0.0259
μ_5	0.0638	0.1010	0.0137	0.1012	0.0133	0.0347	0.0140	0.0000	0.0129	0.0482	0.0092
μ_6	0.0013	0.0723	0.0014	0.0482	0.1650	0.0068	0.0000	0.0241	0.0133	0.0226	0.0880
μ_7	0.0070	0.0799	0.0878	0.0289	0.0620	0.0110	0.1080	0.0479	0.0173	0.0174	0.0364
μ_8	0.0673	0.0083	0.0050	0.1745	0.0003	0.0026	0.0058	0.2441	0.0030	0.0003	0.1308
μ_9	0.0116	0.0914	0.0003	0.0911	0.0032	0.0300	0.0008	0.0207	0.0340	0.1288	0.0435
μ_{10}	0.0007	0.0133	0.1767	0.0473	0.0411	0.0299	0.1336	0.0522	0.0000	0.0046	0.0000
μ_{11}	0.0007	0.1570	0.0017	0.0008	0.0474	0.0044	0.1761	0.0003	0.0389	0.0653	0.0000
μ_{12}	0.0019	0.0074	0.0857	0.0107	0.0048	0.0028	0.0035	0.1706	0.0005	0.0010	0.0270
μ_{13}	0.0414	0.0025	0.0049	0.0346	0.0079	0.0006	0.0168	0.0044	0.1027	0.0003	0.0047
μ_{14}	0.3805	0.0007	0.0187	0.0048	0.0004	0.0155	0.0006	0.0025	0.0033	0.0019	0.0727
μ_{15}	0.0553	0.0438	0.0027	0.0000	0.0182	0.0123	0.0010	0.0102	0.0019	0.0008	0.0014
μ_{16}	0.0187	0.0872	0.0276	0.0643	0.0012	0.0001	0.0027	0.0184	0.0517	0.0388	0.0706
μ_{17}	0.2082	0.1182	0.2654	0.1364	0.1570	0.1297	0.0288	0.0074	0.0338	0.0372	0.2552
μ_{18}	0.0082	0.0179	0.0108	0.0941	0.0194	0.0827	0.0999	0.0210	0.1059	0.0554	0.0281
μ_{19}	0.0334	0.1408	0.2063	0.1263	0.4538	0.5171	0.3894	0.1456	0.4354	0.5543	0.1908

Table 5.12

Variance-Decomposition of Regression Coefficients

Associated Singular Value	Eigenvalue	Condition Index	Proportion of Variance Associated with Each Singular Value								
			Intercept	Size S	Growth g	Average Profit π'	Average Profit Dummy	Profit Trend π^t	Banking Structure B	Urban Hierarchy Factor 1	Urban Hierarchy Factor 3
μ_1	4.908000	1.000	0.0011	0.0024	0.0092	0.0044	0.0068	0.0023	0.0048	0.0067	0.0018
μ_2	2.054000	1.546	0.0000	0.0742	0.0065	0.0001	0.0079	0.0074	0.0010	0.0000	0.0641
μ_3	1.400000	1.872	0.0001	0.0066	0.0010	0.0000	0.0006	0.0367	0.0021	0.1070	0.0019
μ_4	1.217000	2.008	0.0001	0.0067	0.0023	0.0012	0.0061	0.1252	0.0077	0.0109	0.0001
μ_5	1.099000	2.113	0.0001	0.0066	0.0608	0.0005	0.0001	0.0591	0.0036	0.0001	0.0006
μ_6	1.039000	2.173	0.0000	0.0000	0.0137	0.0003	0.0025	0.0191	0.0016	0.0005	0.0023
μ_7	1.015000	2.199	0.0000	0.0065	0.0005	0.0001	0.0005	0.0000	0.0000	0.0006	0.0030
μ_8	1.009000	2.205	0.0000	0.0008	0.0014	0.0004	0.0006	0.0025	0.0003	0.0002	0.0003
μ_9	1.001000	2.215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{10}	1.000000	2.215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{11}	1.000000	2.215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
μ_{12}	0.786532	2.498	0.0000	0.0139	0.0017	0.0017	0.0010	0.6025	0.0047	0.0014	0.0004
μ_{13}	0.621679	2.810	0.0003	0.0210	0.7161	0.0019	0.0009	0.0169	0.0016	0.0222	0.0009
μ_{14}	0.530589	3.041	0.0000	0.4025	0.0605	0.0003	0.0016	0.0034	0.0114	0.0317	0.0210
μ_{15}	0.411976	3.451	0.0001	0.2781	0.0144	0.0008	0.0287	0.0185	0.0049	0.0473	0.5043
μ_{16}	0.372419	3.630	0.0011	0.1489	0.0217	0.0017	0.0306	0.0080	0.0051	0.6336	0.1038
μ_{17}	0.236095	4.559	0.0038	0.0067	0.0029	0.0002	0.3799	0.0003	0.2696	0.0928	0.0210
μ_{18}	0.162881	5.489	0.0040	0.0135	0.0333	0.0007	0.4073	0.0264	0.1960	0.0000	0.0771
μ_{19}	0.114536	6.546	0.0016	0.0061	0.0037	0.7789	0.0931	0.0440	0.0679	0.0130	0.0451
μ_{20}	0.021050	15.269	0.9874	0.0054	0.0502	0.2067	0.0317	0.0279	0.4176	0.0322	0.1521

Table 5.12 (continued)

Associated Singular Value	Proportion of Variation Associated with Each Singular Value: Federal Reserve District Dummies 1 (New York)	2 (Philadelphia)	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minneapolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
μ_1	0.0015	0.0013	0.0019	0.0020	0.0019	0.0014	0.0012	0.0002	0.0013	0.0009	0.0022
μ_2	0.0519	0.0045	0.0013	0.0007	0.0000	0.0036	0.0007	0.0006	0.0046	0.0023	0.0131
μ_3	0.0051	0.0009	0.0098	0.0062	0.0282	0.0484	0.0159	0.0125	0.0064	0.0044	0.0017
μ_4	0.0107	0.0257	0.0769	0.0667	0.0036	0.0081	0.0023	0.0512	0.0334	0.0137	0.0002
μ_5	0.0541	0.0522	0.0022	0.0005	0.0035	0.0064	0.0020	0.1597	0.0898	0.0006	0.0253
μ_6	0.0323	0.0055	0.0273	0.0922	0.0505	0.0001	0.0037	0.0026	0.0376	0.0848	0.0672
μ_7	0.0004	0.2818	0.0875	0.0165	0.0111	0.0102	0.0093	0.1006	0.0013	0.0088	0.0501
μ_8	0.0110	0.0004	0.0197	0.0909	0.0819	0.0002	0.1139	0.0025	0.0398	0.0603	0.0138
μ_9	0.0768	0.0008	0.0002	0.0902	0.0009	0.0026	0.0283	0.2006	0.0010	0.0238	0.1639
μ_{10}	0.0021	0.0075	0.0522	0.0700	0.0001	0.0001	0.2348	0.0319	0.0044	0.0749	0.0069
μ_{11}	0.0000	0.1910	0.0931	0.0397	0.0818	0.0125	0.0046	0.0391	0.0333	0.0157	0.0032
μ_{12}	0.0009	0.0057	0.0893	0.0159	0.0014	0.0004	0.0017	0.1554	0.0009	0.0004	0.0278
μ_{13}	0.0139	0.0062	0.0026	0.0111	0.0000	0.0080	0.0056	0.0116	0.0915	0.0002	0.0023
μ_{14}	0.4025	0.0000	0.0218	0.0256	0.0112	0.0021	0.0022	0.0049	0.0000	0.0046	0.0667
μ_{15}	0.0684	0.0571	0.0021	0.0053	0.0392	0.0356	0.0077	0.0057	0.0001	0.0001	0.0055
μ_{16}	0.0003	0.0087	0.0022	0.0841	0.0492	0.0579	0.0242	0.0094	0.0103	0.0037	0.0135
μ_{17}	0.0190	0.0686	0.0247	0.0275	0.0131	0.0045	0.0132	0.0282	0.0677	0.0498	0.0601
μ_{18}	0.2083	0.1172	0.2642	0.1311	0.1406	0.1293	0.0269	0.0071	0.0322	0.0353	0.2545
μ_{19}	0.0097	0.0180	0.0118	0.0821	0.0115	0.0997	0.0838	0.0170	0.0934	0.0476	0.0300
μ_{20}	0.0311	0.1468	0.2092	0.1418	0.4702	0.5690	0.4078	0.1592	0.4510	0.5682	0.1290

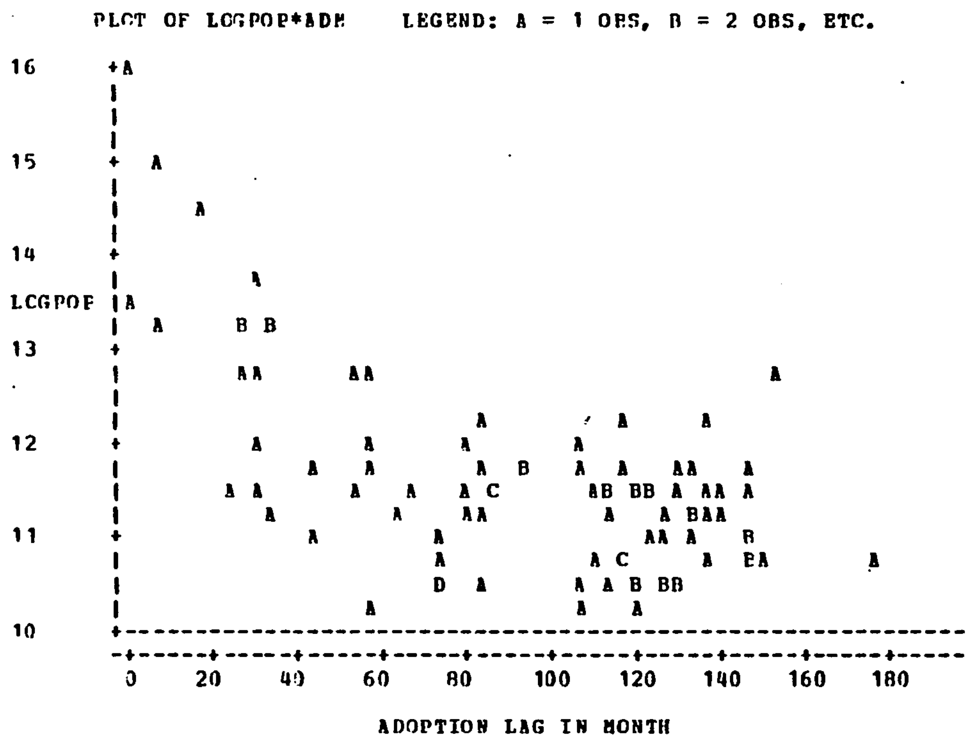


Figure 5.1. Residual Plotting of Equation (5.6).

sult of estimation on remaining variables. Therefore we conclude that although there are theoretical arguments that size and profit are related and so are profit and growth, these relationships do not affect the estimation results in this study.[34]

5.4.3. Interpretation of the Results

We find from Table 5.4 that in previous studies firm size has been a significant factor in explaining interfirm differences in speed of response to innovation. The elasticity of this factor varies between -0.4 and -0.67. Expected profit from adoption of innovation is also found to be an important factor in some studies. In this study firm size is also found to be significant in one estimation and have the expected signs in all estimations. Another factor which is found to be significant is the urban hierarchy factor. In two estimations when this factor was proxied with population characteristics of urban places the results are statistically significant. In another estimation in which income characteristics of urban places were used to proxy the urban hierarchy effect the result also has the expected sign, although the effect is insignificant. These findings support the arguments presented in Chapter IV, and the firm size effect is also consistent with previous studies. The arc elasticity is found to be -0.50, which is also in consistence with previous findings.[35]

The strong effect of the urban hierarchy factor, when contrasted with the insignificant showing of the neighborhood proxies, implies that in the spatial innovation diffusion process the urban hierarchy effect tends to be the dominating factor. A firm's speed of response to an innovation will be determined mainly by its location rank rather than the number of neighboring competitors which have already adopted the innovation, ceteris paribus. The arc elasticity is found to be -0.5 when using the population characteristics of urban places to proxy the urban rank. Thus for a bank in this sample a relocation of its (head) office from the lowest-ranked place to the highest-ranked place will shorten its adoption lag by half, which can be more than seven years in the extreme case.

5.5. Summary

In this chapter empirical estimation of the theoretical model developed in the previous chapter was conducted. The OLS estimating function was chosen as the preformed estimating function based on the criterion suggested by Box and Cox. Proxies were used in measuring both the urban hierarchy and the neighborhood factors. The estimating results after correction of multicolinearity are reported in Table 5.9, in which firm size and urban hierarchy is found to be significant in the estimation(s), thus lending support to the theoretical model presented in Chapter IV. The insignificant results of other variables indicate that more studies are needed to examine the effects of firm growth, general profitability, profit trend, regulatory limitations in branch banking, and (especially) the "neighborhood factor." Based on the findings reported in this chapter, we will examine the spatial innovation diffusion process from another angle by exploring the statistical characteristic of the temporal diffusion function in a spatial economy constructed on an urban hierarchy basis.

ENDNOTES

1. For a statistical discussion on factor analysis, see, e.g., R. J. Rummel, Applied Factor Analysis (Evanston, IL: Northwestern University Press, 1970); Wilson H. Guertin and John P. Bailey, Jr., Introduction to Modern Factor Analysis (Ann Arbor, MI: Edwards Bros., 1970).

2. In this example factor analysis is used to confirm the hypothesis that there are two factors which affect a student's scholastic performance. Often factor analysis is used to detect the number of underlying forces. When used for such purposes, it is called exploratory factor analysis.

3. B. J. L. Berry, "Latent Structure of the American Urban System," pp. 11-60; B. Walter and F. M. Wirt, "Social and Political Dimensions of American Suburbs," pp. 97-123, in City Classification Handbook, ed. B. J. L. Berry (New York: Wiley-Interscience, 1972).

4. An examination of the definition of the three income measures mentioned above reveals that the rental income for owner-occupied housing is not included. See 1970 Census of Population, Vol. 1, Characteristics of the Population, Part 1, United States Summary, Section 2, Appendix B.A, pp. 35-36, 56-58. (Hereby this census will be referred to as 1970 Population Census.)

5. Although an experimental model was installed by Bank of America in 1956, as we have found from the discussion in section 3.2.2, this cannot be considered an operational system and, hence, should not be considered as an innovation.

6. See, e.g., George W. Mitchell, "Exogenous Forces in the Development of Our Banking System," in Banking Markets and Financial Institutions, eds. Thomas G. Gies and Vincent P. Apilado (Homewood, IL: Richard D. Irwin, 1971), pp. 24-26.

7. It is found (on the average) that the adoption decision is made one year before the delivery (and installation) of the computer. Therefore the relevant size should be the size one year before the installation occurs. See Stoneman (1976), p. 60, Fig. 4.1.

8. Mean, median, and per capita income figures are contained in 1970 Population Census, Vol. 1, Tables 89, 107, and 118 of each state under the items "Mean Income and Median Income of All Families and Unrelated Individuals," and "Per Capita Income of Persons." Median number of school years and percentage of high school graduates figures are contained in Tables 83, 103, and 107 of each state. In Table 103 the figure on median school

years is not provided directly. The figure is derived through the following formula:

$$m = b + \frac{d}{f} \times c$$

(where m is the median, b is the lower bound of size class, c is the range of the size class which contains the median, f is the frequency of the class which contains the median, d is $\frac{n}{2}$ minus the cumulative frequency at the lower bound of the class which contains the median, and n is the total sample number) through the information provided on the median school years completed by all males of twenty-five years or older and that of the female. A discussion on the nature of this formula can be found in basic statistics textbooks, e.g., Robert D. Mason, Statistical Technique in Business and Economics (Homewood, IL: Irwin, 1967), p. 119. Percentage of the labor force in manufacturing industries and percentage of the labor force in white-collar occupations figures are contained in Table 41 under the title "Employed Persons: percent in manufacturing industries, and percent in white-collar occupations." Unemployment rate is contained in the same table under the title "Civilian Labor Force - Percent Unemployed." Median age figures are contained in Tables 24, 28, and 31 of each state. Percentage of owner-occupied housing figures are contained in 1970 Housing Census, Vol. 1, Housing Characteristics for States, Cities, and Counties, Table 8 of each state. Median rent figures are contained in Table 10 of the Housing Census. Population, population density, and population growth figures are available in Table 31, U.S. Summary of 1970 Population Census. The figures are adjusted according to the Correction Notes presented before Table 1 of the same issue.

9. This assumption is made purely for the reason that data are unavailable for a theoretically more preferable treatment. Similar assumptions were made implicitly by studies on U.S. urban hierarchy when researchers only had data obtained from the 1960 U.S. Population Census. See, e.g., Berry ed. (1972).

10. Most of these banks will have only basic statistics like deposit and dividend figures reported in Moody's Bank and Financial Manual.

11. Another periodical, EDP Industry Report, estimated that by February 1974 about 2,800 banks had installed computers. But the identities of these banks were not revealed and the author had tried in vain to acquire this information. (See EDP Industry Report, March 27, 1974, p. 5.)

12. International Data Corporation is the only company which collects data on installations of general purpose digital computers in the U.S. But even their data are incomplete. The company admits that the data could at best include about 80% of all installations. See S1167, p. 4934.

13. This case was finally dropped by the Justice Department on January 20, 1982, but this result did not help much in easing the problem of data collection since IBM's position on data revelation remains the same.

14. The results are tabulated to conceal the identities of surveyed banks. Besides, this survey is still not a comprehensive survey but rather a sample survey. The author has tried in vain to acquire the primary data.

15. Even the professional journal publishers admit the difficulty in collecting installation data. See, e.g., Computers and Automation, April 1969, p. 14.

16. EDP Industry Report, March 27, 1974, p. 5.

17. While the 1959 deposit figure of the largest bank, Bank of America, was $15 billion (inflation adjusted), deposits of most banks in the sample were between $10 and $100 million when they installed a computer.

18. J. Aitchison and J. A. C. Brown, The Lognormal Distribution (London: Cambridge University Press, 1957), p. 101. In factor analysis all the manifest variables are assumed to be normally distributed. If this assumption is violated then the variable has to be transformed. Thus if a population is proposed to be lognormally distributed, a logarithm transformation is necessary before factor analysis can be conducted.

19. Berry (1972), pp. 15, 58-60.

20. The technique used is suggested by Stephens. See M. A. Stephens, "EDF Statistics for Goodness of Fit and Some Comparisons," Journal of American Statistical Association, 69 (1974), 730-737.

21. This practice seems to be commonly used in data transformation in city classification. See, e.g., Leo F. Schnore and Hal H. Winshorough, "Functional Classification and the Residential Location of Social Classes," in Berry (1972), p. 128.

22. The merits of the various criteria used in the extraction of initial factors are still an issue of debate. I simply follow one of the most popular criteria, the Kaiser criterion, which extracts any factor with an eigenvalue greater than or equal to one. For a brief discussion of the merit of this criterion, see Jae-on Kim and Charles W. Mueller, Factor Analysis: Statistical Methods and Practical Issues (Beverly Hills, CA: Sage Publications, 1978), pp. 43-44. For a more detailed discussion on this issue, see, e.g., L. Gutterman, "Some Necessary Conditions for Common Factor Analysis," Psychometrika, 19 (1954), 149-161; H. F. Kaiser, "An Index of Factorial Simplicity," Psychometrika, 39 (1974), 31-36.

23. Oblique rotation releases the assumption that observed variables are (statistically) independent from each other; thus it probably could detect the true relationship between observed variables more accurately.

24. Mansfield (1963a), pp. 291-292; Romeo (1975), pp. 316-317.

25. Mansfield (1963a), pp. 302-305. The proposition concerning the second derivative property of the variable investment profitability is also weak. That proposition actually is a statement without any theoretical arguments provided to support it.

26. Davies (1970), p. 132.

27. G. E. P. Box and D. R. Cox, "An Analysis of Transformations," Journal of Royal Statistical Association, Series B, 26 (1964), 211-243.

28. The error sum of squares for the various functional forms are shown as follows:

Error Sum of Squares / Functional Form	When Factor 1 is used to represent urban hierarchy variable	When Factor 3 is used to represent urban hierarchy variable	When Factor 1 and Factor 3 are used to represent urban hierarchy variable
Linear	21.2222	18.5791	18.4759
Log-independent variable	27.3048	24.6091	24.5413
Full log function (except those independent variables which have negative values)	32.3873	30.3918	30.3068

The estimating equation used above is the version used in Table 5.9.

29. David A. Belsley, Edwin Kirk, and Roy E. Welsch, Regression Diagnostics: Identifying Influential Data and Sources of Colinearity (New York: John Wiley & Sons, 1980).

30. Belsley et al. (1980), p. 157, footnote #56.

31. The criterion is suggested in Belsley et al. (1980), p. 168.

32. Residual patterns were also examined and there is no indication of the existence of heteroschedasticity, as diagrams in Appendix A.5 show.

33. The methodology follows Irwin Feller, "Municipal Diffusion Patterns," Progress Report, NSF Grant 50C-7682379 (1978).

34. The estimations are shown in Appendix A.5.

35. The two extreme values were used in the calculation of the arc elasticity.

CHAPTER VI

A STOCHASTIC MODEL FOR DIFFUSION OF INNOVATIONS IN A SPATIAL ECONOMY

6.1. Introduction

In Chapter IV we developed a deterministic model to explain a firm's response to an innovation in a spatial context. The effect of spatial factors on the firm's adoption decision was found to be statistically significant when the urban rank was measured by population characteristics. In this chapter we examine the temporal diffusion patterns across urban ranks.

In existing spatial diffusion studies, although the temporal diffusion pattern is typically S-shaped, researchers have not established an exact relationship between the established temporal diffusion pattern and the spatial innovation diffusion model. The logistic function lacks theoretical support because the assumptions underlying the epidemiology model are not entirely appropriate for diffusion of an innovation. Several other functional forms have been suggested to approximate the temporal diffusion pattern, including the exponential function.[1] But the exact relationship between these alternative functional forms and the spatial diffusion model is not clearly indicated, thus rendering these alternative functional forms at best convenient statistical tools in empirical model fitting. To have a better understanding of spatial innovation diffusion, the relationship between temporal diffusion pattern of innovation and the spatial economy has to be specified. This will be the task of this chapter.

Section 6.2 will discuss the probability distribution of innovation adoptions over all urban places at a point in time. The analysis will then be extended to discuss changes of this probability distribution over time, which will be dealt with in Section 6.3. In Section 6.4 we will discuss characteristics of temporal diffusion function based on the results derived in the previous sections. The implications of the theoretical model will be empirically tested in Sections 6.5 and 6.6,

6.2. Distribution of Probability of Adoption for Urban Places

Urban places differ in economic environments. Thus, for any firm, the true expected return from the adoption of the innovation at time t_i, $ER^*_{t_i}$, will differ across urban places.[2] Let $P^*_{t_j}$ denote the threshold level necessary to induce adoption at location j; i.e., $P^*_{t_j}$ is the minimum requirement for the economic environment which induces at least one firm at location j to adopt the innovation at time t. Let $P^*_{t_j}$ be approximated by population size and call it the threshold population level of adoption for location j; then $P^*_{t_j}$ will vary from place to place due to the reasons mentioned.[3] Then, for each population level P_m, there is a distribution of threshold population level P^*_m. For location j, the probability that at any time there will be at least one firm innovating can be expressed by a (0, 1) attribute:

$$a_{t_j} = 1 \qquad \text{if } P_{t_j} \geqq P^*_{t_j} \tag{6.1}$$
$$= 0 \qquad \text{otherwise}$$

We can call this the adoption criterion of urban place. j. The conditional probability that location j will have at least one firm adopting the innovation at time t_i (given its population size) is given by the following equation:

$$\Pr(t_j)\Big]_{t=t_i} = \Pr(a_{t_j} = 1 | P_{t_j} = P_t)\Big]_{t=t_i} = \Pr(P^*_{t_j} \leqq P_t)\Big]_{t=t_i} \tag{6.2}$$

and the probability that an urban place chosen at random will have at least one firm adopting the innovation at time t_i can then be expressed as $Q_{t_i} = \Pr(P^*_{t_i} \leqq P_{t_i})$. In this expression we have two random variables, the population of an urban place chosen at random, P_{t_i}, and the threshold population level of this randomly chosen urban place, $P^*_{t_i}$. Denote the probability density function of $P^*_{t_i}$ as $f(P^*_{t_i})$, and the probability density function of P_{t_i} as $g(P_{t_i})$. If these two random variables are statistically independent, we can write:

$$Q_{t_i} = \Pr(P^*_{t_i} \leqq P_{t_i}) = \iint_{P^*_{t_i} < P_{t_i}} f(P^*_{t_i})\, g(P_{t_i})\, dP^*_{t_i}\, dP_{t_i}$$
$$= \int^{\infty} [\int_0^{P_{t_i}} f(P^*_{t_i})\, dP^*_{t_i}]\, g(P_{t_i})\, dP_{t_i}$$
$$= \int_0^{\infty} F(P^*_{t_i})\, dF(P_{t_i}) \tag{6.3}$$

where F(x) denotes the cumulative density function of a random variable x, i.e., the probability that an urban place chosen at random will have at least one firm adopting the innovation at time t, is determined by the cumulative probability density functions of P and P^*.[4]

Suppose the threshold population level is the product of many factors which are statistically independent:

$$P^*_{t_i} = f(x_1, x_2, x_3, \ldots, x_n)$$

$$= \prod_{j=1}^{n} x_j. \tag{6.4}$$

Among the many factors which could affect the threshold population size, probably the most important factor is the location's income level. The distribution of income is generally lognormal,[5] and the threshold population size cannot be a negative or zero value. Given the multiplicative form of the central limit theorem, then the distribution of threshold population size is also lognormal.[6] Denote this distribution by:

$$P^*_{t_i} \sim \Lambda(z;\ \mu_{t_i},\ \sigma^2_{t_i}). \tag{6.5}$$

The cumulative probability density function is given by:

$$F(P^*_{t_i}) \sim \Lambda\{z;\ \mu_{t_i},\ \sigma^2_{t_i}\} = \Lambda(z \leq Z;\ \mu_{t_i},\ \sigma^2_{t_i}). \tag{6.6}$$

Substituting (6.6) into (6.3) yields:

$$Q_{t_i} = Pr(P^*_{t_i} \leq P_{t_i}) = \int_o^\infty \Lambda\{P^*_{t_i};\ \mu_{t_i},\ \sigma^2_{t_i}\}\ dF(P_{t_i})$$

$$= \int_o^\infty \Lambda(P^*_{t_i} \leq P_{t_i};\ \mu_{t_i},\ \sigma^2_{t_i})\ dF(P_{t_i}). \tag{6.7}$$

The statistical properties of the cumulative distribution of population, $F(P_{t_i})$, must now be explored before we can obtain further results for the probability distribution of Q_t. In a spatial economy composed of urban places of different population sizes, if population grows in a geometric random stochastic manner, then the distribution of population size can be approximated by a lognormal distribution.[7] Using the same notation, we can write:

$$P_{t_i} \sim \Lambda\ (z;\ \mu_{P_{t_i}},\ \sigma^2_{P_{t_i}}) \qquad (6.8)$$

for the probability density function, and:

$$F(P_{t_i}) \sim \Lambda\ \{z;\ \mu_{P_{t_i}},\ \sigma^2_{P_{t_i}}\} = \Lambda\ (z \leq Z;\ \mu_{P_{t_i}},\ \sigma^2_{P_{t_i}}) \qquad (6.9)$$

for the cumulative probability density function. Incorporating this information into equation (6.7) yields:

$$\begin{aligned} Q_t &= \Pr(P^*_{t_i} \leq P_{t_i}) \qquad (6.10) \\ &= \int_0^\infty \Lambda\ \{P^*_{t_i};\ \mu_{t_i},\ \sigma^2_{t_i}\}\ d\Lambda\ \{P_{t_i};\ \mu_{P_{t_i}},\ \sigma^2_{P_{t_i}}\}. \end{aligned}$$

Due to the convolution property of the lognormal integral to that for the normal integral,[8] equation (6.10) can be rewritten as:

$$Q_{t_i} = \Pr(P^*_{t_i} \leq P_{t_i}) = \Lambda\ \{1;\ \mu_{t_i} - \mu_{P_{t_i}},\ \sigma^2_{t_i} + \sigma^2_{P_{t_i}}\}. \qquad (6.11)$$

Normalizing it, we get:

$$\begin{aligned} Q_{t_i} &= \Pr(P^*_{t_i} \leq P_{t_i}) \\ &= \Lambda\ \{\exp\ (\mu_{P_{t_i}});\ \mu_{t_i},\ \sigma^2_{t_i} + \sigma^2_{P_{t_i}}\} \end{aligned}$$

$$= \Lambda \left\{ \frac{1-\mu_{t_i} + \mu_{P_{t_i}}}{\sqrt{\sigma^2_{t_i} + \sigma^2_{P_{t_i}}}} ; 0, 1 \right\}$$

$$= N \left\{ \frac{\log 1 - \mu_{t_i} + \mu_{P_{t_i}}}{\sqrt{\sigma^2_{t_i} + \sigma^2_{P_{t_i}}}} ; 0, 1 \right\}. \qquad (6.12)$$

This implies that the probability that an urban place will have at least one firm adopting an innovation at any time t is cumulatively lognormally distributed, i.e., this probability increases monotonically with the location's population size, as shown in Figure 6.1.

Hypothesis 1: In a spatial economy composed of urban places of various population sizes, after an invention has been introduced at time t_o, the probability that at some later time, t_i, there will be at least one firm innovating at a location increases with the population size of that location monotonically. This probability could be approximated by a cumulative lognormal distribution.

6.3. Changes in the Probability Distribution of Adoption Over Time

Having developed a model to explain the probability distribution of innovation by location, the next step is to explore changes in that distribution over time.

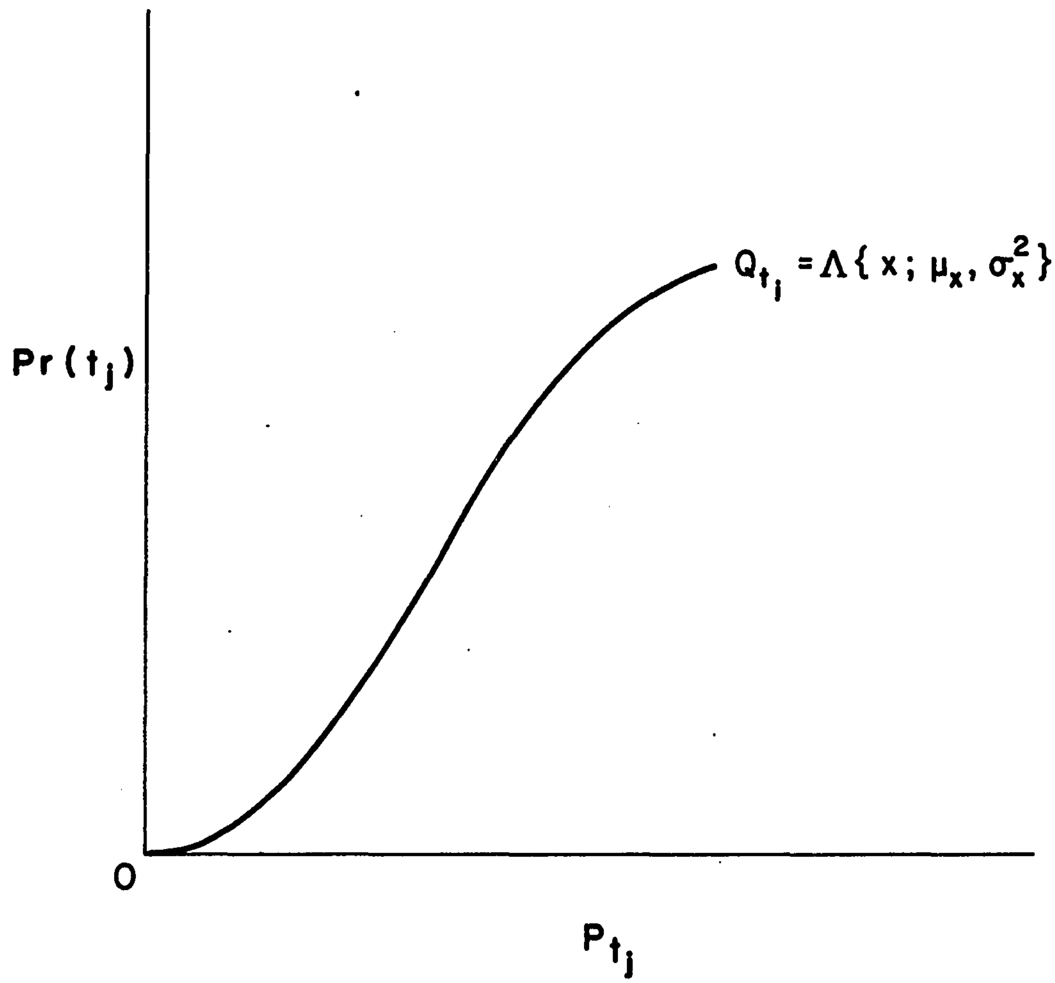


Figure 6.1. Probability of Occurrence of Innovation at a Location at a Point in Time.

In section 4.2.5 we have found that, as time passes, the cost of information will decrease, thereby leading to a decrease in adoption costs. In addition, there might be post-invention improvements in the innovation, which could improve the profitability of adoption, among other things. In terms of the notation used previously, $ER^*_{t_h} > ER^*_{t_g}$ for $t_h > t_g$ if post-invention improvement occurs, other things being equal. If the following situation occurs:

$$(ER^* - R^*)_{t_h} > (ER^* - R^*)_{t_g} \qquad t_h > t_g, \tag{6.13}$$

i.e., the innovation profitability increases over time, then in terms of the current theoretical framework, this implies a decrease in the threshold population level for each urban place. Because of the change of adoption conditions, the urban rank which induces a firm to adopt the innovation will be lower. This means that the distribution of the threshold population level will be shifted to the left or, in other words, the mean of the distribution of threshold population level will decrease. Thus, for:

$$P^*_{t_h} \sim \Lambda\ (z;\ \mu_{t_h},\ \sigma^2_{t_h}) \tag{6.14}$$

and

$$P^*_{t_g} \sim \Lambda\ (z;\ \mu_{t_g},\ \sigma^2_{t_g}), \tag{6.15}$$

$$\mu_{t_h} < \mu_{t_g},$$

as shown in Figure 6.2(a). If we assume that the relative distribution of threshold population level remains constant, i.e., $\sigma^2_{t_h} = \sigma^2_{t_g}$,

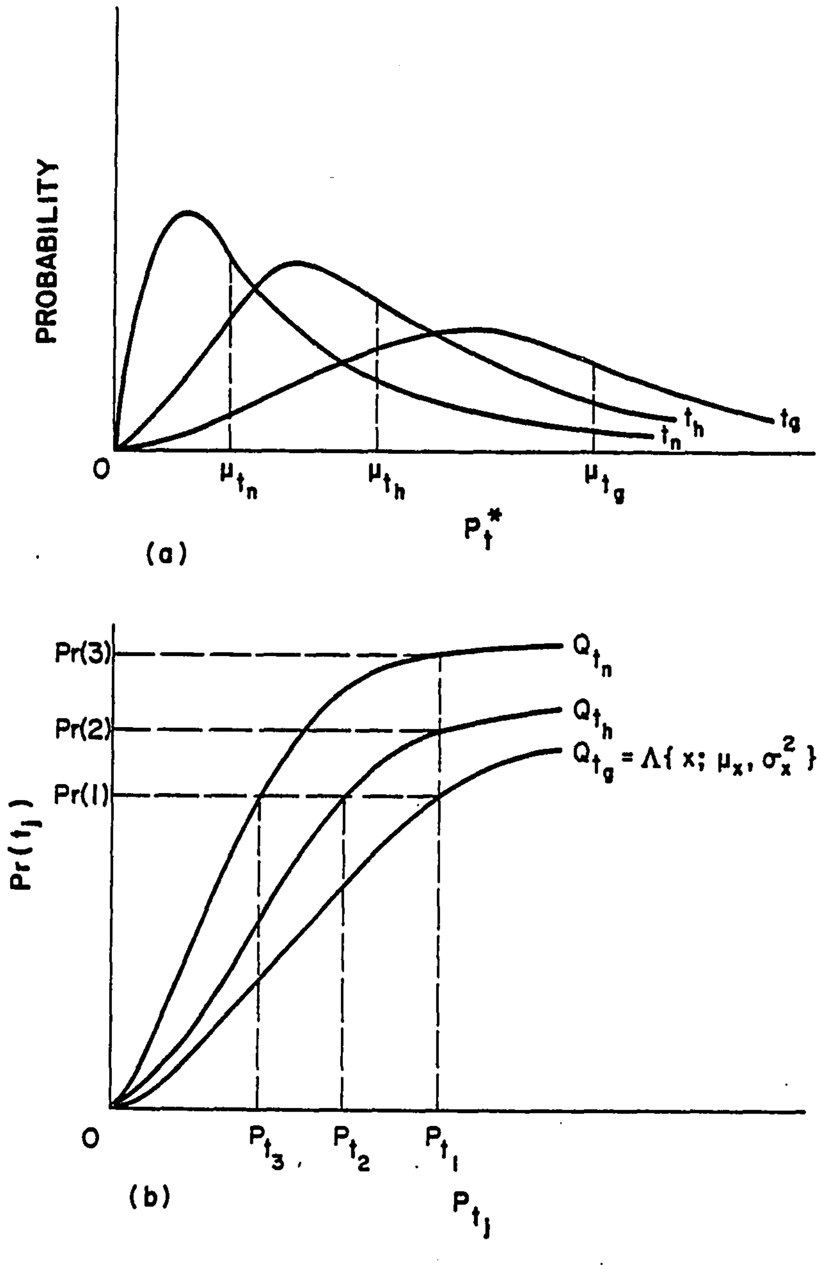


Figure 6.2. Probability of Occurrence of the Innovation at a Location for Different Time Periods.

$$Q_{t_h} = \Pr(P^*_{t_h} \leq P_{t_h}) = \Lambda \{1; \mu_{t_h} - \mu_{p_{t_h}}, \sigma^2_{t_h} + \sigma^2_{p_{t_h}}\} \qquad (6.16)$$

$$Q_{t_g} = \Pr(P^*_{t_g} \leq P_{t_g}) = \Lambda \{1; \mu_{t_g} - \mu_{p_{t_g}}, \sigma^2_{t_g} + \sigma^2_{p_{t_g}}\} \qquad (6.17)$$

and since $\mu_{t_h} < \mu_{t_g}$, $(\mu_{t_h} - \mu_{p_{t_h}}) < (\mu_{t_g} - \mu_{p_{t_g}})$ if $\mu_{p_{t_h}} \geq \mu_{p_{t_g}}$, which is possible if population growth in nonnegative. Therefore the probability of innovation at a location increases over time from t_g to t_h, as shown in Figure 6.2(b) for $t_g < t_h < \ldots < t_n$. For a location of population size P_{t_i}, the probability that at least one firm will innovate increases from Pr(1) to Pr(2) to Pr(3) as the time period is lengthened from $T = t_g - t_o$ to $T = t_n - t_o$, or what amounts to the same thing, for the same innovation probability, the level of population that is required to generate this probability decreases over time. In this figure the size of population that is needed to generate Pr(1) decreases from P_{t_1} to P_{t_2} to P_{t_3} as the time period is lengthened.

Hypothesis 2: If there are post-invention improvements, then over time the probability of adoption will increase for each urban place, causing an upward shift of the curve in Figure 6.2(b).

Equipped with this result, we now extend the analysis to discuss the temporal diffusion function of an innovation in a spatial economy.

6.4. Derivation of a Temporal Diffusion Function in a Spatial Economy

To derive the temporal diffusion function, we assume that during the period of diffusion the relative inequality of city sizes remains constant. Thus, we assume that:

$$\sigma^2_{p_{t_i}} = \sigma^2_{p_t} \qquad \text{for all t.} \tag{6.18}$$

We also assume that the distribution of the threshold population size remains constant over time, so that the relative inequality of sizes remains constant for urban places. Thus:

$$\sigma^2_{t_i} = \sigma^2_{t} \qquad \text{for all t.} \tag{6.19}$$

From equation (6.18), if the size distribution of urban places remains constant over time, then the population of each urban place will grow at the same rate. Therefore, the population mean will increase over time at a constant rate. Denoting that rate of population growth by g_1, we can write:

$$\mu_{p_t} = \mu_{p_o} + g_1 t \tag{6.20}$$

where μ_{p_o} is the original mean of the distribution of urban places when the innovation was first introduced.

The mean of the distribution of threshold population size will decrease over time for reasons already discussed. If we also assume that the rate of decrease is constant, then we can write:

$$\mu_t = \mu_{t_o} - g_2 t. \tag{6.21}$$

We denote the rate of decrease of the mean by g_2 and the original mean when the innovation was introduced by μ_{t_o}. Equipped with these assumptions, we are now ready to explore the time path of the diffusion function.

Equation (6.12) is the stationary state expression for the diffusion of an innovation. It expresses the probability of adoption of innovation for each level of city size at a specific time, t_i. When we incorporate the time path of the probability distribution of population size P_{t_i} and the threshold population size $P^*_{t_i}$ into this equation, we can then express the time path of innovation diffusion in this spatial economy as an implicit function of these two factors. What will be the exact form of this diffusion function? Substituting equations (6.18) through (6.21) into equation (6.12), we get:[9]

$$Q_t = \Pr(P^*_t \leq P_t) \qquad \text{for all } t$$

$$= \int_0^\infty \Lambda\ \{P^*_t;\ \mu_t,\ \sigma^2_t\}\ d\ F(P_t) \quad \text{for all } t \tag{6.7'}$$

$$= \int_0^\infty \Lambda\ \{P^*_t;\ \mu_t,\ \sigma^2_t\}\ d\ \Lambda\ \{P_t;\ \mu_{p_t},\ \sigma^2_{p_t}\} \tag{6.10'}$$

$$= \Lambda\ \{1;\ \mu_t - \mu_{p_t},\ \sigma^2_t + \sigma^2_{p_t}\} \tag{6.11'}$$

$$= \Lambda\ \{1;\ (\mu_{t_o} - g_2 t) - (\mu_{p_o} + g_1 t),\ \sigma^2_t + \sigma^2_{p_t}\}$$

$$= \Lambda\ \{1;\ (\mu_{t_o} - \mu_{p_o}) - (g_1 + g_2)t,\ \sigma^2_t + \sigma^2_{p_t}\}$$

$$= N\ \{\log 1 - (\mu_{t_o} - \mu_{p_o}) + (g_1 + g_2)t\ /\ (\sigma^2_t + \sigma^2_{p_t})^{1/2};\ 0,\ 1\}$$

$$= N\{t(g_1 + g_2) + (\mu_{p_o} - \mu_{t_o}) / (\sigma_t^2 + \sigma_{p_t}^2)^{\frac{1}{2}}; 0, 1\}$$

$$= N\{t; \mu_D, \sigma_D^2\} \quad (6.22)$$

where $\mu_D = \dfrac{\mu_{t_o} - \mu_{p_o}}{g_1 + g_2}$ and $\sigma_D^2 = \dfrac{\sigma_t^2 + \sigma_{p_t}^2}{(g_1 + g_2)^2}$.

Thus, the temporal diffusion pattern of an innovation in a spatial economy follows a cumulative normal distribution curve, as shown in Figure 6.3.

Hypothesis 3: In a spatial economy composed of places of various (population) sizes, if over time the relative size inequality remains constant and the mean for the distribution of actual population grows at a constant rate, while the mean of the distribution of the threshold population decreases at a constant rate, then the temporal diffusion pattern of innovation in this spatial economy can be approximated by a cumulative normal distribution.

Given this basic result, we can extend the analysis by relaxing the restrictive assumptions made through (6.18) to (6.21). Suppose instead of a constant rate of change, the means of the distribution of P_{t_i} and $P^*_{t_i}$ are approximated by the following:

$$\mu_{p_t} = \mu_{p_o} + g_1 t + D_{t_1} \quad (6.20')$$

$$\mu_t = \mu_{t_o} - g_2 t + D_{t_2} \quad (6.21')$$

where D_{t_1} and D_{t_2} are the respective residuals or disturbance terms.

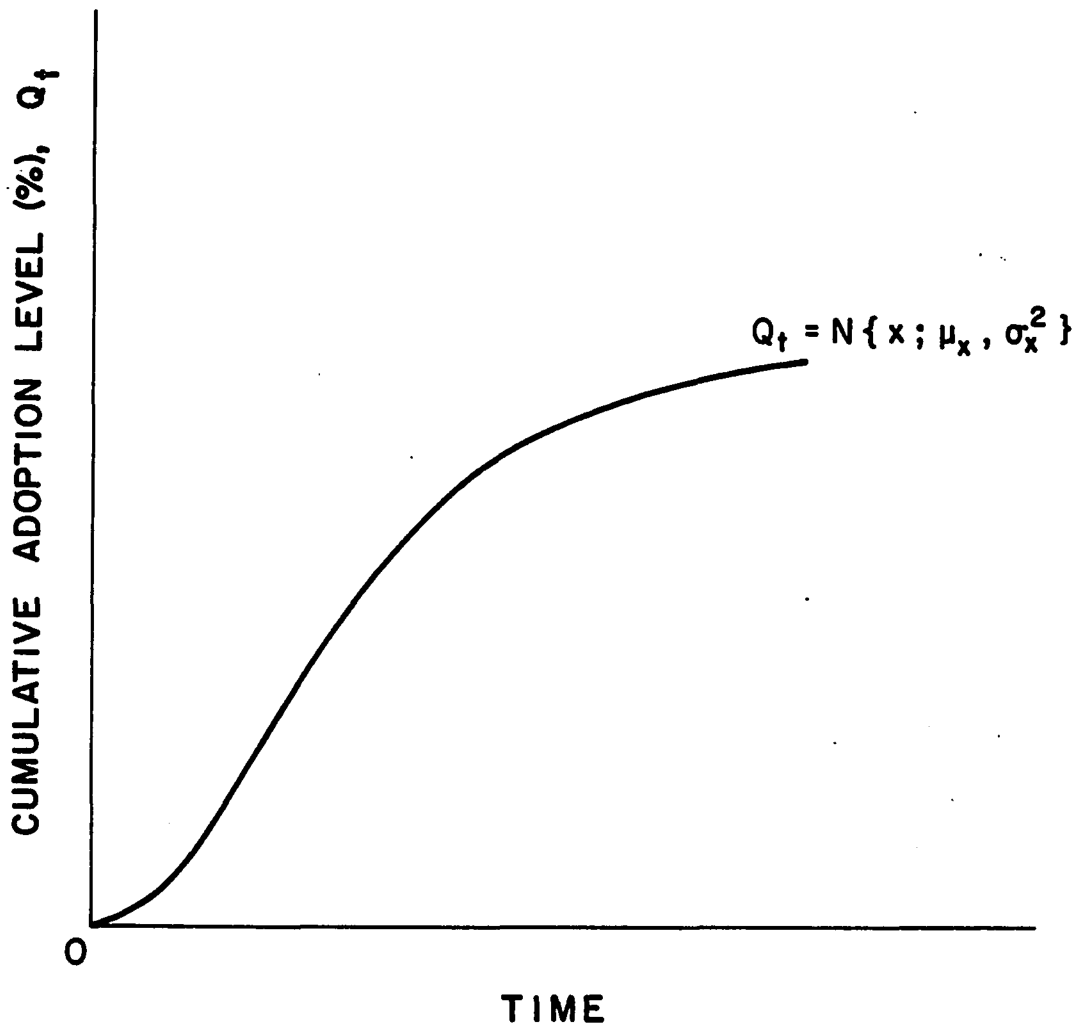


Figure 6.3. Time Path of Innovation Diffusion in a Spatial Economy.

We can substitute (6.20') and (6.21') into (6.11) and get:

$$Q_t = N\{t, \mu_D', \sigma_D^2\} \qquad (6.22')$$

where

$$\mu_D' = \frac{(\mu_{t_o} - \mu_{p_o}) + (D_{t_1} - D_{t_2})}{g_1 + g_2} \qquad \sigma_D^2 = \frac{\sigma_t^2 + \sigma_{p_t}^2}{(g_1 + g_2)^2}.$$

Thus, the basic result of a cumulative normal temporal diffusion function still holds for the case of non-constant rates of changes in the means of the distribution of $P^*_{t_i}$ and P_{t_i}.

Finally, we can discuss the situation where the variances of the distribution change. Again, this change will not alter the nature of the temporal diffusion function; the diffusion function will still possess the basic characteristic of a cumulative normal distribution. The difference is that when the variance is no longer constant, this diffusion function will become an amalgam of different cumulative normal distributions, each with a different variance. While this might cause trouble interpreting any empirical results, there seems to be no point in advancing the discussion any further to explore various characteristics of this amalgam. Unless the change in variances could alter the temporal diffusion pattern to such an extent as to make the approximation by cumulative normal distribution curve inappropriate, the basic prediction of cumulative normal temporal diffusion will still hold. Hence, we will not go any further with this point.[10]

6.5. Empirical Estimation of the Probability Distribution of Adoption

In section 6.2 we constructed a basic model of the probability distribution of adoptions for places (of different population sizes) in a spatial economy. With the assumption that the threshold population size is lognormally distributed, it follows that equation (6.2) can be rewritten as:[11]

$$\begin{aligned} Pr(t_j)\Big| &= Pr(a_{t_j} = 1 \mid P_{t_j} = P_t)\Big|_{t=t_i} \\ &= Pr(P^*_{t_j} \leq P_t)\Big|_{t=t_i} \\ &= \Lambda\{P^*_{t_i} \leq P_{t_i}\} \\ &= \Lambda\{P_{t_i};\ \mu_{t_i},\ \sigma^2_{t_i}\} \\ &= N\{\log P_{t_i};\ \mu_{t_i},\ \sigma^2_{t_i}\} \end{aligned} \tag{6.23}$$

which simply indicates that for any given innovation at time t_i, the probability of occurrence of at least one innovator increases with the population size of that location, and this probability can be approximated by a cumulative lognormal distribution. Because the assumption of a lognormally distributed threshold population level is crucial to the development of (6.11) and (6.22), we first test the validity of this assumption.

In order to linearize equation (6.23) and make it estimable by OLS, we can rewrite equation (6.23) in the form of standard cumulative normal distribution:

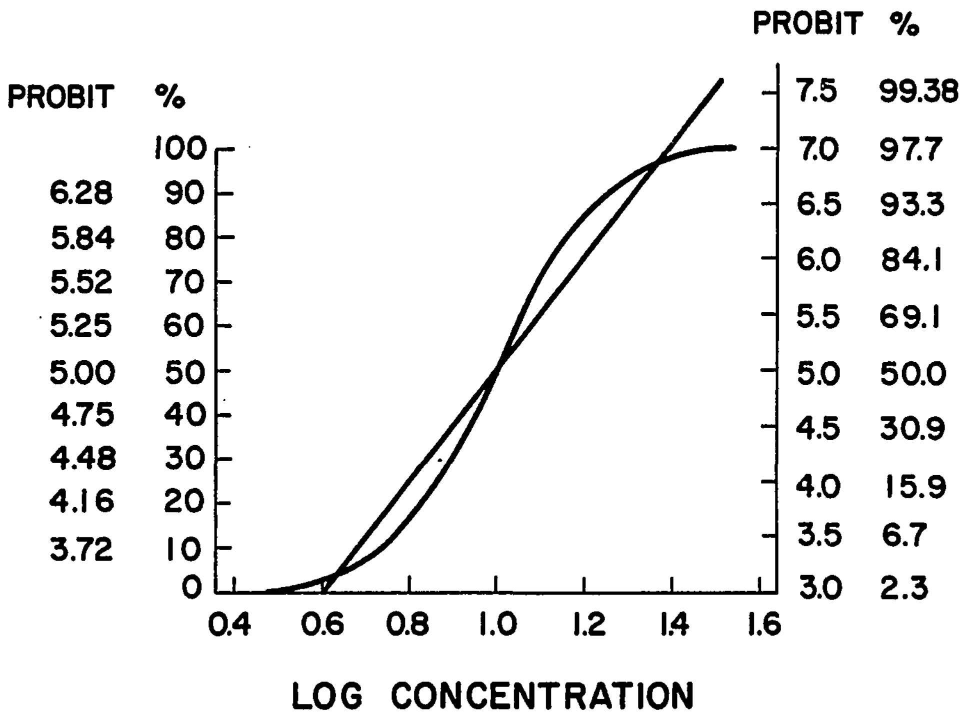
$$\Pr(t_j) = \Lambda\{P_{t_i};\ \mu_{t_i},\ \sigma^2_{t_i}\}$$

$$= N\{\log P_{t_i} - \mu_{t_i} / \sigma^2_{t_i};\ 0,\ 1\}$$

$$= N\{z;\ 0,\ 1\}\Big|_{t=t_i} \qquad (6.24)$$

where $z = -\frac{1}{\sigma^2_{t_i}}\mu_{t_i} + \frac{1}{\sigma^2_{t_i}}\log P_{t_i}$. The relationship between the cumulative (log)normal distribution and its transformation is shown in Figure 6.4. The z value is the standard normal distribution value of $\Pr(t_j)$ and is called the normal equivalent deviate of $\Pr(t_j)$ in probit analysis.[12] Although this transformation linearizes the relationship, it creates another problem: empirically $\Pr(t_j)$ and hence its corresponding z value is not directly observable. It can be approximated by the empirical frequency distribution of $m_{t_{i\ell}} / n_{i\ell}$, where $m_{t_{i\ell}}$ is the number of locations which have adopted the innovation at t_i in size class ℓ and $n_{i\ell}$ is the number of total potential adopters in size class ℓ at t_i. This creates an estimation problem: since $m_{t_{i\ell}} / n_{i\ell}$ is binomially distributed, with mean $\Pr(t_{i\ell})$ and variance $\Pr(t_{i\ell})[1-\Pr(t_{i\ell})] / n_{i\ell}$,[13] the variance of the random variable $m_{t_{i\ell}} / n_{i\ell}$ varies as $\Pr(t_{i\ell})$ varies with the population size of the urban place, causing the use of OLS estimation to be inapplicable due to heteroskedasticity. This problem is illustrated in Figure 6.5.

Two methods have been suggested to solve this problem: the maximum likelihood method suggested by Aitchison and Brown, and the minimum normit chi-square method suggested by Berkson.[14] While both methods generate asymptotically efficient estimators, the latter is



(Adopted from David J. Finney, Probit Analysis, 3rd ed., London: Cambridge University Press, 1971, p. 24, Fig. 3.2).

Figure 6.4. Effect of the Probit Transformation.

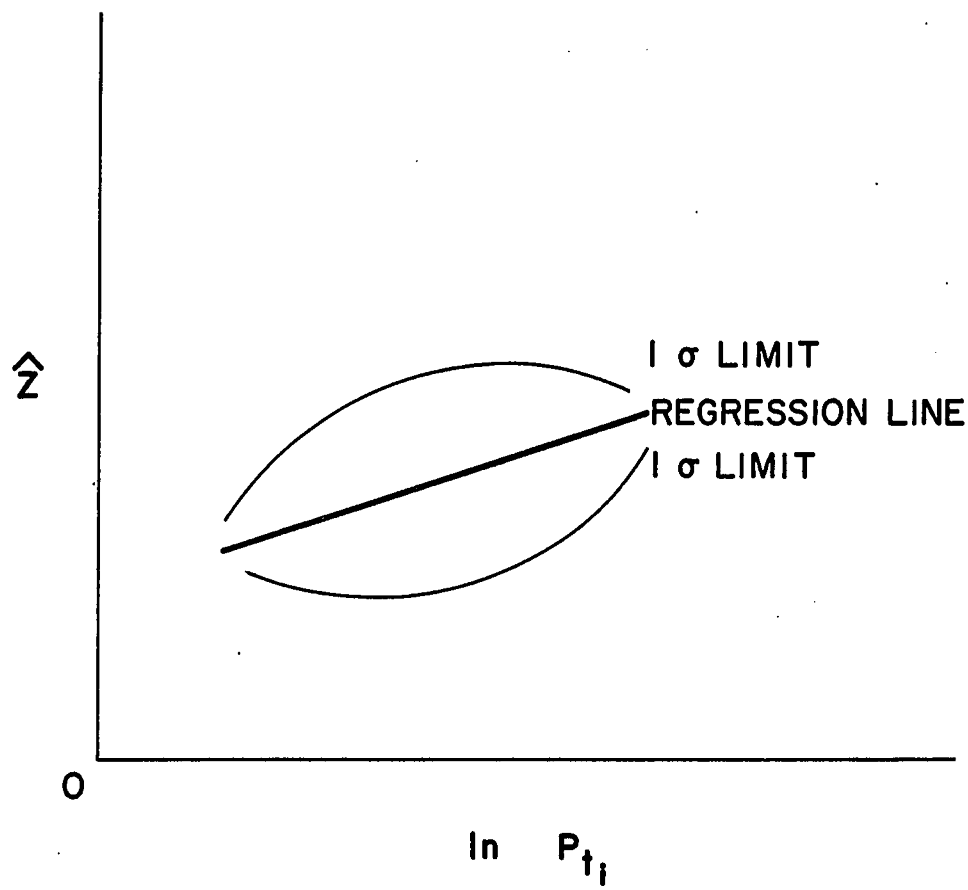


Figure 6.5. Relationship Between the Variance and the Linear Transformation of Lognormal Distribution.

claimed to yield smaller variance in finite sample size.[15] Consequently the minimum normit chi-square method will be used in this study.[16] This method calls for the use of a weight $n_{i\ell}w_{i\ell}$, where $n_{i\ell}$ is the number of potential adopters in size class ℓ for $t=t_i$, and $w_{i\ell}$ is defined as:

$$w_{i\ell} = z_{i\ell}^2 \; / \; \left(\frac{m_{t_{i\ell}}}{n_{i\ell}}\right)\left(1 - \frac{m_{t_{i\ell}}}{n_{i\ell}}\right) \tag{6.25}$$

and $z_{i\ell}$ is the normal equivalent deviate of $Pr(t_j)$ as previously defined. In essence, the method is as follows: denote $\hat{z}_{i\ell}$ as the normal equivalent deviate of $m_{t_{i\ell}} / n_{i\ell}$, then $\hat{z}_{i\ell}$ could be read from a z table given $m_{t_{i\ell}} / n_{i\ell}$. This value will be weighted with $n_{i\ell}w_{i\ell}$ to generate a new value, $\hat{\hat{z}}_{i\ell}$:

$$\hat{\hat{z}}_{i\ell} = n_{i\ell}w_{i\ell}\hat{z}_{i\ell} \tag{6.26}$$

which will be the value of the dependent variable for the regression function:

$$z_i = \frac{1}{\sigma_{t_i}^2}\,\mu_{t_i} + \frac{1}{\sigma_{t_i}^2}\log P_{t_i}\,. \tag{6.27}$$

The weights, $w_{i\ell}$, have already been calculated by Berkson and will be used here.[17]

Previous empirical studies of spatial innovation diffusion concentrate on two areas: consumer products and "cultural" or "social" innovations, which have the municipal governments or the consumers as the potential adopters.[18] The data used in the empirical tests in Chapter IV can also be used here.[19] Again, there are several deficiencies in the data: first, with no possibility of cross-checking with other data sources, we can only assume that the earliest date reported when a firm installs a computer is the date of initial adoption for that location.[20] Thus, there is a bias in the data: it underreports the number of adoptions in the U.S. at any point in time. Second, the temporal diffusion pattern generated from these data might lag behind the actual diffusion pattern as adoption may have occurred earlier than indicated by the data.[21]

Given the small number of available observations on computer installations, only places with populations greater than 30,000 are included in the analysis. Thus, n = 735. These places will be grouped into five classes in accordance with U.S. population census method.[22] Although data on population are available for the years 1960 and 1970, in 1960 diffusion of the computer was in such an early stage that most of the size classes did not have any adopters at all. Therefore, only the year 1970 would be studied, and the results are shown below[23] (standard errors in parentheses):

$$z_i = -6.026 + \underset{(0.067)}{0.433} \log P_t \qquad \text{for } t = 1970 \qquad (6.28)$$

$$\bar{R}^2 = 0.85$$

$$F = 23.68^{**}$$

where z_i is the normal equivalent deviate of $Pr(t_j)$ in equation (6.24) measured by $\hat{z}$ of equation (6.26), $\log P_{t_i}$ is the log value of population of an urban place measured by the mean population of each size class ℓ.[24] A 2-tailed t test rejects the hypothesis that the coefficient of $\log P_{t_i}$ equals zero at the 5% significance level. The double stars indicate significance at the 5% level for the F-test.

The dependent variable increases monotonically with the independent variable, as shown by the sign of the coefficient for the independent variable. This result means that the probability of occurrence of local innovators increases monotonically with population size.

Unfortunately due to data limitations, the implications derived in section 6.3 cannot be tested empirically. A test of the model presented in section 6.4 can be considered as an indirect test of the results derived in section 6.3. In the next section we will proceed with the test of the model presented in section 6.4.

6.6. Testing of the Functional Form of the Temporal Diffusion Function

From equation (6.22), we find the temporal diffusion function of an innovation can be approximated by a cumulative normal distribution under some restrictive assumptions. If these assumptions are relaxed, the result is equation (6.22'), which is approximately a cumulative normal distribution. Standardizing equation (6.22) or (6.22'), we get $Q_t = N\{z_t;\ 0,\ 1\}$ where

$$z = -\frac{\mu_{t_o} - \mu_{p_o}}{(\sigma_t^2 + \sigma_{p_t}^2)} + \frac{(\sigma_t^2 + \sigma_{p_t}^2)}{g_1 + g_2}\, t = \alpha_o + \alpha_1 t \qquad (6.29)$$

for equation (6.22), and

$$z = -\frac{(\mu_{t_o} - \mu_{p_o}) + (D_{t_2} - D_{t_1})}{(\sigma_t^2 + \sigma_{p_t}^2)} + \frac{(\sigma_t^2 + \sigma_{p_t}^2)}{g_1 + g_2} t = \alpha_o' + \alpha_1' t \quad (6.29')$$

for equation (6.22'), and z_t is the normal equivalent deviate or normit of Q_t. The estimating functions (6.29) and (6.29') suffer the same problem of heteroskedasticity discussed previously. Therefore, each observation will be weighted by $n_i w_i$, where n_i is the total number of potential adopters in each year i and w_i is the weight corresponding to each empirical frequency of adoption, $(m/n)_{t_i}$ or m_{t_i}/n_i, calculated by Berkson. Although the number of places with a population of no less than 30,000 changed from 587 in 1960 to 735 in 1970, we will assume for convenience that it is constant and take the value of 735 as the total number of potential adopters. A regression yielded the following results:[25]

$$z_t = -2.36 + 0.09\, t \quad (6.30)$$
$$(0.0048)$$
$$\bar{R}^2 = 0.93$$
$$F = 151.44^{**}$$

where z_t is the normal equivalent deviate of Q_t of equation (6.22) and is measured by $\hat{z}$ of equation (6.26), and t measures the elapsed time from $t_o = 1959$ in years. A 2-tailed t test rejects the hypothesis of zero coefficient for t at the 5% significance level, and the F-test is statistically significant at the 5% level, as indicated by the double stars.

The Durbin-Watson statistic to detect the existence of serial correlation is less applicable in this case due to the transformation of the curvilinear function into a weighted linear regression function. For comparison, the same data were also fitted to the logistic function with the following result:

Empirical model:[26] $\log (m_{t_i}/n_i - m_{t_i}) = \alpha_o + \alpha_1 t$ (6.31)

Empirical results: $\log (m_{t_i}/n_i - m_{t_i}) =$

$$-5.04 + \underset{(0.019)}{0.24t} \quad (6.32)$$

$\bar{R}^2 = 0.91$

$F = 157.18^{**}$.

The 2-tailed t test rejects the hypothesis of zero coefficient for the independent variable t at the 5% significance level and the F-test is significant at the 5% level, as indicated by the double stars.

If we judge the result by the goodness of fit of the different functional forms, it seems that the suggested model is as good in fitting the diffusion pattern as the logistic function. Unfortunately since we do not have enough data to repeat the test on different industries or different innovations, we cannot make any definitive claim as to the superiority in approximating empirical diffusion path of innovations of the proposed model, although this model has a stronger theoretical basis.

6.7. Conclusion: Implications

In this chapter we set out two goals: (1) exploring the probability distribution of innovation adoption of urban places at a given point in time; and (2) developing a temporal diffusion function for an innovation based on a given probability distribution. We found that the probability of an urban place adopting an innovation at any given time increases monotonically with its population size and can therefore be approximated by a cumulative lognormal distribution. From this finding we developed a cumulative normal distribution to approximate the temporal diffusion pattern of innovations.

Myrdal has argued that regardless of initial location advantages (such as natural resources, transport facility, and so on), regions with higher productivity will build up advantages which lead to agglomeration economies.[27] If speedy adoption of innovations contributes to the increase in productivity, then regions which contain relatively more large urban places will in general have more places adopting innovations at any given time than those regions with a relatively small number of large cities. The former regions will have an advantage in building up agglomeration economies. If growth parity among regions is a goal of an economy, then in order to decrease inequality among regions, we may have to consider policies which improve the probability of innovation adoption for regions where relatively large numbers of small cities are found.

ENDNOTES

1. For example, exponential functions in the form of equation (2.31) have been suggested to approximate the temporal diffusion pattern.

2. This is the conclusion we reached from discussions in section 4.2, especially 4.2.2 to 4.2.4.

3. The threshold adoption level, $P^*_{t_j}$, is closely related to H^*_r (discussed) in Chapter IV. The difference is that H^*_r is the threshold urban rank for a firm to innovate, while $P^*_{t_j}$ is the threshold (economic characteristics or) urban rank for a place j to innovate. As an urban place can contain firms of different sizes, and each size has its own H^*_r, $P^*_{t_j}$ does not equal to H^*_r. In addition, we use population size to approximate P^* for the reason that studies of spatial innovation diffusion use population as a measure of (economic) characteristics of urban places. So the use of the same measure here facilitates the comparison of results.

4. J. S. Cramer, <u>Empirical Econometrics</u> (Amsterdam: North-Holland, 1969), p. 37.

5. Aitchison and Brown (1959), p. 109.

6. Aitchison and Brown (1957), p. 13.

7. Aitchison and Brown (1957), p. 101; M. J. H. Mogridge, "Some Factors Influencing the Income Distribution of Households Within a City Region," in <u>Studies in Regional Sciences</u>, ed. Allen J. Scott (London: Pion Limited, 1969), pp. 117-141.

8. Aitchison and Brown (1957), pp. 11, 139; J. S. Cramer, <u>Mathematical Methods of Statistics</u> (Princeton: Princeton University Press, 1945), p. 190.

9. Aitchison and Brown (1957), p. 7.

10. Davies has an extensive discussion which considers all the possible variations when $\sigma^2_{t_i}$ and $\sigma^2_{P_{t_i}}$ change over time. See Davies (1979), pp. 83-84.

11. Aitchison and Brown (1957), p. 125.

12. The relationship between $Pr(t_j)$ and z has been discussed in detail in probit analysis. See, e.g., D. J. Finney, Probit Analysis, 3rd ed. (London: Cambridge University Press, 1971).

13. Joseph Berkson, "Estimate of the Integrated Normal Curve by Minimum Normit Chi-square with Particular Reference to Bio-assay," Journal of American Statistical Association, 50 (1955), 529.

14. Aitchison and Brown (1957), pp. 68-84; Berkson (1955), 529-549.

15. Berkson (1955), p. 531.

16. Actually these two methods are not different from each other in empirical estimation. Both call for the use of a weight in weighing observations before regressing the data, and the weight is the same in both methods. Cf. Finney (1971), Table II, pp. 288-308; and Berkson (1955), Table 3, pp. 540-541.

17. J. Berkson, "Tables for Use in Estimating the Normal Distribution Function by Normit Analysis," Biometrika, 44 (1957), Table 2, 418-419.

18. See, e.g., Pederson (1970); and I. Feller, "Diffusion of Technology in Municipal Governments," Progress Report, NSF Grant DA-44350, The Pennsylvania State University, 1975.

19. Although from a theoretical viewpoint it would be better if we could test the implications on several industries which are scattered in the spatial economy, the reported installations of computers by firms of other industries again prove to be too small in number to present a meaningful test.

20. The two data sources and Computers and Automation and EDP Weekly, as was reported previously.

21. The data set is shown in Appendix A.6.

22. Alternatively a more detailed classification of eight classes is also used. These eight classes and the estimation results are listed in Appendix A.7.

23. The value of the regressor is the mean value for each size class. For the calculation of this regression equation, please see Appendix A.7.

24. The mean population of each size class is shown in Appendix A.6.

25. For the calculation, please see Appendix A.8.

26. The empirical estimation function for the logistic function is derived in Mansfield (1961), p. 750.

27. Gunnar Myrdal, Economic Theory and Under-developed Programs (London: Duckworth, 1957). This theory is referred to as the "cumulative causation" model in Harry E. Richardson, Regional Growth Theory (New York: John Wiley & Sons, 1973), pp. 29-34.

CHAPTER VII

CONCLUSIONS

The main purpose of this study is to examine the effect of geographical space on the diffusion of innovations. A two-part approach is adopted in the theoretical discussion. On the one hand we examine the behavior of a profit-maximizing firm toward innovation in a spatial context and extend this discussion to interfirm differences in the speed of response to an innovation. On the other hand, we also examine the pattern of diffusion of an innovation in a spatial economy and provide a theoretical model to explain such a pattern.

In the first part of the theoretical exploration, that of the behavior of firms toward innovation in a spatial context, previous economic studies have indicated that in a spaceless economy firm size and expected profit from adoption of the innovation are important factors in explaining interfirm differences in speed of response of firms toward an innovation. Less clear are the effects of growth rate, general profitability, profit trend, aggressiveness of the management (measured by the age and education level of the management), amount of research and development activities conducted, and percentage of foreign ownership of the firm. In the model developed in this study we have shown that spatial factors also affect a firm's decision toward innovation adoption through the form of urban hierarchy as well as neighborhood effects. The location rank of a firm will affect its information cost. With imperfect information on a new invention, the amount of information acquired by a firm will affect its calculation of expected profit from adoption of the innovation, which in turn will affect the firm's attitude toward adoption of the innovation. As information cost is inversely related to a firm's location rank, the spatial factor will influence a firm's decision toward adoption of an innovation through its effect on information cost and hence the amount of information acquired by a firm. In addition, the spatial factor can also execute its influence on a firm's attitude toward innovation adoption through the "neighborhood effect," the number of neighboring firms which have already adopted the innovation. The greater the number of neighboring firms which have adopted the innovation, the smaller the cost of information for the remaining firms as the radius of search becomes smaller. This again will affect the amount of information a firm acquires and hence its attitude toward innovation adoption. Therefore interfirm differences in speed of response to an innovation are due in part to differences in location rank and the number of neighboring firms which have adopted the innovation, in addition to the factors which have been pointed out in previous economic studies. Besides, since the phenomenon studied here is related to a regulated industry, differences in regulatory constraints on business practice in the innovation adopter industry also enter the theoretical model in explaining interfirm differences in the speed of response to an innovation.

In the empirical estimation 14 socioeconomic characteristics of urban places from the U.S. 1970 Census were chosen to form a data matrix on which a factor analysis was conducted. Two factors generated from this analysis were used to proxy the urban hierarchy variable of these two factors. One loads on the income characteristics of urban places, while the other loads on population characteristics. The neighborhood effect was proxied by dummies representing different regions of the spatial economy, and since the adopter industry is the commercial banking industry, boundaries of the Federal Reserve Districts serve as the boundaries for the different regions. Empirical estimation results have shown that both the firm size and location rank are important factors in explaining interfirm differences in speed of response to an innovation. Effects of the other factors (growth rate, average profit, profit trend, regulatory constraints, and the number of neighboring firms which have adopted the innovation) are less clear. The arc elasticities of firm size effect and urban rank effect are both -0.5, indicating that a doubling in the size of a firm or a relocation of the firm to a place which has twice the score of the urban rank factor will shorten the time lag of response to innovation adoption by half.

Previous spatial innovation diffusion studies have noted that the temporal pattern of innovation diffusion follows an S-shaped path, but the property of this temporal diffusion function was not clearly indicated in these studies. In the second part of the theoretical exploration a model was built to derive the temporal diffusion function of innovations in a spatial economy. From the notion that a spatial economy is composed of urban places of various sizes, our theoretical discussion finds that the probability that at least one firm will innovate at any time increases with the increase in (population) size of a place, and that probability follows a cumulative lognormal distribution. From this basis we find that over time the cumulative adoption level of an innovation can be approximated by a cumulative normal distribution. In other words, the temporal diffusion pattern of innovations in a spatial economy follows a cumulative normal distribution. Empirical estimation provides supporting evidence for the theoretical model. The proposition that the probability of innovation by at least one firm for a place at any time increases monotonically and follows a cumulative lognormal distribution is supported by statistical hypothesis testing, and the use of cumulative normal distribution to approximate the temporal diffusion pattern is also shown to have a good fit of the trend pattern.

Growth imparity among regions has been an issue discussed in many studies. If differences in the speed of diffusion of innovations also contribute to the difference in the rate of growth of regions, then our study provides a useful means of measuring the speed of diffusion of innovations. Researchers can then compare the differences in the speed of innovation diffusion and explore their relationships with differences in the rate of growth of regions. If parity in regional growth is one of the goals of a country, then these studies can provide useful implications for policy makers. Due to data limitation this part of the work was not conducted in this study, but it is hoped that future researchers will fill in the gap in our knowledge on this part of the world.

In conclusion, it is appropriate to say that the primary purpose of this study is to provide a better understanding of the innovation diffusion phenomenon by presentation of theoretical models and the assembly of data to test such models. More works remain to be done and more empirical studies are needed to provide us with a better understanding of diffusion of innovations, be it in a general (spaceless) sense or in a spatial framework. In view of past efforts on this topic, the latter aspect deserves more attention by researchers, and it is hoped that this current study might provide them with some insights about innovation diffusion in the banking industry.

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Appendix A.1

AMERICAN BANKERS ASSOCIATION
BANK AUTOMATION SURVEY, 1981:
SURVEY QUESTIONNAIRES
(APPLICATION OF COMPUTERS IN
COMMERCIAL BANKING)

AMERICAN
BANKERS
ASSOCIATION

1120 Connecticut Avenue, N.W.
Washington, D.C.
20036

OPERATIONS
AUTOMATION
DIVISION

February, 1981

Dear Fellow Banker:

The ABA NATIONAL OPERATIONS AND AUTOMATION SURVEY is widely recognized as the banking industry's most objective and useful study. Conducted every three years, the survey provides results in a comprehensive report describing—by bank asset size—the allocation of funds, expenses, operation and automation status, and plans. Bankers need this information to compare their operational efficiencies with industry standards and with banks of similar size, as well as to project future developments.

In addition to these valuable comparative data, the survey provides a critical planning reference guide for the vendors who serve the banking industry. The results and trends described in the survey report have led to the development and modification of many products.

You are among a selected group of bankers chosen to participate in the *seventh* ABA NATIONAL OPERATIONS AND AUTOMATION SURVEY, and we request your assistance in making this year's survey the most thorough ever conducted. The cooperation of banks of all sizes is essential to present an accurate picture of the status of operations and automation within the banking industry. Be assured that all replies will be held in strictest confidence, and results will be presented within categories of bank asset size only. Banks responding to this questionnaire will receive a complimentary printed summary of the survey results.

We hope that you will join with others to complete and return your questionnaire within two weeks of receipt. This will make the printed report timely and useful. Please direct the questionnaire to the individual best able to respond on your behalf. We appreciate your continued assistance.

Cordially,

Lois C. Martin
Chairperson
Research and Planning Committee
Operations and Automation Division
Vice President
First National Bank of Minneapolis
Minneapolis, Minnesota

Thomas G. Lynch
Subcommittee Chairman
National Operations and Automation Survey
Senior Vice President
Mercantile Bank of Dallas
Dallas, Texas

NATIONAL OPERATIONS AND AUTOMATION SURVEY—1981

(for the year ended December 31, 1980)

QUESTIONNAIRE INSTRUCTIONS

- Please report information for your domestic banking operations including branches, if any.
- If not otherwise indicated, report all data for the last calendar year, January 1 to December 31, 1980, or as of December 31, 1980, as appropriate.
- Not all questions are applicable to all banks. However, it is important to have your 'NONE' or 'ZERO' answers *as well as* your responses in those areas in which your bank is active. We urge you to respond to this questionnaire as completely as possible. If exact figures are not known, please use best estimates. If any answer is not known or not available, answer with 'N.A.'
- Unless a question specifically states to "CHECK ALL THAT APPLY," only ONE category should be checked within any question or question subsection.
- If you have any questions, phone Kit Needham (202/467-4040), Associate Director, Operations/Automation Division.

GENERAL INFORMATION/ADMINISTRATION

1. Indicate the following information as of December 31, 1980:

	BILL	MILL	THOU	HUND	
a. Your bank's total assets	$			XXX	CD01: 6-13
b. Your bank's total operating expenses	$			XXX	15-22
c. Your bank's total operating expenses but excluding interest paid	$			XXX	24-31

	NUMBER	
d. Full-time personnel for entire bank		33-38
e. Part-time personnel (Indicate full-time equivalent of part-time personnel.)		40-45
f. Deposit accounts:		
1. Individual demand deposit accounts		47-54
2. Partnership/Corporate demand deposit accounts		56-63
3. Other demand deposit accounts (including government deposits)		65-72
4. Savings		CD02: 6-13
5. NOW accounts		15-22
6. Money markets		24-31
7. Certificates of deposit below $100,000		33-40
8. Certificates of deposit $100,000 and above		42-49
9. IRA		51-58
10. Keogh		60-67
11. All other deposit accounts		69-76
g. Average daily number of deposit account on-us transactions:		
1. Paper		CD03: 6-13
2. *Electronic*		15-22

2. How is your bank classified?
   CHECK ALL THAT APPLY

   a. Unit bank ☐ 24-1
   b. Regional bank ☐ 25-1
   c. County bank ☐ 26-1
   d. Money center bank ☐ 27-1
   e. City bank (according to Federal classification) ☐ 28-1
   f. Branch bank ☐ 29-1

   Specify number of domestic branches ______ 31-34

3a. What are your functional application research and development expenses as a percentage of your net income (as shown in your 1980 annual report)? ______ % 36-39

3b. *What are your pure research and development* expenses as a percentage of your net income? (Pure research and development means efforts aimed at the creation of new technology applicable to bank operations and automation problems.) ______ % 41-44

4. Indicate your opinion regarding the likelihood of each of the following items becoming adopted on an industrywide scale and your bank's participation:

	A. ADOPTION ON AN INDUSTRYWIDE SCALE				B. YOUR BANK'S PARTICIPATION	
	Currently Adopted	Likely Within 3 Years	Likely In More Than 3 Years	Not Likely	Participating/ Will Participate	Will Not Participate
1. Interbank electronic mail	☐ 46-1	☐ -2	☐ -3	☐ -4	☐ 15-1	☐ -2
2. Independent bank voice (telephone) network	☐ 47-1	☐ -2	☐ -3	☐ -4	☐ 16-1	☐ -2
3. National (nationwide) banking	☐ 48-1	☐ -2	☐ -3	☐ -4	☐ 17-1	☐ -2
4. Interest on corporate demand deposit balances	☐ 49-1	☐ -2	☐ -3	☐ -4	☐ 18-1	☐ -2
5. Automated (unmanned) office	☐ 50-1	☐ -2	☐ -3	☐ -4	☐ 19-1	☐ -2
6. Productivity measurement standards	☐ 51-1	☐ -2	☐ -3	☐ -4	☐ 20-1	☐ -2
7. High-speed data transmission equipment (above 1.5 million bits per second)	☐ 52-1	☐ -2	☐ -3	☐ -4	☐ 21-1	☐ -2
8. National Clearinghouse Association (not automated)	☐ 53-1	☐ -2	☐ -3	☐ -4	☐ 22-1	☐ -2
9. Check safekeeping	☐ 54-1	☐ -2	☐ -3	☐ -4	☐ 23-1	☐ -2
10. Data encryption from ATMs	☐ 55-1	☐ -2	☐ -3	☐ -4	☐ 24-1	☐ -2
11. Data encryption on wire services	☐ 56-1	☐ -2	☐ -3	☐ -4	☐ 25-1	☐ -2
12. Voice identification systems	☐ 57-1	☐ -2	☐ -3	☐ -4	☐ 26-1	☐ -2
13. Interstate banking	☐ 58-1	☐ -2	☐ -3	☐ -4	☐ 27-1	☐ -2
14. Personal tax accounting services	☐ 59-1	☐ -2	☐ -3	☐ -4	☐ 28-1	☐ -2
15. Private Automated Clearinghouse network	☐ 60-1	☐ -2	☐ -3	☐ -4	☐ 29-1	☐ -2
16. Reduced work week—less than 5 days	☐ 61-1	☐ -2	☐ -3	☐ -4	☐ 30-1	☐ -2
17. Reduced work week—less than 40 hours	☐ 62-1	☐ -2	☐ -3	☐ -4	☐ 31-1	☐ -2
18. Work stations (terminals) in the home	☐ 63-1	☐ -2	☐ -3	☐ -4	☐ 32-1	☐ -2
19. Merger of ABA and BAI technical and operational resources	☐ 64-1	☐ -2	☐ -3	☐ -4	☐ 33-1	☐ -2
20. 100% direct deposit of government recurring payments	☐ 65-1	☐ -2	☐ -3	☐ -4	☐ 34-1	☐ -2
21. GIRO system payments	☐ 66-1	☐ -2	☐ -3	☐ -4	☐ 35-1	☐ -2
22. On-line bank terminals on customer premises	☐ 67-1	☐ -2	☐ -3	☐ -4	☐ 36-1	☐ -2
23. Single nationwide authorization system for charge cards	☐ 68-1	☐ -2	☐ -3	☐ -4	☐ 37-1	☐ -2
24. *Truncation of checks at bank of first deposit*	☐ 69-1	☐ -2	☐ -3	☐ -4	☐ 38-1	☐ -2
25. Miniature check images on statement	☐ 70-1	☐ -2	☐ -3	☐ -4	☐ 39-1	☐ -2
26. Extensive bank at home products via T.V.	☐ 71-1	☐ -2	☐ -3	☐ -4	☐ 40-1	☐ -2
27. Data transmission utility for banking	☐ 72-1	☐ -2	☐ -3	☐ -4	☐ 41-1	☐ -2
28. A single regulatory authority for all financial institutions	☐ 73-1	☐ -2	☐ -3	☐ -4	☐ 42-1	☐ -2
29. Elimination of large dollar paper items (over $25,000).	☐ 74-1	☐ -2	☐ -3	☐ -4	☐ 43-1	☐ -2
30. More non-credit services purchased by fees than by balances	☐ 75-1	☐ -2	☐ -3	☐ -4	☐ 44-1	☐ -2
31. Corporate customers using on-line bank terminals for customer services	☐ 76-1	☐ -2	☐ -3	☐ -4	☐ 45-1	☐ -2
32. Mutual funds sold by banks	☐ 77-1	☐ -2	☐ -3	☐ -4	☐ 46-1	☐ -2
33. Reduction in number of full service banking offices	CD04: ☐ 6-1	☐ -2	☐ -3	☐ -4	☐ 47-1	☐ -2
34. Increase in number of full service banking offices	☐ 7-1	☐ -2	☐ -3	☐ -4	☐ 48-1	☐ -2
35. Reduction in number of non-exempt personnel	☐ 8-1	☐ -2	☐ -3	☐ -4	☐ 49-1	☐ -2
36. Reduction in number of exempt personnel	☐ 9-1	☐ -2	☐ -3	☐ -4	☐ 50-1	☐ -2
37. Increase in merger activity	☐ 10-1	☐ -2	☐ -3	☐ -4	☐ 51-1	☐ -2
38. *Increase in use of ACH facilities*	☐ 11-1	☐ -2	☐ -3	☐ -4	☐ 52-1	☐ -2
39. Use of "benefit flow" pricing techniques for ACH activity	☐ 12-1	☐ -2	☐ -3	☐ -4	☐ 53-1	☐ -2
40. NACHA increasing its influence on the ACH movement	☐ 13-1	☐ -2	☐ -3	☐ -4	☐ 54-1	☐ -2

5. Indicate the areas in which your bank has a formal quality control program.
CHECK ALL THAT APPLY

a. Check processing .... ☐ 56-1
b. Data processing .... ☐ 57-1
c. Operations (non-EDP) .... ☐ 58-1
d. Other: ______________________ (specify) ☐ 59-1

6. Indicate the methods used by your bank to identify customers at the teller stations (for those transactions requiring customer identification):
CHECK ALL THAT APPLY

a. PIN .... ☐ 61-1
b. Visual recognition .... ☐ 62-1
c. Driver's license .... ☐ 63-1
d. Bank card .... ☐ 64-1
e. Bank card plus photograph .... ☐ 65-1
f. On-line system .... ☐ 66-1
g. Microfilm/microfiche retrieval unit .... ☐ 67-1
h. Other: ______________________ (specify) ☐ 68-1

7. Please indicate your bank's 1980 operating losses resulting from (Use "0" if NONE incurred.):

	DOLLAR AMOUNT		PERCENTAGE OF BANK OPERATING EXPENSES	
a. Forgeries	$______	CD05: 6-13	______%	60-63
b. Chargebacks and kites	$______	15-22	______%	65-68
c. Teller (check cashing)	$______	24-31	______%	70-73
d. Counterfeit bills	$______	33-40	______%	75-78
e. ATMs	$______	42-49	______%	CD06: 6-9
f. Other ______ (specify)	$______	51-58	______%	11-14

	YES	NO, BUT PLAN TO	NO, AND NO PLANS
8. Do you presently use an automated energy management system? ...	☐ 16-1	☐ -2	☐ -3
9. Do you presently have a formal disaster plan, i.e., procedures to be used in case of a major operations failure?	☐ 17-1	☐ -2	☐ -3
10. Do you presently control access to your computer room?	☐ 18-1	☐ -2	☐ -3
11. Do you presently control access to your check processing area?	☐ 19-1	☐ -2	☐ -3
12. Do you use flex-time or any other flexible hours working arrangement for your employees?	☐ 20-1	☐ -2	☐ -3
13. Do you use a four day work week?	☐ 21-1	☐ -2	☐ -3

14. What has been the overall reaction of your employees to a flexible hours program?

a. Favorable .... ☐ 22-1
b. Unfavorable .... ☐ 22-2
c. Did not explore .... ☐ 22-3

15. Overall, do your feel a non-traditional flexible approach to working hours is a good or bad idea?

a. Good idea .... ☐ 23-1
b. Bad idea .... ☐ 23-2
c. Did not explore .... ☐ 23-3

WORD PROCESSING

16. *Does your bank presently use telephone dictation systems?*

a. *YES, presently uses* .... ☐ 25-1
b. NO, but plans exist .... ☐ 25-2
c. NO, and no plans exist .... ☐ 25-3

17. Indicate the following with respect to your bank's use of word processing:

a. Current status of use: ....

1. Presently uses .... ☐ 27-1
2. Not using, but plans to use:
   a. Within 1 year .... ☐ 27-2
   b. Within 2-3 years .... ☐ 27-3
   c. Within 4 or more years .... ☐ 27-4
3. Not using, and no plans exist .... ☐ 2

b. 1980 average monthly word processing cost (for all such equipment.): .... $________ 29-36

c. Of total word processing usage, the percentage of usage for the following applications:

1. Trust .... ______ % 38-41
2. DDA .... ______ % 43-46
3. New customer .... ______ % 48-51
4. Loans .... ______ % 53-56
5. Bank operations .... ______ % 58-61
6. Branch operations .... ______ % 63-66
7. Other: ______________ (specify) ______ % 68-71

TOTAL 100%

AUTOMATED SERVICES

18. The following list includes possible objectives with respect to several automated customer services. Indicate whether you offer each service, and the emphasis you will place on each service next year:

AUTOMATED CUSTOMER SERVICE	A. CURRENT STATUS OF SERVICE			B. OBJECTIVE FOR NEXT YEAR IF CURRENTLY OFFERED			
	Currently Offered	Will Offer Within 1 Year	Not Offered	Increased Emphasis	Same Emphasis	Decreased Emphasis	Planning to Discontinue
1. Payroll	☐ 73-1	☐ -2	☐ -3	☐ 46-1	☐ -2	☐ -3	☐ -4
2. Account reconciliation	☐ 74-1	☐ -2	☐ -3	☐ 47-1	☐ -2	☐ -3	☐ -4
3. Correspondent bank services	☐ 75-1	☐ -2	☐ -3	☐ 48-1	☐ -2	☐ -3	☐ -4
4. Accounts receivable	☐ 76-1	☐ -2	☐ -3	☐ 49-1	☐ -2	☐ -3	☐ -4
5. Professional billing	☐ CD07: 6-1	☐ -2	☐ -3	☐ 50-1	☐ -2	☐ -3	☐ -4
6. Sales analysis	☐ 7-1	☐ -2	☐ -3	☐ 51-1	☐ -2	☐ -3	☐ -4
7. Inventory analysis	☐ 8-1	☐ -2	☐ -3	☐ 52-1	☐ -2	☐ -3	☐ -4
8. Mortgage servicing	☐ 9-1	☐ -2	☐ -3	☐ 53-1	☐ -2	☐ -3	☐ -4
9. Accounts payable	☐ 10-1	☐ -2	☐ -3	☐ 54-1	☐ -2	☐ -3	☐ -4
10. Hospital accounting	☐ 11-1	☐ -2	☐ -3	☐ 55-1	☐ -2	☐ -3	☐ -4
11. Insurance premium billing	☐ 12-1	☐ -2	☐ -3	☐ 56-1	☐ -2	☐ -3	☐ -4
12. Freight plan	☐ 13-1	☐ -2	☐ -3	☐ 57-1	☐ -2	☐ -3	☐ -4
13. Rental receipt collection	☐ 14-1	☐ -2	☐ -3	☐ 58-1	☐ -2	☐ -3	☐ -4
14. Tax billing	☐ 15-1	☐ -2	☐ -3	☐ 59-1	☐ -2	☐ -3	☐ -4
15. Credit union accounting	☐ 16-1	☐ -2	☐ -3	☐ 60-1	☐ -2	☐ -3	☐ -4
16. Time-sharing service	☐ 17-1	☐ -2	☐ -3	☐ 61-1	☐ -2	☐ -3	☐ -4
17. Computer output microfilm	☐ 18-1	☐ -2	☐ -3	☐ 62-1	☐ -2	☐ -3	☐ -4
18. Savings and loan accounting	☐ 19-1	☐ -2	☐ -3	☐ 63-1	☐ -2	☐ -3	☐ -4
19. Private label credit card	☐ 20-1	☐ -2	☐ -3	☐ 64-1	☐ -2	☐ -3	☐ -4
20. Corporate financial forecasting	☐ 21-1	☐ -2	☐ -3	☐ 65-1	☐ -2	☐ -3	☐ -4
21. Bank financial forecasting	☐ 22-1	☐ -2	☐ -3	☐ 66-1	☐ -2	☐ -3	☐ -4
22. Student loans	☐ 23-1	☐ -2	☐ -3	☐ 67-1	☐ -2	☐ -3	☐ -4
23. Share draft or NOW processing	☐ 24-1	☐ -2	☐ -3	☐ 68-1	☐ -2	☐ -3	☐ -4
24. Pay-by-phone	☐ 25-1	☐ -2	☐ -3	☐ 69-1	☐ -2	☐ -3	☐ -4
25. Balance reporting	☐ 26-1	☐ -2	☐ -3	☐ 70-1	☐ -2	☐ -3	☐ -4
26. ATM servicing	☐ 27-1	☐ -2	☐ -3	☐ 71-1	☐ -2	☐ -3	☐ -4
27. ACH debit	☐ 28-1	☐ -2	☐ -3	☐ 72-1	☐ -2	☐ -3	☐ -4
28. ACH credit origination	☐ 29-1	☐ -2	☐ -3	☐ 73-1	☐ -2	☐ -3	☐ -4
29. Investment account service	☐ 30-1	☐ -2	☐ -3	☐ 74-1	☐ -2	☐ -3	☐ -4
30. Depository transfer checks	☐ 31-1	☐ -2	☐ -3	☐ 75-1	☐ -2	☐ -3	☐ -4
31. PAC	☐ 32-1	☐ -2	☐ -3	☐ 76-1	☐ -2	☐ -3	☐ -4
32. Retail remittance processing	☐ 33-1	☐ -2	☐ -3	☐ 77-1	☐ -2	☐ -3	☐ -4
33. Corporate remittance processing	☐ 34-1	☐ -2	☐ -3	☐ CD08: 6-1	☐ -2	☐ -3	☐ -4
34. Business savings accounts	☐ 35-1	☐ -2	☐ -3	☐ 7-1	☐ -2	☐ -3	☐ -4
35. Remote disbursements	☐ 36-1	☐ -2	☐ -3	☐ 8-1	☐ -2	☐ -3	☐ -4
36. Controlled disbursements	☐ 37-1	☐ -2	☐ -3	☐ 9-1	☐ -2	☐ -3	☐ -4
37. Electronic mail	☐ 38-1	☐ -2	☐ -3	☐ 10-1	☐ -2	☐ -3	☐ -4
38. Terminal initiated wires	☐ 39-1	☐ -2	☐ -3	☐ 11-1	☐ -2	☐ -3	☐ -4
39. Zero balance accounts	☐ 40-1	☐ -2	☐ -3	☐ 12-1	☐ -2	☐ -3	☐ -4
40. Customer initiated ACH entries	☐ 41-1	☐ -2	☐ -3	☐ 13-1	☐ -2	☐ -3	☐ -4
41. Machine initiated ACH entries	☐ 42-1	☐ -2	☐ -3	☐ 14-1	☐ -2	☐ -3	☐ -4
42. Accounts receivable data via ACH	☐ 43-1	☐ -2	☐ -3	☐ 15-1	☐ -2	☐ -3	☐ -4

TELEPHONE BANKING

19. Does your bank presently offer a telephone banking service?
   a. YES .... ☐ 17-1
   b. NO, but plans exist .... ☐ 17-2
   c. NO, and no plans .... ☐ 17-3

20a. What percentage of your base of transaction accounts (savings, NOW, checking, etc.) utilizes the telephone banking system?
_______ % 19-22

20b. Twelve months ago, what percentage of your base of transaction accounts utilized the telephone banking system?
_______ % 24-27

20c. What percentage of your volume is generated from . . .
   1. . . . rotary dial phones? .... _______ % 29-32
   2. . . . touch-tone phones? .... _______ % 34-37

20d. Do you use recording devices for "off hour" service and subsequent data entry?
YES ☐ 39-1
NO ☐ 39-2

20e. How many merchants are available through your system?
_______ 41-45
NUMBER

20f. Does your system presently offer warehousing capability for payments?
   1. YES .... ☐
   2. NO, but plans exist .... ☐ 47-2
   3. NO, and no plans exist .... ☐ 47-3

20g. Indicate through which of the following accounts you offer telephone bill payment service:
CHECK ALL THAT APPLY
   1. Demand accounts .... ☐ 49-1
   2. Passbook savings .... ☐ 50-1
   3. Statement savings .... ☐ 51-1
   4. NOW accounts .... ☐ 52-1
   5. ATS accounts .... ☐ 53-1
   6. Credit card accounts .... ☐ 54-1

20h. Do you provide a special "lobby phone" in your bank for telephone bill payment service?
YES ☐ 56-1
NO ☐ 56-2

20i. Do you plan on using the ACH to process payments and accounts receivable data to the payee?
YES ☐ 58-1
NO ☐ 58-2

20j. How many hours daily are your bank's telephone banking services available?
HOURS _______

CASH MANAGEMENT

	YES	NO, BUT PLANS TO	NO, AND NO PLANS
21. Does your bank provide any cash management services to customers?	☐ 63-1	☐ -2	☐ -3
22. Does your bank provide any cash management services to correspondents?	☐ 64-1	☐ -2	☐ -3

23. Please indicate which cash management services you are now providing to customers or correspondents: CHECK ALL THAT APPLY

	CUSTOMERS	CORRESPONDENTS
a. Lock box	☐ 66-1	☐ 74-1
b. Remittance processing	☐ 67-1	☐ 75-1
c. Balance reporting	☐ 68-1	☐ 76-1
d. Terminal initiated services	☐ 69-1	☐ 77-1
e. Concentration accounts	☐ 70-1	☐ CD09: 6-1
f. Treasury management services	☐ 71-1	☐ 7-1
g. Investment accounting services	☐ 72-1	☐ 8-1
h. Zero balance accounts	☐ 10-1	☐ 17-1
i. Accounts reconciling services	☐ 11-1	☐ 18-1
j. PAC	☐ 12-1	☐ 19-1
k. Depository transfer checks	☐ 13-1	☐ 20-1
l. Business savings accounts	☐ 14-1	☐ 21-1
m. Other: _______ (specify)	☐ 15-1	☐ 22-1

SAFEKEEPING

24. In your opinion, are current check safekeeping/truncation efforts going in the right direction for the industry? .... YES ☐ 24-1 NO ☐ -2

	YES	NO, BUT PLANS TO	NO, AND NO PLANS
25. Has your bank agreed to participate in the ABA Check Safekeeping Pilot?	☐ 26-1	☐ -2	☐ -3
26. Does your bank presently offer a check safekeeping/truncation program of its own, not connected with any industry effort?	☐ 28-1	☐ -2	☐ -3

PRODUCTIVITY

	YES	NO, BUT PLANS TO	NO, AND NO PLANS
27. Does your bank have an officer specifically in charge of productivity?	☐ 30-1	☐ -2	☐ -3
28. Does your bank have a formal work measurement program?	☐ 32-1	☐ -2	☐ -3

29. In your opinion, is productivity an issue for the banking industry today? .... YES ☐ 34-1 NO ☐ -2

30. In your opinion, is the productivity issue being adequately addressed by the industry today? .... YES ☐ 36-1 NO ☐ -2

INTERNATIONAL BANKING OPERATIONS

31. Are international operations fully integrated (i.e., on the same computer system) with domestic operations in your bank? .... YES ☐ 38-1 NO ☐ -2

32. If "NO," how many levels of management must be gone through before reaching the level where one decision would affect both international and domestic operations? .... NUMBER ______ 40-41

33. Would better integration of domestic and international operations benefit your organization overall? .... YES ☐ 43-1 NO ☐ -2

DATA PROCESSING CONSORTIUMS

34a. Does your bank belong to a data processing services consortium, group, or cooperative?

1. YES, currently belongs .... ☐ 45-1
2. NO, but plans exist .... ☐ 45-2
3. NO, and no plans exist .... ☐ 45-3

34b. Has the service provided by your consortium or cooperative been generally satisfactory?

YES ☐ 46-1
NO ☐ 46-2

34c. Has your bank stopped using the services of a consortium or cooperative?

YES ☐ 47-1
NO ☐ 47-2

35. How many of the data processing services used by your bank are provided by a correspondent bank?

a. All services .... ☐ 49-1
b. Most services .... ☐ 49-2
c. Some services .... ☐ 49-3
d. Almost no services .... ☐ 49-4
e. No services .... ☐ 49-5

36. How would you generally rate the data processing services provided by your correspondent bank?

a. Excellent .... ☐ 51-1
b. Good .... ☐ 51-2
c. Satisfactory .... ☐ 51-3
d. Unsatisfactory .... ☐ 51-4

USE OF CONSULTANTS

37. How frequently does your bank use outside consultants in the operations and automation areas?
   a. Continuously ☐ 53-1
   b. Frequently ☐ 53-2
   c. Sometimes ☐ 53-3
   d. Almost never ☐ 53-4
   e. Never ☐ 53-5

38. Please state total fees paid in 1980 for outside consultants in the areas of automation and operations. (Do not include contract programmers or software purchases.)
   $________ 55-62

39. How do you rate your bank's overall experience with operations and automation consultants?
   a. Excellent ☐ 64-1
   b. Good ☐
   c. Satisfactory ☐ 64-3
   d. Unsatisfactory ☐ 64-4

40. Of the consultants you have used, how would you rate their expertise in their areas of specialty?
   a. Excellent ☐ 66-1
   b. Good ☐ 66-2
   c. Satisfactory ☐ 66-3
   d. Unsatisfactory ☐ 66-4

CURRENT ISSUES: FLOAT

	YES	NO, BUT PLAN TO	NO, AND NO PLANS
41. Do you offer a remote disbursement service to your customers?	☐ 68-1	☐ -2	☐ -3
42. Do you offer a controlled disbursement service to your customers?	☐ 70-1	☐ -2	☐ -3

43a. Will pricing for Federal Reserve services cause you to alter your routing of transit items for presentment?
   YES ☐ 72-1
   NO ☐ 72-2

43b. Do you currently have the matter under study?
   YES ☐ 73-1
   NO ☐ 73-2

44a. What percentage of your transit items are *currently* sent to the Federal Reserve Bank?
   ________% 75-77

44b. What percentage of your transit items were sent to the Federal Reserve Bank in 1980?
   ________% CD10: 6-9

45. Has the Federal Reserve program to reduce float affected your check processing operations?
   YES ☐ 11-1
   NO ☐ 1

46. To what degree has the level of check processing services offered by your Federal Reserve Bank improved over the last twelve months?
   a. Significantly improved ☐ 13-1
   b. Somewhat improved ☐ 13-2
   c. Not at all improved ☐ 13-3

CURRENT ISSUES: REGULATION E

47. Have you had difficulty (i.e., needing senior management attention) complying with Regulation E requirements?
   a. YES, major difficulty ☐ 15-1
   b. YES, some difficulty ☐ 15-2
   c. NO ☐ 15-3

48a. Estimate your total cost for compliance with Regulation E. $________ 16-23

48b. Estimate your average monthly cost for compliance with Regulation E. $________ 25-32

49. How much positive customer reaction have you experienced stemming from your compliance with Regulation E?
   a. Significant amount ☐ 34-1
   b. Some ☐ 34-2
   c. None ☐ 34-3

50. Have you discontinued any customer services because of Regulation E? YES ☐ 36-1
   NO ☐

TRANSACTION PROCESSING-AUTOMATED TELLER MACHINES (ATMs)

51. Indicate the following with respect to your bank's cash dispensing machines and/or automatic teller machines (cash dispensing machines in conjunction with a deposit machine):

		CASH DISPENSING MACHINE	ATM
a. Current status of equipment:	1. None operating, no plans exist	☐ 38-1	☐ 68-1
	2. None operating, but plans exist	☐ 38-2	☐ 68-2
	3. Operating in 1980	☐ 38-3	☐ 68-3
b. Number of machines operating in 1980:		______ 40-43	______ 70-73
c. Number of machines planned for installation in 1981:		______ 45-48	______ 75-78

52. For all machines combined that are currently operating, indicate:

	CASH DISPENSING MACHINE	ATM
a. Average number of monthly transactions per machine for March, 1980:	______ 50-57	______ CD11: 6-13
b. Average number of monthly transactions per machine for September, 1980	______ 59-66	______ 15-22

c. Average dollar amount per ATM transaction:

1. Withdrawal-March 1980 .... $______ 24-27
2. Deposit-March 1980 .... $______ 29-32
3. Withdrawal-September 1980 ...... $______ 34-37
4. Deposit-September 1980 .... $______ 39-42

d. Average monthly number of ATM transactions per machine by type, during 4th quarter, 1980:

	NUMBER
1. Withdrawals	______ 44-48
2. Deposits	______ 50-54
3. Transfers	______ 56-60
4. Payments	______ 62-66
5. Inquiries	______ 68-72

53. What were your reasons for installing ATMs? CHECK ALL THAT APPLY

a. Competitive demand .... ☐ 74-1
b. Improving customer service .... ☐ 75-1
c. Cost avoidance .... ☐ 76-1
d. Image improvement .... ☐ 77-1
e. Increasing banking hours .... ☐ CD12: 6-1
f. Generation of new business .... ☐ 7-1
g. Other: ______ (specify) ☐ 8-1

54. Indicate the number of cards outstanding that activate your ATMs:

	NUMBER OF CARDS		
	DEBIT ONLY	CREDIT ONLY	DEBIT AND CREDIT
a. Bank's own card	______ 10-17	______ 64-71	______ 51-58
b. Visa	______ 19-26	______ CD13: 6-13	______ 60-67
c. MasterCard	______ 28-35	______ 15-22	______ 69-76
d. "Shared Network Card"	______ 37-44	______ 24-31	______ CD14: 6-13
e. American Express Gold Card	______ 46-53	______ 33-40	______ 15-22
f. Other ______ (specify)	______ 55-62	______ 42-49	______ 24-31

55a. Are PINs computer generated or customer selected?

1. Computer generated .... ☐ 33-1
2. Customer selected .... ☐ 33-2

55b. Are PINs verified at the ATMs or at host computer?

1. ATMs .... ☐ 35-1
2. Host computer .... ☐ 35-2

56. Do you use cameras at your ATMs? YES ☐ 37-1 NO ☐ 37-2

57. What is the total number of hours per month that your ATMs are available?

HOURS ________ 39-41

58. Is there a maximum dollar withdrawal per customer at your ATMs?

NO ☐ 43-1 YES ☐ -2 ▶ $______ (45-48) per ______ (day, etc.) 50

59. Is there a maximum number of transactions per customer at your ATMs?

NO ☐ 52-1 YES ☐ -2 ▶ $______ (54-61) per ______ (day, etc.) 63

60. How many accounts and/or transactions *per machine* are required for your ATM program to break even?

a. ________ (65-72) accounts

b. ________ (CD15: 6-13) transactions per ______ (day, etc.) 15

61. Do you share your ATMs with other financial institutions?

a. YES ☐ 17-1
b. NO, but plans exist ☐ 17-2
c. NO, and no plans exist ☐ 17-3

62. If "YES" to question 61:

a. Indicate type of institution(s) sharing ATM: CHECK ALL THAT APPLY

1. Other commercial bank ☐ 19-1
2. Thrift ☐ 20-1
3. Credit union ☐ 21-2
4. Other: ________ (specify) ☐ 22-1

b. What percentage of ATM transactions are made at other institutions' terminals?

________ % 24-26

63. If your bank is in an ATM network, are there fees for any of the following:

	YES	NO	NOT IN NETWORK
a. Retail services	☐ 28-1	☐ -2	☐ -3
b. Interchange	☐ 29-1	☐ -2	☐ -3
c. Switching	☐ 30-1	☐ -2	☐ -3
d. Sharing	☐ 31-1	☐ -2	☐ -3

64. Does your bank operate off-premises ATMs? YES ☐ 33-1 NO ☐ 33-2

a. If "YES," indicate the characteristics of these ATMs: CHECK ALL THAT APPLY

1. Full service ☐ 35-1
2. Cash dispensing only ☐ 36-1
3. Walk-up ☐ 37-1
4. Drive-up ☐ 38-1
5. Serviced by a branch ☐ 39-1
6. Serviced by a third party ☐ 40-1

b. How often are they serviced?

1. Daily ☐ 42-1
2. Weekly ☐ 42-2
3. Other ________ (specify) ☐ 42-3

65. a. Of the total time your ATMs are down, what percentage can be allocated to each of the following reasons? USE "0" IF NONE.

1. Hardware down-time ______ % 44-46
2. System down-time ______ % 48-50
3. Servicing down-time ______ % 52-54
4. Other down-time ______ % 56-58

TOTAL 100 %

65. b. Considering all your ATMs combined, what is their average down-time, expressed as a percentage of their total operating time?

______ % 60-63

66. What is your average number of transactions between ATM failures (excluding host computer or line problems)?

________ 65-72

67. Do you authorize against positive files? YES ☐ 74-1 NO ☐ 74-2

68. Do you authorize against negative files? YES ☐ 76-1 NO ☐ 76-2

69. Do you support conversational mode at the ATM? YES ☐ CD16: 6-1 NO ☐ 6-2

70. Describe your units:

a. Single dispenser ☐ 8-1
b. Dual dispenser ☐ 8-2

71. Indicate which of the following denominations are supplied by your ATMs: CHECK ALL THAT APPLY

a. $1 ☐ 10-1 c. $10 ☐ 12-1 e. $ 50 ☐ 14-1
b. $5 ☐ 11-1 d. $20 ☐ 13-1 f. $100 ☐ 15-1

72. Is your network down at settlement time?

YES ☐ 17-1
NO ☐ 17-2

a. If "NO," briefly describe settlement: ______________________ 19-20

73. Have you experienced any fraud losses at your ATMs?

YES ☐ 22-1 ▶ State 1980 loss: $ __________ 24-31
NO ☐ 22-2

74. If your bank has installed ATMs, did you perform a cost disbursement study?

YES ☐ 33-1
NO ☐ 33-2

POINT-OF-SALE TERMINALS (POS)

75. a. Has your bank installed point-of-sale (POS) terminals in retail merchant locations?

1. NO, and no plans exist .... ☐ 35-1
2. NO, but plans exist .... ☐ 35-2
3. YES .... ☐ 35-3

b. If "YES," please indicate:

1. *Total number of POS terminals* .... ______ 37-41
2. Total number of retail merchant locations .. ______ 43-47

76. *If you have installed or plan to install POS terminals in merchant locations, indicate the transactions which your bank offers or plans to offer at those terminals:*
CHECK ALL THAT APPLY

	NOW OFFERS	PLANS TO OFFER
a. Check verification	☐ 49-1	☐ -2
b. Check guarantee	☐ 50-1	☐ -2
c. Charge card authorization	☐ 51-1	☐ -2
d. Debit card purchase	☐ 52-1	☐ -2
e. Banking transactions (deposits, etc.) .	☐ 53-1	☐ -2
f. Merchant system (accounts receivable, inventory control)	☐ 54-1	☐ -2

CHECK PROCESSING

77. *Describe your bank's check inscribing equipment:*
CHECK ALL THAT APPLY

a. Single pocket .... ☐ 63-1
b. Multi-pocket .... ☐ 64-1
c. No inscribing equipment in this bank .... ☐ 65-1

78. Does your bank offer incentive pay to proof operators?

YES ☐ 67-1
NO ☐ 67-2

a. If "YES," what percentage of your proof operators are working under the incentive plan?

______ 69-71

b. Is this done at central or distributed proof operations?

1. Central .... ☐ 73-1
2. Distributed .... ☐ 73-2

79. What is your average through-put per person hour?

______ CD17: 6-11

80. Do you capture data as the check inscribing function is performed?

a. YES .... ☐ 13-1
b. NO, but plans exist .... ☐ 13-2
c. NO, and no plans exist .... ☐ 13-3

81. Indicate the primary method used by your bank to capture float information:

a. Do not capture float information .... ☐ 15-1
b. Captured during proofing counter work .... ☐ 15-2
c. Captured via computer entry run .... ☐ 15-3
d. Captured manually .... ☐ 15-4
e. Other: ______ (specify) ☐ 15-5

	YES	NO, BUT PLAN TO	NO, AND NO PLANS
82a. Do you receive any items from your corporate customers which are totally pre-encoded with dollar amounts?	☐ 17-1	☐ -2	☐ -3
82b. If "YES," do you offer any incentive pricing for corporate customers who furnish completely pre-encoded dollar items?	☐ 19-1	☐ -2	☐ -3

83. Indicate the percentage of your total check volume that is microfilmed in the following ways:

	TRANSIT ITEMS	ON-US ITEMS
a. Before high speed processing:		
1. During inscribing	______% 21-23	______% 45-47
2. On a stand-alone film unit	______% 25-27	______% 49-51
b. During high speed processing	______% 29-31	______% 53-55
c. After high speed processing	______% 33-35	______% 57-59
d. Other: ______ (specify)	______% 37-39	______% 61-63
e. Not microfilmed	______% 41-43	______% 65-67
TOTAL	100%	100%

84. Does your bank use bulk filing methods?

a. YES ☐ 69-1
b. NO, but plans exist ☐ 69-2
c. NO, and no plans exist ☐ 69-3

85. How often does your bank normally correct transit items that have been rejected from your primary capture system?

a. All the time ☐ 71-1
b. Sometimes ☐ 71-2
c. Never ☐ 71-3

86. Indicate your bank's dominant approach(es) to the correction of MICR items:
CHECK ALL THAT APPLY

a. No corrections made ☐ 73-1
b. Corrects captured data image ☐ 74-1
c. Corrects physical transit items ☐
d. Other: ______ (specify) ☐ 76-1

87. Indicate your bank's acceptability rate on corrected MICR items that have been re-entered into your primary capture system:

CD18:
a. No corrections made ☐ 6-1
b. Below 85% ☐ 6-2
c. 85-94% ☐ 6-3
d. 95% or more ☐ 6-4

88. a. What is the average monthly number of return items processed by your bank? ______ 8-15
b. What percentage of the total number of transit items (excluding on-us) processed monthly are return items? ______% 17-20
c. How many return items are processed per person-hour? ______ 22-27

	YES	NO, BUT PLANS TO	NO, AND NO PLANS
89. Does your bank presently use MICR entry?	☐ 29-1	☐ -2	☐ -3
90a. Does your bank presently use OCR equipment?	☐ 31-1	☐ -2	☐ -3

90b. If you presently use or plan to use OCR equipment, indicate the applications it is or will be used for:
CHECK ALL THAT APPLY

1. Data entry .... ☐ 33-1
2. Check correction .... ☐ 34-1
3. Text entry .... ☐ 35-1
4. Lock box .... ☐ 36-1
5. Other: ______ (specify) ☐ 37-1

91. Excluding cost of funds, indicate your bank's total check processing expense:

a. 1980 (actual) .... $______ 39-46
b. 1981 (budgeted) .... $______ 48-55
c. 1982 (anticipated) .... $______ 57-64

92. For 1980, indicate the *per item* transit and on-us costs in the following categories:

	TRANSIT	ON-US
a. Inscribing	$______ 66-73	$______ 69-76
b. High speed processing	$______ CD19: 6-13	$______ CD20: 6-13
c. Reconcilement	$______ 15-22	$______ 15-22
d. Float	$______ 24-31	$______ 24-31
e. Transportation	$______ 33-40	$______ 33-40
f. Rejects	$______ 42-49	$______ 42-49
g. Other: ______ (specify)	$______ 51-58	$______ 51-58
h. Total check processing cost per item	$______ 60-67	$______ 60-67

93. Estimate the total dollar amount of and percentage increase in your bank's annual check processing operating expense that will be created by Fed pricing. Indicate "0" if "NONE" expected.

a. Annual dollar amount of increase due to Fed pricing .... $______ 66-74
b. Percentage increase due to Fed pricing .... ______ 75-77 %

ON-LINE TELLER TERMINALS

94a. Do you have an on-line teller system?

1. YES .... ☐ 78-1
2. NO, but plans exist .... ☐ 78-2
3. NO, and no plans exist .... ☐ 78-3

94b. If you currently have or plan to install an on-line teller system, which services are or will be supported?
CHECK ALL THAT APPLY

CD21:
1. Check cashing .... ☐ 6-1
2. Accepting deposits .... ☐ 7-1
3. Loan payments .... ☐ 8-1
4. Utility payments .... ☐ 9-1
5. Balance inquiry .... ☐ 10-1
6. Cash control .... ☐ 11-1
7. Paper truncation .... ☐ 12-1

94c. What method of access is or will be employed?
CHECK ALL THAT APPLY

1. PIN pad .... ☐ 14-1
2. Magnetic reader for plastic cards .... ☐ 15-1
3. Keyboard entry by teller .... ☐ 16-1
4. Other: ______ (specify) ☐ 17-1

95. If you presently use or plan to use an on-line teller system and if you also will support paper truncation on this system, which paper documents are or will be truncated?
CHECK ALL THAT APPLY

a. Checks .... ☐ 19-1
b. Deposit tickets .... ☐ 20-1
c. Loan payments .... ☐ 21-1
d. Utility payments .... ☐ 22-1
e. Collection receipts .... ☐ 23-1
f. Safe deposit rental receipts .... ☐ 24-1
g. Other: ____________ (specify) ☐ 25-1
h. Inapplicable, no use of on-line teller system or does not support paper truncation .... ☐ 26-1

96. What is the number of proof and transit differences generated per 100,000 items processed?

________ 28-35

97. What is the number of outstanding proof and transit differences as of December 31, 1980?

	DEBITS	CREDITS
a. 0 - 0.9 months	____ 37-44	____ 33-40
b. 1 - 1.9	____ 46-53	____ 42-49
c. 2 - 2.9 months	____ 55-62	____ 51-58
d. 3 - 3.9 months	____ 64-71	____ 60-67
e. 4 - 5.9 months	____ CD22: 6-13	____ 69-76
f. 6 months or more	____ 15-22	____ CD23: 6-13
g. Total	____ 24-31	____ 15-22

98. Does your bank presently use a computer output microfilm (COM) system?

YES ☐ 24-1
NO ☐ 24-2

DATA PROCESSING

99. With respect to your principal data processing requirements, check the category that best describes your bank's computer status at the present time.
NOTE: See the following question for your secondary status.

a. Presently using on-premise computer operations .... ☐ 26-1
b. Presently using off-premise computer operations/service arrangement .... ☐ 26-2
c. Not presently using computer .... ☐

100. If your bank is presently using computer resources for data processing operations, describe your bank's primary computer status and check all applicable secondary arrangements:

	PRIMARY CHECK ONE	SECONDARY CHECK ALL THAT APPLY
a. On-premise computer operations	☐ 28-1	☐ 30-1
b. Holding company arrangement	☐ 28-2	☐ 31-1
c. Computer servicing arrangement with:		
1. Correspondent bank	☐ 28-3	☐ 32-1
2. Joint venture with other banks	☐ 28-4	☐ 33-1
3. On-premise facilities management	☐ 28-5	☐ 34-1
4. Off-premise facilities management	☐ 28-6	☐ 35-1
5. Non-bank	☐ 28-7	☐ 36-1
d. Other: ____________ (specify)	☐ 28-8	☐ 37-1

101. If a "holding company arrangement" describes your primary status:

a. Is processing centralized in one location for all banks in the holding company?

YES ☐ 39-1
NO ☐ 39-2

b. By whom is processing performed?

1. Holding company .... ☐ 41-1
2. Holding company non-bank subsidiary .... ☐ 41-2
3. Outside .... ☐ 41-3
4. Other: ____________ (specify) ☐ 41-4

102a. Does your bank presently use computer time-sharing?

1. NO, and no plans exist ☐ 43-1
2. NO, but plans exist ☐ 43-2
3. YES ☐ 43-3

102b. If "YES," this done in-bank or by a commercial service?

1. In-bank ☐ 44-1 ▶
   - a. Annual 1980 time-sharing expense: $______ 45-50
   - b. Annual 1981 (budgeted) time-sharing expense: $______ 52-57
   - c. Annual 1982 (anticipated) time sharing expense: $______ 59-64
2. Commercial service ☐ 44-2 ▶
   - a. Annual 1980 time-sharing expense: $______ 66-71
   - b. Annual 1981 (budgeted) time-sharing expense: $______ 73-78
   - c. Annual 1982 (anticipated) time sharing expense: $______ CD24: 6-11

MINICOMPUTERS

103a. Does your bank presently use minicomputers?

1. NO, and no plans exist ☐ 13-1
2. NO, but plans exist ☐ 13-2
3. YES ☐ 13-3

103b. If "YES," how are your bank's minicomputers used?

1. Distributed processing ☐ 15-1
2. Decentralized stand-alone ☐ 15-2
3. Terminal control ☐ 15-3
4. Time-sharing services ☐ 15-4
5. Other: ______ (specify) ☐ 15-5

103c. Who has primary responsibility for development of minicomputer software?

1. Regular systems staff ☐ 17-1
2. User department ☐ 17-2
3. Separate systems staff ☐ 17-3
4. Outside vendor (other than minicomputer vendor/manufacturer) ☐ 17-4
5. Minicomputer vendor/manufacturer ☐ 17-5
6. Other: ______ (specify) ☐ 17-6

DATA PROCESSING COSTS

104a. Does your bank have an established procedure for allocating the cost of data processing services back to user areas?

YES ☐ 19-1

NO ☐ 19-2

104b. If "YES," indicate what method best describes your mode of operation:

1. Cost of services only ☐ 21-1
2. Cost of development and service ☐ 21-2
3. Cost of overhead, development and service ☐ 21-3
4. Hourly charge at standard rate ☐ 21-4
5. Other: ______ (specify) ☐ 21-5

105. Excluding cost of funds, what percentage of your bank's total operating expense is attributable to data processing costs?

- a. 1980 (actual) ______ % 23-25
- b. 1981 (budgeted) ______ % 27-29
- c. 1982 (anticipated) ______ % 31-33

106. *Indicate your bank's average expenditure for domestic computer equipment.* (If equipment is owned or leased, please convert to a yearly rental equivalent. Include local terminals, minicomputers and all cable connected components of your computer system. Do not include auxiliary equipment such as keypunch machines.)

- a. 1980 (actual) $______ 35-39
- b. 1981 (budgeted) $______ 41-45
- c. 1982 (anticipated) $______ 47-51

107. In order to provide comparative cost data, please fill in the following information regarding your bank's operating costs:

	COMPUTER OPERATIONS (A)*	SYSTEMS PROGRAMMING (B)*	ITEM PROCESSING (C)*	CENTRAL OPERATIONS (D)*	WIRE SERVICE (E)*	TOTAL COSTS (F)*
1. Employment	$____ 53-60	$____ 51-58	$____ 51-58	$____ 51-58	$____ 51-58	$____ 51-58
2. Computer equipment	$____ 62-69	$____ 60-67	$____ 60-67	$____ 60-67	$____ 60-67	$____ 60-67
3. Other equipment	$____ 71-78	$____ 69-76	$____ 69-76	$____ 69-76	$____ 69-76	$____ 69-76
4. Transportation	$____ CD25: 6-13	$____ CD26: 6-13	$____ CD27: 6-13	$____ CD28: 6-13	$____ CD29: 6-13	$____ CD30: 6-13
5. Line costs	$____ 15-22	$____ 15-22	$____ 15-22	$____ 15-22	$____ 15-22	$____ 15-22
6. Supplies	$____ 24-31	$____ 24-31	$____ 24-31	$____ 24-31	$____ 24-31	$____ 24-31
7. Other: ____ (specify)	$____ 33-40	$____ 33-40	$____ 33-40	$____ 33-40	$____ 33-40	$____ 33-40
8. Total costs	$____ 42-49	$____ 42-49	$____ 42-49	$____ 42-49	$____ 42-49	$____ 42-49

*(A) Should include: data entry and preparation, production control, computer operations, forms handling and report distribution, as well as COM operations.

*(B) Should include: technical support personnel, applications programmers, systems analysts.

*(C) Should include: check inscribing, reader/sorter operations, on-line reject reentry, reconciling/balancing, cash letter preparation, fine sort operations, etc.

*(D) Should include: check filing operations, deposit administration, corporate services operations (lockbox, account reconciliations, etc.)

*(E) Should include: all costs related to Fedwire, BankWire, SWIFT, CHIPS, etc., as well as any wire room operations. NOTE: Do not include Money Desk costs.

TELECOMMUNICATIONS

108. Does your bank presently use teleprocessing?

a. YES .... ☐ 51-1
b. NO, but plans exist .... ☐ 51-2
c. NO, and no plans exist .... ☐ 51-3

109a. Does your bank have a diagnostic system for network control?

1. YES .... ☐ 53-1
2. NO .... ☐ 53-2

109b. If "YES," who developed this system?

1. In-house .... ☐ 55-1
2. Outside vendor .... ☐ 55-2

SYSTEMS AND PROGRAMMING

110. Do you have a centralized systems function within your data processing department? .... YES ☐ 57-1 NO ☐ 57-2

111a. Has your bank organized a group or commitee to determine needs and priorities within areas of new applications? .... YES ☐ 59-1 NO ☐ 59-2

111b. If "YES," does your management actively participate in this committee?

NO ☐ 61-1 YES ☐ -2 ▶ List functions in the bank which are represented on the committee:

1. ______ 63-64 4. ______ 69-70
2. ______ 65-66 5. ______ 71-72
3. ______ 67-68 6. ______ 73-74

112. Do you have systems personnel assigned to and working in users' departments separate from the data processing department? . YES ☐ CD31: 6-1 NO ☐ 6-2

113. Indicate the full-time equivalent size of your systems staff for the following categories:

a. Management .... ______ 9-12
b. Clerical .... ______ 14-17
c. Applications programmers .... ______ 19-22
d. Systems programmers (technical support) .... ______ 24-27
e. On-line programmers (CICS, IMS, T.P., etc.) .... ______ 29-32
f. Systems analysts .... ______ 34-37
g. Other: ______ (specify) ______ 39-42
h. Total systems staff .... ______ 44-48

114. What is the percentage change in the size of your systems staff?

a. Increased .... ☐ 50-1 ▶ by ______ % 52-54
b. Decreased .... ☐ 50-2 ▶ by ______ % 56-58
c. No change .... ☐ 50-3

115. Indicate your bank's total annual salary (not employment) expense for all systems personnel:

a. 1980 (actual) .... $ ______ 60-67
b. 1981 (budgeted) .... $ ______ 69-76
c. 1982 (anticipated) .... $ ______ CD32: 6-13

116. During the last twelve months, has your turnover of systems personnel increased or decreased?

a. Increased .... ☐ 15-1 ▶ by ______ % 17-19
b. Decreased .... ☐ 15-2 ▶ by ______ % 21-23
c. Remained the same .... ☐ 15-3

117. What was your turnover percentage of systems personnel during the last twelve months?

______ % 25-27

118. Do you currently use flex-time within the systems area?

YES ☐ 29-1
NO ☐ 29-2

119. Do you currently use any form of shortened work week for systems personnel?

NO ☐ 31-1 YES ☐ -2 ▶ ______ 32 work days/week

120. Do you use "Contract Programming Services?" YES ☐ 34-1 NO ☐ 34-2

121. Do you purchase application software? YES ☐ 36-1 NO ☐ 36-2

122. Will you purchase more software in the next 1-3 years?

YES ☐ 38-1
NO ☐ 38-2

123. What is the budget amount for software?

a. 1980 (actual) .... $ ______ 40-47
b. 1981 (budgeted) .... $ ______ 49-56
c. 1982 (anticipated) .... $ ______ 58-65

124a. Do you currently permit systems personnel to work at home using remote terminals?

YES ☐ 67-1
NO ☐ 67-2

124b. Do you plan to permit work at home on remote terminals in the next 1-3 years?

YES ☐ 69-1
NO ☐ 69-2

125. Indicate your bank operations that are presently computerized or are planned for computerization within one year, and also indicate the percentage of total data processing cost allocated to each item.

	A. ON-LINE INQUIRY		B. ON-LINE UPDATING		C. BATCH PROCESSING		D. PERCENTAGE OF COST ALLOCATED PER ITEM
	Presently Computerized	Will Be Computerized	Presently Computerized	Will Be Computerized	Presently Computerized	Will Be Computerized	
1. ATM	☐ 71-1	☐ -2	☐ 49-1	☐ -2	☐ 27-1	☐ -2	____ % CD35: 6-8
2. ATM switch	☐ 72-1	☐ -2	☐ 50-1	☐ -2	☐ 28-1	☐ -2	____ % 9-11
3. Automated clearinghouse	☐ 73-1	☐ -2	☐ 51-1	☐ -2	☐ 29-1	☐ -2	____ % 12-14
4. Accounts payable	☐ 74-1	☐ -2	☐ 52-1	☐ -2	☐ 30-1	☐ -2	____ % 15-17
5. Accounts reconciliation	☐ 75-1	☐ -2	☐ 53-1	☐ -2	☐ 31-1	☐ -2	____ % 18-20
6. Balance reporting	☐ 76-1	☐ -2	☐ 54-1	☐ -2	☐ 32-1	☐ -2	____ % 21-23
7. BankWire	☐ 77-1	☐ -2	☐ 55-1	☐ -2	☐ 33-1	☐ -2	____ % 24-26
8. Bulk filing/cycle sorting	☐ CD33: 6-1	☐ -2	☐ 56-1	☐ -2	☐ 34-1	☐ -2	____ % 27-29
9. Central information file	☐ 7-1	☐ -2	☐ 57-1	☐ -2	☐ 35-1	☐ -2	____ % 30-32
10. Certificate of deposit	☐ 8-1	☐ -2	☐ 58-1	☐ -2	☐ 36-1	☐ -2	____ % 33-35
11. Charge card accounts	☐ 9-1	☐ -2	☐ 59-1	☐ -2	☐ 37-1	☐ -2	____ % 36-38
12. Charge card authorization	☐ 10-1	☐ -2	☐ 60-1	☐ -2	☐ 38-1	☐ -2	____ % 39-41
13. CHIPS	☐ 11-1	☐ -2	☐ 61-1	☐ -2	☐ 39-1	☐ -2	____ % 42-44
14. Christmas club	☐ 12-1	☐ -2	☐ 62-1	☐ -2	☐ 40-1	☐ -2	____ % 45-47
15. Commercial loans	☐ 13-1	☐ -2	☐ 63-1	☐ -2	☐ 41-1	☐ -2	____ % 48-50
16. Consolidated customer statements	☐ 14-1	☐ -2	☐ 64-1	☐ -2	☐ 42-1	☐ -2	____ % 51-53
17. Corporate trust	☐ 15-1	☐ -2	☐ 65-1	☐ -2	☐ 43-1	☐ -2	____ % 54-56
18. Customer analysis	☐ 16-1	☐ -2	☐ 66-1	☐ -2	☐ 44-1	☐ -2	____ % 57-59
19. Debit card	☐ 17-1	☐ -2	☐ 67-1	☐ -2	☐ 45-1	☐ -2	____ % 60-62
20. Demand deposits	☐ 18-1	☐ -2	☐ 68-1	☐ -2	☐ 46-1	☐ -2	____ % 63-65
21. Financial information system	☐ 19-1	☐ -2	☐ 69-1	☐ -2	☐ 47-1	☐ -2	____ % 66-68
22. Fixed assets	☐ 20-1	☐ -2	☐ 70-1	☐ -2	☐ 48-1	☐ -2	____ %
23. Float management	☐ 21-1	☐ -2	☐ 71-1	☐ -2	☐ 49-1	☐ -2	____ % 72-74
24. Foreign exchange	☐ 22-1	☐ -2	☐ 72-1	☐ -2	☐ 50-1	☐ -2	____ % 75-77
25. General ledger	☐ 23-1	☐ -2	☐ 73-1	☐ -2	☐ 51-1	☐ -2	____ % CD36: 6-8
26. Instalment credit	☐ 24-1	☐ -2	☐ 74-1	☐ -2	☐ 52-1	☐ -2	____ % 9-11
27. Investment portfolio (bank's own)	☐ 25-1	☐ -2	☐ 75-1	☐ -2	☐ 53-1	☐ -2	____ % 12-14
28. Kite detection system	☐ 26-1	☐ -2	☐ 76-1	☐ -2	☐ 54-1	☐ -2	____ % 15-17
29. Letter of credit	☐ 27-1	☐ -2	☐ 77-1	☐ -2	☐ 55-1	☐ -2	____ % 18-20
30. Line of credit (revolving credit)	☐ 28-1	☐ -2	☐ CD34: 6-1	☐ -2	☐ 56-1	☐ -2	____ % 22-24
31. Lock box	☐ 29-1	☐ -2	☐ 7-1	☐ -2	☐ 57-1	☐ -2	____ % 26-28
32. Mortgage loan	☐ 30-1	☐ -2	☐ 8-1	☐ -2	☐ 58-1	☐ -2	____ % 30-32
33. Overdraft protection	☐ 31-1	☐ -2	☐ 9-1	☐ -2	☐ 59-1	☐ -2	____ % 34-36
34. Payroll (bank's own)	☐ 32-1	☐ -2	☐ 10-1	☐ -2	☐ 60-1	☐ -2	____ % 38-40
35. Personal trust	☐ 33-1	☐ -2	☐ 11-1	☐ -2	☐ 61-1	☐ -2	____ % 42-44
36. Personnel information system	☐ 34-1	☐ -2	☐ 12-1	☐ -2	☐ 62-1	☐ -2	____ % 46-48
37. Profit center reporting	☐ 35-1	☐ -2	☐ 13-1	☐ -2	☐ 63-1	☐ -2	____ % 50-52
38. Profit sharing	☐ 36-1	☐ -2	☐ 14-1	☐ -2	☐ 64-1	☐ -2	____ % 54-56
39. Proof and transit	☐ 37-1	☐ -2	☐ 15-1	☐ -2	☐ 65-1	☐ -2	____ % 58-60
40. Reports for regulatory, supervisory and monetary authorities	☐ 38-1	☐ -2	☐ 16-1	☐ -2	☐ 66-1	☐ -2	____ % 62-64
41. Responsibility accounting	☐ 39-1	☐ -2	☐ 17-1	☐ -2	☐ 67-1	☐ -2	____ % 66-68
42. Savings	☐ 40-1	☐ -2	☐ 18-1	☐ -2	☐ 68-1	☐ -2	____ % 70-72
43. Safekeeping	☐ 41-1	☐ -2	☐ 19-1	☐ -2	☐ 69-1	☐ -2	____ % 74-76
44. Securities (stock transfer)	☐ 42-1	☐ -2	☐ 20-1	☐ -2	☐ 70-1	☐ -2	____ % CD37: 6-8
45. Specialized audit program	☐ 43-1	☐ -2	☐ 21-1	☐ -2	☐ 71-1	☐ -2	____ % 10-12
46. Student loans	☐ 44-1	☐ -2	☐ 22-1	☐ -2	☐ 72-1	☐ -2	____ % 14-16
47. SWIFT	☐ 45-1	☐ -2	☐ 23-1	☐ -2	☐ 73-1	☐ -2	____ % 18-20
48. Wholesale money transfer	☐ 46-1	☐ -2	☐ 24-1	☐ -2	☐ 74-1	☐ -2	____ % 22-24
49. Other ____ (specify)	☐ 47-1	☐ -2	☐ 25-1	☐ -2	☐ 75-1	☐ -2	____ % 26-28

126. Do you have a work measurement program in effect for your in-house programmers?

YES ☐ 30-1

NO ☐ 30-2

127. Have you implemented any productivity improvement techniques in your in-house programming in the last year?

YES ☐ 32-1

NO ☐ 32-2

128a. Excluding those required by legislation/regulation, are application developments and/or programming needs considered on a return-to-investment basis?

YES ☐ 34-1

NO ☐ 34-2

128b. What is the most common time period (in months) for an optimum return?

______ MONTHS 36-38

129. In comparison to your current level of use, to what extent do you anticipate using the following services during the next three years to meet your systems and programming needs?

	INCREASING USE	SAME USE	DECREASING USE	CURRENTLY NOT USING
a. Internal personnel	☐ 40-1	☐ -2	☐ -3	☐ -4
b. Leasing of application packages from hardware vendor	☐ 41-1	☐ -2	☐ -3	☐ -4
c. Leasing of application packages from other sources	☐ 42-1	☐ -2	☐ -3	☐ -4
d. Purchase of application packages from hardware vendor	☐ 43-1	☐ -2	☐ -3	☐ -4
e. Purchase of application packages from other sources	☐ 44-1	☐ -2	☐ -3	☐ -4
f. Outside software contractors and consultants	☐ 45-1	☐ -2	☐ -3	☐ -4
g. Joint development with other banks	☐ 46-1	☐ -2	☐ -3	☐ -4
h. Other: ______ (specify)	☐ 47-1	☐ -2	☐ -3	☐ -4

130. In your opinion, what are the critical operational issues of the 1980s? (Please rank your top 10 choices.)

1. Federal Reserve pricing ______ 49-50
2. Word processing ______ 51-52
3. Electronic mail ______ 53-54
4. Telecommunications ______ 55-56
5. Merger of voice and data communications ______ 57-58
6. Hardware advances ______ 59-60
7. Application software advances ______ 61-62
8. Image lift capabilities ______ 63-64
9. Mass storage technology ______ 65-66
10. Regulatory actions ______ 67-68
11. Privacy issues ______ 69-70
12. Security issues ______ 71-72
13. Consumerism ______ 73-74
14. Check safekeeping ______ 75-76
15. Check truncation ______ 77-78
16. Shared facilities (ATM system) ______ CD38: 6-7
17. Productivity ______ 8-9
18. Control of staff levels ______ 10-11
19. OCR improvements ______ 12-13
20. Expanded corporate services ______ 14-15
21. Micrographics ______ 16-17
22. Personnel acquisition ______ 18-19
23. Personnel retention ______ 20-21
24. Strategic planning ______ 22-23
25. "Plastic" banking ______ 24-25
26. Bank from home (TV) ______ 26-27
27. Telephone banking ______ 28-29
28. Employee training ______ 30-31
29. Multiple new products and services ______ 32-33
30. Mergers and acquisition ______ 34-35
31. Automated clearinghouse ______ 36-37
32. Examination requirements ______ 38-39
33. Contingency planning ______ 40-41
34. Point-of-Sale processing ______ 42-43
35. Debit card processing ______ 44-45
36. National banking (nationwide) ______ 46-47
37. Level of capital expenditures ______ 48-49
38. Float management ______ 50-51
39. Kite and fraud detection ______ 52-53
40. Corporate service products ______ 54-55
41. Other: ______ (specify) ______ 56-57

131. What do you think are the three most important changes that will occur in bank operations in the 1980s?

1. (Most important) ________ 58-59
2. (2nd most important) ________
3. (3rd most important) ________

132. What do you think will be the major technical development to affect bank operations in the 1980s?

____

________ 64-65

COMPUTERIZATION OF SURVEY RESULTS

133. Would an on-line availability of the data resulting from this survey be of potential benefit to your bank? YES ☐ 66-1 NO ☐ 66-2

134. If appropriately priced, would you use the answer data from the survey on-line? YES ☐ 67-1 NO ☐ 67-2

135. If you answered "YES" to the above questions, would you need to reformat or perform secondary analyses on the data you accessed, or would pre-formatted, standardized reports be adequate?

a. Need to reformat/perform secondary analysis .... ☐ 68-1
b. Standardized report adequate .... ☐ 68-2

136. How can the ABA's Operations and Automation Division best serve your needs in the 1980s?

____

____

137. How can we best improve the next National Operations and Automation Survey?

____

____

THANK YOU FOR YOUR TIME AND COOPERATION

Because of the costs involved in the compilation, analysis and dissemination of results, the Research and Planning Committee of Operations/Automation Division requests that a $125.00 charge be made for each copy of the comprehensive survey results. The non-member charge is $200.00. Please indicate below whether you are interested in receiving a copy of the full survey report when published with billing after delivery to your attention.

Would like to receive full survey report: YES ☐ NO ☐

Name: ________ Phone: ( ) ________
Bank: ________
Street Address: ________
City, State, Zip: ________

Please complete this questionnaire and mail within two weeks of receipt in the enclosed envelope to:

SURVEYS AND STATISTICS DIVISION
AMERICAN BANKERS ASSOCIATION
1120 Connecticut Avenue, N.W.
Washington, D.C. 20036

Appendix A.2

REPORTED INSTALLATIONS OF GENERAL-PURPOSE DIGITAL COMPUTERS BY U.S. COMMERCIAL BANKS, 1959-1974

Date of Installation (Month/Year)	Site of Installation (Name of Bank, City, State)	Model Installed	Data Source*
9/59	Bank of America San Francisco, CA	GE 210	A
9/59	First National City New York, NY	unknown	A
3/60	First National Arizona Phoenix, AZ	GE 210	A
4/60	Harris Trust Chicago, IL	Univac II	A
12/60	First National Pennsylvania Philadelphia, PA	Burroughs B220	A
7/61	Waterbury National Waterbury, CT	unknown	A
9/61	Manufacturers Trust New York, NY	IBM 7070	A
11/61	First National Denver Denver, CO	unknown	A
12/61	First National Oregon Portland, OR	IBM 7070 and 1401/1412	A
12/61	First National Boston Boston, MA	Honeywell H-800	A
1/62	Union Trust Baltimore, MD	IBM 1401/1412	A
1/62	First National Miami Miami, FL	Burroughs B-251	A
1/62	Puget Sound National Tacoma, WA	IBM 1401/1412	A
2/62	South Shore National Quincy, MA	Burroughs (model unknown)	A
2/62	Colonial National Waterbury, CT	Burroughs B-251	A

Appendix A.2 (continued)

Date of Installation (Month/Year)	Site of Installation (Name of Bank, City, State)	Model Installed	Data Source*
3/62	Franklin National New York, NY	IBM 1401	A
5/62	Community National Pontiac, MI	Burroughs B-270	A
6/62**	First National St. Louis St. Louis, MO	GE 210	A
6/62	Pittsburgh National Pittsburgh, PA	GE 225 (2 installed)	A
6/62	Girard Trust Philadelphia, PA	IBM 1410	A
1/63	Louisville Trust Louisville, KY	GE 225	A
2/63	First National New Haven New Haven, CT	Burroughs B-270	A
3/63	South Carolina National Charleston, SC	Burroughs B-270	A
2/64	First National American Duluth, MN	Burroughs B-270	A
4/64	Safe Deposit Springfield, MA	NCR 315	A
4/64	First National Mason Mason City, IA	IBM 1240	A
5/64	Old National Evansville, IN	IBM 1460	A
6/64	Central Valley Oakland, CA	NCR 315	A
1/65	Bank of Delaware Wilmington, DE	IBM 1401/1301	A
2/65	Kellogg - Citizens National Green Bay, WI	IBM 1440	A
8/65	Berkshire Bank & Trust Pittsfield, MA	IBM 1240	A
10/65	National City Marion, OH	NCR 315-100	A

Appendix A.2 (continued)

Date of Installation (Month/Year)	Site of Installation (Name of Bank, City, State)	Model Installed	Data Source*
10/65	First National Dona Ana County Los Cruces, NM	NCR 315-100	A
10/65	First National Highland Park Highland Park, IL	NCR 315	A
11/65	First National Fort Collins Fort Collins, CO	NCR 315	A
11/65	State National Alabama Decatur, AL	IBS 360/30	A
3/66	Continental National Phoenix, AZ	IBM 360/30	A
3/66	Commercial Miami Miami, FL	NCR 315-100	A
5/66	State Capital Oklahoma City, OK	NCR 315	A
5/66	Citizens Bank Hamilton, OH	NCR 315	A
5/66	Northwest Bank & Trust Davenport, IA	NCR 315	A
5/66	Capital Bank & Trust Baton Rogue, LA	NCR 315	A
7/66	Oakland Bank of Commerce Oakland, CA	IBM 360/30	A
7/66	First National Montgomery Montgomery, AL	IBM 360/30	A
8/66	First National Mobile Mobile, AL	IBM 360/30	A
8/66	Wayne Oakland Royal Oak, MI	NCR 315	A
8/66	Citizens National Muskogee, OK	NCR 315	A
11/66	First Commercial National Camden, NJ	RCA Spectra 70/45	A
11/66	Jefferson County Lakewood, CO	NCR 315	A

Appendix A.2 (continued)

Date of Installation (Month/Year)	Site of Installation (Name of Bank, City, State)	Model Installed	Data Source*
12/66	Suburban Bank & Trust Kansas City, MO	NCR 315	A
12/66	Merchants National Cedar Rapids, IA	IBM 360/30	A
1/67	City National Miami, FL	NCR 315	A
5/67	Commercial National Peoria, IL	IBM 360/30	A
7/67	First National Erie, PA	GE 415	A
7/68	Spring Branch State Houston, TX	Burroughs B-340	A
9/68	Fiduciary Trust Boston, MA	Burroughs B-300	A
9/68	Harlendale State San Antonio, TX	Burroughs B-340	A
10/68	Capital Bank Springfield, IL	Burroughs B-340	A
12/68	First National Massillon, OH	Burroughs B-340	A
7/68	National Bank Northern NY New York, NY	NCR 315	B
7/68	Commercial National Little Rock, AK	Burroughs B-300	B
7/68	Mt. Prospect State Mt. Prospect, IL	Burroughs B-300	B
8/68	Lincoln National Fort Wayne, IN	IBM 360-30	B
12/68	Reading Trust Reading, PA	IBM 360/30	B
12/68	American National Muncie, IN	NCR 315	B
11/68**	First National Jannesville, WI	Burroughs B-340	B

Appendix A.2 (continued)

Date of Installation (Month/Year)	Site of Installation (Name of Bank, City, State)	Model Installed	Data Source*
3/69	Capital National Miami, FL	Burroughs B-340	A
6/69	Longview National Longview, TX	unknown	A
7/69	Citizens National Abilene, TX	Burroughs B-500	A
7/69	Union National Lowell, MA	Burroughs B-500	A
8/69	Farmers and Merchants Menemonee Falls, WI	Burroughs B-340	A
8/69	First National Dekalb, IL	Burroughs B-340	A
9/69	Security National Battle Creek, MI	Burroughs B-500	A
10/69	Southern Bank & Trust Greenville, SC	Burroughs B-500	A
10/69	Hillcrest State Dallas, TX	Burroughs B-3500	A
12/69	Millikin National Decatur, IL	Burroughs B-300	A
4/69**	Commercial Bank of Daytona Beach Daytona Beach, FL	NCR 200	B
4/69**	Union Bank & Trust Kokomo, IN	NCR 200	B
12/69**	American National Bank & Trust Mobile, AL	Burroughs B-500	B
12/69**	Citizen's Union National Lexington, KY	NCR 200	B
2/70	New Britain Bank & Trust New Britain, CT	Burroughs B-500	A
4/70	Hancock Bank & Trust Quincy, MA	Burroughs B-500	A

Appendix A.2 (continued)

Date of Installation (Month/Year)	Site of Installation (Name of Bank, City, State)	Model Installed	Data Source*
5/70	Tracy-Collins Bank & Trust Salt Lake City, UT	Honeywell 120	A
7/70	Georgia Bank & Trust Macon, GA	Burroughs B-350	A
7/70	Irving Bank & Trust Irving, TX	Burroughs B-3500	A
9/70	First National St. Joseph, MO	IBM 360-25	A
12/70	Security First National Sheboygen, WI	NCR 200	A
1/70	Tower National Lima, OH	Burroughs B-500	B
4/70	First National Waukesha, WI	Burroughs B-500	B
5/70	First National Findley, OH	Burroughs B-500	B
8/70	Oak Park Trust Oak Park, IL	Burroughs B-3500	B
9/70	Empire Springfield, MO	Burroughs B-2500	B
9/70	Nevada National Reno, NV	NCR 100	B
5/70**	Peoples Bank & Trust Rocky Mountain, NC	Burroughs B-500	B
1/71**	Corpus Christi Bank & Trust Corpus Christi, TX	Burroughs B-3500	B
2/71	Bank of New Hampshire Manchester, NH	NCR 200	A
3/71**	American Bank & Trust Baton Rogue, LA	Burroughs B-3500	B
4/71	Bank of Idaho Boise, ID	Burroughs B-3500	A
5/71	Kansas State Bank & Trust Wichita, KS	NCR 200	A

Appendix A.2 (continued)

Date of Installation (Month/Year)	Site of Installation Name of Bank City, State	Model Installed	Data Source*
9/71	Fidelity National Lynchburg, VA	Honeywell 6040	A
9/71**	Ann Arbor Bank Ann Arbor, MI	IBM 370/145	B
10/71	Second National Richmond, IN	NCR 200	B
11/71	First National Fort Smith, AR	IBM 370/135	A
11/71	First Security National Beaumont, TX	NCR 300	A
12/71	First National Santa Fe, NM	IBM 370/135	B
12/71	First National Decatur, IL	NCR 100	A
1/72	Second National Danville, IL	IBM System 3/10	B
4/72	West Bank & Trust Green Bay, WI	Burroughs B-2500	B
5/72	North Side Bank Omaha, NE	IBM System 3/10	A
7/72	City National Fort Smith, AR	NCR 200	A
5/73	Guaranty Bank & Trust Cedar Rapids, IA	NCR 50	A
7/73	St. Petersburg Bank & Trust St. Petersburg, FL	NCR 200	A
3/74	American National Danville, VA	NCR 101	A

*A: Computers and Automation
B: EDP Weekly

**On some occasions, a bank announced the awarding of a contract to install a computer and several months later also announded the installation. Computers and Automation and EDP Weekly reported both the contracts and the installation when they were announced. But there were occasions when only the awarding of contracts was reported and the actual installation date was not reported later. On thise occasions, the installation date was estimated to be four months later than the date when the contract was awarded. (Such time lag was observed in other installations reported in these two journals.) These estimated installation dates were marked by double asterisks.

Appendix A.3

DESCRIPTIVE STATISTICS OF COMMERCIAL BANK DATA

Statistics \ Variable	Adoption Lag (months) (Sept. 1959=1)	Total Deposits ($000 omitted)	Deposit Growth Rate	Average Profit	Profit Trend
Number of Observations	113	113	113	113	113
Mean	94.36	472,941	38.94	11.21	0.027
Median	107	81,548	22.27	10.1	0.02
Mode	81	14,834	28.28	8.2	0
Maximum Value	175	15,593,888	458.67	25.6	0.7
Minimum Value	1	14,834	-11.19	2.0	-0.42
Uncorrected Sum of Squares	1,216,695	3.998×10^{14}	661,738	16747.8	1.789
Corrected Sum of Squares	210,504	3.745×10^{14}	490,380	2539.7	1.692
Variance	1879.5	3.344×10^{12}	4378.39	22.676	0.013
Standard Error for Sample Mean	4.078	172,024	6.224	0.448	0.010
Standard Deviation	43.35	1,828,641	66.17	4.762	0.115

Appendix A.4

STATISTICS RELATED TO DATA MATRIX USED IN THE CONSTRUCTION OF URBAN HIERARCHY OF U.S., 1970

Table A.4.1. Examination of Degree of Skewness of Urban Hierarchy Data Matrix Variables using 1970 Population Census Data

Statistics / Variable	Mean	Median	Standard Deviation	Variance	Degree of Skewness*
Median Income ($)	8333.07	7966	2690.05	7,235,356	0.4827
Mean Income ($)	9603.96	9071	2639.88	6,968,948	1.3118
Per Capita Income ($)	3381.37	3232	823.45	678,079	2.6523
Median Rent ($)	102.88	96	34.14	1165.33	0.7145
Percent Owner-Occupied Housing (%)	60.1	61.5	13.97	195.19	-0.3535
Median School Years (yrs.)	12.04	12.2	0.91	0.83	-0.6463
Percent High School Graduates (%)	57.05	55.9	12.49	156.06	0.1553
Unemployment Rate (%)	4.42	4.2	1.54	2.38	0.9301
Percent Labor Force in Manufacturing Industries (%)	25.72	25.3	11.82	139.71	0.1642
Percent Labor Force in White-Collar Jobs (%)	52.83	51.7	10.39	107.93	0.4923
Median Age (yrs.)	28.7	28.0	4.51	20.32	1.5295
Population Growth (%)	37.66	12.6	126.723	16058.70	8.6252**
Population	116,512	53,524	360,580	1.30×10^{11}	15.6985
Log Population	11.10	10.89	0.7848	0.6159	1.8801
Population Density (per sq. mile)	4853.63	3813	4008.41	16,673,364	3.7602
Log Population Density	8.25	8.24	0.6740	0.4543	0.0788

*Degree of skewness is measured by the following formula:

$$\frac{N}{(N - 1)(N - 2)} \Sigma z_i^3$$

where $z = \frac{(x - \bar{x})}{s}$, N is the number of observations, $\bar{x}$ the sample mean, and s the standard deviation. The formula is adopted by SAS MEANS and UNIVARIATE Procedures. See SAS User's Guide, 1979 ed., (Raleigh, NC: SAS Institute, Inc.), p. 303.

**No transformation was performed since there are negative values in the sample.

Table A.4.2. Scoring Coefficient (Oblique Rotation) of Factor Analysis

	Factor 1	Factor 2	Factor 3	Factor 4
Median Income	0.25148	-0.10519	-0.07196	0.06519
Mean Income	0.24053	-0.30943	-0.04514	-0.01273
Per Capita Income	0.17981	0.08765	0.11118	-0.20790
Median Rent	0.19999	0.06287	0.13930	0.11019
Percent Owner-Occupied Housing	0.09359	-0.07033	-0.38632	0.14535
Median School Year	0.02273	0.25444	-0.06405	0.04315
Percent High School Graduates	0.04860	0.25152	-0.03678	0.09829
Unemployment Rate	-0.06635	-0.03502	0.23777	0.30592
Percent Labor Force in Manufacturing Industries	0.14518	-0.33348	-0.04427	0.03397
Percent Labor Force in White-Collar Jobs	0.05395	0.26987	0.03027	-0.08218
Median Age	0.05000	-0.01167	0.08345	-0.51133
Population Growth	0.08235	-0.00232	0.06721	0.44649
Log Population	-0.00729	0.01815	0.33614	0.08903
Log Population Density	0.11745	-0.07301	0.45453	-0.07646

Table A.4.3. Scoring Coefficient Matrix (Orthogonal Rotation) of Factor Analysis

	Factor 1	Factor 2	Factor 3	Factor 4
Median Income	0.27769	-0.14954	-0.05242	0.07494
Mean Income	0.25424	-0.07684	-0.03598	-0.00426
Per Capita Income	0.17637	0.07226	0.09527	-0.19038
Median Rent	0.21899	0.03331	0.17481	0.14490
Percent Owner-Occupied Housing	0.07620	-0.09618	-0.37537	0.10095
Median School Year	-0.02465	0.25821	-0.05362	0.02940
Percent High School Graduates	0.00837	0.24981	-0.01522	0.09214
Unemployment Rate	-0.02501	-0.03383	0.29066	0.34876
Percent Labor Force in Manufacturing Industries	0.20671	-0.36900	-0.03903	0.04675
Percent Labor Force in White-Collar Jobs	0.00987	0.27481	0.02707	-0.08494
Median Age	0.04055	-0.00159	0.00971	-0.51355
Population Growth	0.11394	-0.02875	0.14424	0.47708
Log Population	0.02862	0.02085	0.36362	0.14087
Log Population Density	0.18048	-0.08538	0.46635	-0.00283

Appendix A.5

STATISTICS RELATED TO EMPIRICAL ESTIMATIONS

OF CHAPTER V

Appendix A.5.1

CORRELATION MATRICES OF EQUATION (5.3)

S	g	π'	π'_D	π^t	B	H_r^*	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}
1.0000																				
-0.0167	1.0000																			
0.0066	0.0148	1.0000																		
0.0329	-0.1080	-0.1957	1.0000																	
0.0121	-0.0658	0.2395	-0.0000	1.0000																
-0.0583	0.0355	0.0620	0.1132	0.0556	1.0000															
-0.0772	0.0291	0.2096	-0.0385	0.0559	0.1760	1.0000														
0.0179	0.0016	-0.0990	-0.1556	-0.1180	-0.0650	-0.0356	1.0000													
0.0853	0.0113	-0.0780	-0.0990	-0.1574	-0.0451	-0.0102	0.7262	1.0000												
-0.0101	0.0106	-0.0517	-0.1494	-0.2052	-0.0340	-0.0274	0.5827	0.8299	1.0000											
-0.0138	-0.0212	-0.1282	-0.0782	-0.1955	-0.0191	0.0313	0.5693	0.8148	0.8728	1.0000										
-0.0199	0.0092	-0.0111	-0.1310	-0.1417	0.1057	0.0797	0.5780	0.8349	0.8995	0.8832	1.0000									
0.0661	0.0315	-0.0899	-0.1607	-0.1272	0.0276	-0.0669	0.9261	0.7516	0.6300	0.6114	0.6347	1.0000								
0.0054	0.1059	0.0763	0.0000	0.0400	0.3962	0.2250	-0.0143	-0.0065	-0.0158	-0.0066	0.0529	0.0127	1.0000							
-0.0382	0.1367	0.0808	-0.0707	0.1241	0.2736	0.1465	-0.0315	-0.0284	-0.0206	-0.0205	0.0302	-0.0022	0.2887	1.0000						
-0.0169	-0.0476	-0.0738	-0.1330	-0.1393	0.1905	0.0315	0.5642	0.8085	0.8724	0.8596	0.9111	0.6284	0.0712	0.0409	1.0000					
-0.0154	0.0234	-0.0244	-0.1334	-0.1347	0.2024	0.0407	0.5619	0.8117	0.8767	0.8585	0.9181	0.6299	0.0839	0.0542	0.9096	1.0000				
0.0035	0.0230	-0.0934	-0.1333	-0.1124	-0.0438	-0.0210	0.9229	0.7435	0.6203	0.6077	0.6209	0.9655	-0.0097	-0.0179	0.6045	0.6048	1.0000			
0.0860	0.0257	-0.0522	-0.1010	-0.0132	-0.0368	-0.0024	0.7181	0.2457	0.0195	0.0174	0.0131	0.7429	0.0014	-0.0075	0.0153	0.0127	0.7369	1.0000		
0.0713	-0.0272	-0.1151	-0.1402	-0.1227	-0.0547	-0.0404	0.9236	0.7484	0.6212	0.6097	0.6184	0.9684	-0.1243	-0.0810	0.6070	0.6026	0.9583	0.7392	1.0000	
-0.5485	0.0731	-0.0069	0.2448	0.0305	0.1414	0.0370	-0.3097	-0.2289	-0.0444	-0.0289	-0.0223	0.1958	0.0034	0.0665	-0.0249	-0.0165	-0.1737	-0.2243	-0.2166	1.0000

*Factor 1 of Table 5.2.

S	g	π'	π'_D	π^t	B	H_r^*	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}
1.0000																				
-0.0183	1.0000																			
0.0224	0.0099	1.0000																		
0.0129	-0.0873	-0.1812	1.0000																	
0.0064	-0.0568	0.2328	0.0435	1.0000																
-0.0585	0.0440	0.0291	0.1743	0.0814	1.0000															
-0.0617	0.0611	0.0161	0.2598	0.1595	0.2301	1.0000														
0.0244	-0.0066	-0.0950	-0.1895	-0,1377	-0.0924	-0.1520	1.0000													
0.0847	0.0115	-0.0776	-0.0962	-0.1552	-0.0430	-0.0007	0.7180	1.0000												
-0.0131	0.0123	-0.0468	-0.1417	-0.1991	-0.0255	0.0145	0.5733	0.8299	1.0000											
-0.0129	-0.0206	-0.1374	-0.0682	-0.1912	-0.0187	0.0241	0.5606	0.8153	0.8744	1.0000										
-0.0134	0.0064	-0.0286	-0.1259	-0.1461	0.0893	-0.0071	0.5773	0.8384	0.9047	0.8835	1.0000									
0.0631	0.0314	-0.0782	-0.1668	-0.1276	0.0313	-0.0336	0.9202	0.7522	0.6289	0.6139	0.6434	1.0000								
0.0057	0.1147	0.0338	0.0791	0.0703	0.4108	0.2724	-0.0476	-0.0043	-0.0056	-0.0069	0.0327	0.0183	1.0000							
-0.0379	0.1426	0.0538	-0.0156	0.1427	0.2851	0.1805	-0.0533	-0.0269	-0.0139	-0.0206	0.0172	0.0015	0.3002	1.0000						
-0.0197	-0.0432	-0.0805	-0.1050	-0.1256	0.2018	0.0845	0.5445	0.8063	0.8720	0.8582	0.9081	0.6268	0.0861	0.0512	1.0000					
-0.0175	0.0273	-0.0321	-0.1048	-0.1213	0.2122	0.0857	0.5426	0.8098	0.8768	0.8570	0.9145	0.6289	0.0969	0.0633	0.9102	1.0000				
0.0096	0.0157	-0.0924	-0.1614	-0.1293	-0.0683	-0.1260	0.9240	0.7377	0.6133	0.6007	0.6206	0.9625	-0.0392	-0.0373	0.5879	0.5884	1.0000			
0.0932	0.0176	-0.0545	-0.1307	-0.1336	-0.0657	-0.1304	0.7239	0.2437	0.0173	0.0142	0.0142	0.7421	-0.0336	-0.0305	0.0042	0.0015	0.7417	1.0000		
0.0753	-0.0332	-0.1103	-0.1677	-0.1376	-0.0746	-0.1214	0.9245	0.7432	0.6144	0.6041	0.6203	0.9650	-0.1461	-0.0961	0.5922	0.5882	0.9591	0.7438	1.0000	
-0.4669	0.0387	-0.0205	0.1031	-0.0432	0.0215	-0.4303	-0.2101	-0.2061	-0.0454	-0.0375	-0.0199	-0.1604	-0.1216	-0.0228	-0.0598	-0.0531	-0.1007	-0.1447	-0.1408	1.0000

*Factor 3 of Table 5.2.

S	g	π'	π'_D	π^t	B	$H_{r_1}^{*}$	$H_{r_3}^{**}$	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}
1.0000																					
-0.0212	1.0000																				
0.0038	0.0174	1.0000																			
0.0135	-0.0875	-0.1788	1.0000																		
0.0001	-0.0540	0.2425	0.0428	1.0000																	
-0.0738	0.0503	0.0698	0.1693	0.0941	1.0000																
-0.0845	0.0362	0.2125	-0.0080	0.0736	0.1973	1.0000															
-0.0706	0.0648	0.0396	0.2572	0.1664	0.2464	0.1129	1.0000														
0.0287	-0.0085	-0.1039	-0.1888	-0.1410	-0.1009	-0.0526	-0.1568	1.0000													
0.0852	0.0111	-0.0780	-0.0962	-0.1555	-0.0442	-0.0104	-0.0018	0.7175	1.0000												
-0.0109	0.0113	-0.0512	-0.1414	-0.2004	-0.0301	-0.0259	0.0115	0.5737	0.8298	1.0000											
-0.0158	-0.0194	-0.1269	-0.0684	-0.1881	-0.0116	0.0342	0.0278	0.5577	0.8144	0.8727	1.0000										
-0.0200	0.0093	-0.0110	-0.1261	-0.1394	0.1030	0.0794	0.0019	0.5705	0.8349	0.8995	0.8829	1.0000									
0.0688	0.0287	-0.0914	-0.1658	-0.1322	0.0165	-0.0711	-0.0413	0.9203	0.7510	0.6290	0.6095	0.6341	1.0000								
-0.0154	0.1200	0.0845	0.0746	0.0861	0.4389	0.2466	0.2902	-0.0590	-0.0068	-0.0118	0.0018	0.0511	0.0001	1.0000							
-0.0512	0.1465	0.0869	-0.0167	0.1525	0.3082	0.1648	0.1955	-0.0612	-0.0282	-0.0180	-0.0146	0.0300	-0.0102	0.3276	1.0000						
-0.0231	-0.0416	-0.0699	-0.1052	-0.1221	0.2057	0.0411	0.0885	0.5412	0.8052	0.8699	0.8584	0.9077	0.6218	0.0936	0.0573	1.0000					
-0.0217	0.0291	-0.0206	-0.1050	-0.1171	0.2177	0.0505	0.0908	0.5385	0.8082	0.8740	0.8571	0.9144	0.6230	0.1063	0.0706	0.9103	1.0000				
0.0125	0.0144	-0.0977	-0.1610	-0.1314	-0.0739	-0.0353	-0.1291	0.9241	0.7375	0.6136	0.5988	0.6154	0.9620	-0.0466	-0.0426	0.5856	0.5856	1.0000			
0.0943	0.0169	-0.0569	-0.1306	-0.0348	-0.0678	-0.0172	-0.1315	0.7237	0.2438	0.0178	0.0136	0.0128	0.7413	-0.0368	-0.0329	0.0034	0.0006	0.7414	1.0000		
0.0795	-0.0351	-0.1191	-0.1670	-0.1410	-0.0837	-0.0541	-0.1266	0.9247	0.7426	0.6147	0.6010	0.6131	0.9650	-0.1547	-0.1035	0.5886	0.5838	0.9590	0.7436	1.0000	
-0.4639	0.0381	-0.0233	0.1032	-0.0442	0.0181	-0.0152	-0.4292	-0.2089	-0.2059	-0.0450	-0.0380	-0.0210	-0.1589	-0.1216	-0.0250	-0.0604	-0.0538	-0.1001	-0.1444	-0.1397	1.0000

*Factor 1 of Table 5.2.

**Factor 3 of Table 5.2.

Appendix A.5.2

CORRELATION MATRICES OF ALTERNATIVE ESTIMATION OF EQUATION (5.2) SHOWN IN TABLE 5.9

S	g	π'	π'_D	π^t	B	H_r^*	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}
1.0000																	
0.0278	1.0000																
-0.0034	0.0106	1.0000															
0.2022	-0.1343	-0.2151	1.0000														
0.0286	-0.0797	0.2252	-0.0221	1.0000													
0.0220	0.0239	0.0603	0.0794	0.0474	1.0000												
-0.0700	0.0229	0.2060	-0.0537	0.0465	0.1713	1.0000											
-0.3589	0.0866	0.0048	-0.0070	-0.0253	-0.0010	0.0086	1.0000										
-0.0185	0.1534	0.0588	0.0728	-0.0246	0.0291	0.0909	0.2748	1.0000									
-0.0180	0.1620	0.1223	-0.1583	-0.1274	-0.0010	0.0542	0.2948	0.3469	1.0000								
-0.0054	0.0781	-0.0554	0.0006	-0.1043	0.0262	0.1754	0.2659	0.3230	0.3653	1.0000							
-0.0116	0.1586	0.2224	-0.1288	0.0221	0.3244	0.3064	0.3032	0.3866	0.4548	0.4081	1.0000						
0.0243	0.2199	0.0828	-0.1227	-0.0551	0.3205	-0.1225	0.3527	0.4123	0.5111	0.4077	0.5897	1.0000					
0.0020	0.0962	0.0564	-0.0165	0.0093	0.4012	0.2189	0.2572	0.3234	0.3579	0.3504	0.5307	0.5290	1.0000				
-0.0057	0.1266	0.0704	-0.0994	0.1067	0.2658	0.1396	0.1258	0.1603	0.1838	0.1672	0.3053	0.2958	0.2754	1.0000			
-0.0079	0.0197	0.0627	-0.1242	0.0185	0.4814	0.1744	0.2511	0.3027	0.3679	0.3438	0.5539	0.5766	0.5185	0.2988	1.0000		
0.0076	0.1697	0.1672	-0.1287	0.0267	0.4978	0.1908	0.2628	0.3343	0.3994	0.3475	0.5961	0.6166	0.5379	0.3214	0.5855	1.0000	
-0.1959	0.1553	0.0574	-0.0286	-0.0013	0.0114	0.0526	0.3899	0.3829	0.4263	0.3800	0.4562	0.5107	0.3782	0.1952	0.3713	0.3984	1.0000

*Factor 1 of Table 5.2.

S	g	π'	π'_D	π^t	B	H^*_r	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}
1.0000																	
-0.0020	1.0000																
0.0146	0.0050	1.0000															
0.0722	-0.0973	-0.2016	1.0000														
-0.0174	-0.0670	0.2167	0.0268	1.0000													
-0.0537	0.0424	0.0220	0.1642	0.0747	1.0000												
-0.3325	0.0894	-0.0118	0.3187	0.1421	0.2563	1.0000											
-0.2567	0.0641	0.0057	-0.0766	-0.0563	-0.0592	-0.2215	1.0000										
-0.0133	0.1518	0.0410	0.0757	-0.0279	0.0147	0.0053	0.2671	1.0000									
-0.0571	0.1708	0.1112	-0.1045	-0.1091	0.0238	0.1318	0.2557	0.3416	1.0000								
-0.0448	0.0879	-0.0957	0.0587	-0.0899	0.0358	0.1544	0.2246	0.3103	0.3748	1.0000							
-0.0280	0.1677	0.1686	-0.0752	0.0242	0.3075	0.1136	0.2808	0.3766	0.4690	0.3887	1.0000						
-0.0960	0.2405	0.1010	-0.0112	0.0006	0.4034	0.3312	0.2546	0.4060	0.5323	0.4606	0.6600	1.0000					
-0.0607	0.1113	0.0088	0.0696	0.0322	0.4153	0.2323	0.1967	0.3050	0.3731	0.3480	0.5088	0.6037	1.0000				
-0.0561	0.1382	0.0402	-0.0292	0.1242	0.2820	0.1802	0.0807	0.1482	0.1975	0.1701	0.2926	0.3552	0.2844	1.0000			
-0.0841	0.0390	0.0237	-0.0223	0.0477	0.5017	0.2650	0.1797	0.2835	0.3834	0.3487	0.5417	0.6445	0.5304	0.3148	1.0000		
-0.0705	0.1858	0.1250	-0.0240	0.0558	0.5169	0.2707	0.1898	0.3135	0.4145	0.3509	0.5810	0.6863	0.5478	0.3360	0.6020	1.0000	
-0.1954	0.1573	0.0471	-0.0116	0.0020	0.0127	0.0406	0.3710	0.3801	0.4259	0.3786	0.4642	0.5053	0.3752	0.1940	0.3656	0.3921	1.0000

*Factor 3 of Table 5.2.

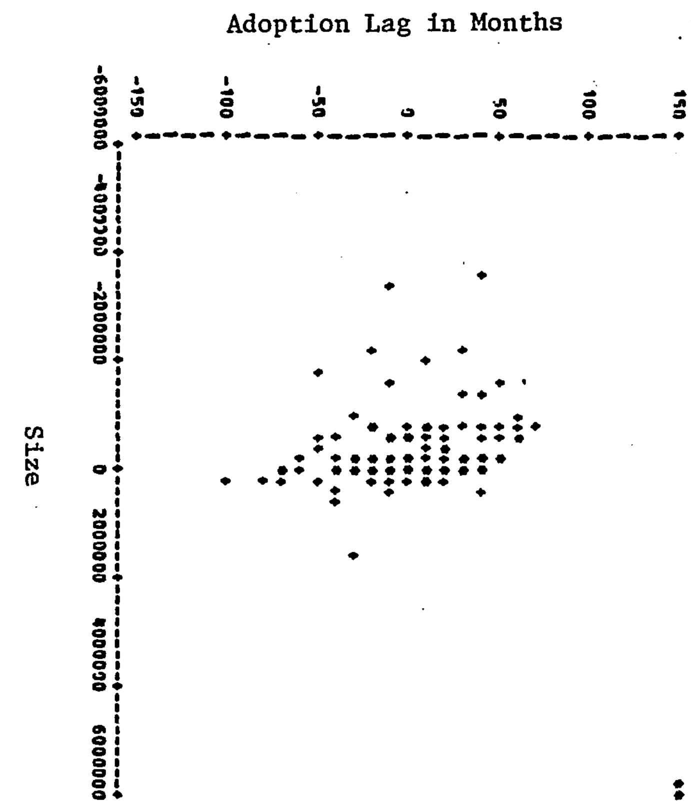
S	g	π'	π'_D	π^t	B	$H^{*}_{r_1}$	$H^{**}_{r_3}$	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}
1.0000																		
-0.0054	1.0000																	
-0.0071	0.0117	1.0000																
0.0734	-0.0978	-0.2004	1.0000															
-0.0238	-0.0648	0.2244	0.0258	1.0000														
-0.0725	0.0480	0.0612	0.1581	0.0853	1.0000													
-0.1036	0.0331	0.2060	-0.0153	0.0623	0.1943	1.0000												
-0.3402	0.0925	0.0116	0.3149	0.1479	0.2716	0.1122	1.0000											
-0.2536	0.0635	0.0021	-0.0764	-0.0572	-0.0613	-0.0166	-0.2220	1.0000										
-0.0227	0.1541	0.0589	0.0740	-0.0220	0.0323	0.0921	0.0156	0.2644	1.0000									
-0.0638	0.1726	0.1228	-0.1053	-0.1043	0.0366	0.0689	0.1384	0.2539	0.3456	1.0000								
-0.0635	0.0925	-0.0526	0.0547	-0.0762	0.0716	0.1910	0.1720	0.2173	0.3208	0.3802	1.0000							
-0.0593	0.1694	0.2218	-0.0761	0.0427	0.3477	0.3174	0.1426	0.2610	0.3849	0.4655	0.4225	1.0000						
-0.0869	0.2370	0.0822	-0.0099	-0.0044	0.3790	-0.0796	0.3191	0.2551	0.3957	0.5238	0.4355	0.5986	1.0000					
-0.0836	0.1159	0.0575	0.0639	0.0461	0.4420	0.2387	0.2510	0.1871	0.3169	0.3779	0.3773	0.5443	0.5654	1.0000				
-0.0714	0.1416	0.0713	-0.0313	0.1323	0.3038	0.1578	0.1946	0.0771	0.1602	0.2055	0.1951	0.3241	0.3370	0.3104	1.0000			
-0.1025	0.0447	0.0635	-0.0248	0.0590	0.5209	0.1978	0.2803	0.1728	0.2949	0.3885	0.3733	0.5663	0.6140	0.5521	0.3359	1.0000		
-0.0907	0.1884	0.1635	-0.0268	0.0677	0.5369	0.2138	0.2867	0.1818	0.3247	0.4186	0.3773	0.6061	0.6513	0.5707	0.3578	0.6188	1.0000	
-0.1999	0.1588	0.0578	-0.0124	0.0056	0.0236	0.0574	0.0467	0.3694	0.3832	0.4282	0.3819	0.4577	0.4983	0.3775	0.2003	0.3692	0.3947	1.0000

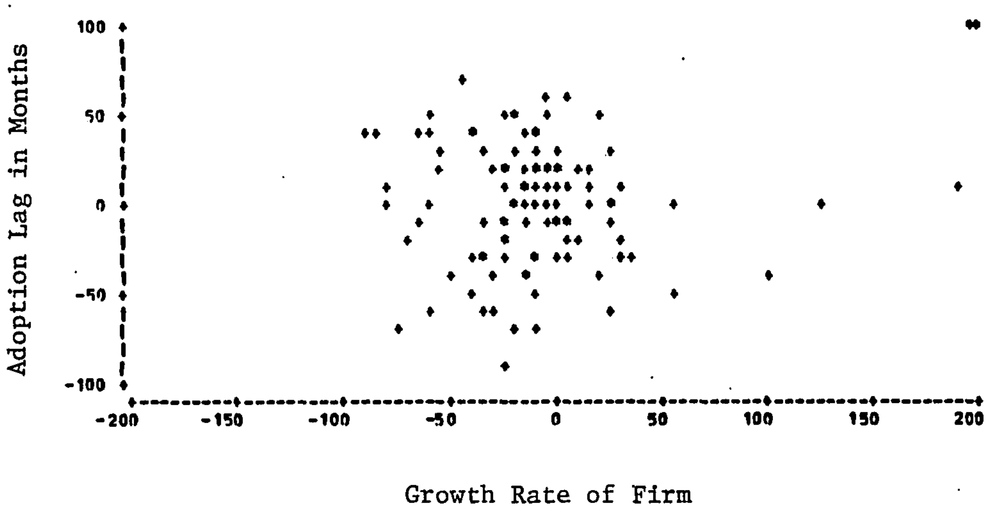
*Factor 1 of Table 5.2.

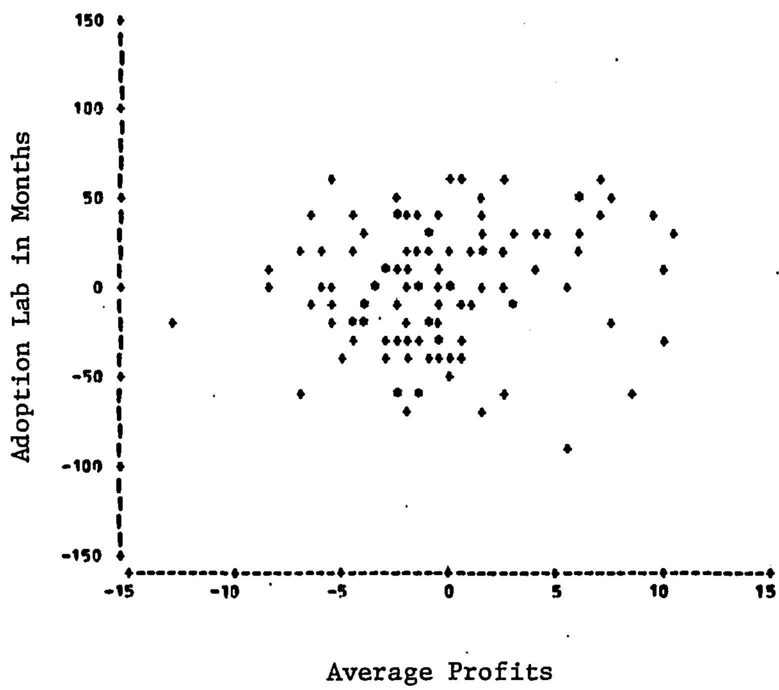
**Factor 3 of Table 5.2.

Appendix A.5.3

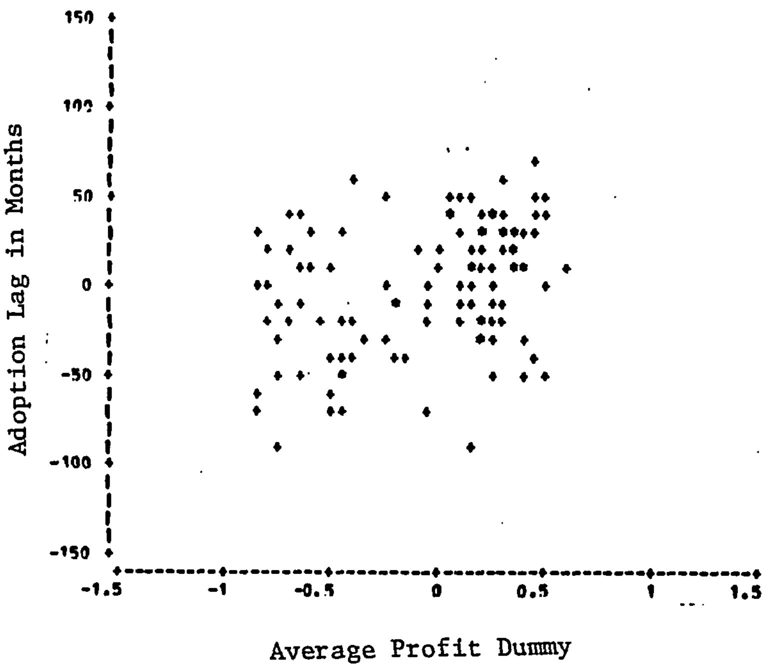
RESIDUAL PLOTTINGS OF ESTIMATION EQUATION IN TABLE 5.9, VERSION 1 (IN WHICH FACTOR 1 OF TABLE 5.2 IS USED TO PROXY URBAN HIERARCHY FACTOR)

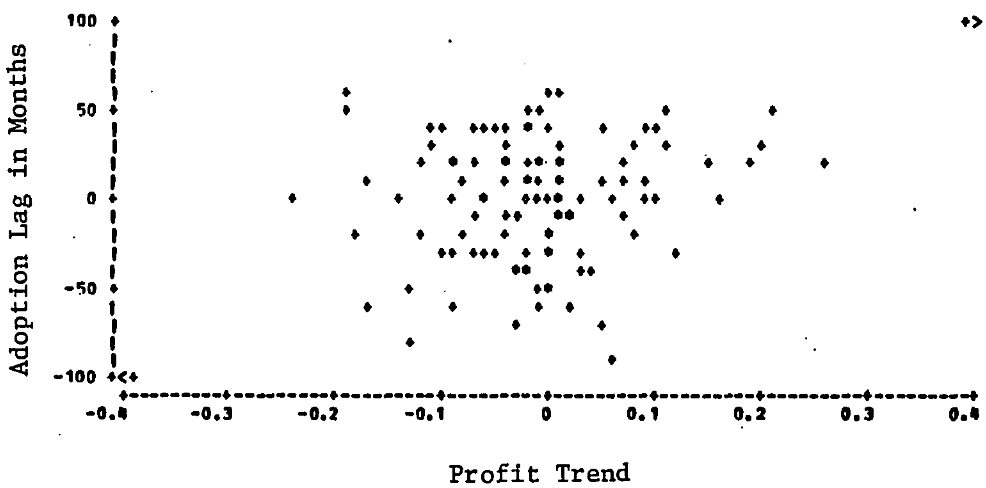

Adoption Lag in Months
-150
-100
-50
0
50
100
150
Size
-6000000
-4000000
-2000000
0
2000000
4000000
6000000

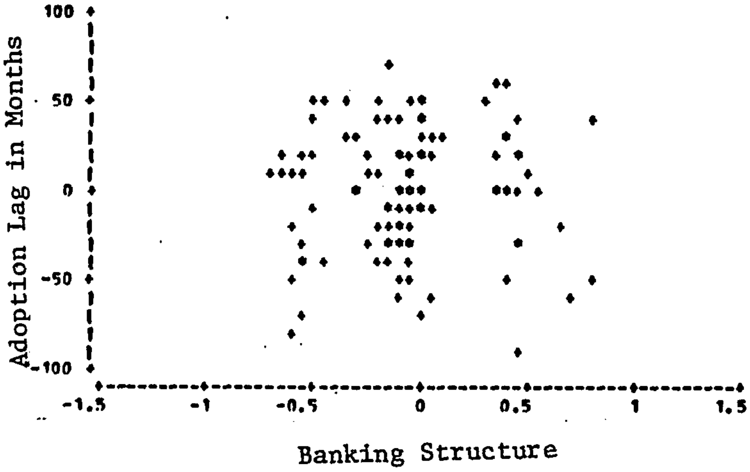

100
50
0
-50
-100
-200
-150
-100
-50
0
50
100
150
200
Adoption Lag in Months
Growth Rate of Firm

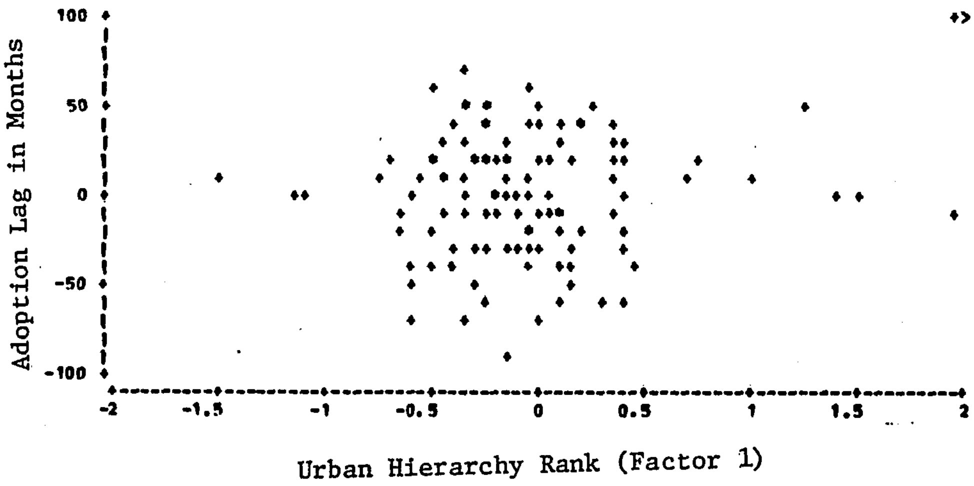


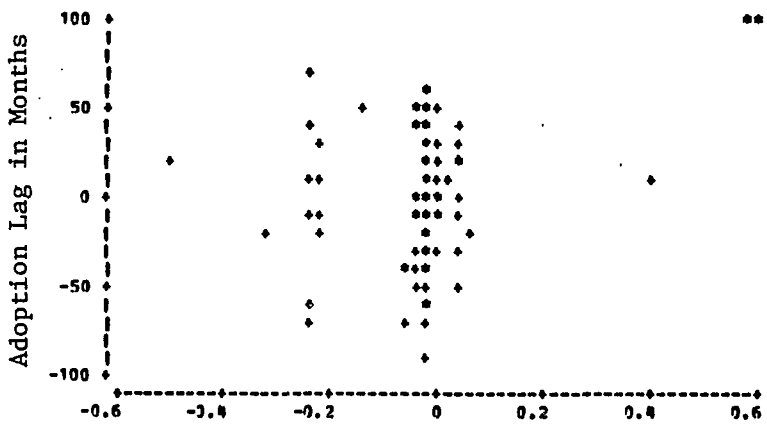
150
100
50
0
-50
-100
-150
Adoption Lab in Months
-15
-10
-5
0
5
10
15
Average Profits


Adoption Lag in Months
150
100
50
0
-50
-100
-150
-1.5
-1
-0.5
0
0.5
1
1.5
Average Profit Dummy

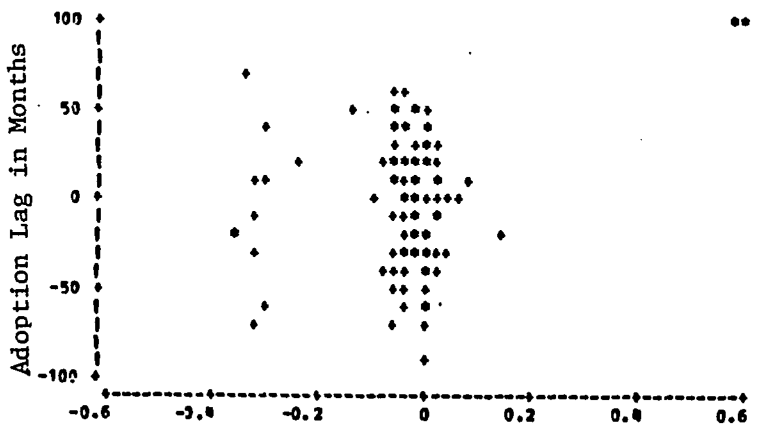

100
50
0
-50
-100
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
Adoption Lag in Months
Profit Trend


Adoption Lag in Months
100
50
0
-50
-100
-1.5
-1
-0.5
0
0.5
1
1.5
Banking Structure

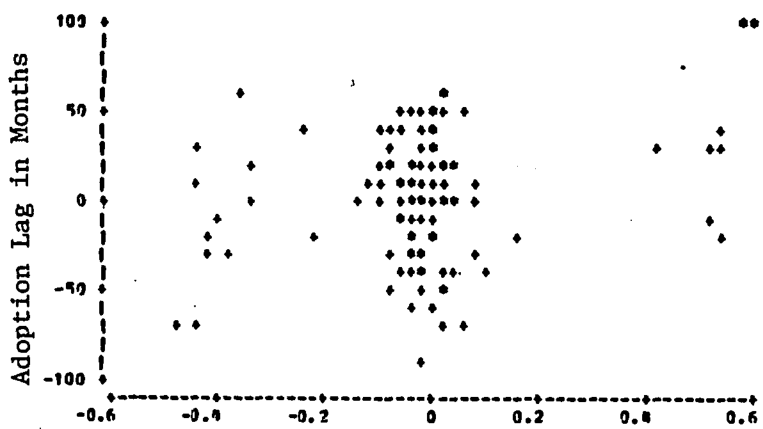

Adoption Lag in Months
100
50
0
-50
-100
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Urban Hierarchy Rank (Factor 1)



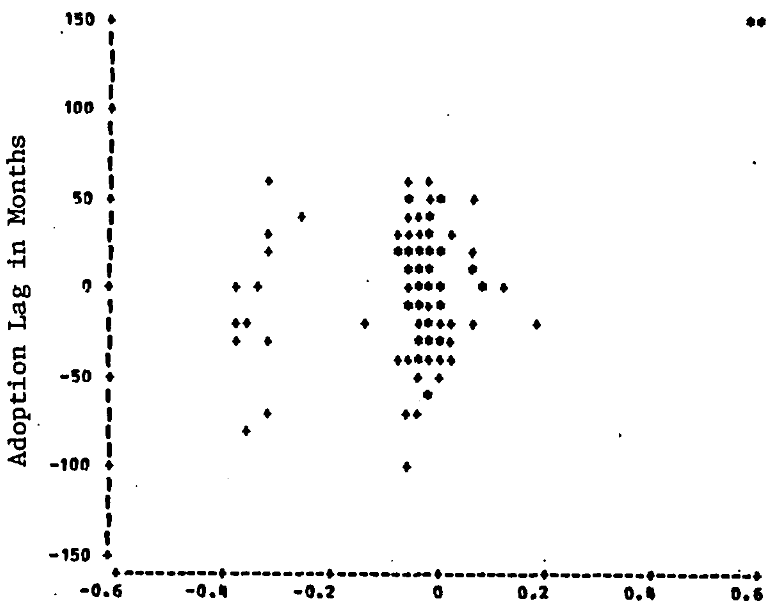
Federal Reserve District Dummy
(New York FRD)



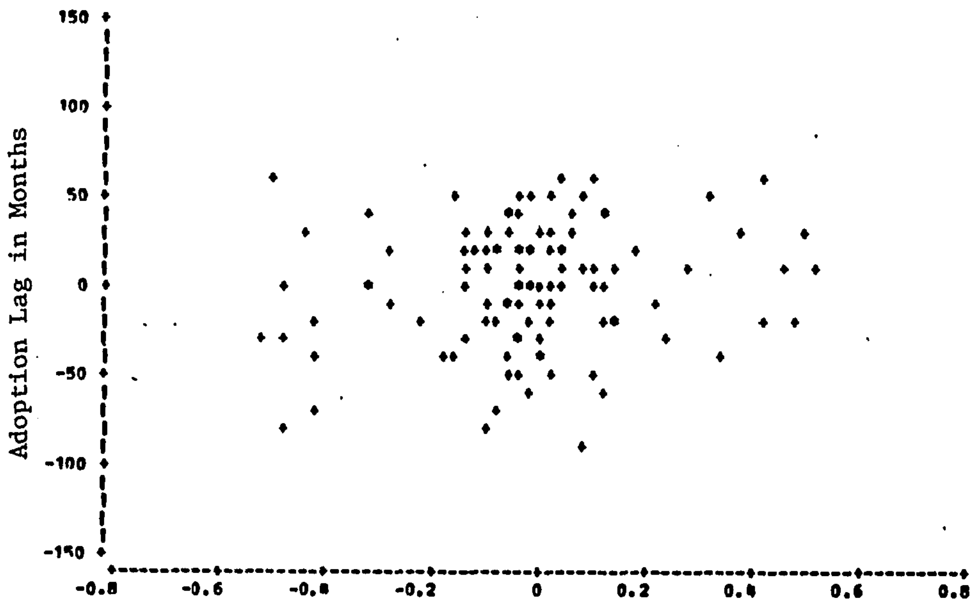
Federal Reserve District Dummy
(Philadelphia FRD)



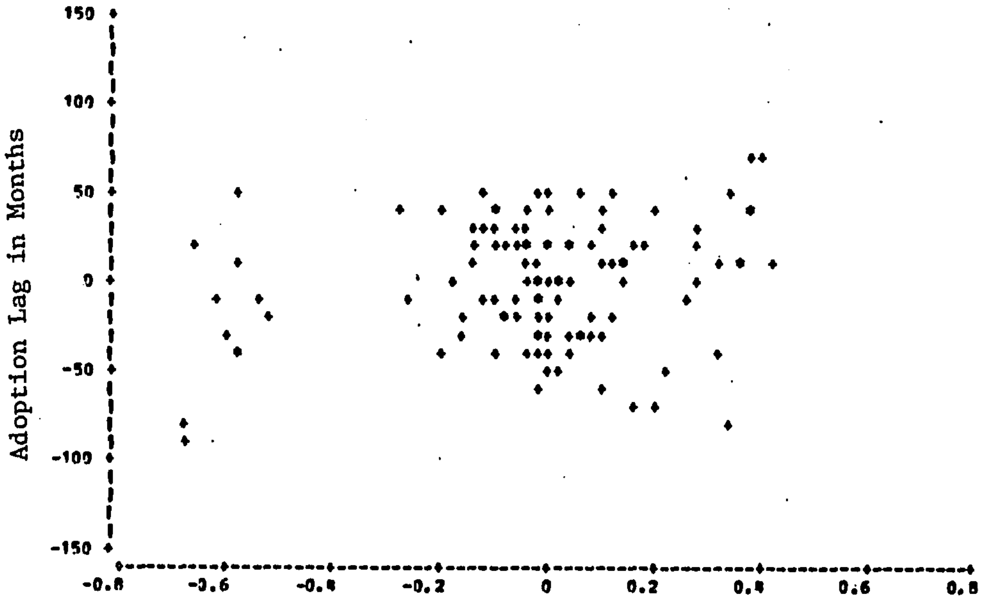
Federal Reserve District Dummy
(Cleveland FRD)



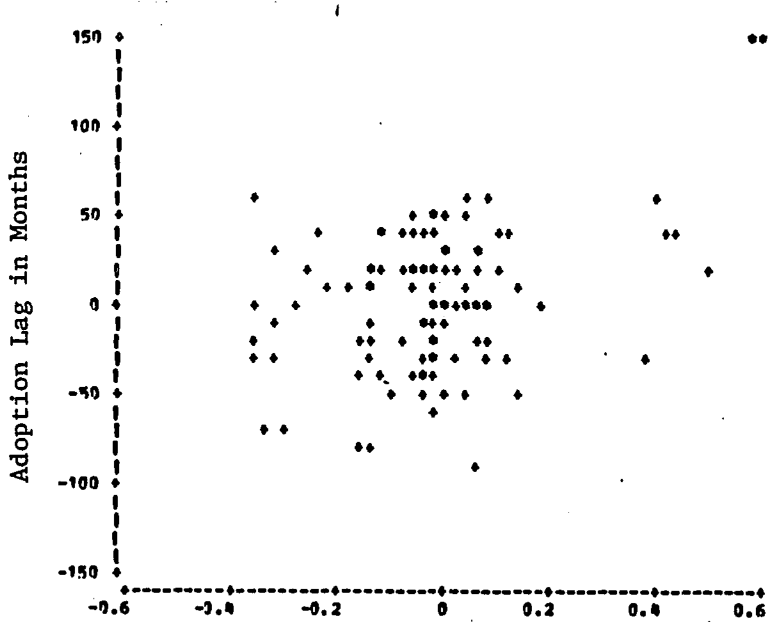
Federal Reserve District Dummy
(Richmond FRD)



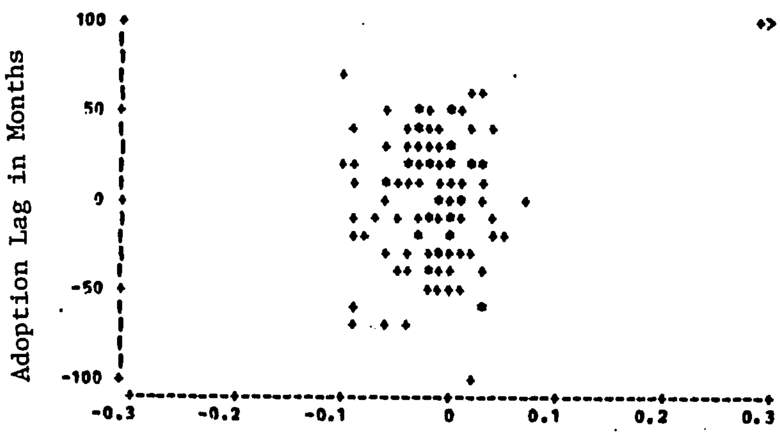
Federal Reserve District Dummy
(Atlanta FRD)



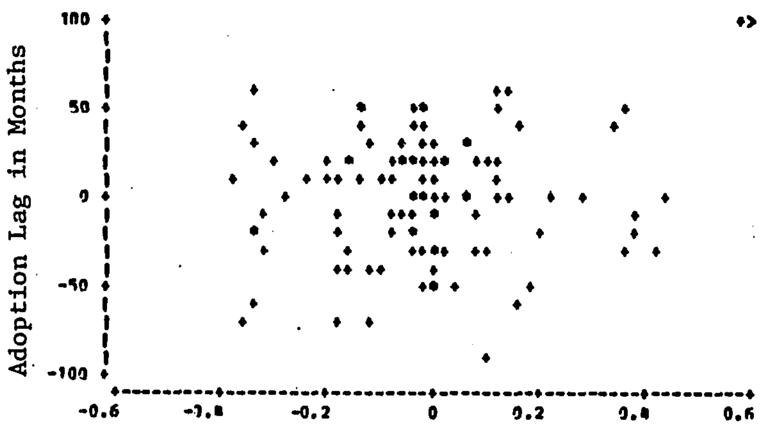
Federal Reserve District Dummy
(Chicago FRD)



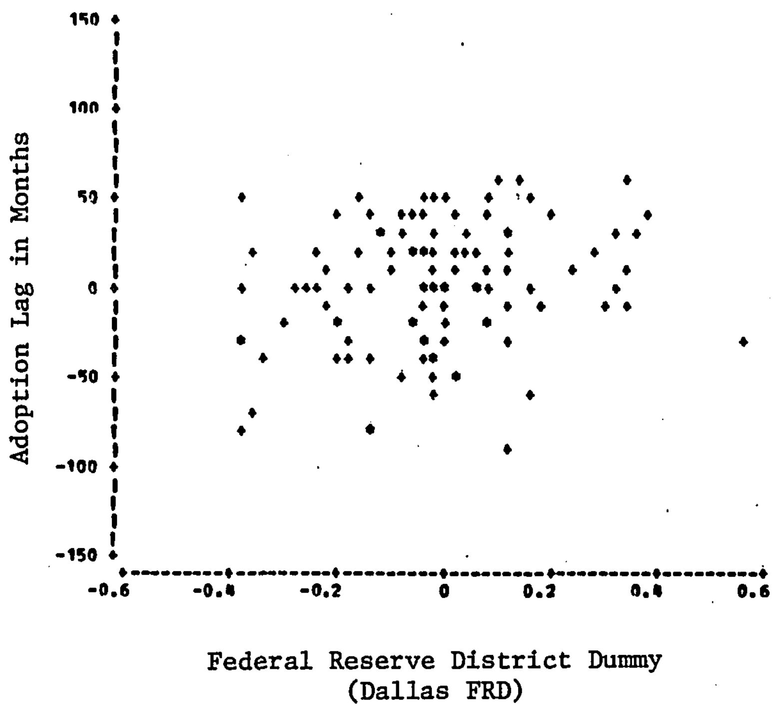
Federal Reserve District Dummy
(St. Louis FRD)

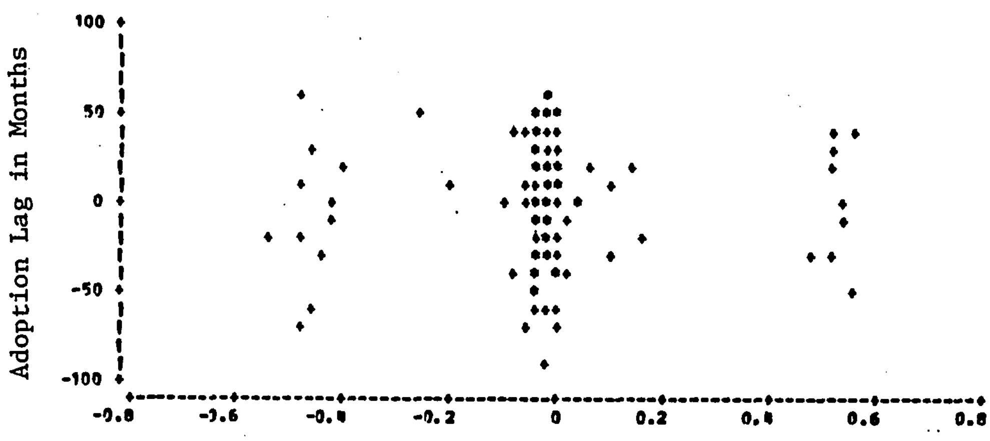


Federal Reserve District Dummy
(Minneapolis FRD)

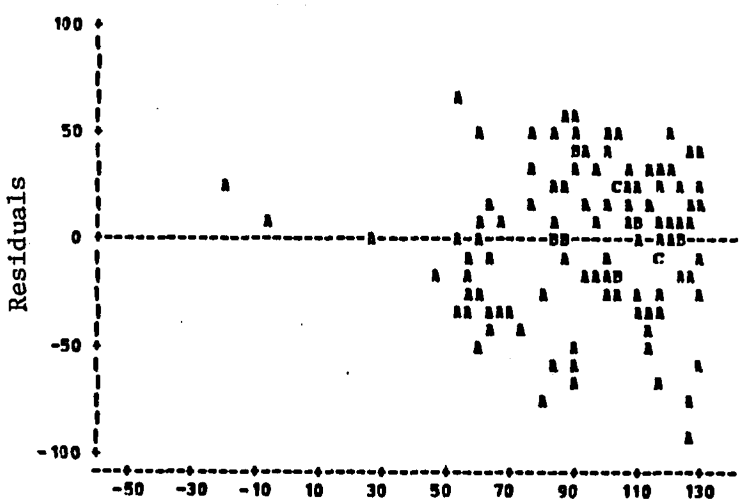


Federal Reserve District Dummy
(Kansas City FRD)


Adoption Lag in Months
150
100
50
0
-50
-100
-150
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Federal Reserve District Dummy
(Dallas FRD)



Federal Reserve District Dummy
(San Francisco FRD)

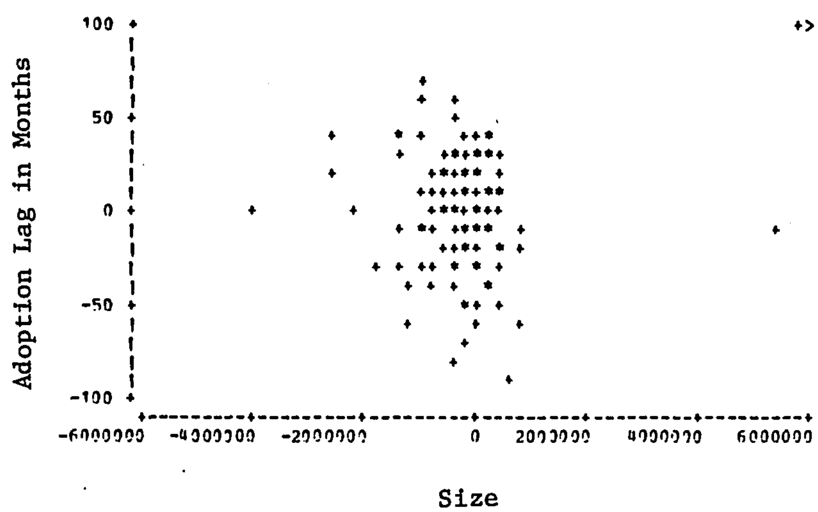


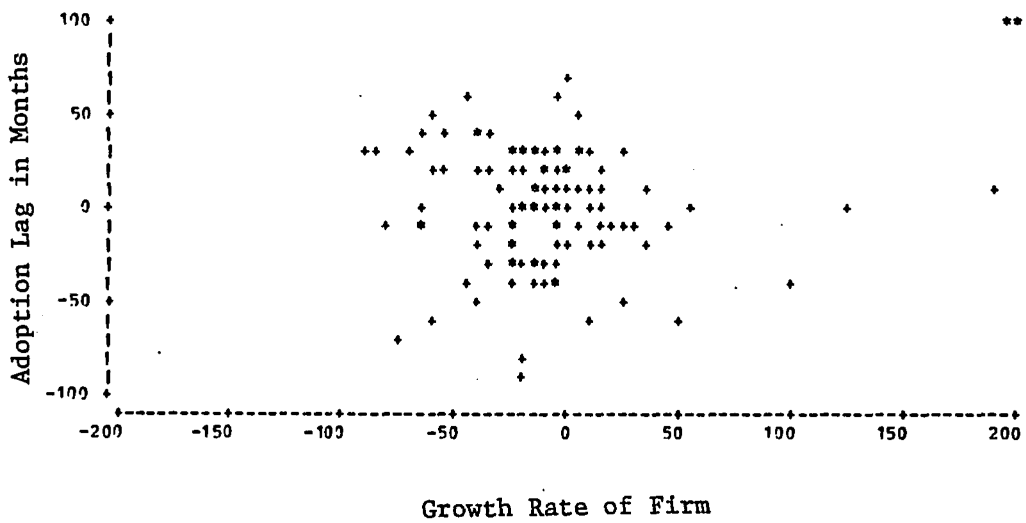
Predicted Values

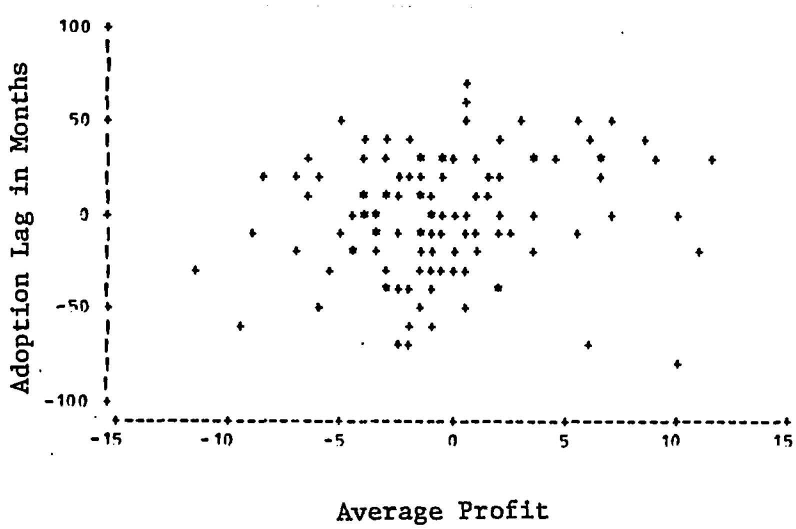
Legend: A = 1 observation, B = 2 observations, etc.

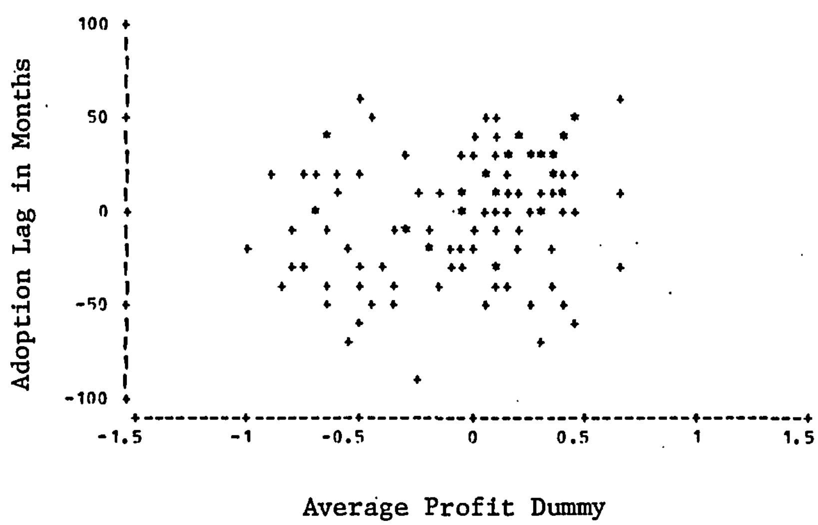
Appendix A.5.4

RESIDUAL PLOTTINGS OF ESTIMATION EQUATION IN TABLE 5.9, VERSION 2 (IN WHICH FACTOR 3 OF TABLE 5.2 IS USED TO PROXY URBAN HIERARCHY FACTOR)

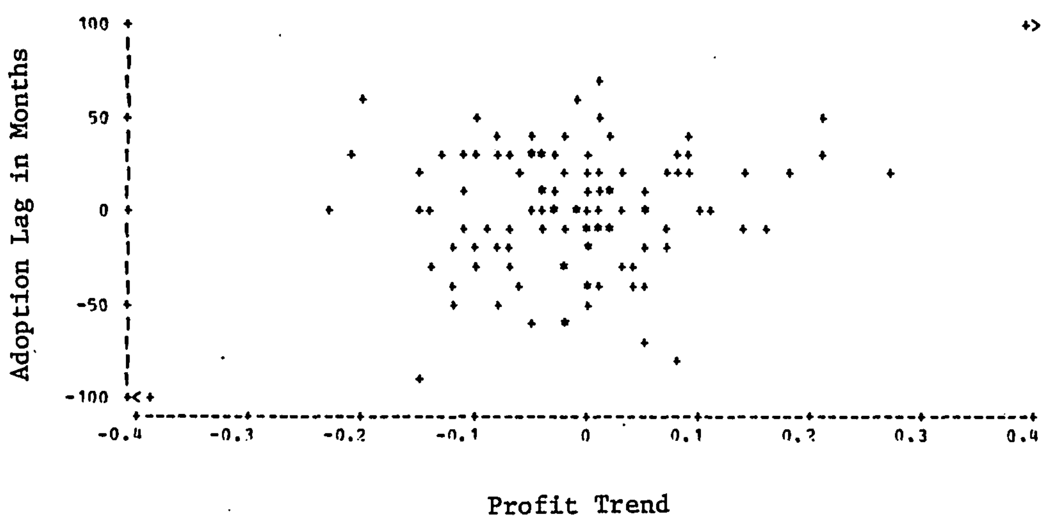

Adoption Lag in Months
100
50
0
-50
-100
-6000000
-4000000
-2000000
0
2000000
4000000
6000000
Size


100
50
0
-50
-100
Adoption Lag in Months
-200
-150
-100
-50
0
50
100
150
200
Growth Rate of Firm

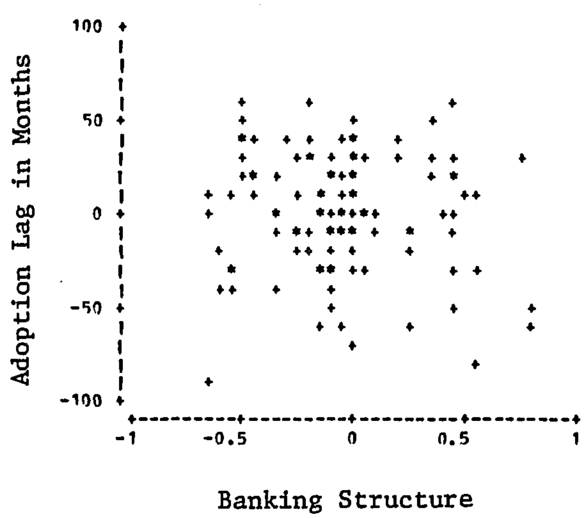

Adoption Lag in Months
100
50
0
-50
-100
-15
-10
-5
0
5
10
15
Average Profit

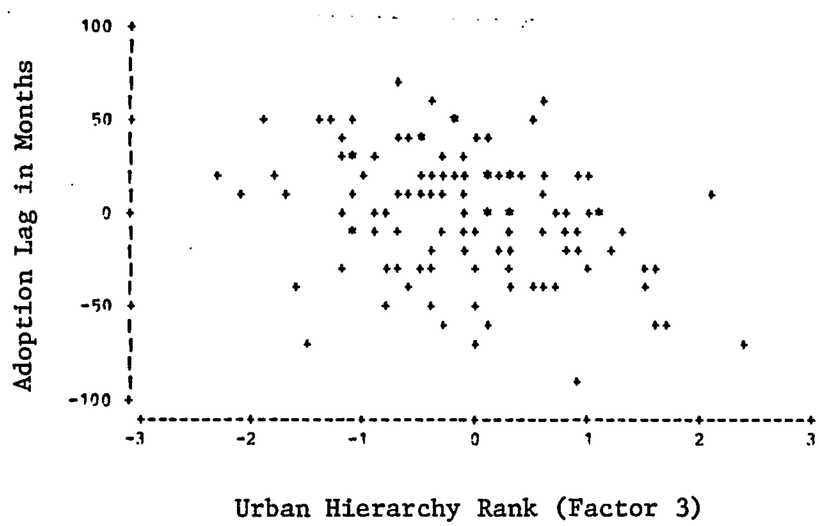


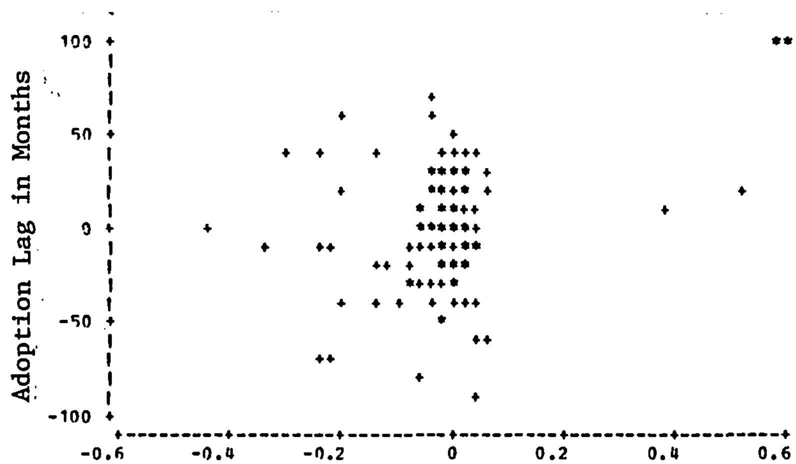
Adoption Lag in Months
100
50
0
-50
-100
-1.5
-1
-0.5
0
0.5
1
1.5
Average Profit Dummy



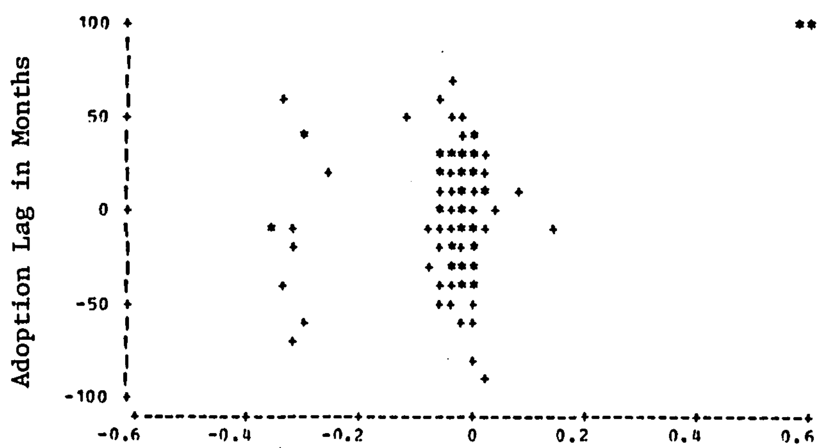
Adoption Lag in Months
100
50
0
-50
-100
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
Profit Trend


Adoption Lag in Months
100
50
0
-50
-100
-1
-0.5
0
0.5
1
Banking Structure

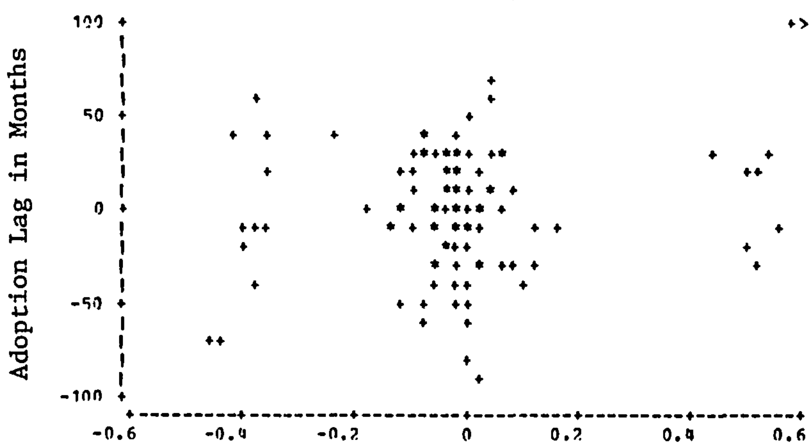

100
50
0
-50
-100
Adoption Lag in Months
-3
-2
-1
0
1
2
3
Urban Hierarchy Rank (Factor 3)



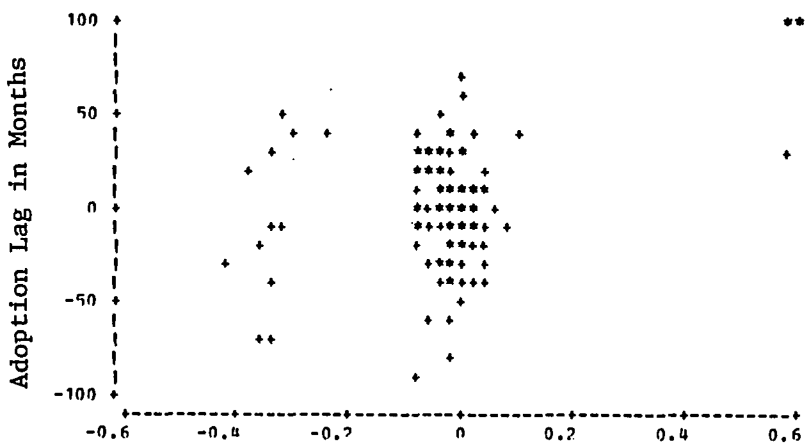
Federal Reserve District Dummy
(New York (FRD)



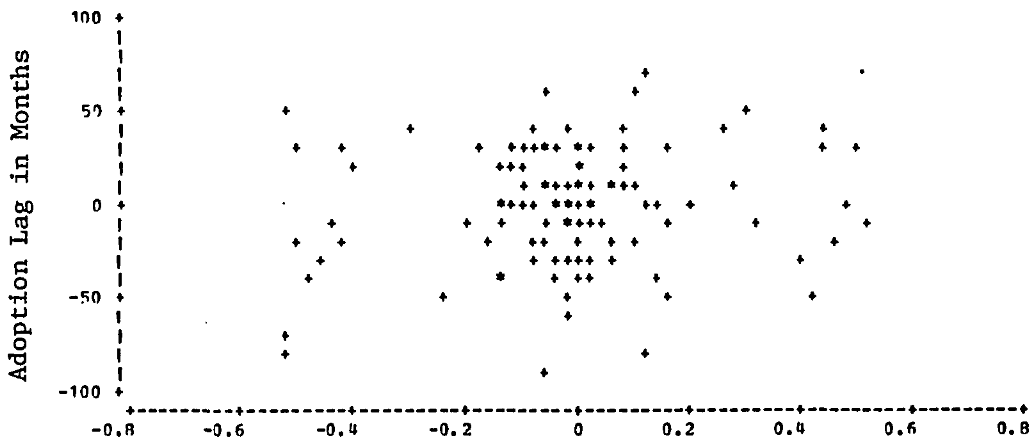
Federal Reserve District Dummy
(Philadelphia FRD)



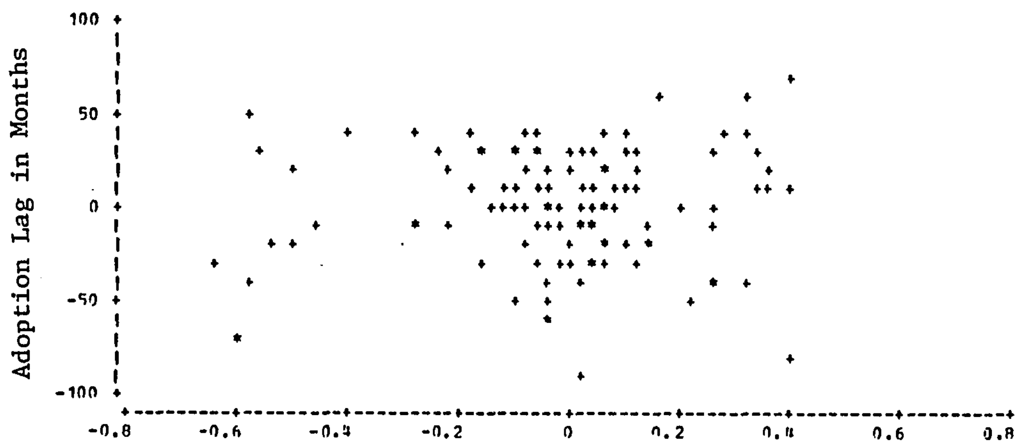
Federal Reserve District Dummy
(Cleveland FRD)



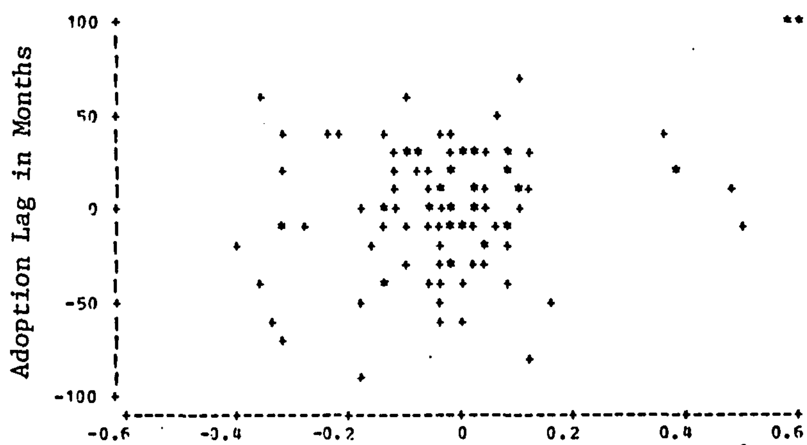
Federal Reserve District Dummy
(Richmond FRD)



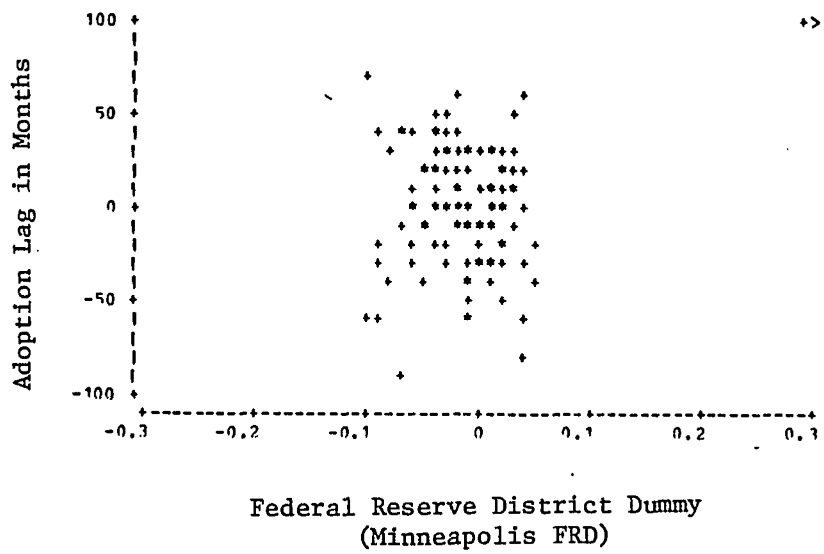
Federal Reserve District Dummy
(Atlanta FRD)

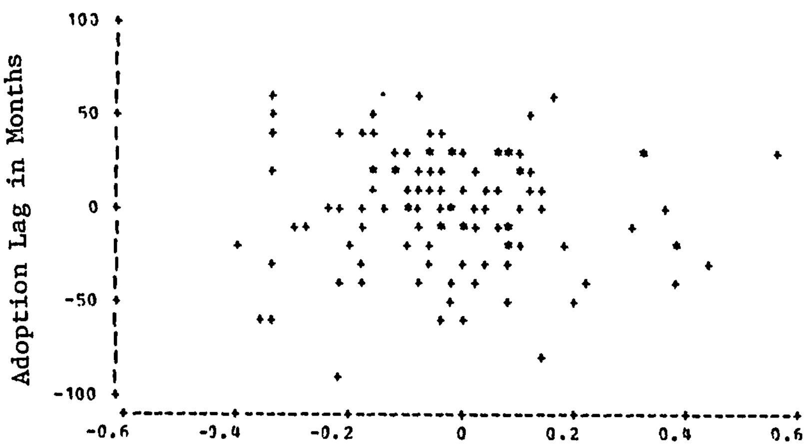


Federal Reserve District Dummy
(Chicago FRD)

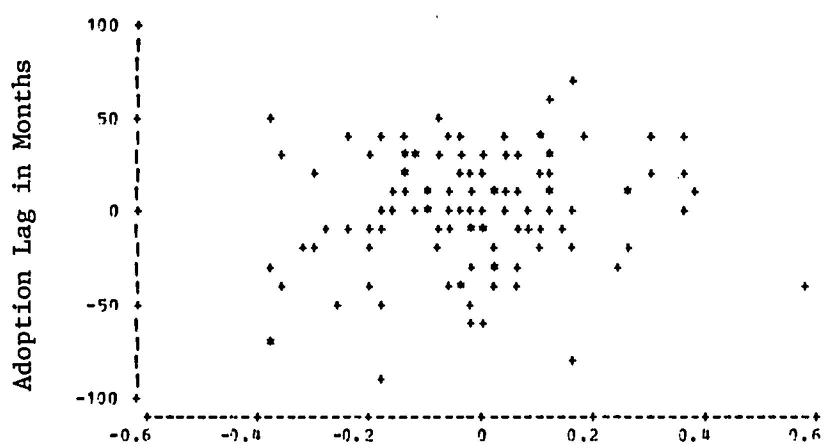


Federal Reserve District Dummy
(St. Louis FRD)

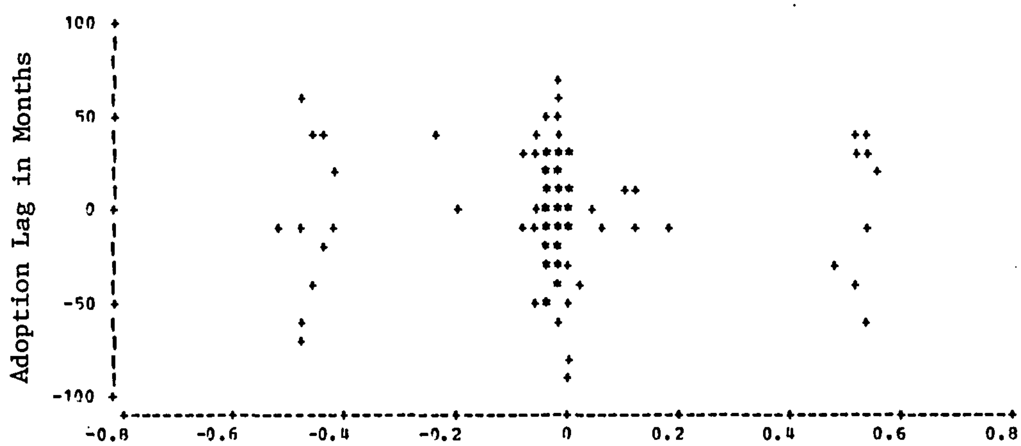

100
50
0
-50
-100
Adoption Lag in Months
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Federal Reserve District Dummy
(Minneapolis FRD)



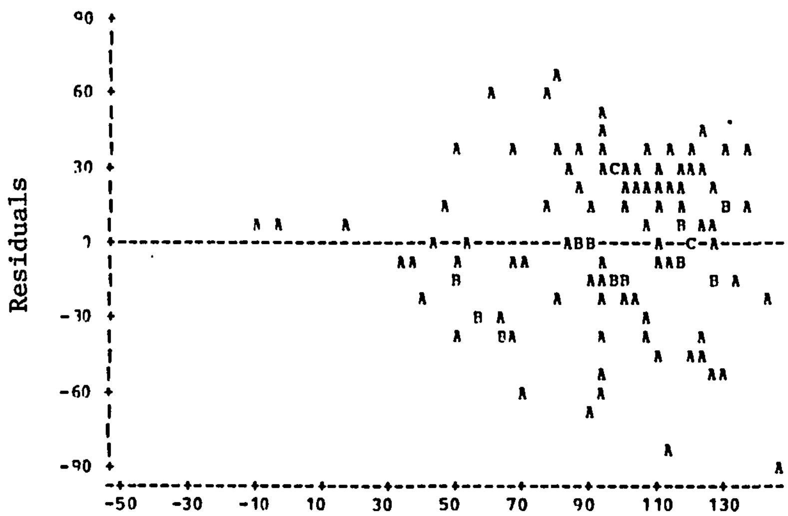
Federal Reserve District Dummy
(Kansas City FRD)



Federal Reserve District Dummy
(Dallas FRD)



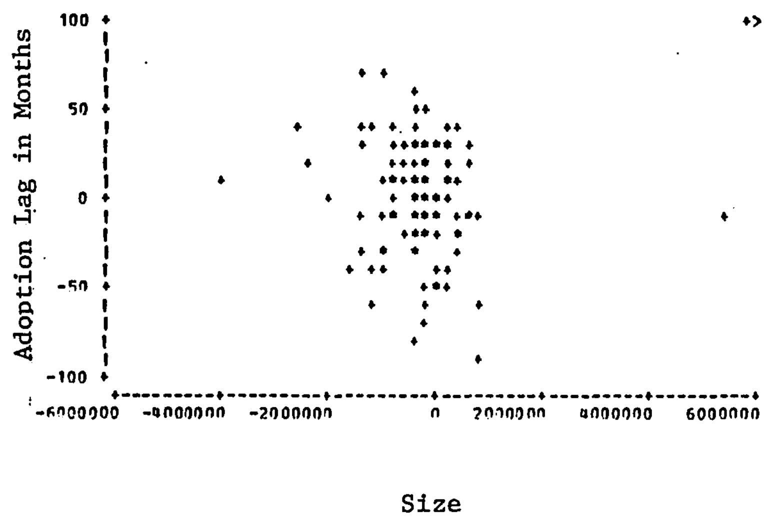
Federal Reserve District Dummy
(San Francisco FRD)

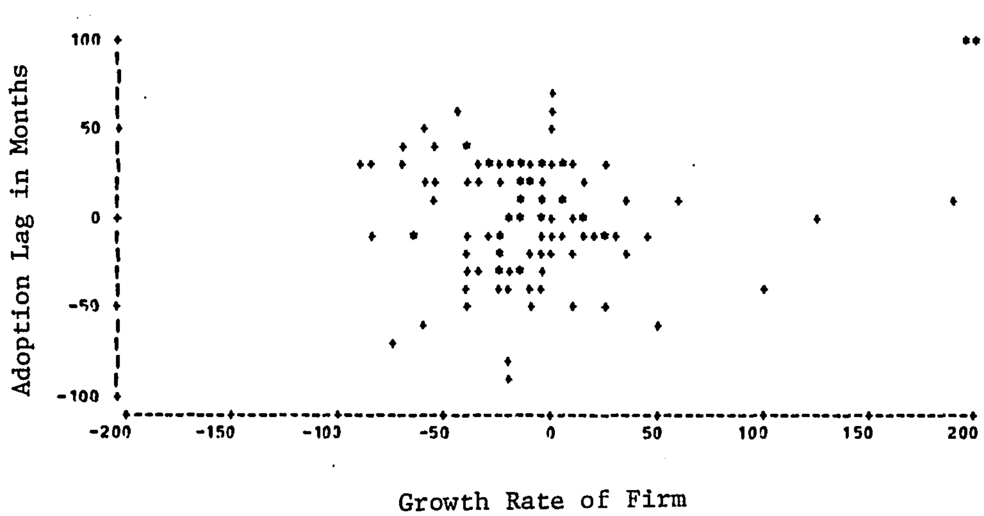


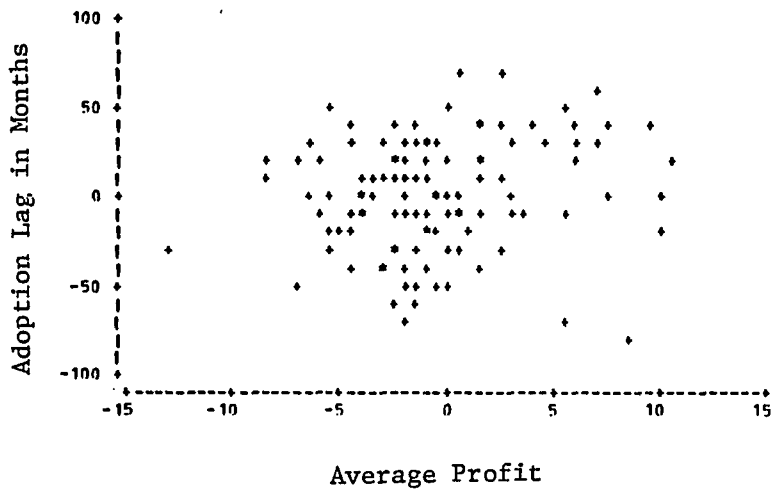
Legend: A = 1 observation, B = 2 observations, etc.

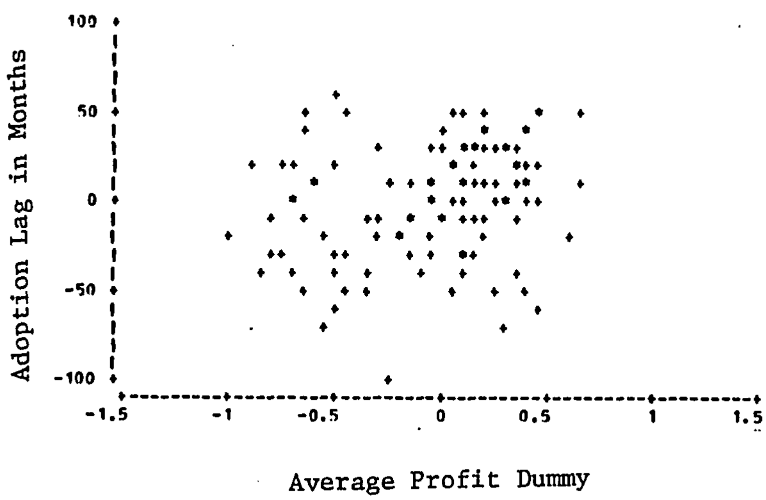
Appendix A.5.5

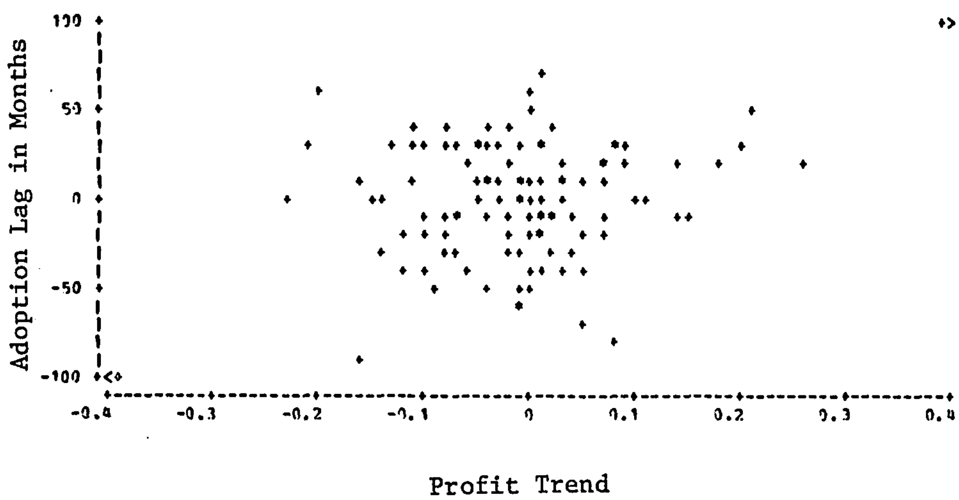
RESIDUAL PLOTTINGS OF ESTIMATION EQUATION IN TABLE 5.9, VERSION 3 (IN WHICH FACTORS 1 AND 3 OF TABLE 5.2 IS USED TO PROXY URBAN HIERARCHY FACTOR)

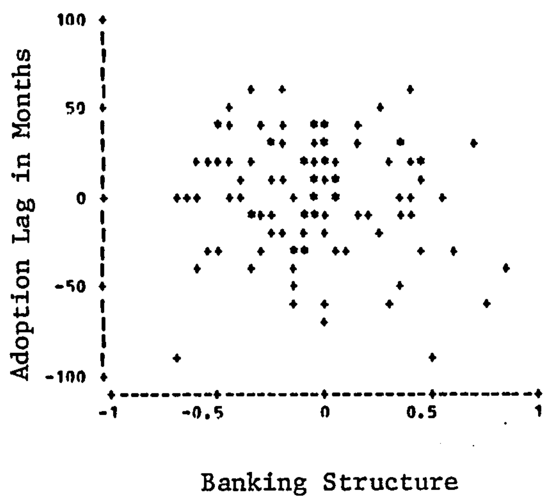

Adoption Lag in Months
100
50
0
-50
-100
-6000000
-4000000
-2000000
0
2000000
4000000
6000000
Size

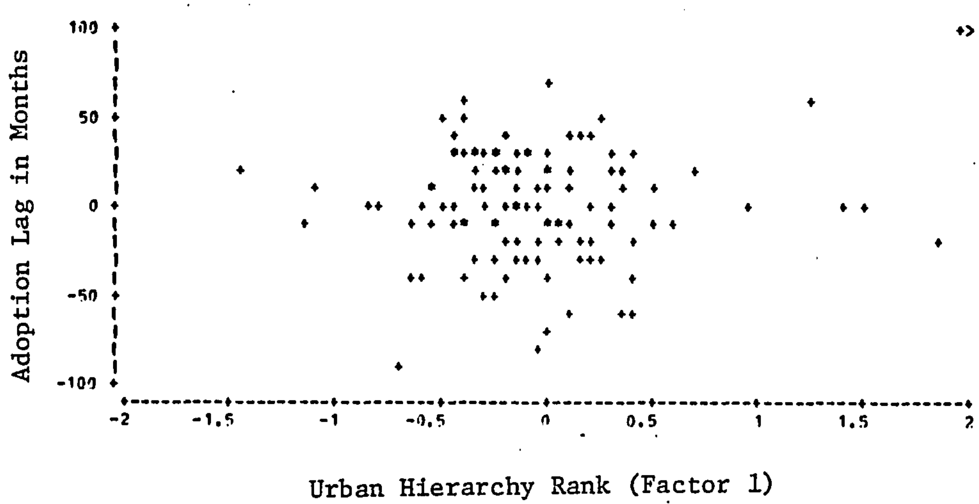

Adoption Lag in Months
100
50
0
-50
-100
-200
-150
-100
-50
0
50
100
150
200
Growth Rate of Firm

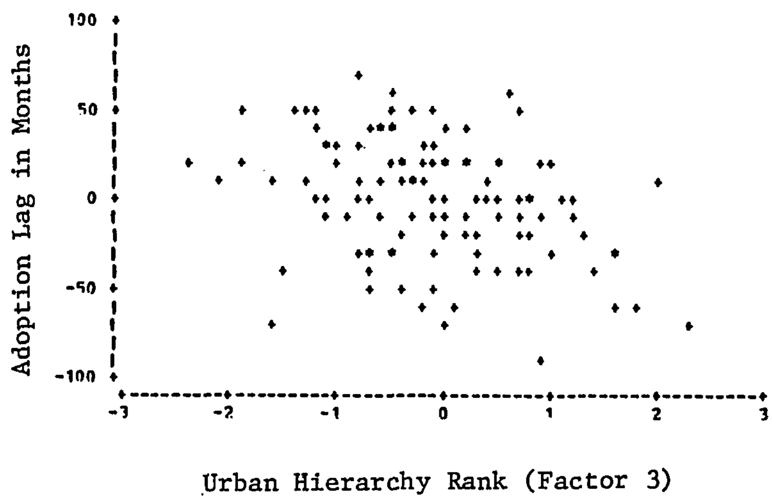

Adoption Lag in Months
100
50
0
-50
-100
-15
-10
-5
0
5
10
15
Average Profit

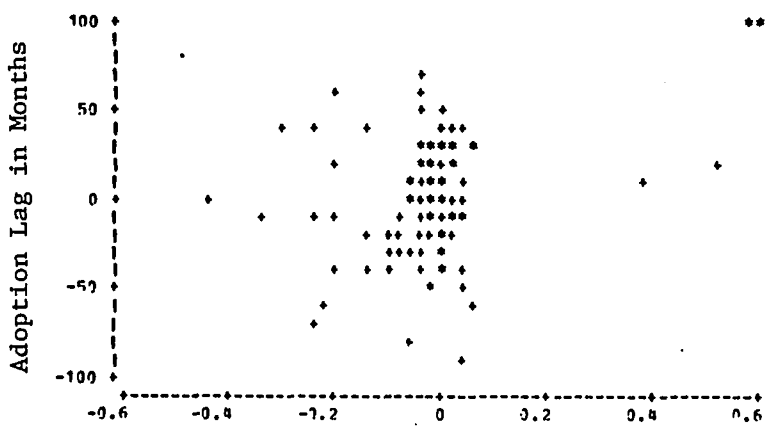

100
50
0
-50
-100
Adoption Lag in Months
-1.5
-1
-0.5
0
0.5
1
1.5
Average Profit Dummy


Adoption Lag in Months
100
50
0
-50
-100
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
Profit Trend

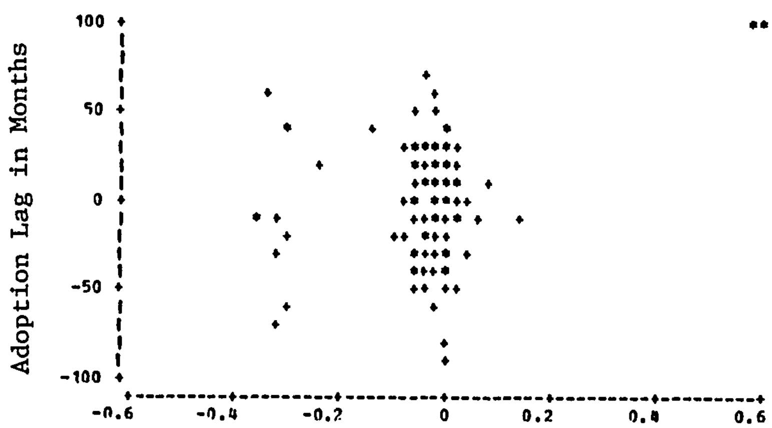

100
50
0
-50
-100
Adoption Lag in Months
-1
-0.5
0
0.5
1
Banking Structure


Adoption Lag in Months
100
50
0
-50
-100
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Urban Hierarchy Rank (Factor 1)

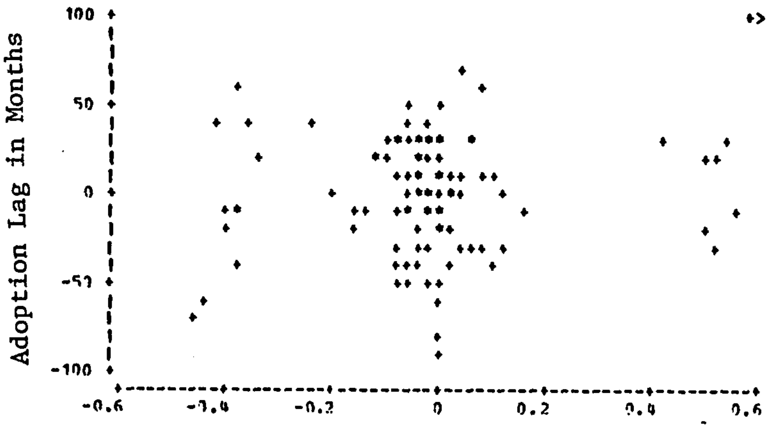

Adoption Lag in Months
100
50
0
-50
-100
-3
-2
-1
0
1
2
3
Urban Hierarchy Rank (Factor 3)



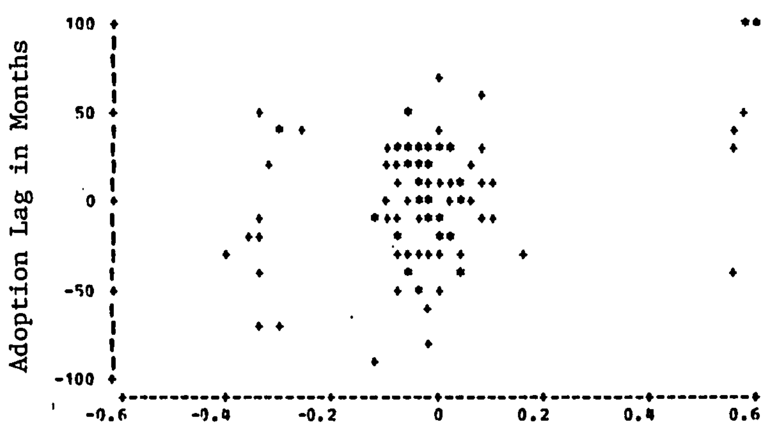
Federal Reserve District Dummy
(New York FRD)



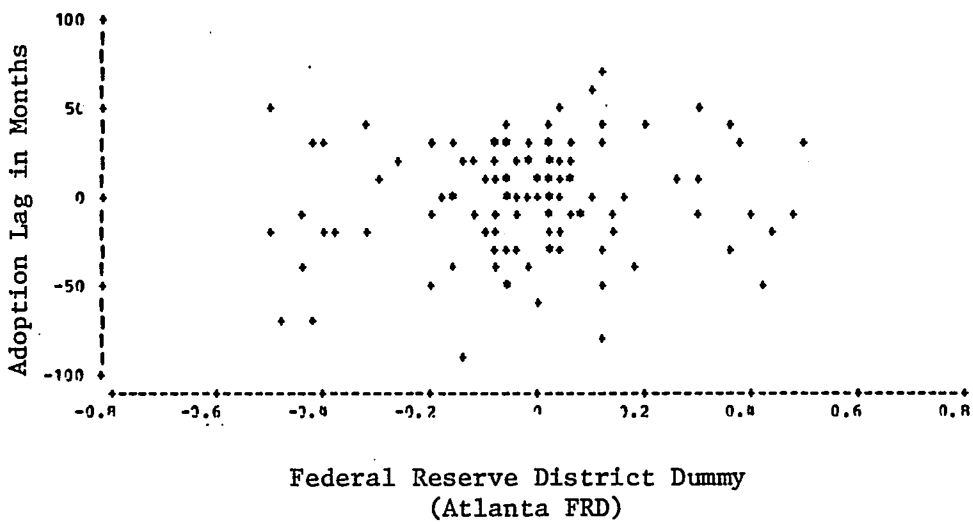
Federal Reserve District Dummy
(Philadelphia FRD)



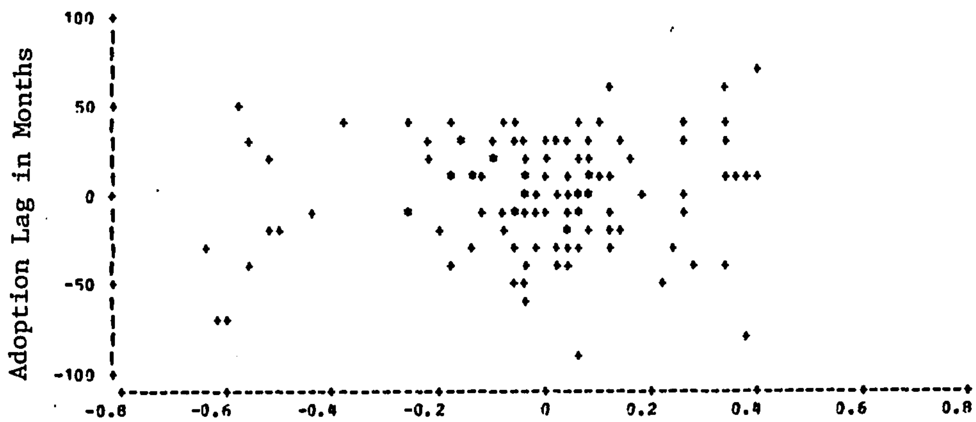
Federal Reserve District Dummy
(Cleveland FRD)



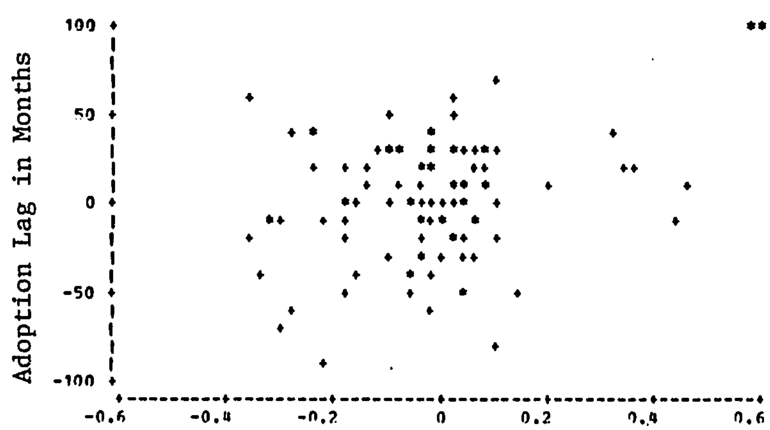
Federal Reserve District Dummy
(Richmond FRD)



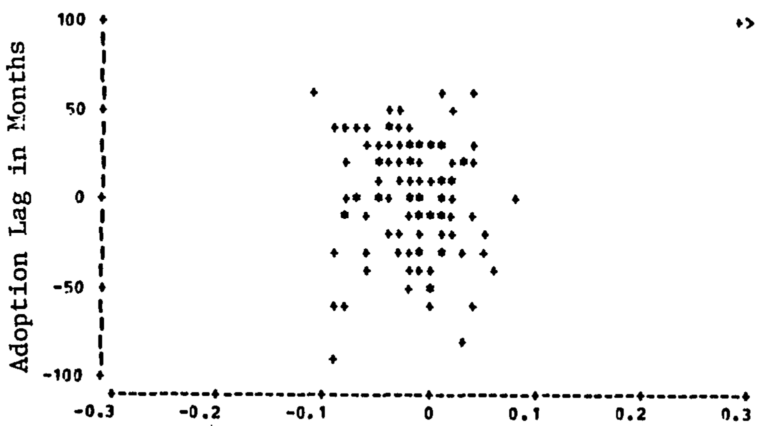
100
50
0
-50
-100
Adoption Lag in Months
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Federal Reserve District Dummy
(Atlanta FRD)



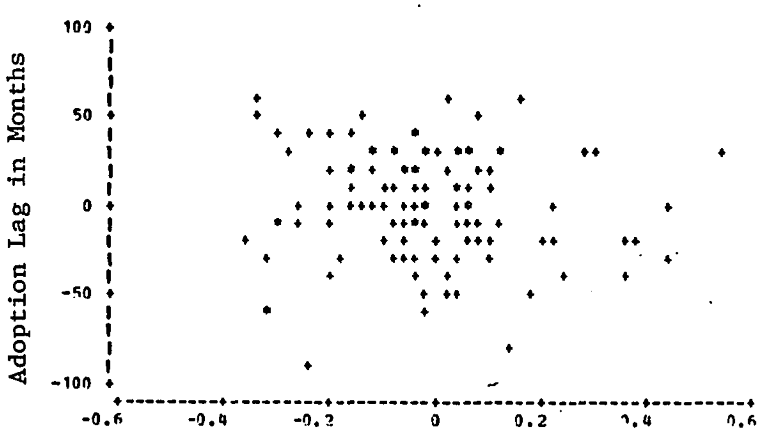
Federal Reserve District Dummy
(Chicago FRD)



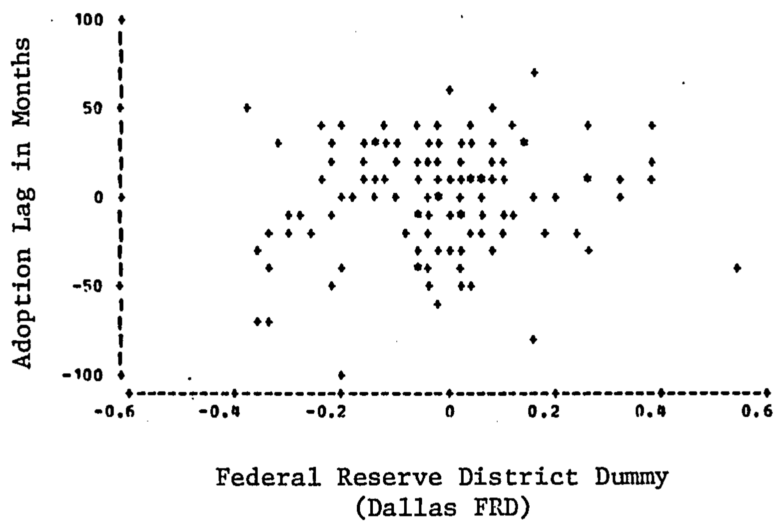
Federal Reserve District Dummy
(St. Louis FRD)

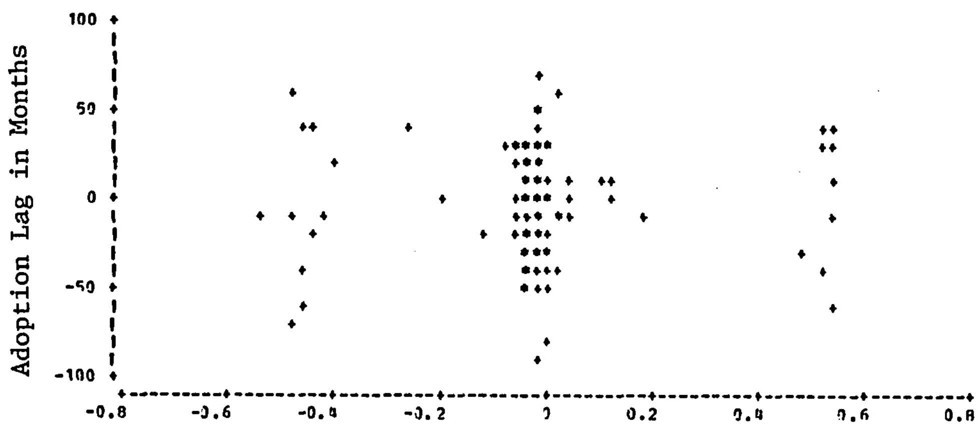


Federal Reserve District Dummy
(Minneapolis FRD)

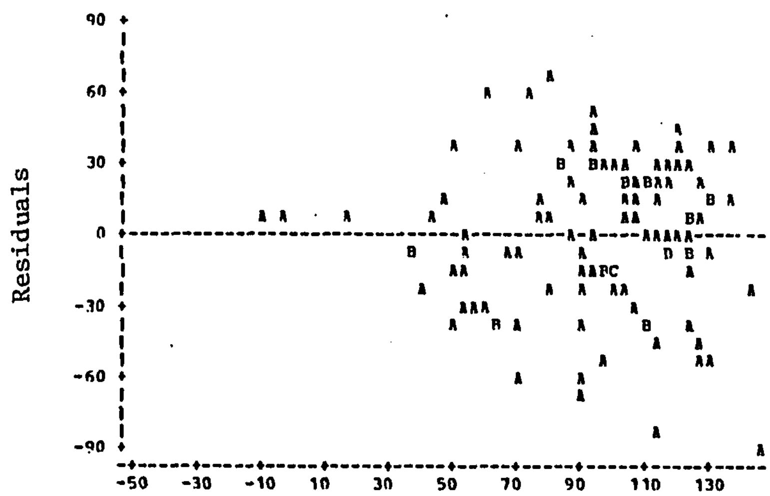


Federal Reserve District Dummy
(Kansas City FRD)


Adoption Lag in Months
100
50
0
-50
-100
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Federal Reserve District Dummy
(Dallas FRD)



Federal Reserve District Dummy
(San Francisco FRD)



Predicted Value

Legend: A = 1 observation, B = 2 observations, etc.

Appendix A.5.6

ESTIMATION OF INTERFIRM DIFFERENCES IN SPEED OF RESPONSE TO INNOVATION WITH VARIABLE(S) DROPPED FROM THE ESTIMATING EQUATION USED IN TABLE 5.9

	Intercept	Size S	Growth g	Average Profit π'	Average Profit Dummy	Profit Trend π^t	Banking Structure B	Urban Hierarchy Factor 1	Urban Hierarchy Factor 3
Version 1	37.67		0.011	1.200	34.124**	25.720	3.468	-2.833	
			(0.057)	(0.083)	(8.174)	(31.833)	(10.409)	(6.317)	
	42.90	-5.57×10^{-6}**		1.205	30.095**	23.789	3.052	-1.756	
		(2.18×10^{-6})		(0.799)	(8.002)	(30.712)	(10.070)	(6.125)	
	75.18	-7.41×10^{-6}**	0.037			9.576	-1.771	-3.400	
		(2.32×10^{-6})	(0.060)			(32.746)	(10.922)	(6.542)	
	44.31	-5.61×10^{-6}**	0.010	1.069	30.091**		2.719	-1.955	
		(2.19×10^{-6})	(0.055)	(0.781)	(8.097)		(10.091)	(6.138)	
	38.43			1.198	34.350**	26.215	3.601	-2.863	
				(0.822)	(8.050)	(31.570)	(10.354)	(6.283)	
Version 2	68.05		-0.010	1.300	21.273**	7.944	-6.211		-14.512**
			(0.052)	(0:740)	(8.017)	(29.375)	(9.687)		(3.337)
	66.55	-2.97×10^{-6}		1.286	20.340**	8.279	-5.426		-12.854**
		(2.16×10^{-6})		(0.732)	(7.923)	(29.032)	(9.599)		(3.490)
	100.97	-3.51×10^{-6}	0.005			-8.682	-10.818		-16.220**
		(2.27×10^{-6})	(0.054)			(29.904)	(9.988)		(3.500)
	68.27	-2.95×10^{-6}	-0.009	1.238	20.420**		-5.715		-13.060**
		(2.16×10^{-6})	(0.052)	(0.715)	(7.960)		(7.583)		(3.469)
	67.27			1.300	21.127**	7.576	-6.134		-14.454**
				(0.735)	(7.939)	(29.161)	(9.630)		(3.305)
Version 3	70.23		-0.011	1.167	21.326**	6.436	-7.792	-4.932	-14.747**
			(0.052)	(0.756)	(8.029)	(29.471)	(9.878)	(5.803)	(3.353)
	68.31	-2.81×10^{-6}		1.176	20.408**	6.936	-6.776	-4.120	-13.129**
		(2.17×10^{-6})		(0.750)	(7.944)	(29.168)	(9.808)	(5.781)	(3.520)
	101.68	-3.25×10^{-6}	0.003			-9.166	-12.853	-6.477	-16.639**
		(2.28×10^{-6})	(0.054)			(29.879)	(10.152)	(5.952)	(3.518)
	70.04	-2.79×10^{-6}	-0.010	1.132	20.520**		-7.084	-4.250	-13.328**
		(2.17×10^{-6})	(0.052)	(0.731)	(7.980)		(9.785)	(5.774)	(3.497)
	69.32			1.169	21.158**	6.027	-7.691	-4.891	-14.678**
				(0.753)	(7.951)	(29.261)	(.817)	(5.770)	(3.320)

Notes: 1. ** indicates significance at the 5% level, and * indicates significance at the 10% level by the 2-tailed t test.
2. All F values are significant at the 5% level.

Appendix A.5.6 (continued)

	Federal Reserve District Dummies										
	1 (New York)	2 (Phila-delphia)	3 (Cleveland)	4 (Richmond)	5 (Atlanta)	6 (Chicago)	7 (St. Louis)	8 (Minne-apolis)	9 (Kansas City)	10 (Dallas)	11 (San Francisco)
Version 1	-24.064	2.032	14.426	27.141	22.882	30.815**	21.798	-32.347	9.384	41.924**	-1.118
	(21.792)	(20.378)	(17.739)	(19.203)	(16.984)	(14.505)	(19.777)	(41.311)	(19.239)	(19.301)	(16.274)
	-3.617	2.574	14.855	27.211	23.032	29.548**	21.465	-32.418	9.714	41.153**	6.592
	(22.503)	(19.485)	(16.937)	(18.521)	(16.224)	(13.693)	(19.044)	(39.645)	(18.609)	(18.402)	(15.861)
	-2.963	-5.910	21.630	29.840	23.480	34.421**	20.424	-21.769	16.712	44.175**	6.630
	(24.648)	(21.398)	(18.417)	(20.241)	(17.419)	(15.177)	(20.846)	(43.344)	(20.141)	(19.997)	(17.490)
	-2.931	3.333	16.879	28.874	23.091	30.534**	21.565	-35.016	7.499	41.181**	6.929
	(22.647)	(19.770)	(17.075)	(18.532)	(16.476)	(14.057)	(19.189)	(39.856)	(18.665)	(18.721)	(16.103)
	-24.499	1.426	13.869	26.850	22.360	30.200**	21.431	-33.359	9.311	41.291**	-1.634
	(21.566)	(20.034)	(17.415)	(19.048)	(16.683)	(14.081)	(19.586)	(40.771)	(19.138)	(18.925)	(15.973)
Version 2	6.740	2.775	6.350	17.401	18.062	10.773	6.007	-58.096	-8.747	23.071	0.873
	(21.153)	(18.153)	(16.311)	(17.475)	(14.870)	(13.887)	(18.103)	(37.959)	(17.897)	(17.947)	(14.871)
	14.854	3.629	8.132	18.751	19.088	13.212	7.881	-54.230	-6.562	25.412	5.342
	(21.631)	(18.164)	(15.943)	(17.258)	(14.524)	(13.411)	(17.851)	(37.292)	(17.774)	(17.509)	(14.830)
	19.162	-2.921	8.512	19.294	16.120	9.757	3.325	-55.421	-6.483	20.826	3.757
	(22.813)	(19.311)	(16.913)	(18.189)	(15.316)	(14.510)	(18.910)	(39.706)	(18.769)	(18.663)	(15.835)
	14.749	3.263	8.144	18.930	18.523	12.593	7.339	-56.584	-6.943	24.503	4.895
	(21.648)	(18.375)	(16.088)	(17.259)	(14.733)	(13.821)	(17.958)	(37.372)	(17.773)	(17.796)	(15.021)
	6.999	3.301	6.870	17.687	18.527	11.399	6.383	-57.118	-8.617	23.693	1.316
	(21.001)	(18.246)	(15.990)	(17.319)	(14.586)	(13.408)	(17.900)	(37.404)	(17.793)	(17.545)	(14.605)
Version 3	7.542	1.345	5.478	14.588	13.884	11.834	2.329	-63.053	-11.682	19.850	0.396
	(21.205)	(18.657)	(16.367)	(17.811)	(15.683)	(13.963)	(18.639)	(38.459)	(18.253)	(18.369)	(14.903)
	14.933	2.481	7.400	16.379	15.625	14.078	4.775	-58.405	-9.109	22.706	4.781
	(21.691)	(18.282)	(16.017)	(17.619)	(15.351)	(13.501)	(18.420)	(37.845)	(18.175)	(17.962)	(14.889)
	19.542	-4.602	7.641	15.138	11.152	11.329	-1.555	-61.846	-10.422	16.975	2.954
	(22.794)	(19.354)	(16.917)	(18.568)	(15.968)	(14.568)	(19.417)	(40.105)	(19.097)	(18.977)	(15.837)
	14.957	1.988	7.240	16.375	14.907	13.406	4.112	-60.803	-9.548	21.676	4.260
	(21.702)	(18.500)	(16.174)	(17.645)	(15.564)	(13.898)	(18.528)	(37.898)	(18.164)	(18.248)	(15.082)
	7.834	1.959	6.082	14.940	14.452	12.543	2.791	-61.889	-11.509	20.591	0.909
	(21.054)	(18.341)	(16.040)	(17.645)	(15.378)	(13.495)	(18.420)	(37.880)	(18.143)	(17.948)	(14.634)

Appendix A.5.6 (continued)

	F	R^2	$\bar{R}^2$
Version 1	3.276	0.370	0.257
	3.883	0.410	0.304
	2.450	0.290	0.172
	3.827	0.407	0.300
	3.514	0.369	0.264
Version 2	5.019	0.473	0.379
	5.226	0.483	0.391
	4.311	0.418	1.321
	5.220	0.483	0.390
	5.384	0.473	0.385
Version 3	4.766	0.477	0.377
	4.938	0.486	0.388
	4.135	0.425	0.322
	4.936	0.486	0.388
	5.095	0.477	0.383

Appendix A.6

DATE OF APPEARANCE OF LOCAL INNOVATOR (FOR THE INNOVATION OF GENERAL PURPOSE DIGITAL COMPUTERS) IN THE U.S. COMMERCIAL BANKING INDUSTRY

Population Size Class	Date of First Appearance of Local Innovator*	Location
30,000 - 50,000 (Total number of potential adopters in this class $n_{i\ell}$ = 342. Mean population size = 37,840 in 1970).	4/64	Mason City, IA
	10/65	Marion, OH
	10/65	Las Cruces, NM
	10/65	Highland Park, IL
	11/65	Decatur, AL
	11/65	Fort Collins, CO
	8/66	Muskogee, WI
	7/68	Watertown, NY
	7/68	Mt. Prospect, IL
	11/68	Jannesville, WI
	12/68	Massillon, OH
	4/69	Kokomo, IN
	4/69	Daytona Beach, FL
	6/69	Longview, TX
	8/69	Menomonee Falls, WI
	8/69	Dekalb, IL
	9/69	Battle Creek, MI
	1/70	Bowling Green, KY
	4/70	Waukesha, WI
	5/70	Rocky Mount, NC
	5/70	Findlay, OH
	12/70	Sheboygen, WI
	12/70	Arvada, CO
	10/71	Richmond, IN
	12/71	Santa Fe, NM

Appendix A.6 (continued)

Population Size Class	Date of First Appearance of Local Innovator*	Location
	1/72	Danville, IL
	3/74	Danville, VA
50,000 ~ 100,000 (Total number of potential adopters in this class $n_{i\ell}$ = 238. Mean population size = 69,578 in 1970).	2/62	Quincy, MA
	5/62	Pontiac, MI
	3/63	Charleston, SC
	1/65	Wilmington, DE
	2/65	Green Bay, WI
	8/65	Pittsfield, MA
	5/66	Hamilton, OH
	5/66	Davenport, IA
	8/66	Royal Oak, IL
	11/66	Lakewood, CO
	3/67	Reading, PA
	10/68	Springfield, IL
	12/68	Muncie, IN
	7/69	Lowell, MA
	7/69	Abilene, TX
	10/69	Greenville, SC
	12/69	Decatur, IL
	1/70	Lima, OH
	2/70	New Britain, MA
	7/70	Irving, TX
	8/70	Oak Park, IL
	9/70	St. Joseph, MO
	9/70	Reno, NV
	2/71	Manchester City, NH
	4/71	Boise City, ID
	9/71	Lynchburg, VA
	11/71	Fort Smith, AR

Appendix A.6 (continued)

Population Size Class	Date of First Appearance of Local Innovator*	Location
100,000 - 250,000 (Total number of potential adopters in this class $n_{i\ell}$ = 100. Mean population size = 139,085 in 1970).	7/61	Waterbury, MA
	1/62	Tacoma, WA
	2/63	New Haven, CT
	2/64	Duluth, MN
	4/64	Springfield, MA
	5/64	Evansville, IN
	5/66	Baton Rouge, LA
	7/66	Montgomery, AL
	8/66	Mobile, AL
	11/66	Camden, NJ
	12/66	Cedar Rapids, IA
	5/67	Peoria, IL
	7/67	Erie, PA
	7/68	Little Rock, AR
	8/68	Fort Wayne, IN
	12/68	Stamford, CT
	3/69	Las Vegas, NV
	6/69	Des Moines, IA
	12/69	Lexington, KY
	5/70	Salt Lake City, UT
	7/70	Macon, GA
	9/70	Springfield, MO
	1/71	Corpus Christi, TX
	3/71	Trenton, NJ
	9/71	Ann Arbor, MI
	11/71	Beaumont, TX
	7/73	St. Petersburg, FL

Appendix A.6 (continued)

Population Size Class	Date of First Appearance of Local Innovator*	Location
250,000 - 500,000 (Total number of potential adopters in this class $n_{i\ell}$ = 29. Mean population size = 361,418 in 1970).	12/61	Portland, OR
	1/62	Miami, FL
	1/63	Louisville, KY
	5/66	Oklahoma City, OK
	7/66	Oakland, CA
	5/71	Wichita, KS
	5/72	Omaha, NE
500,000 and up (Total number of potential adopters in this class $n_{i\ell}$ = 26. Mean population size = 1,220,989 in 1970).	9/59	San Francisco, CA
	9/59	New York, NY
	3/60	Phoenix, AZ
	4/60	Chicago, IL
	12/60	Philadelphia, PA
	11/61	Denver, CO
	12/61	Boston, MA
	1/62	Baltimore, MD
	6/62	St. Louis, MO
	6/62	Pittsburgh, PA
	12/66	Kansas City, MO
	12/67	Houston, TX
	9/68	St. Antonio, TX
	10/68	New Orleans, LA
	10/69	Dallas, TX

*Data from Computers and Automation and EDP Weekly, 1959-1974.

Appendix A.7

STATISTICS RELATED TO EQUATION (6.28)

Appendix A.7.1

THE CALCULATION OF REGRESSION FUNCTION FOR EQUATION (6.28)

Size Class	$m_{t_{i\ell}}/n_{i\ell}$	$\hat{z}$ $(z_{i\ell})$	$w_{i\ell}$	$\hat{\hat{z}}$ $(n_{i\ell}w_{i\ell}z_{i\ell})$	$x_{i\ell}$ $(\log P_{t_{i\ell}})$	$P^*_{t_{i\ell}}$	$e_{i\ell}$
30,000 ~ 50,000	23/342	-1.496	0.26955	-137.91040	10.5411	37,840	0.001
50,000 ~ 100,000	23/238	-1.301	0.33629	-104.12816	11.1502	69,578	-0.066
100,000 ~ 250,000	22/100	-0.772	0.51091	- 39.44225	11.8428	139,085	0.168
250,000 ~ 500,000	5/29	-0.944	0.45642	- 12.49495	12.7978	361,418	-0.417
500,000 and up	15/26	0.194	0.62794	3.16733	14.0152	1,220,989	0.190

*$P_{t_{i\ell}}$ is the mean population size for the class ℓ at t_i. (In this case, t_i = 1970).

$$\hat{\alpha}_1 = \frac{\Sigma\, n_{i\ell}w_{i\ell}(z_{i\ell}-\bar{z})(x_{i\ell}-\bar{x})}{\Sigma\, n_{i\ell}w_{i\ell}(x_{i\ell}-\bar{x})^2} = \frac{99.85}{230.41} = 0.433$$

$$\bar{z} = \frac{\Sigma\, n_{i\ell}w_{i\ell}z_{i\ell}}{\Sigma\, n_{i\ell}w_{i\ell}}$$

$$\bar{x} = \frac{\Sigma\, n_{i\ell}w_{i\ell}z_{i\ell}}{\Sigma\, n_{i\ell}w_{i\ell}}$$

$$\hat{\alpha}_o = \bar{z} - \hat{\alpha}_1\bar{x} = -6.026$$

$$\text{Percentage of Unexplained Variance} = \frac{\Sigma\, e_{i\ell}^2/n-2}{\Sigma(z_{i\ell}-\bar{z})^2/n-1}$$

$$= \frac{0.0809}{0.5335}$$

$$= 0.15 \qquad \text{(n = number of size classes)}$$

$$\bar{R}^2 = 0.85$$

$$F_{1,3} = \frac{\hat{\alpha}_i^2\, \Sigma(x_{i\ell}-\bar{x})^2}{\Sigma\, e_{i\ell}^2/n-2}$$

$$= \frac{(0.1875)(10.2185)}{0.0809}$$

$$= 23.68$$ (The F value is significant at the 5% level)

$$\sigma_{\hat{\alpha}_1}^2 = \frac{1}{\Sigma\, n_{i\ell} w_{i\ell}(x_{i\ell}-\bar{x})^2}$$

$$= 0.0046$$

$$s_{\hat{\alpha}_1} = 0.067$$

Appendix A.7.2

ALTERNATIVE CALCULATION OF REGRESSION FUNCTION FOR EQUATION (6.28)

Size Class	$m_{t_{i\ell}}/n_{i\ell}$	$\hat{z}$ $(\hat{z}_{i\ell})$	$w_{i\ell}$	$\hat{z}$ $(n_{i\ell}w_{i\ell}\hat{z}_{i\ell})$	$x_{i\ell}$ $(\log P_{t_{i\ell}})$	$P^*_{t_{i\ell}}$	$e_{i\ell}$
30,000 ~ 40,000	16/228	-1.475	0.27693	-93.16764	10.4493	34,519	0.080
40,000 ~ 50,000	7/114	-1.543	0.25423	-44.8191	10.7029	44,483	-0.107
50,000 ~ 75,000	9/163	-1.596	0.23809	-62.02313	11.0316	61,800	-0.313
75,000 ~ 100,000	14/75	-0.890	0.47495	-31.66800	11.3677	86,461	0.237
100,000 ~ 150,000	15/65	-0.736	0.52157	-24.93660	11.6975	120,285	0.237
150,000 ~ 300,000	7/43	-0.983	0.44456	-18.77595	12.2069	200,159	-0.247
300,000 ~ 500,000	5/21	-0.713	0.52803	- 7.90356	12.8459	379,248	-0.275
500,000 and up	15/26	0.194	0.62794	3.17096	14.0152	1,220,989	0.087

$^*P_{t_{i\ell}}$ is the mean population size for the class ℓ at t_i. (In this case, t_i = 1970).

$$\hat{\alpha}_1 = \frac{\Sigma\, n_{i\ell}w_{i\ell}(z_{i\ell}-\bar{z})(x_{i\ell}-\bar{x})}{\Sigma\, n_{i\ell}w_{i\ell}(x_{i\ell}-\bar{x})^2} = \frac{106.46}{228.38} = 0.466$$

$$\bar{z} = \frac{\Sigma\, n_{i\ell}w_{i\ell}z_{i\ell}}{\Sigma\, n_{i\ell}w_{i\ell}}$$

$$\bar{x} = \frac{\Sigma\, n_{i\ell}w_{i\ell}x_{i\ell}}{\Sigma\, n_{i\ell}w_{i\ell}}$$

$$\hat{\alpha}_0 = \bar{z} - \hat{\alpha}_1\bar{x} = -6.424$$

$$\text{Percentage of Unexplained Variance} = \frac{\Sigma\, e_{i\ell}^2/n-2}{\Sigma(z_{i\ell}-\bar{z})^2/n-1}$$

$$= \frac{0.0621}{0.3860}$$

$$= 0.16 \qquad (n = \text{number of size classes})$$

$$\bar{R}^2 = 0.84$$

$$F_{1,6} = \frac{\hat{\alpha}_1^2\, \Sigma(x_{i\ell}-\bar{x})^2}{\Sigma\, e_{i\ell}^2/n-2}$$

$$= \frac{(0.2172)(9.5067)}{0.0621}$$

$$= 33.25$$ (The F value is significant at the 5% level)

$$\sigma_{\hat{\alpha}_1}^2 = \frac{1}{\Sigma\, n_{i\ell} w_{i\ell} (x_{i\ell}-\bar{x})^2}$$

$$= 0.00556$$

$$s_{\hat{\alpha}_1} = 0.075$$

Appendix A.8

THE CALCULATION OF REGRESSION FUNCTION FOR EQUATION (6.30)

m_{t_i}/n_i	$\hat{z}$ (z_i)	w_i	$\hat{\hat{z}}$ $(z_i w_i)$	x_i^*	e_i
2/735	-2.27	0.03523	-0.09343	1	-0.380
5/735	-2.18	0.05463	-0.13424	2	-0.275
9/735	-2.09	0.08228	-0.18572	3	-0.169
16/735	-2.00	0.12803	-0.25787	4	-0.074
19/735	-1.91	0.14404	-0.27989	5	-0.034
23/735	-1.82	0.16273	-0.30370	6	-0.044
31/735	-1.73	0.19976	-0.34517	7	0.002
44/735	-1.64	0.25160	-0.39118	8	0.085
45/735	-1.55	0.26453	-0.40052	9	0.035
59/735	-1.46	0.30029	-0.42193	10	0.054
73/735	-1.37	0.34026	-0.43800	11	0.082
88/735	-1.28	0.37894	-0.44525	12	0.105
99/735	-1.19	0.40369	-0.44529	13	0.086
101/735	-1.10	0.40682	-0.44502	14	0.005
102/735	-1.01	0.40993	-0.44470	15	-0.075
103/735	-0.92	0.41147	-0.44451	16	-0.160

$^*x_i$ measures the elapsed time from $t_0 = 1959$, measured in years.

$$\hat{\alpha}_1 = \frac{\Sigma\, w_i (z_i - \bar{z})(x_i - \bar{x})}{\Sigma\, w_i (x_i - \bar{x})^2} \qquad \bar{z} = \frac{\Sigma\, w_i z_i}{\Sigma\, w_i}$$

$$= \frac{5.24602}{58.02897} \qquad \bar{x} = \frac{\Sigma\, w_i x_i}{\Sigma\, w_i}$$

$$= 0.0904$$

$$\hat{\alpha}_0 = z - \hat{\alpha}_1 \bar{x}$$

$$= -2.364$$

Appendix A.8 (continued)

$$\text{Percentage of Unexplained Variance} = \frac{\Sigma\, e_i^2/n-2}{\Sigma(z_i-\bar{z})^2/n-1}$$

$$= \frac{0.0232}{0.3432}$$

$$= 0.07 \qquad \text{(n = number of elapsed years)}$$

$$\bar{R}^2 = 0.93$$

$$F_{1,14} = \frac{\hat{\alpha}_1^2\, \Sigma(x_i-\bar{x})^2}{\Sigma\, e_i^2/n-2}$$

$$= \frac{(433.761)(0.0081)}{0.0232}$$

$$= 151.44 \qquad \text{(The F value is significant at the 5\% level).}$$

$$\sigma_{\hat{\alpha}_1}^2 = \frac{1}{\Sigma\, n_i w_i (x_i-\bar{x})^2}$$

$$= 0.0000233$$

$$s_{\hat{\alpha}_1} = 0.004827$$

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