To the Graduate Council:

I am submitting herewith a dissertation written by Stella Sherrouse Schramm entitled "Beyond Firm Learning: The Emergence of a Concurrent Model of Technological Change." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of PhD, with a major in Economics.

William E. Cole, Major Professor

We have read this dissertation and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and
Dean of the Graduate School

BEYOND FIRM LEARNING:

THE EMERGENCE OF A CONCURRENT MODEL OF TECHNOLOGICAL CHANGE

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Stella Sherrouse Schramm

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DEDICATION

To Walton, who got me going, and
to Mimi and Bill, who wouldn't let me quit.

ABSTRACT

This study examines the conventional approach to incorporating technology within the theory of the firm in light of recent organizational forms observed in Japanese Continuous Improvement Firms (CIFs). The conventional linear model of technological change in economics is depicted in this work as a sequentially organized and functionally segmented process in which the role of the directly productive operations of the firm is restricted to rote learning and minor technology modification. This work attributes the assumed limits to firm improvement without investment in externally developed technology to the restricted role given to directly productive operations in theory and practice.

This work explores new organizational forms introduced by CIFs and their implications for conventional models of technological development. Two technology development systems within the CIF, kaizen (continuous improvement) and concurrent design, are examined. As an outcome of this analysis, a concurrent model of technological change is suggested, characterized by the functional integration and

concurrent temporal involvement of a broad span of participants.

Several analytic tools are introduced in this study for examining the affects of a firm's approach to technology on performance. The productivity changes described in economics as firm learning are treated in this analysis as a performance gap between the productive capability of a technology and the performance a firm is able to achieve with its use. The concept of firm learning as introduced by Arrow (1962) is described here as on-line learning, where a firm develops technological competence on actual output in real time. Off-line learning, in contrast, is described as those factors within a firm's control that can improve performance with a new technology, including selection of appropriate technology, preparation for technology changeover, and applicable employee training and experience. These factors are enhanced by a concurrent, rather than a sequential, approach to technological change. It also is observed that, in the case of the CIF, performance improvement does not follow a set learning function, as depicted in the sequential model of technological change, and that the CIF creates technology within its directly productive activities, rather than depending solely on externally developed technology.

PREFACE AND ACKNOWLEDGMENTS

This study is part of a larger research agenda on the Continuous Improvement Firm (CIF) organized by Professor William E. Cole at the University of Tennessee. William Cole and Jack Mogab (Southwest Texas State University) have written in depth on integrating CIF strategies into economic analysis. Antonio Bos and Steve Wilson conducted field research collecting comparative data on Multinational Corporations (MNCs) in Brazil and Mexico. In its work with corporations and government agencies, the Management Development Center (MDC) at U.T. has worked to build a framework for examining quality, Statistical Process Control, and the organizational capabilities of firms. Harlan Carothers and Richard Sanders, in particular, have worked with the economics team headed by William Cole to examine ties between organization and competitive performance. The present study is another chapter in this on-going research project.

More so than in most graduate research, I have depended heavily on the intellectual support and guidance of my mentors, Professors William Cole and Hans Jensen. I am heavily indebted to William Cole for his seminal concepts, for his help and endless patience in constructing these arguments, and for his ability to see new facets of the debate. The direction for this work has been provided by Dr. Cole's written work and the interchange of numerous conversations, workshops and memos on the subjects addressed here.

Because this particular portion of the broader U.T. research initiative is conceptual and seeks to address theoretical issues, I have relied heavily on U.T.'s outstanding capabilities in History of Thought, embodied in the person of Hans Jensen. He has provided insight into how recent issues and phenomena fit into the broader historical context and questions of economic thought. My understanding of these issues is embryonic, but I am deeply indepted to him for his support.

I have also borrowed heavily from my brother, Mark Sherrouse, in developing a framework for viewing the CIF approach to technology. As an aerospace engineer, he is experienced in using the concurrent design approach, and has helped me to draw inferences from concurrent design to describe the CIF approach to technology development.

The staff of Nippondenzo Tennessee have been extremely helpful in making information available and answering countless questions about their operations, management systems and observations. Their efforts have inspired this work and are the basis for the kaizen case history in Chapter 3.

My committee members have each contributed to formulating (and completing) this work. Richard Sanders has provided stimulating questions and discussions on CIF operations over the past three years. Charles Garrison has carefully coached me through the arguments presented here, and helped me to remember how this work relates to other economic research on the topic. Feng-Yao Lee did not plan to serve on my committee, but had heart enough to jump in when I needed his help. Although not all officially on my committee, the staff of the Management Development Center has been generous in aiding me on this project, both in their personal time and in including me in their seminars and training programs.

Last, and most importantly, I am indepted to Bill, my husband, for helping me to formulate the ideas presented here, for listening tirelessly, and for providing me with the opportunity to pursue a PhD.

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CHAPTER 1

INTRODUCTION

As the determinant of the productive capability of firms, technology is fundamental to the economic prosperity of nations. Improving technological capability, therefore, is the focal point of economic development. Technology has for the most part been developed in the industrialized countries of the world. The *modus operandi* of economic development, thus, has been dependent on the transfer of industrial country technology to Less Developed Countries (LDCs) through international trade. Technology comes into the picture embodied in capital equipment and in the form of knowledge of the use of that equipment. Because investment in capital equipment is essential to the acquisition of capital-embodied technology, capital formation is the lever and fulcrum of development cum technology change. While domestic saving is a basic determinant of the size of the fulcrum and the length of the lever for an LDC, domestic savings alone is insufficient. There must also be sufficient foreign exchange at hand to facilitate the translation of domestic savings into capital imports. This common sense notion is implicit in the basic theories and strategies of the development field, which all revolve in some fashion around the theme of capital formation. Over the decades, much of the focus of development economics has, therefore, been upon general strategies and policies to foster capital formation. Recently, policy recommendations have centered upon the removal of protection and the reduction of government's active role in the economy.

The inspiration for this work stems from concern about changes in the way technology is developed, and the implications of these changes for technology transfer and economic development. Changes taking place in organizational systems may make technology transfer increasingly more difficult, especially in industries with rapid technological innovation. Concern over these changes is heightened by the fact that the underlying treatment of technology in the theory of the firm may obfuscate and distort the development implications of technology change. For example, comparative advantage trade theory assumes that, due to competitive pressures, appropriate technology is available for transfer and that "there is no problem in assimilating the transferred technology in the developing country."[1]

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[1]Lall (1992: 165). Lall's full statement on the matter says that "In the highly simplified models used in [Neoclassical] trade theory, for instance, technology is

The conventional approach in the theory of the firm is to conceive of "technology as information that is generally applicable, and easy to reproduce and reuse, one where firms can produce and use innovations by dipping freely into a general 'stock' or 'pool' of technological knowledge."[2] Recently, however, a literature has developed in which the ability to turn information into technological innovations is said to be firm-specific. This literature distinguishes between technology and information, treating information as a subset of technology[3]:

> It has been found that information about what other firms are doing spreads quite quickly (Mansfield, 1985); however, the ability to produce or replicate innovative results is much more sticky. Successful

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taken to be freely available to all countries and within all countries, to all firms. Countries simply settle on appropriate level of capital/labor intensity in accordance to their factor price ratios, determined by their relative endowments of physical capital and labor. Firms in a given industry are all on the same production function and select their techniques with reference to relative factor price ratio, shifting costlessly along the function as this ratio changes. To the extent that technological lags are admitted, developing countries are taken to receive all relevant improvements from developed country innovators: there is no problem in assimilating the transferred technology in the developing country; there are no adaptations required, since alternatives are available for all factor prices; all firms remain equally efficient; firm-specific learning or technical effort are unnecessary and irrelevant . . ."

[2]Dosi (1988) attributes this view to Arrow (1962b).

[3]See Dosi (1988), Teece (1982, 1986), and Mansfield (1985). Although not part of the theory of the firm, endogenous growth theory uses technology related variables in modelling national growth. See Romer (1990) for an example. This study, however, addresses only micro foundations for technology development.

> innovations are more closely related to firms' existing ranges of technological and marketing skills than unsuccessful ones. . .[4]

In such a case, the standard approach in economics of assuming technology to be generally applicable and available among countries and firms is inadequate to explain competitive outcomes. Dosi and others have introduced evolutionary theories to explain the "permanent existence of asymmetries among firms, in terms of their process technologies and quality of output."[5] As explained by Dosi, the conventional attributions of differences in technological ability to economies of scale and vintage of capital goods may explain some asymmetry, but also important are "the different innovative capabilities, that is, . . . different efficiencies in the innovative search process." In Dosi's analysis, some firms are more efficient in turning information into technology. This depiction is also used by Lall (1992: 166), who says "[t]echnological knowledge is not shared equally among firms, nor is it easily imitated by or transferred across firms. Transfer necessarily requires learning because technologies are tacit, and their underlying principles are not always clearly understood. Thus, simply to gain mastery of a new technology requires skills, effort and investment by the receiving firm, and the extent of mastery achieved is uncertain and necessarily

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[4]Dosi (1988: 1131).

[5]Dosi (1988: 1155).

varies by firm according to these inputs." The most advanced firms, according to Lall, feature in-house R&D, making their advances even more firm-specific. It follows then, that industrial countries featuring firms that have a long history of innovation tend to be the countries that produce new innovations. This means that there is a propensity for technological change to occur where there is already a technological base and that the ability of putative Third World entrepreneurs to tap into that technological stream is problematic. In short, "success breeds success."[6] This depiction implies an increasing asymmetry among firms biased toward innovators. While standard economic treatments of follower and leader advantages assume an eventual equalization among firms due to competition, Dosi and Lall's works suggest a more serious challenge for follower firms and nations.

The present work builds upon evidence of a type of firm that is particularly pertinent to discussions of internal technological capability. Firms of this type have been described as especially adept at turning information into technology. Nor is innovation in these firms limited in origin to R&D divisions, as is demonstrated later in this work. Through an internal system called kaizen,[7] constant

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[6]Dosi (1988: 1161).

[7]This system is explained in Chapter 3.

incremental change emerges within the confines of the production process itself. The ability to generate a constant stream of innovations in situ has led this firm to be called the Continuous Improvement Firm (CIF). Many of the improvements generated through kaizen are undocumented and undocumentable,[8] making it extremely difficult for other firms to assimilate the CIF's improvements. By virtue of its approach to organization, the CIF is also particularly adept at new product and process development. In this regard, we look at a feature of modern industrial development called concurrent design, which represents a new approach to R&D. Concurrent design is part of an overall approach to technological development within the CIF, but it may be employed independently from kaizen. We, therefore, see concurrent design appearing in non-CIF firms in industrialized countries.[9]

Kaizen and concurrent design are both organizational systems for producing technology and reflect a different approach to technology development within the CIF. The new product and process technologies produced by these systems are more firm-specific and, therefore, more difficult to

[8]Cole and Mogab (1994); Watanabe et al. (1991).

[9]Concurrent design has been widely referred to as concurrent engineering in its transferred form. Concurrent engineering, however, may not encompass the same scope of participation as the CIF concurrent design process.

transfer than in the general cases described by Dosi and Lall. While some of the characteristics of the CIF technology development systems are suggested in Dosi and Lall's descriptions of a technology/information dichotomy, a direct examination of technology systems has not yet been undertaken in the analysis of firm abilities to develop and assimilate technology. Also, the characteristics of the CIF technology system are not limited to the skills, effort, investment and R&D described in Dosi and Lall's work, but encompass a different approach to technology and industrial organization within CIFs. This work can, therefore, be seen as a new chapter in the Dosi, et al. examination of technological asymmetries among firms.

Because the CIF technology development systems are inclusive of the production process per se and take a new approach to R&D, it is necessary to freshly examine the standard approach to technology used in neoclassical analysis of firm behavior. In this work, particular attention will be given to the concepts of a sequential model of technology development and learning-by-doing. These two concepts together serve as the theoretical basis for using a neoclassical model of the firm in explaining competitive outcomes in the presence of technological change. The sequential model is the basis for assuming technological development to be external to the directly productive activities of the firm, and learning-by-doing is the metaphor for activities within the production process per se that enhance productivity.

THE STANDARD APPROACH TO TECHNOLOGY AND THE FIRM

Conceptualizations of economic behavior have evolved in the context of western economic history and experience. Adam Smith observed fledgling enterprises on the eve of the industrial revolution and wrote about the productivity advantages resulting from division of labor and the labor saving capabilities of machines.[10] Economics today still looks to output measures, specialization, and 'capital-embodied' technology in order to understand performance differences among firms. This view of economic advantage is reflected as well in the Scientific Management/Mass Production (SM/MP) organizational structure that evolved over the last 150 years in the U.S. This organizational approach is oriented toward taking advantage of productivity gains made possible by economies of scale, as more specialized equipment and labor are employed.

Both in the analysis of the firm and the management of SM/MP firms, technology has been treated as an exogenous

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[10]Smith, 1910: Volume 1, pp. 7-9.

factor and is assumed to be generally available in a competitive marketplace. If a new technology is developed, firms may choose to invest in it, shifting their production functions upward. With the assumed general availability of technology, the questions of how technology comes into being and what is involved in its successful application have not been central to the analysis of the firm. Nor has there been reason to expect significant or persistent differences in performance capabilities of firms. Although this has been a troubling aspect of economic analysis in developing economies (where failure to develop technology appropriate to divergent circumstances and to transfer technology from one setting to another has long been evident), variations in technological capability have not previously been of major concern in the analysis of the firm.

EMERGING TECHNOLOGICAL FORMS

The need for explicit consideration of factors shaping firm technological capability has heightened in recent years with the emergence of a different type of firm organization reflected in the CIF. This organizational approach has evolved among Japan's industrial giants in the past 20 years, and, in contrast with the SM/MP, has been described as cross-functional, decentralized in decision making,[11] and flexible in production. These characteristics have allowed CIFs to capitalize not only on economies of scale, but on economies of scope and flexibility, as well.[12] The CIF capabilities have been attributed to the development of such dramatic breakthroughs in industrial methods as Just-in-Time, Single Minute Exchange of Dies, and Zero Defect Manufacturing.[13] Collectively, these methods have given CIFs the ability to raise quality, delivery and service standards. Simultaneously, these methods have allowed CIFs to reduce cost, increase production flexibility and reduce the economic order quantity of production. Production flexibility and reduced product development time have improved the firm's ability to respond to changing customer needs.[14]

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[11]Decentralized decision making within the CIF does not include strategic decision making, but giving workers greater scope of responsibilities in controlling and improving the activities in which they are involved.

[12]The benefits of innovation to the CIF beyond productivity and economies of scale have been explored by Cole and Mogab (1994).

[13]Monden (1983) provides an in-depth examination of these technologies as they are used in Toyota.

[14]These points are developed in later chapters. They are widely reported in works by economists. Best (1990) and Cole and Mogab (1994) examine these organizational phenomena in economic terms.

The CIF's potential for improvement goes beyond these new production methods, as the methods are themselves the products of an organizational system for improving firm performance. Research on the evolution of these improvements points to a process of incremental change within the companies spanning years, rather than single events of technological shift.[15] The CIF's system for developing technological improvements incrementally and continuously within the firm can itself be examined as an organizational technology for creating and implementing technology. The same factors that produce internal technology development may also provide for a more effective transfer of externally developed technology. This better ability to transfer technology has been noted by Mansfield (1988) and Rosenberg and Steinmueller (1988).

CIF approaches to technological development and organization are no longer restricted to Japan and the industrial giants who pioneered them. CIFs have expanded internationally and other firms seek to duplicate their innovations, their approach to technology development, and internal organization.

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[15]Empirical research describing these organizational approaches is included in Imai's Kaizen (1986) and Watanabe et al.'s The Inducing Power of Japanese Technological Innovation (1991).

STATEMENT OF PROBLEM

The emergence of the CIF approach to technology development raises the question of how this new organizational capability can be understood in economic terms. CIF capabilities, as described above, introduce onto the economic stage a differential among firms in the ability to produce systematic and continuous internal technological improvements, and to transfer externally developed technologies into use. The questions to be addressed by this study are:

- How can the CIF approach to technology be conceptually explained,
- How does the CIF approach compare to current economic approaches to technological change, and, finally,
- What are the implications of this analysis for economic development?

Within this analysis, a central question is whether the CIF approach can be incorporated into current economic models of technological change and firm learning. Specifically, the question is addressed of whether in theory CIF internal improvements ultimately are limited, as in the concept of firm learning.

APPROACH OF STUDY

This study is composed of four principal sections. The first is a synopsis of how technological change is currently incorporated into economic models of the firm. In particular, this synopsis focusses on the potential within economic models for firms to contribute to technology, the possibility for significant and persistent differentials among firms in technological capability, and the manner in which technology may impact firm operations. From this synopsis, it is then possible to consider fully the strategic choices before the firm with regard to technology.

The second section of this study is a description of the CIF approach to technological change. This consists of an examination of two reported systems for technology development in the CIF: 1) the kaizen system for continuous internal improvement, and 2) the concurrent design system for cross-functional technology development. A case study of Nippondenzo Tennessee will be used to demonstrate how a kaizen system works.

The third section of this study compares CIF innovation with current models of technological change and firm learning in economics. Two analytical tools, the performance gap and a dichotomy between on-line and off-line learning, are introduced to evaluate differences in firm behavior and organizational impacts on technological capability.

The final section in the study is an analysis of the comparative performance of different approaches to technological change. Two issues are addressed in this comparative analysis. First, the appropriability of firm-generated technology is examined in light of the CIF's approach to technology development. Second, firm approaches to technology development are considered in a dynamic context. On the basis of these comparative analyses, some conclusions are made about: 1) the appropriateness of a conventional conceptual framework for examining differences in firm approaches to technology development, and 2) the likely comparative performance of firms using CIF and conventional approaches to technology development.

DEFINITIONS AND LIMITATIONS

The goal in this analysis is not to focus on who the CIFs are in their many facets and manifestations, but rather to use their abilities in making internal improvements and transferring technology as an aid to understanding technological change and firm performance. Certainly other firms have been able at least temporarily to achieve the types of internal improvements attributed to CIFs. This will become more apparent as this ability is more clearly defined and examined. The CIF, however, offers a clear and timely basis for illustrating the possibilities of in-situ technological change both because CIFs provide a group of firms with similar characteristics, rather than a single firm that, it may be argued, reflects an individual personality or unique circumstance; and because the firms are heavily described and, therefore, provide both a broad information base from which to draw and familiarity to readers.

Not all of the characteristics and circumstances of CIFs, however, are relevant to their technological abilities. For the purposes of this study, the general organizational characteristics of these firms are largely taken as a given. The inner logic of these general methods is not developed here. Rather, the focus of this work is on the CIF's approach to technology development in comparison with economic depictions of the firm's role in technology development. This study, therefore, focuses on those aspects of CIF organization that relate to factors in the technological change process. The characteristics used here to describe the CIF are a composite of common attributes observed in these firms. Individual firms may display each attribute to varying degrees. The significance of these attributes for the purposes of this analysis lies in their effect on technological outcome, whether intentional or accidental.[16]

Likewise, the SM/MP paradigm used to describe conventional approaches illustrates a common cultural perspective upon which individual firms more or less loosely model themselves. Neoclassical economics, also, is a wide spectrum of concepts within which, it is likely, there are many conflicting views. Yet, a textbook treatment gives a common foundation upon which economists and noneconomists more or less converge. This textbook economics approach has formed a common language and approach to understanding and directing economic activity. It is not expected to describe the range of beliefs or approaches of individual theorists or researchers, but to illuminate an archetype for technology development that serves as the foundation for the economic analysis of the firm.

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[16]Paul Romer (1993) wrote: "Much of the contemporary debate about developments in Japan turns on narrow issues such as whether lifetime employment, restrictions on corporate takeovers, or a government planning bureaucracy have helped or hurt the Japanese economy. A look at the emergence of mass production suggests that we should focus first on deeper questions about the nature of production." This study examines the broader role given to production in technology development within the CIF.

A number of terms are used in this study that have multiple meanings in economics. Many of these terms are defined as they occur in discussion. A list of definitions is included in Appendix A. Some terms, however, need to be clarified from the outset. The most important of these is the use of the word "firm." Firm has two uses in this analysis. Primarily, firm is used to mean activities that directly contribute to the production of a product. This use is consistent with the conventional unit of analysis in the theory of the firm. In discussions of the internal organization of R&D, firm is also used in the sense of a larger corporate entity that may or may not own its own R&D laboratory. The more restrictive use of the term is distinguished in discussion by stipulating that the directly productive activities of the firm are intended.[17]

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[17]The use of the term "directly productive activities" is intended to include activities that are directly involved in assembling resources, producing a product, and delivering products (or services) to customers. Productive activities need not be limited to manufacture or delivery of tangible goods. R&D, however, is not included in this category, as it is not part of the productive processes of the firm. This distinction is to allow consideration of product and process improvements that do not stem from separate specialists within the firm, but directly from participants in the productive activities of the firm.

CHAPTER 2

ECONOMIC MODELS OF TECHNOLOGICAL CHANGE

To determine whether the conceptual treatments of technological change in economics encompass the range of current practices of major firms, it is first necessary to explore the basis for incorporating technological change in models of the firm. In considering the role of technology in a firm's competitiveness, economic analysis focuses primarily on unit cost and productivity measures.[18] From a textbook perspective, technology is the "how to" of production. Better technology utilizes improved methods to convert given amounts of capital and labor into greater quantities of output.

Adam Smith first described technology as the creation of laborers using machines, manufacturers of machines, and

[18]Productivity is typically measured in terms of output per hour of labor.

"philosophers or men of speculation" whose occupation is invention.[19] Due to perceived benefits from the division of labor and specialization, however, economic thought has come to focus on inventors outside of the domain of production as the prime source of technological advance. Thus, firms and organizations specializing in research and development are responsible for advances in technology. Based on inventive research, new machinery is developed and sold to entrepreneurs for utilization in manufacturing.[20] This rough sketch of technological change is the underlying premise by which technological advance is incorporated into economic models of firm behavior.

THE LINEAR MODEL OF TECHNOLOGICAL CHANGE

The process of technological change is conceptualized as following the same organizational principles as economic activity in general: that of a specialization in function and division of labor to achieve performance superiority and efficiencies of scale. The division of tasks into separate

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[19]Adam Smith (1910), Volume 1, pages 9-10.

[20]This holds as the basic model in spite of the fact that some firms have their own R&D organizations. How the facts are made to fit the model is explained subsequently.

functions and the sequential performance of these tasks by specialists is the means by which technological change is accomplished. It is important to note that these moves toward specialization have removed any role for production workers in the development of new technology. Where that role had appeared to be important in Smith's view, it had ostensibly disappeared from theory by our own time.

Accordingly, technological change has typically been analyzed in economics by division of the process into three distinct stages.[21] Figure 2.1 depicts the progression of technology from stage to stage: within each stage a different type of activity is undertaken. Technology originates within the specialized activity of R&D. This activity can be conducted within commercial, government, or university labs, or in separate units within companies.

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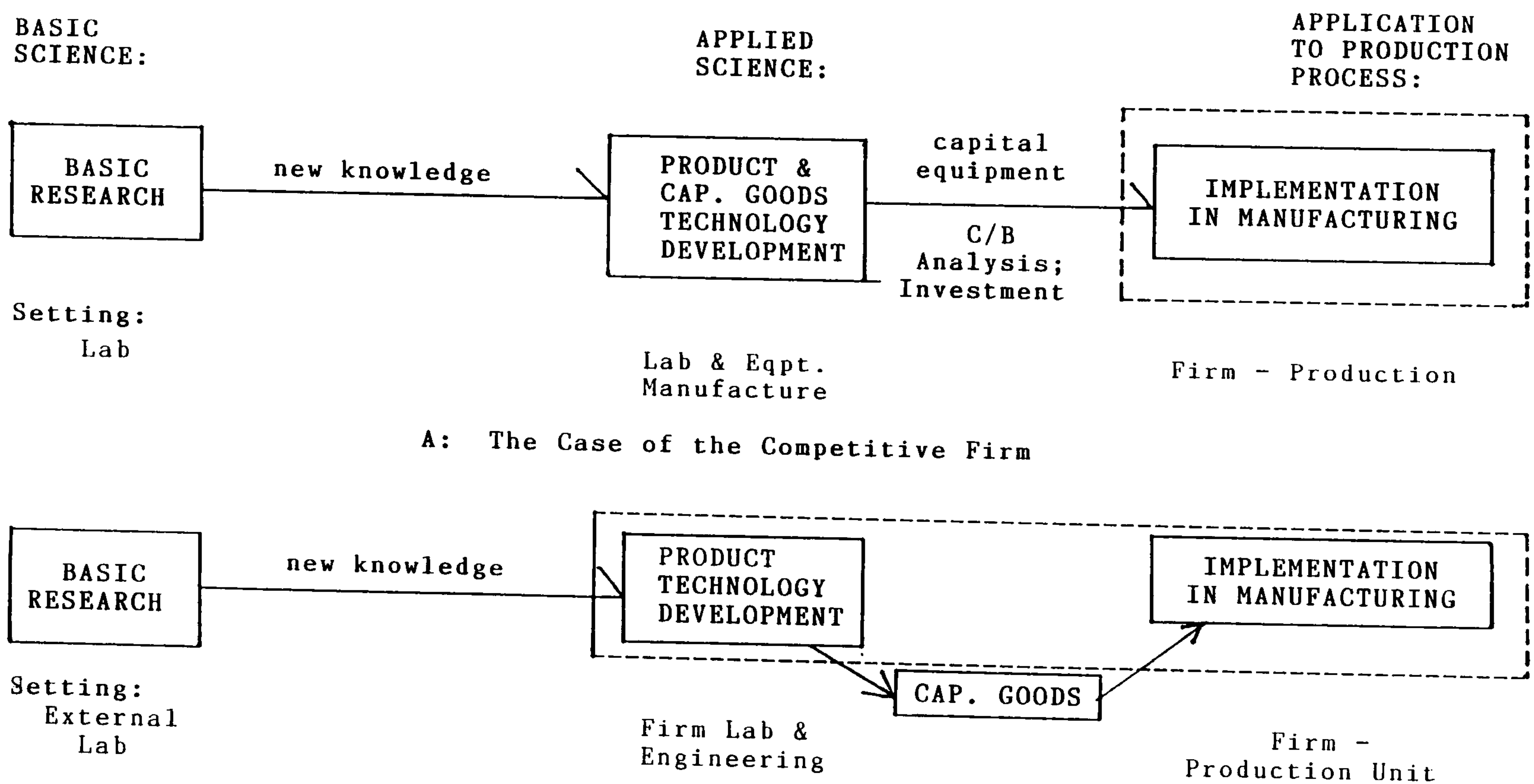
[21]The model of technological change explored here has rarely been fully described in economic literature, but is tacitly used in model building and in references to the technology development process. An exception to this elusive treatment is Aoki and Rosenberg (1987), who provide an articulation of what they term the linear model of technology development. Aoki and Rosenberg focus on extending conceptual consideration of technology development as exogenous to the firm, to consideration of technology development within a R&D unit of a firm, and possible interactions between specialized functions. Aoki and Rosenberg's model is explored at greater length in a later section of this work.

The focus in this work is involvement within the firm in technology creation beyond separate R&D activities. Special attention is given to examining the role of directly productive units within the firm in technology development.



A: The Case of the Competitive Firm

B: The Case of the Imperfectly Competitive Firm

Figure 2.1. The Linear Stage Model of Technological Change

It is assumed that within such an environment, specialists with skills and training in the generation and testing of new ideas can develop new equipment that will be able to perform productive activities more efficiently and effectively. This stage of technological development is sometimes further fragmented into basic research, where knowledge creation and scientific breakthrough occur; and development, where ideas are modified to conform with specific commercial settings and needs. The product of the development stage may be referred to as invention or innovation (the distinction between the two is based loosely on the magnitude of the new development). Most often, the product of the development stage is modelled as a new product or capital equipment with greater capabilities than prior technologies.

In this linear model, the development of technology is external to the directly productive activities of the firm. Technology is moved into productive use by the decision of a firm to purchase new equipment or embark on the production of a new product. In the model of the competitive firm, as seen in Figure 2.1, technology enters the firm by means of a capital investment. The investment decision is made by the firm on a basis of cost/benefit analysis of available technologies. If the benefits outweigh the costs, the firm will invest.

In models of imperfect competition, firms decide whether to develop their own or purchase externally developed technology based on their evaluation of the costs and risks of internally recreating this staged process with in-house R&D. As shown in Figure 2.1, intra-firm technology development generally relates to product development, rather than to capital equipment. In both the competitive and imperfectly competitive models, the firm is dependent on technology developed externally to its directly productive activities. The benefit/cost calculus is applied no less rigorously to new products and/or processes originating from internal R&D than to those from external sources.

Because investment is the firm's sole source of technology advancement, technology is assumed to be equally accessible to firms on the basis of willingness to pay. Based on this conceptual foundation, investment is used in economic modelling of the firm as the measure of technological change and capability.

CONCEPTS OF FIRM LEARNING

In economic models, the firm does not contribute to technology advancement beyond a decision to acquire new technology through capital investment.[22] Yet, it has been observed that, based on manufacturing productivity rates, firm performance has often advanced significantly even in time spans without capital investment. Wright (1936) first observed that, while this phenomenon resulted from a wide range of factors, the trend in improvements could be described as a constant rate of decrease in average cost per unit as cumulative output doubled.[23] The typical representation of this function is depicted in Figure 2.2. As shown in the diagram, this trend also is described as a change in productivity (expressed as a ratio of output to direct labor hours), and most typically is estimated as approximating an 80% "learning rate."[24] Based on this, a firm could expect an increase in labor (or cost) of only 80% for every doubling of output.[25] This curve has been variously referred to as a manufacturing progress function, the 80% curve, and the learning curve. With this

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[22]Strictly speaking, in the competitive model, the firm does not advance technology. In the integrated firm of imperfectly competitive models, the same point is made by saying that the manufacturing function does not contribute to the development of new technology. In the integrated firm, technology change takes place in R&D and learning takes place within the functions engaged in production.

[23]Wright's analysis was based on observation of the emerging aircraft manufacturing industry of the 1920s.

[24]See Asher (1956) and Yelle (1979) for surveys of learning curve research spanning from 1936 to 1979.

[25]This has alternately been described as a progress ratio of 20%.

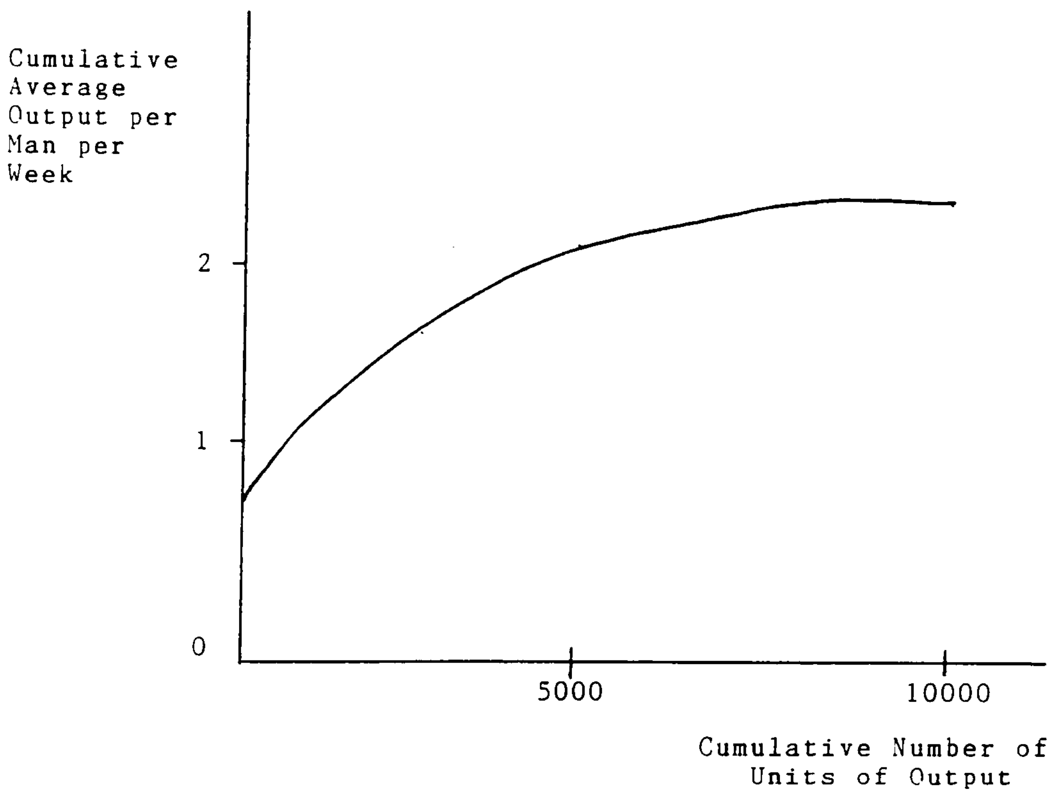

Figure 2.2. The Learning Curve as Used in Economics

Source: The MIT Dictionary of Modern Economics, 4th edition. Cambridge, Mass.: MIT, 1992. S.v. "Learning Curve," p.242.

representation, improvements in firm performance are considered strictly as a function of cumulative output, and as affecting only productivity.

Based on Wright's findings and subsequent research, the U.S. military used the "80% curve" to forecast costs in wartime aircraft and ship manufacture during World War II. After the war, Alchian (1950; 1963) used WWII military manufacturing data to test the assumption of an 80% progress function and found that, while he had insufficient data to test the functional form of productivity improvements, the evidence of improvement itself was indisputable.[26] Rates of improvement varied, however, by product type and a single 80% rate could not be assumed. Hirsch (1956) duplicated this finding in his study of a manufacturer of seven capital equipment products.

Because data used in early empirical research on progress functions was from military equipment manufacture, widespread reporting and subsequent extension of learning curve analysis to other industries were delayed until the 1950s and 1960s. Popularization of the learning curve as a strategic planning tool was especially advanced by the work of the Boston Consulting Group, starting with their 1970

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[26]Alchian (1963: 680).

publication. The learning curve has been used extensively since to forecast average cost for new products, set labor standards, plan future labor and production needs, and explore the strategic implications of early versus late market entry. Most empirical research on firm learning has focussed on determining precise learning rates and functional forms for different industries, in order to improve forecasts of future costs and productivity. The concept of firm learning has also been expanded to describe performance capabilities of not just single start-up production processes, but the combined activities within a firm (termed the experience curve); and whole industries, which at some point are thought to exhaust the opportunities for further improvements in production methods as an industry becomes "mature."[27] Theoretical research in economics on the learning curve has focussed on issues of leader and follower advantages with varying assumptions of the "spillover" of learning gains to late market entrants.[28]

In all these approaches, the rate of improvement remains a function of cumulative output, improvement is limited to productivity or cost effects, and the potential

[27]See Boston Consulting Group (1970), Pappas and Hirschey (1987), and Douglas (1987).

[28]See Mookherjee and Ray (1993), Yelle (1979), and Jovanovic and Lach (1989).

for improvement slows over time, ultimately approaching zero. While determining learning rates and market timing advantages have become popular research questions, a robust explanation for changes in manufacturing productivity has been lacking in the theory of the firm, which leaves a conceptual approach for incorporating these phenomena into the economics of technological change incomplete.[29]

Learning-By-Doing:

Arrow (1962) proposed the concept of learning-by-doing as a theoretical basis for the use of a learning curve to describe reports of productivity growth within firms. In Arrow's concept of learning-by-doing, a firm gradually improves its ability to use a new technology over time by virtue of experience. Productivity gains result when firms first employ new technologies and are due to worker skill development and technology adaptations made by firms. According to Arrow, firm productivity growth could be described as firm learning, and could be treated with the same analytic tools used by psychologists to describe individual learning.[30] Arrow drew upon research on wartime

[29]See Mookherjee and Ray (1993), Abernathy and Wayne (1974), and Alberts (1989).

[30]Arrow (1962).

aircraft manufacture as evidence of the effect of experience on productivity and the existence of an asymptotic learning function for firms.

In modelling this phenomenon, Arrow treated technology as fully embodied in the capital equipment employed by the firm, and technology change as distinct from firm learning:

> "At any moment of new time, the new capital goods incorporate all the knowledge then available, but once built their productive efficiency cannot be altered by subsequent learning."[31]

This treatment of the learning curve as an asymptotic function of cumulative output is the way performance improvement within the firm is incorporated into the analysis of the firm today.[32]

Arrow's concept of firm learning has several salient characteristics:

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[31]Arrow (1962: 157). Arrow discussed the possibility of multiple capital-labor ratios before and after a capital good is built. While Arrow's model assumes only one efficient capital-labor ratio for new investment, Johansen (1959) introduced a model that allowed alternate capital-labor ratios before investment, but only one after investment "congealed into a capital good." Both conceptualizations assume capital equipment to be rigid in its employment, which does in fact describe the type of equipment and method frequently employed by firms. However, the flexible manufacturing practices of Continuous Improvement Firms has lead to an awareness of the possibility of building capital equipment that is not rigid in its use. This is reflected in the emergence of capital equipment that is designed to allow adaptation by users.

[32]Tirole (1988: 74) describes learning as "practice makes perfect."

1. Improvement rates for firm performance without further capital investment ultimately approach zero,

2. Improvements affect productivity, while production attributes (such as reliability, timeliness, and product quality) remain unchanged, and

3. Improvement accrues automatically as a function of cumulative output.[33]

As described by the concept of firm learning and the learning curve, possible performance improvements rising within the firm are ultimately limited in scope and impact. Although various causes of productivity improvement have been identified, learning is modelled as a function of cumulative output, not individual factors. It is expected, therefore, to occur automatically and to be similar for different firms and production processes within an industry. Furthermore, product and production process attributes are assumed to be unaffected by learning improvements. The potential for productivity improvement diminishes over time and the firm is dependent on capital (and technological) infusion to advance further.

That the potential for firm improvement can be described as limited, as is assumed by an asymptotic learning function, is generally considered a moot point.

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[33]Jovanovic and Lach (1989) provide a recent example of learning curve analysis using Arrow's assumptions of capital embodied technology and learning as purely a function of cumulative output.

Yet, evidence for this depiction is not conclusive. Problems in the specification of the learning curve as an aggregate function of a wide range of contributing factors, analytic techniques, and problems determining cause and effect raises questions about the reliability of empirical results.

Intriligator (1978) describes problems that plague productivity analysis; such as price inflation, heterogeneous inputs, changes in output levels, changes in exogenous factors over time, and insufficient data points. Statistical practices in learning curve analysis have made research results questionable. Critics cite practices of using synthetic data for missing intervals, failures to isolate input price inflation (when using an average cost approach), aggregation of diverse production activities into a single learning function, and failure to separate scale effects from changing output levels; making evidence of constant learning rates and functional forms inconclusive.[34]

While firm learning is depicted as a single asymptotic function, some research demonstrates that learning is not uniform within even a single firm. Alchian (1963)

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[34]Alberts (1989) demonstrates that learning curve analysis has failed to separate scale and learning effects, due to changes in output levels.

demonstrated that while a "80% rule" was commonly assumed in cost forecasting, the learning curve associated with different products varied from approximately 16 to 24%. Hirsch (1956) extended this disaggregation by examining the learning rate in capital equipment manufacture, and found that the rate of improvement varied substantially between assembly and machine work within a single product manufacturing process. Wright, Alchian and Hirsch findings were in agreement that productivity improvements were variable based on product and specific manufacturing process. Hirsch also confirmed Alchian's finding that prior production experience increased the progress ratio for a firm.[35]

Hirsch's distinction of labor-intensive and equipment-paced tasks further raises the issue of the difference in causes lumped under the heading of a single learning function. Hirsch examines possible reasons for divergent progress ratios between assembly and machine work and suggests assembly work lends itself to reductions in direct labor inputs more readily than machine work. He notes that the progress ratio of the machine work component of

[35]Neither Alchian nor Hirsch state whether the intercept for progress functions remained the same for firms with prior production experience. Because both authors treated the higher progress ratios as gains for experienced firms, it is assumed here that the intercepts were equal to or greater than for inexperienced firms.

production may be small because some machine work does not change with a change in product, meaning experience has already been gained for some tasks. Skilled operators of machinery "have little opportunity to learn and, thus, can make little progress in operating machines more efficiently."[36] However, neither Alchian nor Hirsch found conclusive evidence that the potential for further internal improvement was limited.

While the concept of a constant and asymptotic firm learning function attributes production performance improvement to individual learning and experience, Hirsch's research provides a more detailed account of factors contributing to the learning curve:

> Progress reducing labor input is made by direct labor, management, engineers, and suppliers. The more complicated the manufacturing process, the more important the contribution of the engineer. His work can lead to liberalization of the tolerances to which parts are machined, to the use and improvement of special tools and holding devices, to secondary design improvements, to improvement in plant lay-out, routing, and material handling, as well as to the use of improved material and equipment. Also changes in the arts outside the company will greatly affect the internal improvements, their timing and rate.[37]

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[36]Hirsch (1956: 140). Interestingly, Hirsch's remark reveals the limited scope given for workers to make changes when using a system of highly specialized division of labor.

[37]Hirsch (1956: 139).

In contrast to Arrow's treatment of technology as fully embodied in capital equipment and technology change as distinct from learning, Hirsch described the learning curve as an irreversible progress of technological knowledge.[38]

A second level of problems with learning curve analysis and the concept of firm learning was raised by Hirschmann (1964) and Conway and Schultz (1959) as to whether learning plateaus reflect real limits to the potential for improvement or reflect the attainment of target performance levels. Conway and Schultz observed that products that plateaued in one firm continued to fall in unit costs when transferred to another firm. Hirschmann hypothesized that firm performance improvement parallelled the achievement of previously set improvement targets, suggesting learning plateaus might reflect management expectations, rather than an improvement potential inherent in capital goods.

Learning-By-Using:

While in the concept of learning-by-doing advancement in capital equipment technology is excluded from the scope of possible improvements made within the firm, Rosenberg (1982) has outlined a case in which a firm may contribute to

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[38]Hirsch (1956: 137).

technological advance in the capital equipment industry which supplies it. Figure 2.3 illustrates Rosenberg's concept of learning-by-using, a process in which capital equipment users provide ideas for equipment improvement to equipment manufacturers. While learning-by-doing refers to the mastery of a technology by a user, learning-by-using refers to the insights the user gains into ways in which the technology could be improved. Preserving Arrow's treatment of technology as fully embodied in capital equipment, Rosenberg described the process by which users may feed insights back to the capital equipment producers for incorporation into the next generation of capital goods. As revealed in Figure 2.3, users can benefit from their contributions to technology only when they invest in the next generation of equipment.

The type of learning described by Rosenberg includes interaction between user and technology, allowing expansion of existing knowledge and, hence, technological advancement. Rosenberg identified an important source of ideas for technological advancement by describing the potential for feedback loops between users and manufacturers of capital equipment. The learning-by-using concept implies that in order to harness this potential for gains, close user/supplier communication would be essential. This is the case in the aircraft and airline industries Rosenberg refers

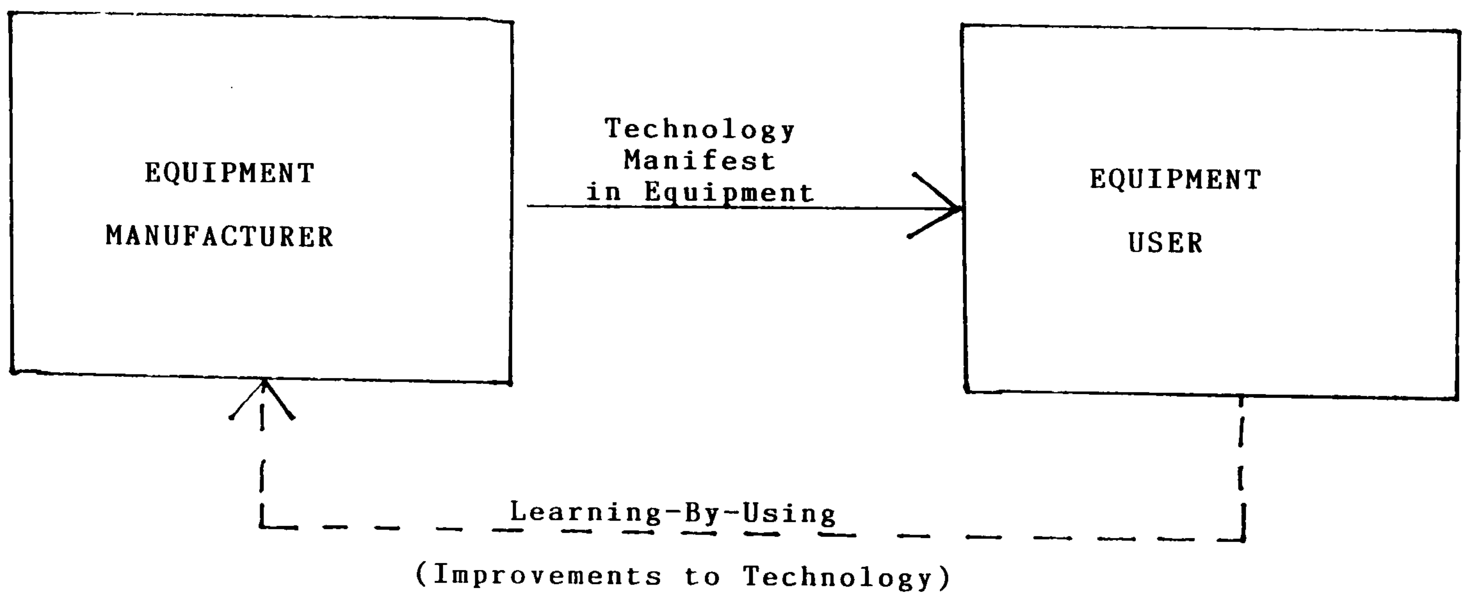

Figure 2.3. Learning-By-Using

to, where airframes are made to order for individual airlines. It is more problematic in other industries.

The possibility of mutually beneficial feedback loops presupposes long term relationships and close communication between capital equipment users and manufacturers. These potential benefits suggest that arm's length interfirm transactions may not be optimal when technological concerns are included in market analysis. In any case, technological advance can not be incorporated into the equipment user's production until improved equipment is manufactured, purchased and installed. The equipment user's performance, therefore, remains unimproved between the time that improvements are discovered and the time that an investment in a new generation of capital equipment is made. Once improvements have "gelled"[39] into capital equipment, further improvement possibilities can not be utilized without embarking upon another generation of capital equipment manufacture, investment and implementation.

Strategically, a firm's contribution to capital equipment improvement poses some dilemmas for the firm, as pointed out by Jovanovic and Lach (1989). If use of capital equipment leads to learning that will be incorporated into

[39]This term is borrowed from the putty/clay discussions and refers to the point in time when capital becomes fixed for the firm (Arrow, 1962; Johansen, 1959).

the next generation of equipment, latecomers to a market may be able to benefit from early entrants by purchasing equipment that has appropriated the early entrants' technological contributions. Early entrants are handicapped by not being able to capture this learning benefit unless they replace their prior generation of capital equipment with the new equipment.

The strategic impact of learning-by-using for the firm depends on the degree to which other firms can gain access to these improvements before the learning firm can invest in the new generation of equipment. If the firm's learning benefits are incorporated into generally available capital equipment as the firm learns, before the firm itself can afford to reinvest, the firm will be penalized by its own experience, as Jovanovic and Lach conclude. An alternate outcome is possible, however, if the firm can incorporate improvements into its next generation of capital equipment by establishing communication links with an exclusive equipment supplier. In this case, the firm may benefit from technological advancement not available to other firms.

ITERATIVE MODELS OF TECHNOLOGICAL CHANGE

Attempts have been made since Arrow's 1962 article to model possible further contributions to technological change made by a firm's directly productive operations. These models are grouped here under the heading of iterative models to reflect the process by which technological changes are introduced.

Iterative Models in Economics:

In the field of economics, Aoki and Rosenberg (1987) have described an intra-firm iterative process in which a firm can advance its technological capability using intra-firm feedback loops.[40] In this model, incipient technologies circulate between internal R&D, engineering, production and marketing units. This intra-firm model has the benefit of allowing user feedback to be incorporated into technological design without requiring the initial design to be implemented before production feedback can be given. As a new product is developed and moved toward

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[40]This process is used by the firm in introducing new products, which, in turn, require changes in the production methods used by the firm.

production, it is passed from one functional area to another within the firm. Each functional area reviews the design and further completes the design for implementation. As each group reviews the design, problems with implementing the design surface. These problems are redressed by returning the project to R&D for re-design. In this model, Aoki and Rosenberg demonstrate that input for technological change is not limited to R&D and that technological development does not always have a uni-directional flow from R&D to implementation. Also, the catalyst for design change may come from the implementation stage, precipitating R&D work.

Other Iterative Models of Technological Change:

Not surprisingly, the disciplines that have done the most extensive work on modelling intra-firm technological development are the disciplines most intimately involved in bringing about technological improvements within the firm: industrial engineering and management.[41] Approaches developed in these fields first added to the linear model of technological change by incorporating a process of developmental iterations within the firm. Firms internalize

[41]Adler and Clark (1991) provide a review of management literature on learning and technological development within the firm.

the stages of technological change described in the linear stage model, bringing the R&D contributions within the scope of the firm. R&D, in turn, has access to external technological information and developments. Technological advances are incorporated within engineering solutions and their application to product and production design. In these models, the impetus for technological change may start with problems observed in production, product design, or may originate as opportunities identified in R&D.

In some of these approaches, functions "downstream" from research and development may provide feedback for technology adaptation and refinement. The technology is then re-routed through the original stages of development to incorporate new information and feedback into technology design. Iterations are a means of incorporating information and feedback from later functions into early design and development stages. It can involve a correction to earlier design flaws or the requirement to go to another functional area within the firm to get changes made to existing product or process design.

Both engineering/management and economic iterative models of technological change reflect accurately the industrial context in which intra-firm innovation typically takes place. The mode of organization these models describe is based on the Scientific Management/Mass Production method of dividing tasks into a series of separate functions to be performed sequentially by specialists in each function. In the SM/MP firm, coordination among functions is achieved through a hierarchy of oversight in which specific tasks are assigned and coordinated. It is presumed that economies of scale can be achieved by: 1) hiring, in each job function, only those skills that are essential to a narrowly defined task, and 2) increasing the volume performed by each job station. As Adam Smith pointed out,[42] this specialization makes the use of specialized equipment financially feasible. Problems of coordination between tasks and sub-employment of work stations within the process are not considered significant enough to dampen the benefits from greater functional division and specialization of labor. This is especially true if output is great enough to allow for full utilization of all work stations.

As this method of organization is applied to technology development, tasks within the process are performed by different people with limited interaction, except in the exchange of a project between stages.[43] In cases where the

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[42]Smith (1910), p. 7.

[43]Cole and Mogab (1994) describe the functional silo character of SM/MP organization, which is the basis of the technology development process described here. The work of Clark and Fujimoto (1991) provide evidence of this characterization in their research on new product design in

iterative approach to technology development is utilized, the time delays and cost increases that result from the feedback of information and needs from downstream stages are considered less significant than the benefits produced by it. The addition of feedback loops does not alter, however, the basic sequential nature of the process. The functionally segmented and sequential character of the technology development process described by linear and iterative technology development models is abundantly apparent in industry.[44]

Based on the linear and iterative models of technological change and the concept of firm learning, the technological possibilities faced by individual firms have several salient characteristics. In both the linear and iterative models of technological change, an SM/MP organizational paradigm is assumed. In all these models, technological change is a functionally segmented sequence

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the automotive industry. The conventional approach had been for the design project to pass from one development stage to another by the exchange of the project from one department to the next in a single "batch," upon completion of one department's contribution.

[44]While the iterative approaches add an element of realism, they have been largely ignored in the textbooks and journals. The basic approach, therefore, is represented by linear stages in which technology is developed externally to the firm. As a result, technology is treated as generally available to all firms. While this is not the case when R&D is "internal" and when technology is a new product, even with internalized R&D, technology development is thought to be equivalent for firms on the basis of investment.

occurring outside the scope of normal productive operations. Since this process of innovation is external to normal productive operations, it can in theory be represented as firm investment.[45] As a result of these characteristics, technological improvement is expensive and disruptive for the firm, and can not be undertaken frequently. A firm's choice of the product it will make and its production methods are fixed for the productive life of its capital equipment, making changes to product characteristics and production methods infeasible in the short run.

The potential for organization within the firm to impact technological and productive capability is not included in economic models of the firm. Consequently, most research on technological capability focusses on R&D and capital equipment investment. There is no means within this conceptual framework for representing differentials in firm technological capabilities except in investment quantities.

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[45]This is true whether the technology is internally or externally developed, capital embodied or "soft" technology, product or production technology. While some economic modelers of technological change have extended the definition of technology to include soft technologies not embodied in capital equipment, these models have also assumed soft technology is externally developed and acquired through investment. The basic technique of representing technology change as a function of investment remains unchanged.

CHAPTER 3

THE CONTINUOUS IMPROVEMENT FIRM APPROACH TO TECHNOLOGICAL CHANGE

Undoubtedly, the standard view of infrequent and large scale investment followed by a period of learning describes a great deal of firm experience with technological change. For example, when Toyota started a manufacturing operation in the United States, it required a lump investment in capital, the employment of a new labor force, and the formation of a new organization. It could be expected that this start-up operation was accompanied by a breaking in (or learning) period, in which organizational capabilities lag initial capital investment. Nevertheless, within Toyota, and within other Continuous Improvement Firms, significantly different organizational structures and management systems have been introduced that call into question the efficacy of a sequential model in which technology development takes place in isolation from the directly productive activities of the firm.

The CIF is a firm using a systematic, broad-based, and integrative approach toward technology development and performance improvement. These activities within the firm (and between the firm and its external associates) are holistically, rather than atomistically, defined. The orchestration of the multitude of activities (in which any large organization must engage) are based on the integration, rather than the functional segmentation, of activities. This the CIF does while still using principles of specialization, mass production and scientific management. The CIF has moved away from large production batch sizes (necessitated by high economic order quantities);[46] inflexible use of capital and labor; centralized information, planning and analysis; and infrequent changes to technology, methods and products.[47] This different approach is made possible by adaptations to capital and labor that allow quick changeover between

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[46]The economic order quantity for a product is the number of units corresponding to the minimum point on the average cost curve. It is determined by the cost (especially of time) in change-over between different products on a production line. The less time and other expenditures necessary in changing production processes over from one product to another, the smaller batches a firm may run economically. The smaller the necessary batch size for each product, the less inventory and forecasting of future demand will be required of the firm, as the time needed between starting production of a product and delivery (without increasing unit cost) diminishes.

[47]Clark and Fujimoto (1991: 40) provide data that the number of products, and frequency of product changes are higher for Japanese than European or U.S. automakers. The volume of each model sold is also smaller.

product types (reducing the minimum economic size of production runs) and internal systems for the continuous development of technology and performance improvements.[48]

Two major organizational systems for continuous internal improvement are of interest to us: (1) kaizen (incremental changes made to technology in situ within the routine activities of the firm), and (2) concurrent design. Kaizen is a system for making incremental improvements to firm operations by the continuous review of current methods at all levels of the organization. Concurrent design is a method of integrating functional activities in technology development.[49] Because concurrent design is usually associated with large investment projects to develop new or significantly changed products, it can be compared with a

[48]Monden (1983) describes the flexible use of capital and labor in Toyota, where workers are rotated between jobs, and product types are mixed on a single production line. The reader wishing to read in more depth on the CIF is referred to Imai (1986) on the kaizen system, Monden (1983) on production methods, Best (1990) on industrial organization, Clark and Fujimoto (1991) on new product development, Cole (1991) on a comparison of CIF and SM/MP organization from the perspective of economic analysis, and Cole and Mogab (1994) on the role of CIF organization in competition.

[49]Concurrent design has been widely reported in engineering literature, but has not been incorporated into economic models of technological change. This approach has been credited with significantly reducing design time and cost, and improving the market and production success of new technologies. Concurrent design is, therefore, important to the analysis of firm technological capability and technology development.

conventional sequential approach to intra-firm technology development. Both kaizen and concurrent design more closely align technology development with the productive activities of the firm than functionally segmented approaches. In the case of kaizen, the impetus for most changes originates within the manufacturing function. In the case of concurrent design, the activities of R&D, engineering, input suppliers, manufacturing and marketing functions are to a significant degree merged in the technology development process.

These two methods occur together in the CIF approach to technology development. Aspects of both of these techniques increasingly are being copied by firms that have been historically SM/MP in organization.[50] These techniques have been described as separate (or even conflicting) technology development strategies.[51] While kaizen and

[50]Widespread evidence of attempts to copy aspects of kaizen and concurrent design are documented respectively in Kenney and Florida (1993), and Clark and Fujimoto's (1991) analysis of the automobile industry. Clark and Fujimoto's report "[t]he shift from purely functional forms of organization to more integrated structures has become a trend that we find everywhere" (Ibid.: 103). This statement indicates the pervasiveness of the shift away from conventional means of organizing technological change, and toward an integrative approach.

[51]Clark and Fujimoto (1991: 135) distinguish the "rapid inch-up" technology development strategy of Japanese automakers from the "infrequent great-leap-forward" strategy of U.S. automakers. Japanese automakers introduce model changes more frequently, but each generation of models incorporates less change than in new American models. The

concurrent design techniques may be used separately, they are complimentary as used by leading Japanese firms. Organizational and managerial features that promote one of these approaches also supports the other.[52]

Both of these technology development channels in the CIF reflect enduring systems of innovation, rather than ad hoc problem solving groups.[53] Based on kaizen and concurrent design, it is possible to see in the CIF a holistic, rather than atomistic, approach to technology advancement. In the conventional approach to technology

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total change in Japanese models, however, is greater than in American counterparts due to more frequent (even if more minor) improvement. One possible explanation for Clark and Fujimoto's findings is that this difference results from the added production flexibility and product development skill of Japanese automakers. New developments can be introduced as they become technologically feasible, without requiring technological improvements to be "saved up" to reach a high production and development threshold before introducing a new model. In this sense, the "rapid inch-up" in product innovations is not in conflict with "infrequent great-leaps-forward," but rather demonstrates an ability to incorporate improvements into products more routinely.

[52]Nor are these technology development processes distinct in the CIF. Cole and Mogab (1994) report that, in Nippondenzo Tennessee, robotics are developed in-house. Worker input plays a major role in innovation to this capital equipment. Kaizen-style worker innovations and large scale technology development, therefore, are integrated in the design of production equipment.

[53]Clark and Fujimoto (Ibid.: 135) suggest that the product development process for Japanese automakers is eased by the frequency of product changes. This ease they attribute to the product development organization establishing a "rhythm" of development, streamlining the development process, and orienting the entire organization to continual learning and improvement.

development, technology moves in a segmented and sequential fashion from basic scientific research, to capital equipment design and manufacture, to capital investment, to use in production. In the CIF approach, all functions participate in technology development in an integrated manner from project formulation to completion. This work seeks to demonstrate that the CIF approach is evidence of a concurrent model of technology change and that technology development can itself be approached by the firm as a production process.

THE KAIZEN SYSTEM

Incremental in situ improvements initiated by workers at all levels of the CIF have lead to the creation of such dramatic breakthroughs in industrial methods as Just-In-Time (JIT), Single Minute Exchange of Dies (SMED), and Zero Defect Manufacturing. Collectively, these methods have given CIFs the ability to raise quality, delivery and service standards. Simultaneously, these methods have allowed CIFs to reduce unit cost, increase production flexibility and reduce the economic order quantity of production.[54]

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[54]See Best (1990) for an explanation of the role of production flexibility in reducing the minimum economic batch size, inventory requirements and necessary production

Major innovations, such as Just-In-Time and Single Minute Exchange of Dies, were the result of a long string of incremental modifications to processes. "When viewed after the fact, the change is seen by outsiders as a discontinuous breakthrough innovation . . . when a more accurate conceptualization would view it as a continuous process of incremental changes."[55] Incremental changes within the production processes may be imperceptible at a point in time and may go by unnoticed outside the firm. However, in accumulation, these changes have significantly increased productivity and other aspects of firm performance. These innovations do not come exclusively from separate R&D units, but often originate with employees involved in production and are developed as a part of routine job activities. Many of these incremental process and product changes may not be significant enough to have warranted individual development through external R&D, making these minor improvements unlikely to emerge in the setting of a research lab.[56]

In economic theory, all improvements that were readily available and of sufficiently low cost would be assumed to have occurred on the basis of economic incentives. Why, then, have not all economically justified changes already

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lead time for the firm.

[55]Bos and Cole (1994: 4).

[56]Cole and Mogab (1994).

been discovered and implemented? Paul Romer gives an important clue in a related discussion of technological change.[57] In his Economist essay, Romer provides an example of a simple industrial process that entails the combination of 20 parts. These parts can be combined in 10 (exp 18) different ways.[58] It is clearly beyond the capability of a firm to fully consider every possible combination. It is even difficult to imagine that all of the possible combinations would be discovered for consideration. It is unlikely, then, that any given firm is operating with the best technological configuration.

Borrowing Romer's analogy and Williamson's concept of the bounded rationality of firm decision makers, CIF methods might then be described as a means of expanding the rational capacity of a firm to explore possibilities for performance improvement. This expansion is achieved by reducing the internal impediments to discovering and implementing process and product changes, and increasing the number of people working to develop possible improvements. The inclusion of most of the workforce in product and process improvement also reduces the difficulty of making changes and improves

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[57]Romer (1993).

[58]Romer is assuming the parts and methods of combination are unchanging. The permutations considering the possibility of component and process change are infinite.

the effectiveness of the production system by increasing coordination and focussing the workforce on firm goals.

The incremental improvements made to CIF products and production processes are not captured by capital investment data, as many changes use existing equipment and require no investment expenditure to employ.[59] Nor could these gains be fully understood by examining productivity levels; as quality, process flexibility, delivery, and product design are also given constant attention by those engaged in kaizen activities.

Because the CIF is structured and managed in ways that promote the generation of improvements, the potential for improvement goes far beyond current developments such as JIT manufacturing. Imai (1986) and Watanabe et al. (1991) have described the CIF's kaizen system whereby improvements to processes and products are routinely developed and implemented on all levels of the firm, including that of production line workers. The system is designed to enhance both the willingness and ability of all personnel to initiate improvements in any aspect of productivity broadly defined to include cost, quality, and delivery. This requires that a broad base of information be made available to all employees together with specialized training to

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[59]See Watanabe et al. (1991).

facilitate its use. Furthermore, a set of incentives is cultivated to support cooperation and implementation of improvements.

A key aspect in dynamizing the improvement process is the promotion of transfunctional views for all employees. This allows employees to see how parts of a process fit within the whole. A work force member becomes aware of how his/her performance fits into upstream and downstream activities in the production process. For floor workers, this is achieved by frequent rotation of jobs. For managers and engineers the broad perspective is achieved by promotion across functions, rotation, and membership on multi-functional committees. This cross-functional training and experience enhances the product development process, as is developed later.

Another prominent tool of the CIF, the kaizen circle or quality circle, as it is sometimes called, will serve as our window for a detailed look at the internal improvement process.[60] In this analysis, a specific case history of the kaizen system in operation will be used to illuminate

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[60]It is not our point to elaborate all significant aspects of continuous improvement systems nor to evaluate their efficacy. Details about the incentive systems and other organizational and managerial aspects of the CIF can be found in Imai (1986), Best (1990), Cole and Mogab (1994), and many other sources.

the process for continuous improvement within a CIF and to furnish the basis for a subsequent comparison of kaizen activity with learning-by-doing. While kaizen activities have been previously documented, the purpose in presenting this case is to detail the kaizen process in a manner that allows a comparison with conceptual treatment of technological change in economics. This case history is from a kaizen circle within Nippondenzo's Maryville, Tennessee plant.[61] The information collected for this case on a kaizen project case history is used to delineate kaizen as a standardized process of innovation based on organization.

While kaizen circle activities result in process improvements, the stated primary objective for kaizen circles at Nippondenzo Tennessee is to build the ability of employees to work cooperatively. Kaizen circle activities also provide an opportunity for employees to develop analytic and leadership skills and to deepen their knowledge

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[61]Nippondenzo Tennessee is an automotive parts manufacturing facility. This case has not been previously published, but the Dream Team's results have been reported within Nippondenzo and presented in public forums. The innovation project examined in this study brought the kaizen team the prestigious annual kaizen circle award for Nippondenzo in Tokyo. The information for this case has been collected by the author from discussions with the Human Resource Development staff and the Dream Team spokesperson at Nippondenzo, presentation materials prepared by the Dream Team, a facility tour of the Nippondenzo plant in Maryville, and published information on Nippondenzo.

of the production process.[62] Kaizen circles are formed for every group of people who work together. The kaizen group can be within a single work area and function, such as the shift workers on a particular section of the production line, or it may span functions, as in the case of plant managers. Individuals may belong to more than one kaizen circle if they work with more than one group of people. For example, a support staff person may simultaneously participate in kaizen circles including cohorts within their immediate functional area, managers across a spectrum of areas, and may also serve as a resource person to one or more kaizen circles of other employees. The kaizen circle used here, the "Dream Team," is comprised of line workers in the plating division of the Maryville plant.

At Nippondenzo, participation in kaizen circles is voluntary but highly encouraged. The company defines the participation of associates in the firm's efforts as the way in which the company achieves profitability. Employee performance, therefore, is evaluated for participation, and kaizen circle activity is considered an indicator of an employee's participation. Nippondenzo Tennessee set a goal in January of 1993 to increase participation in kaizen

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[62]While the purpose of this work is to examine technology development, this does not detract from the possible productive benefits that can result from improved coordination, skill, morale, and labor flexibility through kaizen team work.

circles to 85% of the workforce. This goal was achieved in August of 1993.[63] Currently, there are 106 active circles at the Maryville plant, with group size ranging from 3 to 18 members.

Kaizen circles meet for an hour every week on company time. This is done without disruption to workflow by scheduling work within the section to cover time spent in circle meetings. In some work areas, this can mean building up inventory prior to meetings or swapping work tasks with other employees.

The kaizen process is a systematic approach to directing efforts to improve performance within the firm. Kaizen circles follow guidelines for operation and organization. The people consulted, the analytic tools used and the scope of actions taken depend on the particular kaizen objectives being pursued more than on the functional designation of the kaizen group. At Nippondenzo Tennessee, all kaizen circles use an 8 step process as the basic framework for making improvements, based on the plan-do-check-act wheel outlined by Deming.[64]

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[63]Kenney and Florida (1993: 135) reported 100% participation of workers in kaizen circles at Nippondenzo Michigan.

[64]Deming's wheel for process improvement can itself be viewed as contradicting a treatment of a firm's production methods and products as static in the short run.

The process of making decisions includes consultation and discussion with management resource personnel. In the case of kaizen circles in Nippondenzo, the human resource development department often plays this support role in providing guidance. While this might be called supervision, there is an important distinction from a typical SM/MP management approach, in that the employees' rights to make their own decisions is strongly regarded by management, although groups unskilled and inexperienced in decision making may need a great deal of guidance in learning appropriate behavior. The goal of management resource personnel is to utilize the kaizen process as a means to convey responsible decision making ability to circle members. Management, therefore, seeks to develop the ability of members to work through difficult situations, rather than stepping in and making decisions for the group. In this way, each member of the organization learns to think and to behave with high standards of skill, creativity and responsibility, rather than depending on control and decision making by management.[65]

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[65]The heightened ability of employees to analyze situations and make decisions can reduce the time necessary to evaluate problems and to make changes by reducing demands on management time and by reducing delays from decisions referred to upper management. Management still has the ability to aid employee decisions, but is able to delegate more of the decision process to those closer to the situation without sacrificing analytic competence.

While kaizen circles decide on their own arrangements and rules, groups are encouraged to assign specific roles within the circle and to rotate these functions from project to project. Each role has attendant tasks and opportunities for training. It is the goal of the company that each member of the organization gain experience performing each role within the team. For the Nippondenzo Dream Team, these roles included leader, scribe, computer graphics person, lab analyst, and support members. The kaizen circle is obligated to document its proceedings and activities for the purpose of keeping management and absent group members informed.

After the selection of roles for individuals within the group, the kaizen circle embarks on a guided process for project selection and completion. The group develops its own list of suggestions for performance improvement themes. The group is prohibited from selecting themes dealing with employee benefits, hours, or pay. Major topics for selection are safety, environmental, quality and cleanliness objectives. The Dream Team's list of theme ideas for the project studied included efficient box return, plumb detrix still directly to distiller, safety training for associates, and water usage reduction.

At Nippondenzo, kaizen circles evaluate theme suggestions for appropriateness as kaizen objectives before final selection. This includes considering the relevance of each theme to the mission statements of the organization. In the case of the Nippondenzo Maryville plant, the stated missions of the organization are:

- To provide satisfaction to customers (both internal and external),[66]

- To be a contributing member of the community, and

- To assist associates in their development and growth.[67]

Personal agreement with and commitment to these missions are considered fundamental requirements of employment at Nippondenzo.

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[66]In CIF terms, "customers" are defined to include people who use the output of another person's effort. This means that a worker's "customers" include both the ultimate user of the firm's products and services, and workers who are "downstream" in the production system or otherwise are affected by the worker's output. Consideration of customers includes, therefore, how the output of one section in the firm is delivered to the next stage in the production process. External customers for Nippondenzo Tennessee include General Motors and Toyota.

[67]Interestingly, these missions correspond to the concept of stakeholders in the firm's operations with the obvious exception of shareholders. It could be argued that these missions are more operational goals than directly attempting to maximize profit, in that any employee can readily determine if an action positively or adversely effects these missions, while the ultimate impact of an action on profit is often not directly observable. The use of missions is not incompatible with the concept of profit maximization, but may provide directives in how profit maximization is achieved over the long term. These missions add criteria by which actions must be considered.

Once a list of appropriate kaizen themes has been generated, exploratory research is conducted by the group to collect background information on each theme. Staff support people are consulted to determine if the group's adoption of a theme is in conflict with other efforts underway in the organization. Any themes that are in conflict with other efforts in the organization are modified or dropped from consideration.

In some cases, investigating possible themes results in the generation of possible solutions. Any theme objectives that are easily achieved through obvious and acceptable remedy are agreed upon and implemented by the group. If it is not appropriate for the group to implement the solution, the group may issue a work order to the appropriate individual or group within the company. This decision is made after discussing the required action with the appropriate group for implementation and consulting management resource personnel. In the case of the Dream Team's list of possible themes, it was decided by the group that the "efficient box return" theme could be easily achieved by moving the box collection site. This change was implemented directly by group members. Also, it was decided that the "plumb detrix still directly to distiller" theme was best accomplished by issuing a work order to maintenance personnel to make the desired plumbing change. It was discovered by the group that the Human Resource Department was currently planning a program to address the "safety training for associates" theme and preferred that the group not pursue this theme at the moment. In researching the appropriateness of the "water usage reduction" theme, the group discovered that the plating division accounted for 42% (or 1.1 million gallons annually) of the total water consumption of the Maryville plant. This water consumption accounted for a substantial proportion of local water usage in the community. The group decided that "water usage reduction" was a theme consistent with the company's mission to be a contributing member of the community and selected water reduction as their kaizen objective.

The next step in the kaizen process is for the kaizen circle to set a target for the circle to achieve. This goal should be realistic but present a challenge to the abilities of the group. The Dream Team set a goal of a reduction in the plating division's water usage by one third as a target for their kaizen efforts.

Once a theme and target have been set by the kaizen circle, the theme is analyzed to determine factors that contribute to the current situation. This is done by Nippondenzo teams using Ishikawa's "fishbone," or cause and effect, diagram shown in Figure 3.1. In using the

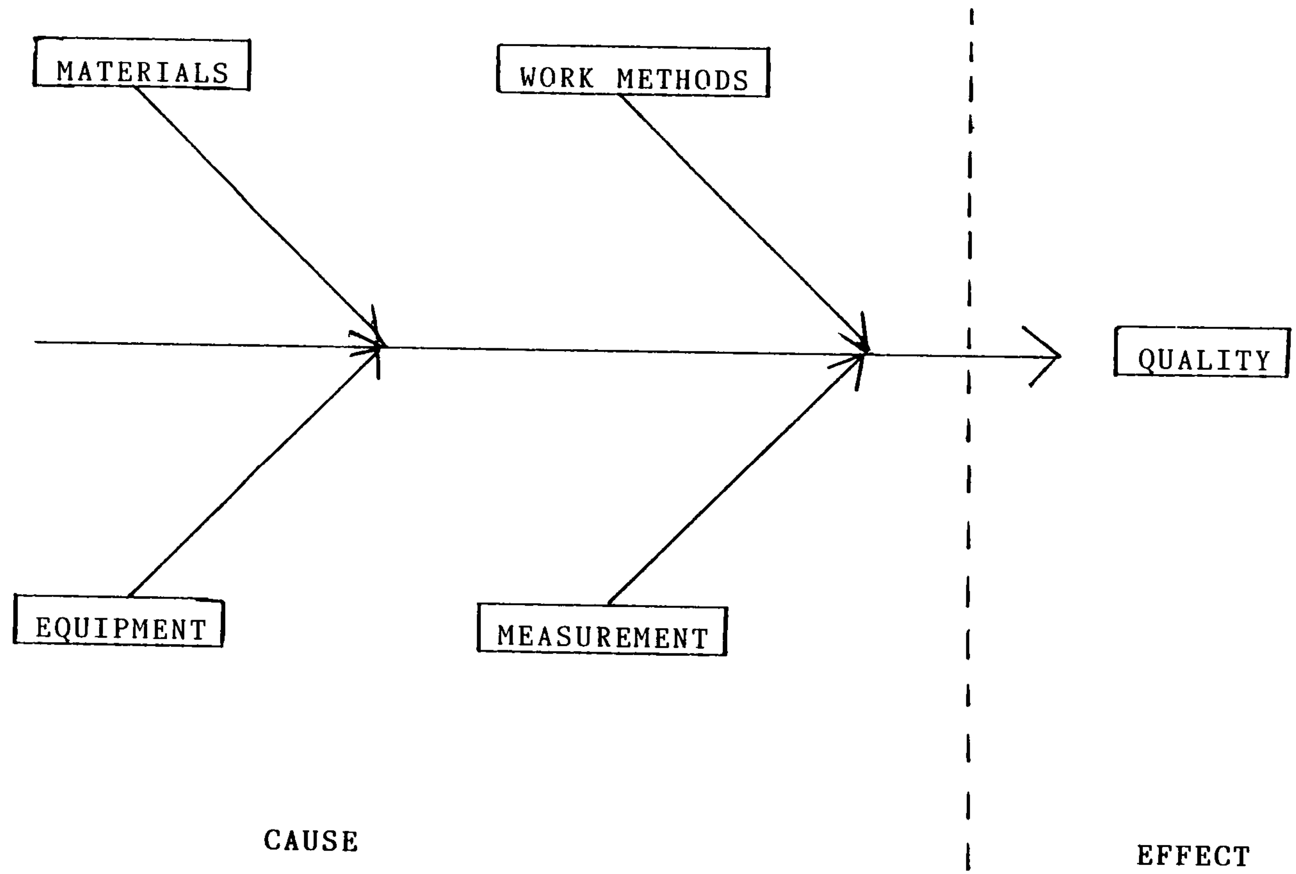

Figure 3.1. Ishikawa Cause and Effect Diagram

Source: Ishikawa, Kaoru. <u>Guide to Quality Control</u>. White Plains, N.Y.: Kraus International Publications, 1987, p. 19.

"fishbone" diagram, team members enumerate the possible causes that lead to the situation the group is seeking to change. In the diagram, each contributing factor to the current situation is itself analyzed as the product of other factors.[68] The "five whys" approach is employed to trace further effects to their original sources. With this analytic tool, every time a cause is identified, the question of why that cause occurs is asked, tracing the sources of the current situation further back in the production system.[69] At this point in the kaizen process, the Dream Team generated the cause and effect diagram in Figure 3.2. In the Dream Team's case, the effect to be analyzed in the diagram is water usage. The Dream Team divided their diagram into groups of causal factors including man, materials, method, machine, environment and measurement systems.

Other analytic tools may be used by a kaizen group at this point to trace sources of current production

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[68]Each cause can itself be looked upon as an indication of an undesirable outcome of activities "upstream" of the observed condition. In some cases, variation in raw materials introduce product and production variations. Eliminating variation in components at their source removes variation and its attendant problems throughout the production process and in the product itself.

[69]It is this fracturing of causes down into finer and finer detail that has given this diagram its "fishbone" appearance.

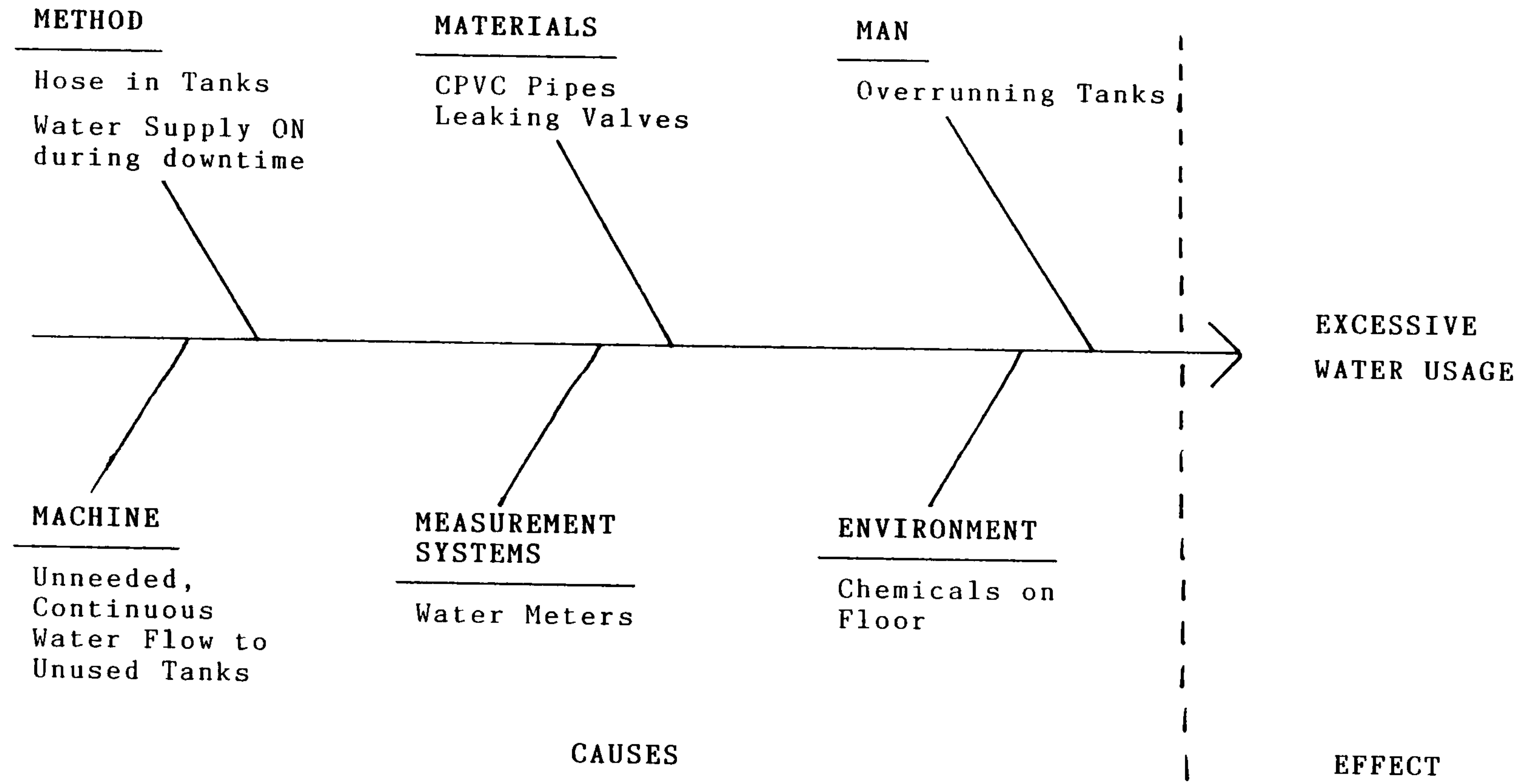

Figure 3.2. Nippondenzo Dream Team Fishbone Diagram

Source: Adapted from Nippondenzo Dream Team unpublished materials. Nippondenzo Tennessee; Maryville, Tennessee, 1992.

characteristics.[70] The specific research design will depend on the factors to be investigated. Sampling techniques are important to determining variation sources. Statistical process control may be used to test for process variation. Laboratory, engineering, or observation and documentation research may be needed to explore some factors.

From among the factors contributing to a kaizen circle's chosen theme, the group will identify those factors that can be most easily addressed. Plans for addressing these issues are evaluated and implemented. The effect of kaizen actions on the theme are subsequently evaluated. The group then returns to the fishbone diagram to examine what other factors might be addressed by the group. Using the fishbone diagram in Figure 3.2, the Dream Team reviewed the feasibility of addressing each cause of water usage. The team determined that "chemicals on the floor" was an area where water usage reduction would not be appropriate, since doing so would interfere with the objective of cleanliness in the workplace (a high priority at the plant). The contribution of leaking valves to water usage was eliminated by reporting leaks to maintenance personnel for repair. To address the problem of water running during downtime

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[70]In Nippondenzo's case, workers are trained in seven quality control tools, which are used as appropriate.

(resulting from workers forgetting to shut water valves when leaving a station), the group introduced "water harnesses" at each work station. Workers put on a tethered harness when turning on the water at each station. When leaving the station, the workers were reminded by the tethered harness to turn off the water before leaving. These efforts in the aggregate reduced water consumption of the plating division from 248,000 to 212,000 gallons per week, a reduction of 15%. The pre-established goal set by the group was 170,000 gallons per week (a reduction of one third), so the group had not yet reached its objective.

If no remaining contributing factor identified by a kaizen circle is readily addressed and the group has not reached its target, the group will research the remaining factors in more detail. Research will focus on determining what requires these factors to take the form they do within the firm's activities. In its research, the group may consult with support staff within the organization to ask questions about current production methods. In responding to kaizen group requests, support staff will act as internal consultants, explaining process engineering characteristics and generating alternative engineering designs to address the group's concerns. This background information on process design issues and alternatives is collected from sources throughout the firm and evaluated by the kaizen circle. Possible approaches are evaluated for effectiveness, other impacts, cost and difficulty.

In the case of the Dream Team, it was determined that the plating process itself was the chief consumer of water. Three types of plating were done by the division: nickel/tin, zinc and copper. Of these, nickel/tin and zinc each used over 100,000 gallons of water per week, making the group's goal unattainable without a change in the plating process itself. Water was used in multiple rinsing stages in the plating process.[71] The group consulted with the engineering staff at Nippondenzo to determine whether the system could be changed to consume less water. The engineering staff suggested two possibilities: that it might be possible to reuse rinse water at certain stages, and that solenoids might be used to time rinse cycles more precisely.

When an improvement is considered by a kaizen circle, the change is first evaluated for possible impacts on other aspects of production, as well as for its impact on the group's chosen theme. If examination of the possible impacts of the change yields favorable results, methods of implementing the change are explored by the group. The group may choose to implement the change itself, if the technological capability is within the group's reach and if

[71]Appendix B, Figure B.1.

making the change would help the group to understand the production process better. A plan for action, including timing, method of implementation and cost will be developed by the group. This plan, including the research upon which it is based, is presented to management for approval.[72] Management checks to see that the group has properly evaluated the problem and planned a course of action, and approves the plan unless an oversight or conflict has been discovered. Management has been informed throughout the kaizen process of the group's chosen objective and progress, so approval of the plan of action is forthcoming unless a specific problem with the solution is revealed. Other than a problem with how the research or decision process was carried out, management does not exercise the right to decline the group's choice. Management will insist, however, that the kaizen circle coordinate its actions with the missions of the organization and the activities of others, and insure that production not be adversely impacted.

In the case of the Nippondenzo Dream Team, the group decided to test the quality effects of reusing water at four

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[72]Kenney and Florida (1993) found that kaizen changes were implemented by the kaizen circle and only subsequently reported to management for approval. In the Dream Team case, the major changes made were discussed with management and resource staff before implementation of the change.

stages in the plating process.[73] This research was conducted by the member of the group designated as lab analyst. With experimental results showing no adverse quality effects from reused rinse water, the kaizen circle set about designing a method of re-routing water between rinse cycles to fit the new rinse flow design. PVC pipe was selected for plumbing because of ease of installation, but a method of pumping water into tanks was needed. The group again approached engineering staff for possible methods of pumping the rinse water. Of the possible methods examined, the group selected an air lift method that required minimal expenditure and met performance needs. Possible methods for implementing the design changes were to issue a work order, or to implement the changes themselves. Because the installation was considered relatively simple and offered the group an opportunity to better understand the plating process on which they worked, the group chose to install the plumbing changes by themselves. The group completed the project in one day.

Following the implementation of changes, the next step in the kaizen process is to evaluate the impact of the changes on the production process and the kaizen objective. If other improvement ideas surface at this stage, they will

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[73]These changes are depicted at (a), (b), (c) and (d) in Appendix B, Figure B.2.

in turn be evaluated and implemented. Progress in achieving the group's target is charted. Upon implementation of a chosen set of remedies and achievement of the pre-established target, the group may choose to move on to another kaizen project if no obvious further improvement possibilities are suggested, or the group may decide to pursue its current kaizen theme further.

The Nippondenzo Dream Team discovered that after re-routing water between rinses, they had reduced water consumption from 212,000 to 96,000 gallons per week, a reduction of an additional 46% over previous improvements. This achievement surpassed their goal by 74,000 gallons. Upon examination of the water inflows in the plating process, the team determined that installing solenoids on water pipes,[74] would allow more precise timing of water flows within the rinse cycles and would further reduce water consumption. The installations were made as depicted, reducing water usage to 73,000 gallons, for a total reduction in water usage of 72%.

The final stage in a kaizen project is to summarize the circle's activities, including the methods and outcome of every stage of organization, analysis, implementation and evaluation. These results are reported to management in the

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[74]Appendix B, Figure B.3.

form of a presentation. In the Dream Team's case, process improvements resulted in an annual cost savings of $52,316 and cost the group $2,000 to implement. The group's process innovations are being considered for implementation in Nippondenzo's Tokyo plant.[75] While the group received Nippondenzo's annual kaizen award for their efforts, the group was credited not for the amount of savings it generated, but for the kaizen process it followed: the group continued to search for improvement when the target was not initially reached, and continued to make improvements after the target was surpassed.

While the Dream Team's example is not likely to represent the most frequent type or magnitude of kaizen improvements, it allows several more subtle characteristics of the kaizen process to be brought out. Improvements are the result of a systematic and continuous process of investigation by workers at every level of the organization. This flow of innovation should not be viewed as an infrequent occurrence as in economic models, but as a continuous process of improvement. The kaizen process does not typically involve large capital expenditure or high risk. Improvements are not necessarily observable by or applicable to other firms. Efforts to innovate processes

[75]This finding offers evidence of a potential transfer of kaizen improvement from a satellite CIF facility back to the home plant.

are supported by upper management and technical staff, but the initiative, research, planning and implementation responsibilities are placed on every worker in the organization. Management teaches workers how to fulfill these responsibilities by training, guiding and supporting worker efforts. While management retains the right to review and approve actions taken by the group, it pushes for worker initiative, creativity, careful consideration, and follow through. In this style of organization, sharing information, cooperation and discipline become instrumental in technology development. Withholding of information or sloppiness in considering actions jeopardizes this system.

The importance of the kaizen process for the organization goes beyond the innovations it generates. While the kaizen circle's focus is on following a kaizen process and on a chosen theme, the process itself focusses worker attention on the impact and importance of individual and group actions for the effectiveness of the firm. It also teaches workers to think critically and creatively, to take initiative, and to work cooperatively. In the Nippondenzo case, several process improvements were made before a theme had even been selected by the group. This level of worker skill, integration and influence builds a sense of worker ownership in the activities of the organization. This sense of ownership is a primary objective of Nippondenzo management in working with employees.

The focus of workers on the missions of the organization, rather than on the volume of throughput at a single work station allows workers to more effectively coordinate efforts among functions. In innovation activities, this broader perspective also leads to a differing definition of production problems and to a wider range of possible solutions. In the Nippondenzo example, perspectives on production problems are changed from a simple volume per work station focus to the final fulfillment of customer, community and worker expectations outlined in the company's mission statements. At every stage of the kaizen process, the relationship of the group's actions to the firm's goals and other activities within the firm is considered.

Unlike in a learning curve approach to firm improvement, in the CIF there is an expectation of workers and management that the performance of the organization will continue to improve and that the source of these improvements will be the constant review by employees of the firm's effectiveness in meeting its missions.

While an SM/MP approach tacitly assumes there is a "best method" that the firm seeks to employ, the CIF assumes the method is evolving. This results in a very different attitude toward problems that surface in either firm. In an SM/MP, a problem is an apparent breakdown in the "best method" that needs to be corrected for the system to get back on track. In a CIF, a problem indicates not only a need to remedy the apparent crisis, but to investigate the firm's methods. Once an immediate problem is resolved, efforts focus on determining the reason current practices allowed the problem to occur. This method of examining the firm's activities is used not only to eliminate apparent problems, but to pursue improvement goals. With the statement of an improvement objective, current activities can be investigated for causes of inconsistencies with desired outcomes. This procedure of root cause searches is referred to as the "Five Whys" of asking why causes of problems occur. This allows the factors shaping an undesirable characteristic of the production process to be traced as far back as possible in the architecture of the production system. This approach has led to CIF efforts to collaborate with suppliers. In the area of process variation, for example, collaboration with suppliers has improved specifications and reduced variation in materials. This, in turn, has allowed production processes to be sped up with fewer machine breakdowns and higher product quality.[76] A more narrowly defined SM/MP approach to problem resolution often fails to provide a framework for the CIF solution to surface. A summary view would be that the SM/MP firm engages in problem solving to fix breaks in the system ("if it's broke, fix it"), whereas, the CIF engages in problem solving in order to advance the "state of the arts." Needless to say, advances in the state of the arts constitute technological change.

The CIF's approach to constant process and product innovation results in framing current practices in a way that challenges the organization to improve. An example is the development of Just In Time manufacturing by Toyota. The impetus for this change in manufacturing was an inspiration of Toyota's President Toyoda when learning of supermarket stocking strategy. Supermarkets typically use a "pull" inventory system, in which the purchase of a good off the shelves of the supermarket is a cue to order another unit of the item. This approach contrasts with the conventional mass (or batch) production approach used in manufacturing, where goods are manufactured based on demand forecasts and economic lot sizes and subsequently "pushed" into retail channels.

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[76]An examination of the role of reduced variation in simultaneously improving quality and increasing throughput can be found in Cole (1991).

Toyoda envisioned a system in which goods would be manufactured to replace units that had been purchased, instead of manufactured based on extended demand, price and cost forecasts and very large lot sizes. To do this fully would eliminate overproduction and inventory, and exactly match products produced to products purchased by customers. In such a circumstance, supply becomes as quickly flexible as demand.

In framing this vision of an ideal system in which units are manufactured as purchased, the existing manufacturing system based on an SM/MP organization could be examined in a new light. What now stood out in the organization were the impediments to realizing the new vision. The production principles that had since the dawn of the Industrial Revolution been considered immutable, in which processes revolved around the inflexibility of machines,[77] now came under scrutiny. Instead of accepting these characteristics of industrial manufacturing and machinery as fixed, Toyota foccussed employee attention upon developing ways to reduce the impediments to manufacturing products as demanded, while maintaining mass production speed. It is no exaggeration to say that Toyota went from being a prime example of inflexible mass production to

[77]Karl Polanyi (1944) gave a historical account of how economic institutions and industrial organization were formed around the assumed inflexibility of machines.

featuring the prototype Just-In-Time manufacturing system almost entirely on the basis of the type of kaizen activity depicted in the Nippondenzo example.[78]

The evolution of JIT from incremental changes within the production process illustrates a central characteristic of CIF improvement efforts in which a creative friction is generated by forming a vision toward which the company strives. By forming this vision, the company's activities can be reconsidered in a way that suggests problems upon which attention should focus.

CONCURRENT DESIGN

A second process for technology development in the CIF more closely parallels conventional sources of technology for firms, although the development process is substantially modified from conventional forms. This process has been widely referred to as concurrent design or concurrent engineering. This concept assumes that the firm is more broadly based than that assumed in competitive models. More specifically, the firm has internal R&D capability.

[78]Matsumoto (1982: 43) says that the "single-minute-exchange-of-dies" breakthrough was "simply the result of the accumulation of innumerable small improvements made within the factory." Monden (1983) provides a similar depiction of the evolution of the entire Just-In-Time system developed within Toyota.

In the case of the CIF, technology development does not follow a sequential movement from one developmental (and functional) stage to another. Rather, concurrent design starts with the identification of a technology development team which will be responsible for work performance throughout technology development and implementation. The team is defined broadly to include providers of inputs and users of output. In conventional technology development terms, this can be described as a reorganization of the separate sequential functions into a team with members representing each function. Rather than passing off the project between individuals from one function to the next, those designated for a technology development project are assigned to work as a part of the team for the duration of the development process, spanning from project definition to implementation. Team members are individuals responsible for carrying out work at each stage, rather than managers serving strictly in an oversight or coordination capacity. The team jointly defines the project to be accomplished and sets a schedule to be followed. The team bears responsibility for determining every detail of the project, including availability of appropriate supplies, manufacturability, quality, reliability, and marketability of the final product. For this reason, the team includes research and development, engineering, production, and marketing staff, as well as suppliers for major components.[79]

The team follows a series of steps in developing technology. The team:

- Defines its objective for the completed technology,
- Defines characteristics of the final technology,
- Researches means for achieving characteristics in technology design,
- Evaluates and chooses among the various means for achieving the identified characteristics,
- Tests the chosen design solutions for impact on all aspects of the design,
- Evaluates possible methods for implementing the chosen design solutions,
- Develops a detailed plan and schedule for implementation,

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[79]While suppliers are typically not included in conventional product design, Clark and Fujimoto (Ibid.: 136-137) found that in the Japanese automotive industry, suppliers perform 30% of the product engineering effort:

> "[These] differences [in supplier involvement] do not reflect marginal choices. They reflect suppliers with very different capabilities. Moreover, they reflect a different system of supplier relationships that includes different communication channels, contracts, and incentives. The role of suppliers in engineering and development is part of a larger pattern of supplier participation in the industry. The choices firms make about project scope are made in the context of this larger supplier system."

- Gets approval for the plan of action,
- Implements the plan, and
- Monitors the outcome of the plan.[80]

As the team works through this process, members research each issue based on their area of training and experience. The scope of each individual's activities is, however, more broadly defined than in a SM/MP firm.[81] The research information is brought together to be evaluated by the group, and the group decides on possible means for meeting objectives. This evaluation of technical issues can be a challenge for group members without experience or training in an area of consideration. For example, production personnel may have difficulty reading engineering drawings due to lack of familiarity with visualizing without the benefit of prototypes. To bridge this gap in technical knowledge, two approaches are used. Team members work to explain technical information outside of other team members'

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[80]This process is very similar to the process followed in kaizen innovation.

[81]Clark and Fujimoto (Ibid.: 268) found that for a new car model, an engineer's assignment in a U.S. firm might be for a single door latch, while a Japanese engineer might be assigned the door latch and the entire door lock mechanism. In addition, an individual's specific role may change as the project progresses to insure continuity and integration of design progress. Aoki and Rosenberg (1987) observed that a new engineer might be assigned to a technology development project and change functional assignment (and division) as the design progresses from stage to stage.

experience, and staff is cross-trained to develop a greater range of the knowledge and skills that go into the company's products. The team approach to technology development itself contributes to this transdisciplinary training and experience for its participants.

Developing a time table and evaluating design considerations jointly as a group compresses both the length of time and labor hours necessary to complete the technology development process. This results from simultaneously considering the needs of each stage of development from earliest project formulation stages, instead of stretching the review of technology design out in a sequential process. This allows problems and alternatives to be jointly addressed, and removes communication and coordination delays. Labor hours are also saved by identifying and correcting design deficiencies early in the development process, rather than requiring redesign after extensive development. This is especially true in regard to problems of manufacturability of new designs.[82] For this reason,

[82] Wright's study (1936) of the emerging aircraft manufacturing industry provides insightful discussion of the difference between prototype and mass production design characteristics. Those processes, designs and materials that lend themselves most readily to single unit manufacture (such as no specialized equipment, labor or materials), do not have much in common with mass production concerns. These differences are major when it is realized that they affect every aspect of a product's design, including basic materials. Not only unit cost, but production feasibility (and, consequently, product reliability) depend on these

concurrent design is not iterative in the sense of sequential models of technology development, and does not depend on moving backward in the development process to incorporate information from functions that enter into the technology development process after an initial attempt at design has been completed.[83] The group also shares responsibility for the time necessary to complete the entire design and implementation process. In a sequential system, each member is responsible only for the time necessary to complete his or her function, without regard for problems that arise at other stages of development or implementation. Joint development also allows separate tasks to be performed simultaneously and cooperatively, instead of sequentially.[84]

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design issues. The difficulties imposed by separating consideration of product and process design are substantial and have far-reaching impact on the firm's ability to competently produce the product.

[83]The difficulty in making changes at later stages of design is similar to the concept of capital rigidity and "gelling". As a design progresses, more engineering labor has been expended and more time has passed. Revisions require both the expenditure of more time on corrections and the removal of work already completed. In addition, design changes at later stages are technically more difficult to incorporate, and alternatives are more limited due to interrelated design decisions that have already been made.

[84]Clark and Fujimoto (1991: 217) observe that product and process engineering stages of product design were completely overlapped for Japanese automakers. In some cases this overlap indicates separate but simultaneous activities, but in many cases it involves intensive communication and joint problem-solving by individuals working on different aspects of a design (Ibid: 225).

A comparison of the time necessary to develop technology using concurrent engineering and iterative sequential approaches was made by Design and Manufacturing Institute, showing a 40% time savings from concurrent as opposed to conventional sequential design.[85] Using automated concurrent engineering technology, time savings increased to 70% of the conventional approach. This time savings not only affects the labor costs incurred by the firm in technology development, but reduces the lead time needed by the firm to introduce a new technology. This reduced lead time in turn shortens the time horizon for which the firm must forecast, reducing uncertainty in demand for the firm.

Joint consideration of technology objectives, criteria, research and solutions also improves the design solutions developed by the technology team. By improving the information available at each stage of the development process, the possible solutions made apparent to the group are increased over what information and possible solutions would be apparent to each member of the development process if performing their functions in isolation from other functions. For firms that treat design as the exclusive specialty of design engineers, it has come to be expected that many problems will be encountered when the

[85] As reported by Leonard (1993).

manufacturing function tries to produce samples of a prototype of the new product. Indeed, there are stories of hundreds of iterations back and forth between design specialists and manufacturing specialists as they try to work out the "bugs" in the design and adjust the manufacturing processes.

In the concurrent approach of the CIF, the presence of manufacturing engineers on the design team allows for many potential "bugs" to be anticipated. Furthermore, Best (1990) emphasizes the role played by representatives of major suppliers who also participate on the design team.[86] Suppliers are expected to participate in the design of parts they will supply and to integrate the design of those components with the production process in which the components will be used. This involvement of suppliers in product design greatly reduces the number of start-up problems encountered in obtaining high quality components on a timely basis. Because those who must eventually manufacture the product are included in its design, the amount of time required to develop a new product is significantly reduced. For example, in the automobile industry, Clark and Fujimoto estimate that Japanese firms

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[86]In Clark and Fujimoto's study (1991), Japanese automobile part suppliers performed 30% of the total engineering work load, as opposed to supplier performance of 7% of the total engineering effort in the U.S. automobile industry (Ibid.: 137, 157).

complete engineering on a new design in 24 months, as opposed to 34 months in U.S. firms (Ibid.: 217).

A major contrast between the concurrent and iterative approaches is the fact that with the former, the product development is completed prior to production; while in the latter, the back and forth iterations typically continue after production and marketing have commenced. This is especially the case where quality problems persist in both the manufacturing department and supplier firms. Sometimes final customers participate in the iterative process as they bring quality problems to the attention of the firm. The contrast between these two processes has implications for firm learning that will be the focus of analysis in the next chapter.

The improvements in technology development associated with the concurrent approach can not be described in terms of the nature of the capital goods that result in reductions in the time and cost necessary to acquire new technology. By reducing the time between investment in and utilization of a new technology, the company further reduces its investment and especially uncertainty.

THE DIFFUSION OF THE CIF APPROACH TO TECHNOLOGY

Just as in the concepts of SM/MP, firms vary across a broad spectrum in how they organize activities and the degree to which they use certain management techniques. The CIF approach was brought to the forefront of management discussion by large Japanese companies exporting to the U.S. market and competing with more conventionally organized firms. Indeed, in the automobile industry in which this contrast in organizational approach was most dramatic, U.S. firms had epitomized the SM/MP approach.[87] Today even in the automobile industry, many firms are moving to adopt technology development and production approaches introduced to the U.S. market by these Japanese firms. As with most newly recognized technologies, these organizational approaches have been adopted and investigated in a fragmented or piecemeal fashion with various components, both architectural and artifactual, described and adopted as separate technologies. In the firms in which these technologies have most recently developed, the techniques are integrated into a firm-wide architecture supporting their use and development.

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[87]Ford pioneered the assembly line manufacturing approach. Best (1990) provides a comprehensive history and examination of the Scientific Management/Mass Production approach to industrial organization.

In the case of the adoption of some techniques separately from the system architecture which support them, the technology may be less productive than in the original context in which it was developed. Techniques may even be counter-productive in cases where the use of the technique is made feasible by other supporting methods which are not adopted by the copying firm. Examples of this experience have been the use of JIT inventory methods without JIT manufacturing capability, and lean management without a workforce skilled in fulfilling what have been treated conventionally as management responsibilities.[88] In other cases, adoption of the technology may be partial. Concurrent design has been variously defined by adopting U.S. firms to include only simultaneous product and process engineering, or to include the broader spectrum included in the CIF, spanning from suppliers to customers. In the case of concurrent design, partial utilization of the technique does not damage the firm's operations, but brings only partial benefits. In still other ways, adopted CIF techniques may be offset by other organizational characteristics that conflict with or do not enhance the use of the technique. Concurrent design, for instance, is more effective with high levels of collaboration and information

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[88]In a related issue, recent management literature frequently discusses decentralization of control without attendant training and procedures for workers to assume management skill and responsibility (Fortune, March 1994).

exchange.[89] Organizational aspects that support the effectiveness of collaboration and information exchange will also enhance concurrent design. For example, the CIF's practice of rotating managers across functions enhances the effectiveness of the concurrent approach.

In some economics literature, the ability to improve technology in situ has been treated as conceptually distinct from the capacity to generate new technology innovations quickly. Indeed, kaizen and concurrent design have been seen as contrasting technology strategies.[90] However, in looking at the coexistence of kaizen and concurrent design systems within the CIF, it is clear that in situ improvements and large scale technology development projects need not be mutually exclusive strategies. Indeed, both systems are supported by the same organizational approaches, and enhanced by the inclusive activities within both systems. While each system can be employed independently of the other, there is a synergy of using both simultaneously. In contrasting the two methods, an important characteristic

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[89]Clark and Fujimoto (1991: 212) provide a graphic illustration of the degrees of interaction and information exchange between engineering functions within the auto industry, and the effect on the time necessary for new product design.

[90]For a review of leader/follower technology literature see Mookherjee and Ray (1993). Technological leadership is assumed to place greater cost and risk on the leader than followers, due to the uncertainty of technology development, production feasibility, and customer acceptance.

of both systems is overlooked: both methods use a broad-based, inclusive and integrative approach of systematic and incremental performance improvement. The existence of this continuous development process makes discovering, coordinating and implementing technological change more facile for participants than for firms using an ad hoc approach to technology development efforts. It is this continuity in technology development that allows a CIF to create and improve a system of technology development and to reduce the disruption, cost, and uncertainty generally associated with technological change.

In contrasting the CIF approach with conventional depictions of the firm's role in technology development, two characteristics of the CIF approach to technology stand out:

- Concurrent design and kaizen reduce (or eliminate) the need for a period of firm learning and technology adaptation, and

- Concurrent design and kaizen have the potential to improve on the technology available to the firm beyond what would be possible through a segmented sequential approach.[91]

The technological capabilities of kaizen and concurrent design are both based on organizational structure of the

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[91]Looking at the development of JIT manufacturing for example, it should strike one as near to impossible that such a broad-based and complex technology could have been conceived of in an organization devoted to functional specialization.

firm and the management systems that propel it. These capabilities are further enhanced by extending these organizational features to suppliers and customers of the firm. Organizational differences, therefore, are directly responsible for differences among firms in technology availability and cost, initial performance gaps, ultimate performance levels with a given technology, and the speed and frequency with which the firm can change technology. The next two chapters will explore the conceptual basis for treating the CIF approach as distinct from sequential treatments of technology, and the strategic implications of these divergent technological capabilities among firms.

CHAPTER 4

THE LEARNING CURVE REVISITED

Several features of the CIF give it the potential to outperform firms following a conventional sequential approach to technology change. The CIF ability is based on utilizing a broad-based and integrative system of concurrent functional participation to generate and implement a continuous stream of improvements. The question remains of how these new approaches to technological change fit within the framework of economics.

As described in Chapter 2, economics conceptualizes technology change as the result of a sequential development process, moving from basic research, to technological incorporation in equipment and product design, to implementation by the firm. Most discussion assumes that in the competitive framework in which the firm operates, the firm does not become involved with technology until the implementation stage.[92] Technology development,

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[92]As discussed previously, the term "firm" is used here to represent directly productive activities, rather than in a broader corporate sense.

therefore, is external to directly productive activities and is taken to be an exogenous factor in the analysis of the firm. In models of imperfect competition, firms can choose to "vertically integrate" in the technology development sequence, internalizing R&D efforts for new product development into a single corporate entity.[93] Otherwise, firms are on an equal footing in purchasing and utilizing new technologies. Because technology change is implemented via capital equipment fixed in technological "vintage,"[94] each firm, competitive or integrated, acquires its technology in lumps with extended intervals between infusions.[95] Just as with capital equipment, the firm's technology is fixed in the short run.

It is recognized, however, that, even in the competitive model, firms may have a role in technology advancement. This role may be either in the form of improvements in the use of a technology, or of recommendations for design changes to future generations of technology. The potential for the firm to make direct improvements in technology is subsumed under the concept of

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[93]R&D, however, still remains functionally segmented from the firm's productive activities.

[94]Arrow (1962).

[95]In this sense, the sequential and concurrent continuous improvement approaches can be contrasted as stock versus flow approaches to technology within the firm.

firm learning. This concept is used to encompass a broad range of firm activities and possible sources of performance improvement. Based on the concept of firm learning, firms can experience limited productivity growth as they gain experience using new technologies. Because learning is modelled as a function of cumulative output, firms are expected to show similar performance improvement patterns following capital investment.

Beyond direct improvements derived from learning, a limited literature suggests that some firms may feedback recommendations for changes to be incorporated in future generations of capital. While the firm cannot capitalize on these improvements until its next round of investment, these same improvements will be available to other firms willing to make the investment.[96] In general, therefore, the technological options and results available to firms in

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[96]Some models go beyond this dependence on external investment. In iterative intra-firm models of technological change, initial product designs can be returned to R&D for modification before implementation. This iterative process is less costly and time consuming than the purely linear approach in which capital equipment is produced and installed before implementers have substantive input. In the linear approach, there is more limited scope in the implementation stage for modification to equipment design once equipment has been built and put in place. The iterative approach still has several limitations, however, in comparison with concurrent design: the scope for "downstream" input is more limited and difficult to incorporate once design has progressed to the point where it is presented for approval to "downstream" functions, and the time and cost involved in iterations is substantial.

economic analysis are identical and independent of firm characteristics.

To determine whether the standard treatment of technology can be used to explain firms that use a continuous improvement approach, it is necessary to look at the conceptual basis of learning in firms. Two questions arise in determining the appropriateness of this conceptual framework for the task of explaining continuous improvement: 1) What is the potential for firms to vary in their ability to fully utilize new technology introduced via investment, and 2) What is the potential for firms to directly institute technological changes within the manufacturing function?

THE PERFORMANCE GAP

While learning is looked upon optimistically as a source of productivity gain for the firm, the concept of a learning function has two disturbing ramifications: 1) it indicates a lag between the time of technological infusion in the firm and the attainment of full technological capability, and 2) it limits improvement to productivity gains from learning to use a specific set of capital.

Rather than viewing the learning curve as a source of gain, an alternate perspective is that the learning curve reflects a performance gap, where realized productivity trails the acknowledged potential of a new technology. Figure 4.1 shows the gap between the firm's actual and potential productivity levels in the period following the introduction of a new technology. This productivity difference is one reflection of a performance gap between the capabilities "embodied" in a new technology and what is actually achievable in initial production.

In firm learning, the organization attempts to integrate a new technology that was developed separately from the firm's productive activities into the actual circumstances of production. Looking at the overall sequential process of technological change, learning can be described as a subcomponent of the implementation stage in which newly developed technology is fitted together with other resources into a mass production environment.[97] As the gradual mastery of a newly infused capital-embodied

[97]This "fitting" is required for both new product and production technologies, as each shapes and is affected by the other. Wright (1936) gives an interesting perspective on the interrelated nature of product and process design.

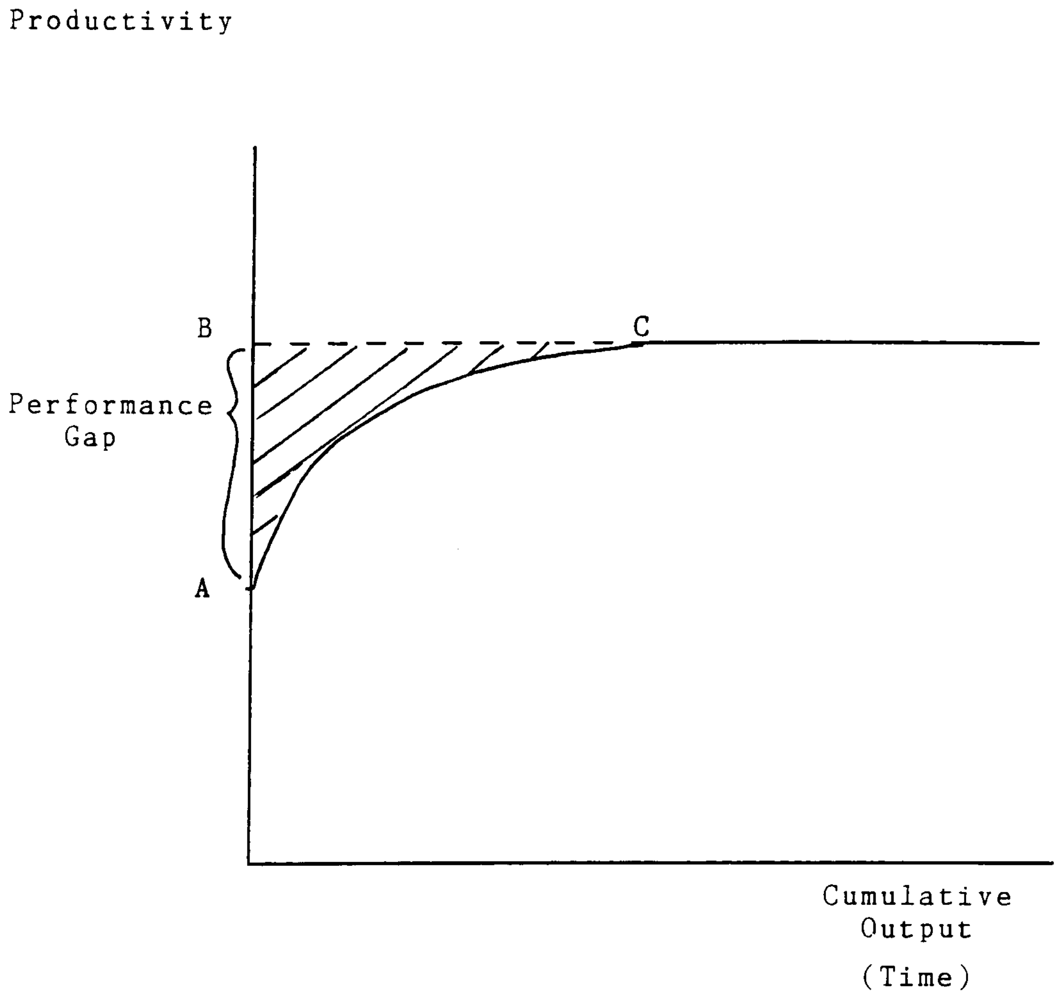

Figure 4.1. The Learning Curve and the Performance Gap

technology, learning evidences a gap occurring between the development[98] and implementation stages of technological change. The performance gap reflected by the learning-implementation phase can be largely attributed to serial, rather than a concurrent, participation of functional specialists in technology development. The gap reflects an absence of coordination and communication between technology developers and technology implementers, where process design follows completion of capital equipment design. Any input from the implementation phase occurs after the development of capital equipment cum technology is complete.

There is another and possibly more disturbing dimension to the performance gap. While firm performance is traditionally measured by productivity, a lack of technological competence will also be reflected in other aspects of the firm's performance. While the learning curve assumes the product to be unchanging, a lack of full competence with a new technology would effect not only productivity, but product quality, timing, and reliability. These other ramifications of learning could be far more important to the firm's survival than initial productivity levels. If the gap is seen simply as a productivity shortfall, the firm will be said to suffer some loss of

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[98]The stage in which technology is made physically manifest in capital equipment.

revenue while learning. Achieving a profit position is, therefore, a matter of time (or cumulative output). If the gap represents a shortfall in product quality, however, the firm's reputation may be tarnished and markets forfeited while the learning curve is being traversed.[99]

POTENTIAL FOR VARIATION IN LEARNING AMONG FIRMS

Viewing learning as a gap between functional stages in the development of technology raises the question of whether learning is an essential and unvarying production experience. The concept of firm learning also leaves unaddressed whether firms may extend technological development beyond what is "embodied" in capital equipment, and whether firms can directly impact product and production characteristics other than cost.

In learning curve analysis, research has focussed on determining the learning curve parameters for each industrial sector and determining market outcomes under varying assumptions of market entry timing and learning appropriability. To the extent that firms within a sector are similar in their approach to implementing a new

[99]Cole and Mogab (1994) examine the competitive implications of differences of productive capabilities (including quality) among firms.

technology, learning curves for firms in an industry might be expected to closely approximate one another. If firms are similar in organization and ability to adopt and develop technological improvements, a model of the firm based on a universal rate of learning and potential improvement may be sufficient to describe the potential for change in firm performance capabilities. However, if firms differ in their ability to prepare for and adapt new technologies, assumptions of a set learning function will prove inadequate to describe firm technological capabilities. Furthermore, if some firms generate incremental technological change directly within their production process, the efficacy of the learning curve is subject to serious questioning.

Firm learning as modelled in economics implicitly limits a firm's ability to change technology both in the restrictions of learning costs in investment, disruption and time requirements, and in limiting the potential for internal direct contributions to technology change. This may adequately represent firms in which technological change is infrequent and the opportunity for worker improvements is limited.[100] To determine if these same characterizations hold for firms using a continuous improvement approach to technology development, it will be necessary to go beyond an

[100]The SM/MP method of organization itself may limit the ability of workers within the firm to improve methods.

assumption of a progress function based on cumulative output, and explore the basis of firm performance improvement.

To argue against the universality of learning-by-doing may seem counter-intuitive. While the argument can be made that experience is necessary for an individual to master a new technology, the extension of a concept of individual learning to the context of the firm presents major problems. When Arrow introduced his explanation of learning-by-doing, he borrowed the concept of an asymptotic learning function from industrial psychology and learning theory, where researchers describe an asymptotic progression as a subject approaches full proficiency with a new skill. Figure 4.2 depicts the learning curve as used in psychology. The curve evidences a relationship between the amount of material learned in each interval and the amount of information remaining. As seen in the graph, the individual tends to learn a constant percentage of the remaining material in each interval.[101] As can be seen in Figure 4.2, the learning curve stops at 100%, at which point the individual has mastered all the information. This type of learning is described as rote learning because the information to be learned is externally defined and is not subject to change

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[101]This means that the amount of additional material learned in each subsequent period diminishes in absolute terms as the material is exhausted.

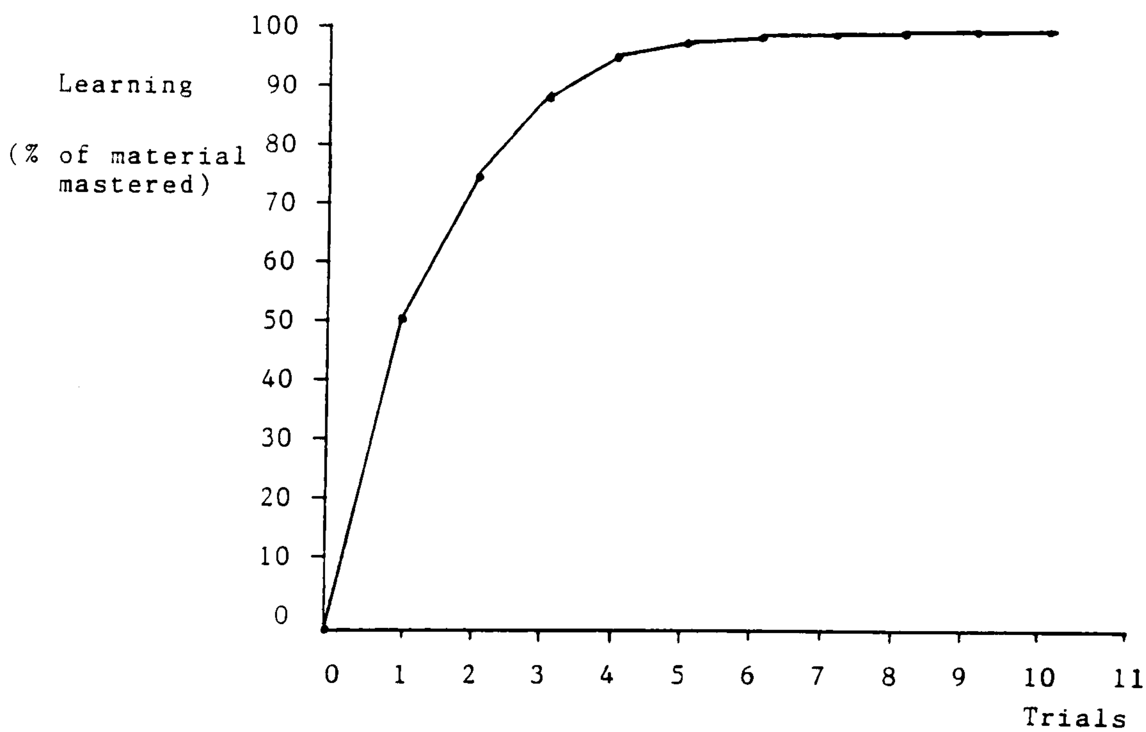

Figure 4.2. The Learning Curve as Represented in Psychology

Source: Encyclopedia of Learning and Memory, 1992 edition. New York: Macmillan, 1992. S.v. "Repetition and Learning," pp. 562-565.

or enhancement by the learner.[102] In rote learning, the limit to the potential for knowledge gain by an individual is due to exhaustion of the material to be learned, not due to the inability of the individual to learn more.

Arrow's concept of firm learning uses industrial psychologists' depiction of individual rote learning to describe productivity improvements in firms undertaking start-up operations. Arrow attributed productivity gains to the firm learning how to use a new technology. As in the individual learning context, Arrow described a firm's learning curve as stopping when its mastery of new technology was complete.

As discussed in Chapter 2, individual factors affecting firm learning are not differentiated in economic models.

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[102]The individual is not required to contribute to or reflect upon the information to be learned. The learning that occurs is specific to the individual. There are other characteristics of learning beyond initial retention of information. Learning is also dependent on relevance and use. The information gained is subject to "fading" as the time between learning and recall lengthens. To be useful, the connection between the knowledge and opportunities for its use must be apparent. Therefore, knowledge must be integrated with other information in the possession of the individual for the information to be useful. These characteristics have been extensively studied in the field of psychology. Much of the early learning curve analysis was pioneered by Ebbinghaus, who used not just a curve describing the amount of information learned as a function of time, but analysis of many other dimensions of learning situations, as well. For a comprehensive review of learning theory, see Hilgard (1975).

However, empirical observations and conceptual discussions on the sources of productivity improvements have attributed the learning function to a range of factors.[103] The sources of learning cited by Arrow are skill mastery, and technological and organizational adaptation.[104]

To what extent is the concept of individual rote learning appropriate for describing all of the attendant changes associated with implementation of a new technology? In Arrow's extension of the learning curve concept from the individual to the firm, several aspects of the learning situation change: The firm learning curve is used to describe not just mastery of a pre-existing knowledge base, but the development of new skills and production processes. Skill mastery in this context is not for individuals, but

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[103]The full range of attributed causes of the learning function in economic, management and engineering literature is broad. The seminal study by Wright (1936) attributed productivity improvements to design, scale, tooling, labor/materials ratios, raw material purchases, arithmetic-geometric relationships in production, volume increases, design changes, unit size and overhead. These factors are not all conceptually defendable as "learning" (as Arrow, not Wright, termed them) even in the broadest textbook definition. Some are scale effects (see Alberts, 1989 and Pappas & Hirschey, 1987 for a distinction in scale and learning concepts), and some represent capital investment and technology change.

[104]Yelle (1979) and Pappas and Hirschey (1987) provide similar definitions for the scope of firm learning factors to Arrow's. As noted in Chapter 2, technological adaptation refers to adjustments in the capital equipment to accommodate technology to the organization. Organizational adjustment, in turn, is the adjustment of the organization's structure to accommodate the new capital.

the entire firm. Some of the knowledge gained through firm learning is mastery of pre-existing information and skills. Part of the knowledge gained, however, was not previously known, but was developed by the firm. In the broadest sense, there are two kinds of cognitive activities occurring within the firm in the "learning" phase following the infusion of externally developed technology:

- mastery of knowledge given to the firm by the technology developer, and

- development of additional knowledge associated with fitting the acquired technology into the firm's manufacturing system.

While Arrow's learning curve lumps these two kinds of activities into a single function, they are very different in character and unlikely to result from the same factors.

SKILL MASTERY

That portion of the learning process that could be described as rote learning is limited to the mastery by individuals of skills and knowledge passed on by the technology's originator. In this case, the firm's learning curve could be construed as the summation of the learning curves of individuals within the firm each mastering new skills required by a new technology.[105]

To what extent does a firm have an opportunity to change its aggregate rote learning experience? The potential improvement from rote learning is ultimately limited to the mastery of the externally generated information. Productivity improvement stops when that information supply has been absorbed, just as in the case of an individual learning a skill or set of information.

While ultimate performance improvement using pre-defined skills may be limited, the initial starting level and speed of skill mastery will be functions of the individuals' stocks of knowledge and their several abilities to learn. Putting this in terms of the learning curve - or performance gap - we can see that the intercept would be lower for a person without experience with any vintage of relevant technology than for the person who was well-trained in an earlier generation of technology. Furthermore, the slope will be steeper for the educated worker than for one who is illiterate, ceteris paribus. How far below full proficiency and how quickly learning is completed is,

[105] This skill mastery is not generalizable and must be developed by each individual. Labor turnover, therefore, would result in a skill loss for the firm and would negatively impact firm learning.

therefore, subject to a number of factors for which the firm has some control. It might be argued that rote learning patterns among firms would necessarily be closely aligned, since ultimately they must assimilate the same knowledge. The learning circumstances for the firm, however, are not necessarily the same as (although there are similarities to) the circumstance of an individual presented with new tasks or information to learn. First, the firm can not learn, only people can. Learning is not generalizable among people in the firm - learning is particular to individuals.

Second, rote learning can take place in a variety of contexts. Arrow described a circumstance where, in a start-up operation, skill mastery of workers occurred while production was underway, rather than in a dedicated learning environment. This can be described as the firm-wide equivalent of on-the-job training. We use the term "on-line learning" to cover the learning that occurs while production is underway. In such cases, the amount of learning necessary to master a given task and the speed and quality with which it is mastered would appear to be affected by the amount of relevant skills workers have attained prior to using the new technology in production, and the amount and quality of training and guidance to aid in new skill mastery.

ADAPTATION

The concept of firm learning and an asymptotic learning curve are used to explain not only expected improvement in skill mastery, but the potential of the firm to improve performance by adaptations to organization, production methods and technology.[106] It is broadly recognized that new technologies are likely to require that organizations be modified somewhat before they will function effectively. Modifications are expected to involve a "smoothing of the edges" of the new technology to fit the peculiar characteristics of the firm. Conceptually, both in the case of organization and technological adaptation, the catalyst for change is the new technology and the changes are in the direction of achieving a "best fit" of organization, work force, and technology. Improvement ceases when this "best fit" has been discovered.

Evidence for the importance of adaptation to productivity improvement is extensive. Hirsch (1952) found that most reductions in direct labor per unit of output were attributable to advancements in technological knowledge made by the firm, rather than skill acquisition. Koike and Inoki

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[106]Most firm learning studies make specific mention of this point. Wright (1936) discussed this in design considerations for airplane production. For further examples, see Arrow (1962), Hirsch (1963), and Yelle (1979).

(1990) described experiences in the steel industry in which the process of adaptation spanned decades before the firm was able to fully utilize new capital equipment as intended in design.

While process and technological adaptation have been widely cited as contributors to internal productivity improvements, these contributions are not treated in economic analysis as technological advancement.[107] As Arrow described the possible contributions of a firm to technological development, a firm can become more adept at utilizing a technology, but it can not itself contribute to the advancement of technology. Technology is completely embodied in the capital equipment employed by the firm (1962: 157). While learning may improve firm performance to a point, technological advance occurs outside the scope of the firm's productive activities. A firm's performance, therefore, is ultimately limited to the productive potential of the externally developed technology in which the firm invests. This does not mean, however, that firms necessarily have the same learning capabilities or follow the same learning strategies.

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[107]This is reflected in economic modelling by the requirement that technology formation be exogenous to the firm.

Clearly, the absence or presence of a means for effectively instilling knowledge in the firm will greatly affect the firm's learning performance. The level of relevant skills and knowledge individuals in the firm have of the new technology before initiating on-line learning is dependent on the match between the technology requirements and the firm's existing capabilities, and the preparation for the new technology initiated before the new technology is used in production. The match between the technological requirements and the firm's capabilities depends on the planning the firm has done, and the prior level of the firm's capabilities. The more that a firm is pre-aligned with the demands of a new technology, the less the firm would need to learn, i.e., the higher would be its initial productivity level (or learning curve intercept). This is depicted in Figure 4.3, where the productivity performance represented by Function B demonstrates more initial preparation for a given new technology than does the performance associated with Function A. From one perspective, the firm represented by Function A will learn more on-line than will the firm represented by Function B. From the performance gap perspective, the firm represented by A suffers more revenue shortfall than B, and is afflicted by many more quality problems.

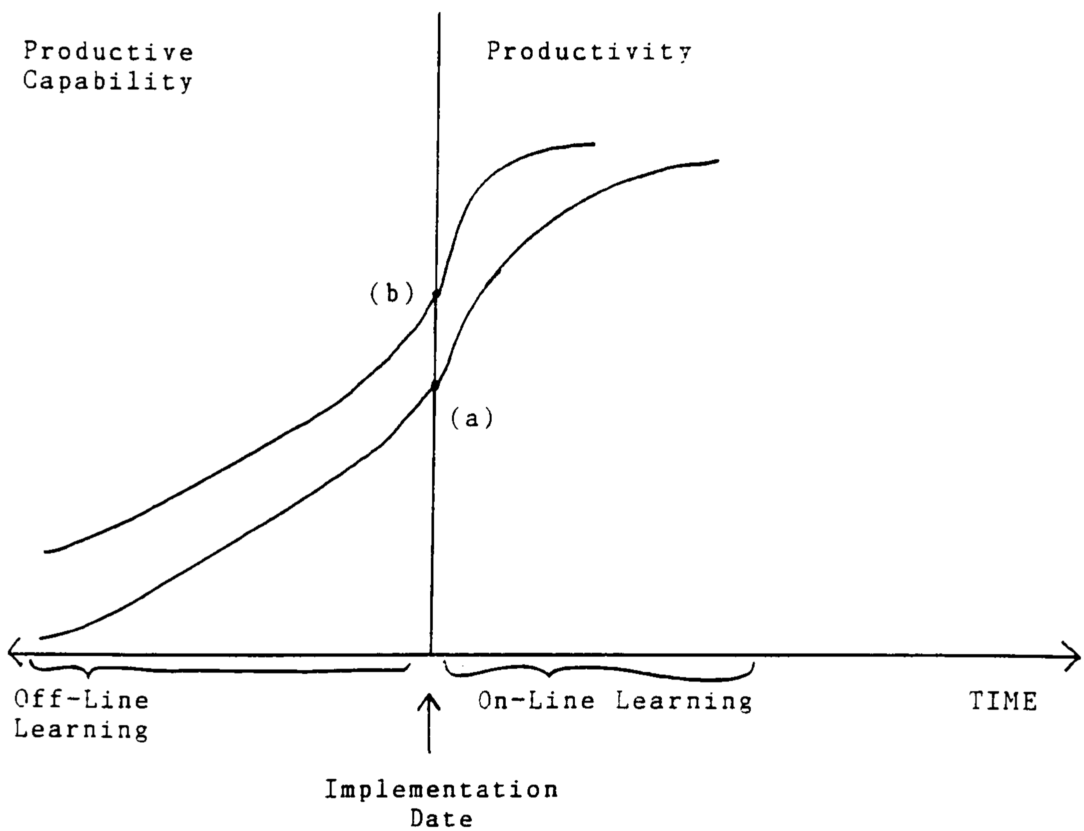

Figure 4.3. The Role of Advanced Preparation in Shaping the Learning Experience of the Firm

The impact of moving learning off-line by engaging in more advance preparation can be illustrated by extending the learning curve graph to include pre-implementation time intervals. In Figure 4.3, the vertical axis is positioned at zero, or the point in time when production begins.[108] In this case, the firm represented by Function B is better prepared to use the new technology than is the firm represented by Function A. Put differently, Firm B has had more learning "off-line,"[109] so that it requires less learning "on-line." The greater prior preparation for using new technology, the further the learning curve will shift and the higher will be the intercept. Off-line learning includes any combination of the following: (a) the levels of education and training in general, (b) training with specific relevance to the new technology, including trial production runs, and (c) learning that is incorporated in

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[108]In Figure 4.3, the horizontal axis measures time instead of the usual cumulative output.

[109]The idea of "off-line" learning is analogous to the concept used by Toyota engineers to develop the SMED technique. Time can be separated into internal and external time: some tasks in the exchange of dies can only take place with the die presses stopped. Other tasks can be performed while the presses are running, and, therefore, not delay production. The concepts of external and internal time as used by Toyota are described in Monden (1983). With respect to learning, learning costs in terms of both time and deficiencies in performance criteria can be separated into those that must be carried out during actual on-line production, and those effects which can be isolated to off-line time and effects. Efforts can be made over time to further refine production methods to allow greater insulation and circumscription of learning effects away from actual production time and outcome.

the new product design by the coordination across functions in the concurrent design process. Thus, new design is better suited to manufacturing because the engineers from that function were involved in the design process. The same logic applies to the participation in the design process by major suppliers. Methods of technology planning that are inclusive of the several relevant functions will enhance the ability of the firm to reduce the performance gap.[110]

In short, it is the off-line learning that determines the learning curve intercept and, therefore, the size of the performance gap. At this point, it will be useful to take a look at the economics of off-line learning. First, it is recognized that off-line learning can have costs as well as benefits. We can approach the matter by comparing Functions A and B in Figure 4.3. It is obvious that Firm B has reduced its performance gap relative to Firm A by engaging in more off-line learning. If we follow the usual procedure and take the product as a given, the benefit is the difference in revenue shortfall associated with the gaps. This benefit can then be compared with the incremental cost

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[110]If a firm were faced with the question of whether to start production using a new technology without prior off-line preparation and skill development or to delay implementation of the new technology until off-line learning could be completed, the firm would need to compare the expected productivity loss from a delay in implementation with productivity loss from learning. Also critical to this decision would be other learning impacts not fully represented in productivity data.

associated with the higher level of off-line activity. Off-line activity can be conceptually examined, in part, from the perspective of cost. For example, if Firm B has hired workers with higher levels of education than those in Firm A, it should show up in a wage differential. On-the-job training also has obvious costs.[111] For the sake of pursuing the present point, it may be granted that the assignment to the design team of persons from other functional units and suppliers has opportunity costs for their "home" units. These several costs can then be summed. In conventional terms, it would follow that a firm should increase off-line training up to the point where marginal cost of doing so equalled the marginal benefit. If we view the performance gap more broadly, however, the easy decision rule disappears. If reduction of the performance gap means fewer flawed products in the market and more on-time deliveries for Firm B than for Firm A, the off-line learning may be seen as a strategic move by Firm B to capture markets. It might be viewed as a situation of Schumpeterian competition in which those who try to live by marginal cost-marginal benefit calculations risk losing their market positions.

[111]Here we speak of "on-the-job" training that takes place prior to the implementation of a new technology or on-line learning phase.

If we shift our focus to the slope of the learning curve, we can see that there is also room for performance differences across firms. One would expect that the better the system of performance monitoring, feedback and correction of problems, the faster the firm would be able to learn how to use a new technology effectively. Viewed from a perspective of iterations, as in Aoki and Rosenberg's model of technology development within the firm, the shorter the iterative loop in the time needed to identify and correct problems, the faster the firm will move to full technological proficiency. In learning curve terms, Figure 4.4 shows how better support and quicker problem identification and resolution would increase the slope of the learning curve. We might, therefore, expect a firm that could obtain and utilize information more effectively to have a faster progress function (or more steeply sloped learning curve), <u>ceteris paribus</u>, than the firm that lacks such features. Features such as quality circles, open office space, job rotation, and cross-functional promotion all enhance the ability to gather and process information. Each, therefore, contributes to the pace of learning. Referring to Figure 4.4, we could say that Firm C features more of the aforesaid organizational and managerial factors than Firm B. By having the ability to complete the learning phase more quickly, Firm C has less performance gap costs. In terms of Figure 4.4, the performance enhancement is the

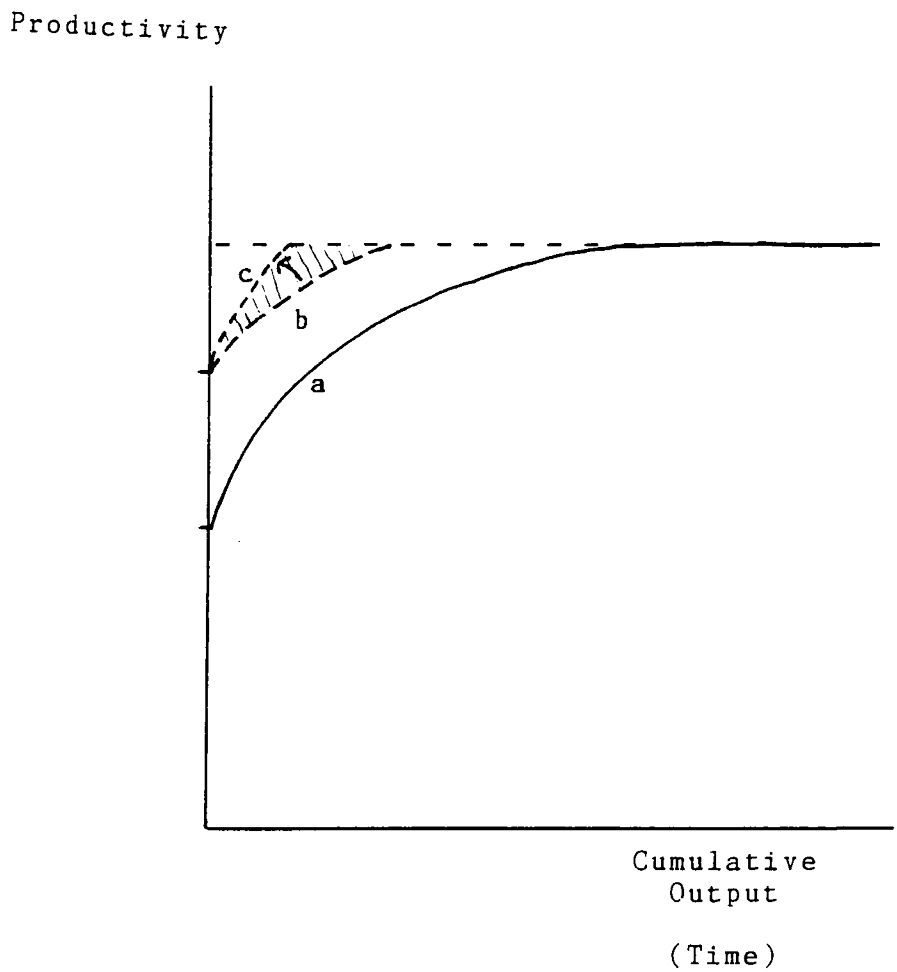

Figure 4.4. The Role of the Firm in Shaping On-Line Learning

shaded distance between Functions B and C. At this level of analysis, it is difficult to assign a cost (including opportunity cost) to all of the factors that promote faster learning. Take, for example, the use of open offices in CIF organizations. It is difficult to attribute a cost to the absence of walls, unless one could show, for example, that the reduction of privacy had to be compensated in salary. The literature on the CIF entertains the question of possible lost production due to quality circle meeting time during regular work hours. There is also speculation that job rotation and cross-functional promotion have costs in the form of losses in the economies of specialization.[112] If we concede the existence of costs to offset the benefits, we can say that if the product and other production characteristics are given, the firm will invest in learning performance enhancement up to the point where the marginal cost of enhancement equals the marginal benefit.

The ability of a firm to improve upon learning experience has not been explicitly examined in economic literature. However, some research findings can be interpreted to suggest support for a conclusion that experience with firm learning is variable and, hence, potentially determined in scope and magnitude by characteristics peculiar to the firm. Wyer (1953) found

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[112]Aoki (1990).

that in the aircraft industry initial unit costs were affected by the amount of planning that the firm had done prior to initiating production. As shown in Figure 4.5, DeJong (1957) determined that prior skill levels heightened initial operator productivity and shortened the learning period. While DeJong's research was aimed at determining labor standard-setting procedures, his findings as presented in Figure 4.5 demonstrate that prior skill levels and experience using related technologies affect initial performance levels and progress ratios when changing production processes. Given this, one would expect that if a new technology builds on skills used for a prior generation of technology, a start-up firm with no prior skill development would be at a handicap relative to a second generation producer. Alchian (1963) and Hirsch (1956) both found that prior manufacturing experience resulted in a higher progress ratio than a lack of prior manufacturing experience.[113] Learning curves, therefore, can not be treated as independent of prior firm

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[113]As stated in Chapter 2, neither Alchian or Hirsch report whether the curve intercept and limit remained unchanged for firms with experience. Because both authors treated experience as a boon to firm performance, it is assumed here that the intercept for firms with experience was at least as high as for firms without experience. This raises the question of whether learning function limits remained unchanged or if performance peaks were higher for firms with experience.

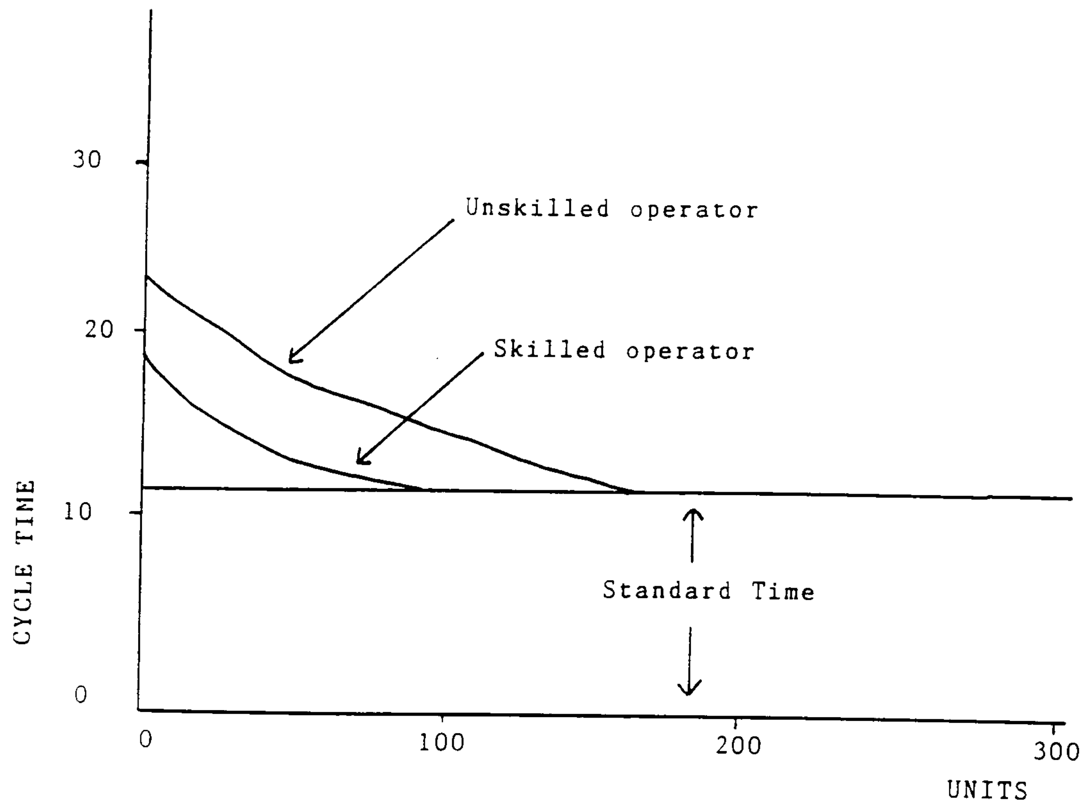

Figure 4.5. The Relationship Between the Learning Curve and the Standard Time Per Cycle

Source: J. R. DeJong. "The Effects of Increasing Skill on Cycle Time and Its Consequences for Time Standards." Ergonomics, Vol. 1, No. 1 (1957), as reproduced in Yelle, 1979, p. 307.

experience.[114] These findings also suggest that a firm could change the time (and output) necessary to reach peak performance levels by improving cross-functional coordination, advance preparation and initial skill levels of workers.

BEYOND THE ASYMPTOTIC LEARNING CURVE

The evidence presented by Hirsch (1956) and Koike and Inoki (1990) on the significance of user adaptations to new technologies raises the question of whether technology can be considered complete and fully embodied in capital investment, when it requires substantial adaptation to reach its potential. The fact that the distance between technology design and implementation has not fully been spanned in R&D suggests that technology development continues into the manufacturing stage, where workers make what amounts to contributions to technology design.[115] From this perspective, technology extends to the process of production, not just capital. The technology that is passed

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[114] This contrasts with treatments like Jovanovic and Lach (1989) where latecomers fully appropriate incumbent firm experience.

[115] Related to this point, Koike and Inoki (1990) describe the importance of worker experience and understanding of the production process to overcome deficiencies in technology design.

from R&D to manufacturing is, therefore, incomplete. Clark and Fujimoto (1991) provide an example in which product development for U.S. automakers extends even beyond product introduction to the market. This suggests that product and production revisions are still being made after a new car model has been released for sale.

While skill development in the firm has conceptual overlap with the concept of rote learning by individuals, adaptation is distinct from rote learning in the kind of activity it involves. Adaptation is not the mastery of existing information, but the development of new insights and adaptations to knowledge. Firm performance improvement resulting from adaptation involves a cognitive process in which workers and managers create new knowledge, adapting the process to reflect new insights. This new knowledge reflects an interaction between people and the initial information set, transforming the production process.

Firm adaptation to processes and technology may move technological capability beyond any potential perceived by the initial creators. A key distinction between the empirical basis of the asymptotic learning curve in psychology and how it has been applied in economics is that in psychology it is used to describe how a new worker acquires competence using established technology; while in economics, it is used to describe the potential for a firm to improve the performance of an incomplete technology. These two uses of an asymptotic learning curve are dissimilar: the use of the learning curve to describe rote learning presupposes no change in the technology to be learned, while the use of the curve in economics implies a limit to the potential for technological innovation within the firm. Again, it is worth noting that the learning curve does not encompass improvements (or failures) that are not directly reflected in productivity measures.

As noted, the learning curve concept does not address the possibility of a firm making improvements to technology it uses beyond those envisioned by the original equipment inventors and makers. It is the exclusion from consideration of innovation within the production process that forces the characteristic asymptotic shape of the learning curve.[116] On theoretical grounds, there is no reason a priori to expect this type of learning to be described by an asymptotic curve. A very different path of improvement is also possible. In empirical research, as well, evidence that firm improvements are ultimately limited

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[116]Arrow describes this constraint on firm learning: "[L]earning associated with repetition of essentially the same problem is subject to sharply diminishing returns. . . To have steadily increasing performance, then, implies that the stimulus situations must themselves be steadily evolving rather than merely repeating." Ibid., pp. 155-156.

has not been conclusive. Hirsch (1956) and Alchian (1963) both stated they saw no evidence of a limit, although both used functional forms with diminishing increases. Difficulties with functional specification and data leave wide berth for alternate hypotheses about improvement trajectories. However, as pointed out earlier, the diversity of contributing factors and the multi-dimensional impacts of firm improvements make the use of a single function for describing firm performance changes ill-advised.[117]

The importance of this distinction and the magnitude of the second type of knowledge-creating learning depends on the internal characteristics of the firm that may stimulate or prevent the creation of knowledge and adaptation of the production process. Where no alteration of technology or methods is allowed within the production process, a firm may very well follow a path of technological infusion, development of competence, and plateau until the next capital infusion. The diminishing gains of the learning curve may, in this case, be due not to the limited potential for improvement, but due to institutional, psychological and managerial rigidities that prohibit or inhibit knowledge creation, information flows and new approaches. Thus, if a

[117]See Adler and Clark (1991), Alberts (1989) and Yelle (1979) for critiques on problems with learning function specifications.

plateau in advances occurs, it is not necessarily due to limited potential for firm innovation. This is supported by the evidence of further productivity improvements obtained when moving a product that had plateaued in one firm to another firm.[118] This view is also consistent with Hirschmann's hypothesis that plateaus result from achieving pre-established objectives.[119]

THE CIF AND LEARNING

By now there should be some skepticism about the relevance of the asymptotic learning function for explaining technological development resulting from kaizen activity within the CIF. Because the kaizen system is a process in which workers are prompted to change the production process in which they are involved, their activity can hardly be equated with rote learning. Surely, it would take a great stretch of imagination to see the development of the Just-In-Time manufacturing system, for example, as the result of Toyota trying to "get up to speed" in the use of a certain stock of capital. According to that perspective, the JIT system would have been the more or less automatic result of producing more and more output. Where the shape of the

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[118]Conway and Schultz (1959).

[119]Hirschmann (1964).

learning curve implies that the pace of learning necessarily diminishes, if we take technology change as our metaphor, we shift from an asymptotic function to an increasing function in which the pace of change accelerates.[120] Change begets change because employees are given greater access to information (elements), more tools for analysis of the information, and incentives to become actively engaged in the change process.[121] The incremental changes that

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[120]The notion that the pace of technological change accelerates follows the generally accepted view of new technology being a recombination of existing elements (Westrum, 1991: 53-54). Equating technological change with invention, Ogburn (in Duncan, 1964: 25-26) illustrates the change process with a general mathematical formula:

$$C = \frac{N(N-1)}{2}$$

With N as the number of elements, the formula assumes that an invention is made up of a combination of two existing elements, so that C is the number of pair combinations possible. In such cases, if there are only two elements available, only one invention (technological change) is immediately possible, but that invention itself then makes three elements available.) With three elements, there could be three combinations or pairs. With four elements, there could be six combinations or pairs. Because each new element allows the creation of N-1 new combinations, incremental element number 1000 would allow for 999 new combinations. Instead of converging on zero, change possibilities tend to explode.

[121]Kenney and Florida (1993) give an example from Nippondenzo that illustrates the comprehensive span of information and tools provided to workers. When starting one of their North America operations, Nippondenzo management contracted with a junior college to provide training to the newly recruited work force with nine different aspects of Nippondenzo's production process. When asked by the college for a breakdown of trainees by type of training desired, the management responded that every worker should be trained in every aspect. The added cost of generalizing the workers can be taken as a cost for

propelled the development of that "state of the art" technology originated inside the manufacturing function, with the original ideas originating with employees directly involved in manufacturing. Whereas learning is usefully viewed as reducing the performance gap, kaizen activity is more properly viewed as extending the state of the art. Instead of being a tool to promote deeper understanding, in this case, the learning curve becomes a screen that obfuscates opportunity for technological improvement.

As was discussed in Chapter 3, the CIF also has special features that facilitate the process of new product development. Known widely as concurrent design, this method brings representatives from all of the major functions of the firm and of suppliers together on a team that deals with new product development from conceptualization through implementation. The question now becomes the relationship, if any, between this type of activity and learning-by-doing and sequential technology development. Logically, the process of introducing a new product is going to require that the firm engage in learning-by-doing. It has been seen, however, that the learning is not taken as subject to externally established parameters, but is amenable to alteration by the firm. Indeed, its particular uses of

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imparting kaizen capabilities and for reducing the performance gap.

learning become part of the market strategy of the CIF. Its system greatly expands the amount of information available to all parties and improves the timing of information availability.[122] Where the standard approach to technology change has the development and implementation phases separated in linear fashion, concurrent design overlaps the timing and merges activities of the two phases. The organizational features of concurrent design are widely credited with significantly shortening the product development period, as shown in Figure 4.6. The information in the figure compares the typical product development cycles of major Japanese and U.S. automakers. The plotted data represents the number of changes in design of product and/or production processes made over time. It is noteworthy that the Japanese firms are shown as requiring less total activity to complete the development process for a new product than the U.S. firms. Another important feature is the fact that the Japanese firms are pictured as fully completing the development process before production for the market commences.

What is depicted for Japanese automakers in Figure 4.6 can be explained in terms of the current analysis as off-

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[122]As noted earlier, in the iterative system, manufacturing engineers do not enter the picture until after a prototype design is complete. With concurrent design, they are present from the outset.

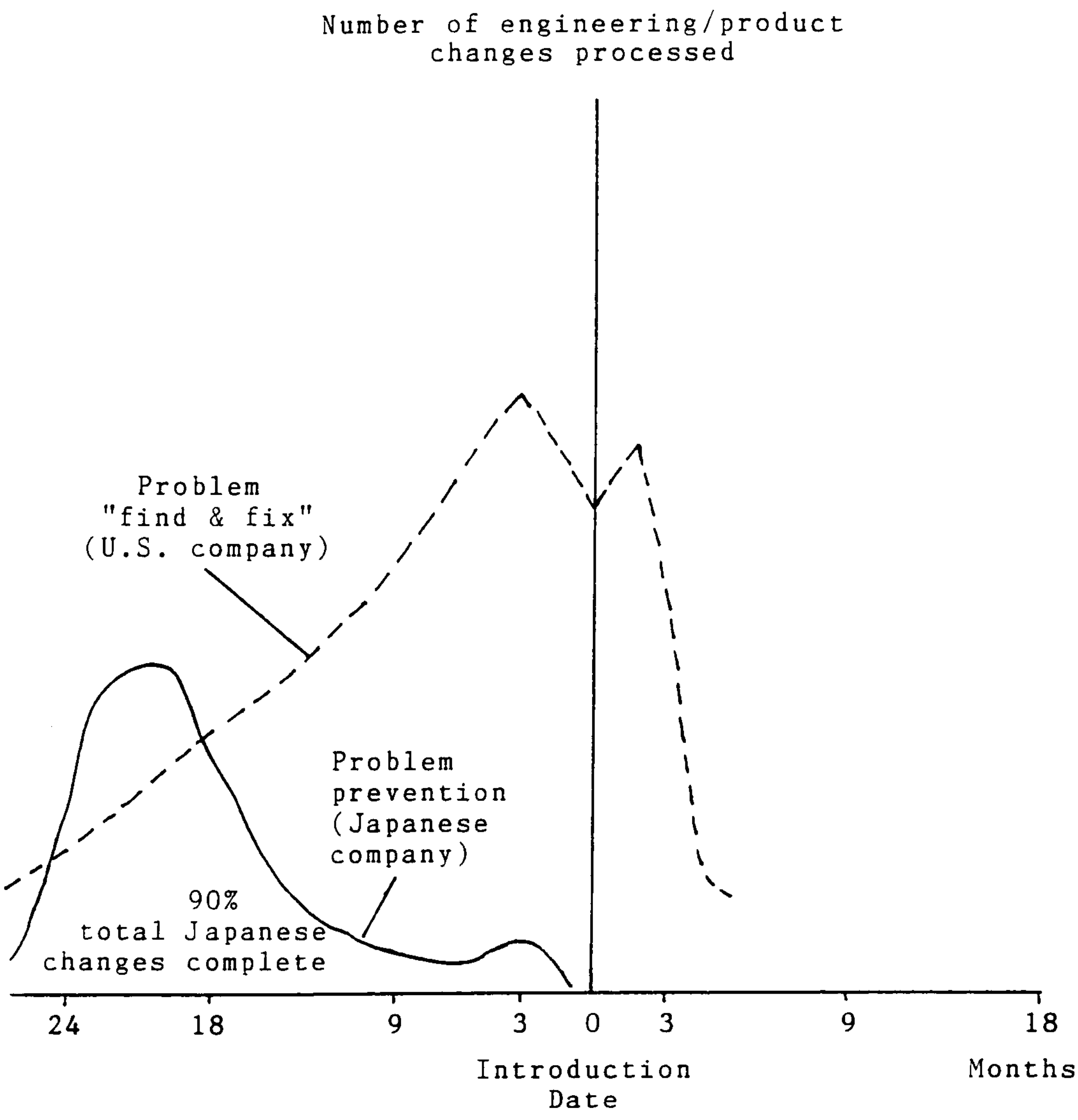

Figure 4.6. Comparison of New Product Development Cycles

Source: Adapted from Don Clausing and Bruce H. Simpson. "Quality by Design." Quality Progress, January 1990, p. 42.

line learning. While the data is presented only in relative terms, what is obvious is that more changes are required by the U.S. firms and that the change process continues after the production for market has begun. Those changes taking place after **t(0)** can be interpreted in terms of the performance gap. For the Japanese firm, the conclusion is that the product development process itself does not contribute to a performance gap. It is highly likely that on-line learning associated with post **t(0)** design and process changes in the U.S. firms is symptomatic of quality problems, some of which undoubtedly get into the market. This comparison then can be seen as a graphic depiction of the strategic use of off-line learning to promote a competitive edge in terms of quality and early market entry. It might be concluded that in industries where quality, and timely delivery are important, off-line learning is critical to success. Indeed, the complete elimination of the performance gap might be seen as an appropriate competitive strategy for automobiles or consumer electronics.

The concurrent involvement of all of the major functions in the development of a new technology from the project formulation stage onward will allow technology to be tailored to the circumstances of its use before the technology is implemented. Mastery and adaptation of the technology will, therefore, be shifted to pre-implementation stages, or off-line.

Inclusion of all permanent employees in evaluating firm operations for opportunities to make improvements provides the CIF with greater operations monitoring and systems knowledge, as well as a steady stream of improvements directed at the firm's own performance goals. As seen in the Nippondenzo kaizen case, through these improvements and continuous system evaluation, the firm can move forward more quickly and surely on a range of goals tailored to fit the needs of a complex external environment.

Because the initiative for improvement takes place at all levels of the firm, the CIF is not restricted to capital investment in external technology to create the opportunity for technological change. Improvements in firm performance resulting from internal improvements in technology can not be represented by movement up a single learning curve, but rather are due to an advancement in the technology used by the firm. These performance improvements, therefore, are not subject to the performance limits of a set technology as described by Arrow. A learning curve function with its asymptotic shape no longer is a valid model for the potential gain a firm can realize from internal improvements.

The trial and error nature of a sequential technology development process and the resulting necessity of a firm "learning" or technology break-in phase lengthen the technology development process, increase the cost and risk of new technology to the firm, and exclude the firm from becoming substantively involved in technology advancement. By actively including "downstream" concerns and information in initial technology design, the CIF is able to shorten the technology development process, decrease the cost and risk of technology, and actively shape technology to fit its needs and goals. By reducing the cost, risk and time necessary to undergo technological change and by increasing its sources (and volume) of improvements, the CIF is able to undergo technological change much more frequently than a firm using a sequential development and learning approach to technology.

CHAPTER 5

THE PERFORMANCE OF A CIF APPROACH TO TECHNOLOGICAL CHANGE IN A COMPETITIVE ARENA

In the previous chapter, we proposed two analytic tools as a means for interpreting the experience of learning curves when changing technology within the firm. The first of these is the depiction of learning curves as reflecting a performance gap between the developmental state of new technology and the capabilities of the firm in using it. The second is a dichotomy of firm learning into on-line learning and off-line learning. The learning curve reflects on-line learning, where the technological shortcomings in the use of a new technology effect productivity and other dimensions of the firm's performance. Because the learning curve is a function of cumulative output, on-line learning is a function of real time and scale of production. Off-line learning, in contrast, does not adversely impact other dimensions of firm performance and allows the firm's initial productivity to be higher when changing to a new technology.

In the previous chapter, we also established that firms vary in their ability to develop and implement technology. Firms need not be restricted to on-line learning or the performance gap created by it, and need not be limited in their ability to further develop technology. In particular, the CIF-type organization is able to reduce the time and production experience necessary to reach the full productive potential of an externally developed technology and to generate technology change within its directly productive activities.

As a result of this variation among firms, we currently have in the competitive arena the existence of firms that require real time and production to achieve full productive (and qualitative) competence with a new technology, and are dependent on sources external to directly productive activities for new technology. In the same competitive arena, we have firms that do not require real time and production to achieve full competence with a new technology, and are able to generate technology within directly productive activities.

This chapter examines two aspects of a competitive environment in which firms differ in technological capabilities. First, we explore the appropriability of CIF developed technology by other firms. Second, a comparative analysis is made of performance capabilities of these two types of firms for the cases of externally developed technology and internally-developed technology. Performance capabilities are examined over time with different rates of technological change.

THE APPROPRIABILITY OF CIF IMPROVEMENTS

In considering the effect of technological advances on competitive outcome, technology has been treated as generally available to firms on the basis of capital investment. The ability of firms to advance technological capability through internal R&D and learning has, however, been recognized in economic literature. As in the case of externally developed technology, technological capabilities resulting from internal R&D and learning are the product of investment by the firm. It is assumed that technology advancements made by one firm will become available to other firms, but followers may be delayed in their access to this technology. The effect of variations in the technological capability of firms has been examined, therefore, as investment and timing decisions. Firms may choose to lead in technological capability by investing early, while other firms may choose to wait and copy technological innovations. The learning experience of leaders may also accrue to followers, and in some analytic scenarios is available in capital equipment improvements to followers sooner than early market entrants.[123] Variations in technological capability among firms, therefore, are analyzed on the same basis as market entry timing and leader and follower positions in a market.

Because technology becomes generally accessible over time, a technological innovator is seen to have a temporary and costly technological advantage.[124] The innovator can, however, charge higher prices until competitors are able to enter the market using the new technology. Thus, the advantages of higher initial prices must be weighed against a smaller and riskier initial market and high development costs and risks. This standard analysis of the strategic import of firm-generated technology centers on four characteristics of the technology development process:

- Technology is costly to develop,
- Technology is risky to develop and market,

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[123]Jovanovic and Lach (1989) provide an example of analysis using an assumption of learning benefits accruing to followers before the learning (early entrant) firms. This treatment results from an assumption that learning benefits are only available through investment in new generations of capital equipment. Assumptions of the proprietary nature of firm learning and "spillover" of learning benefits to followers are explored in Porter (1985) and Mookherjee and Ray (1993).

[124]In addition, innovators are viewed as facing considerable risk in the development and market acceptance of new technologies.

- Technological innovations can be readily copied (at lower cost than initial development) by competitors, and

- Technology generations are infrequent enough for other firms to catch up to the innovator.[125]

There are, however, important differences between the technological capabilities of firms as depicted in standard conceptualizations of competition and CIF technological capabilities. By incrementally improving products and production processes with kaizen and by including more information in product formulation through concurrent design, the CIF is able to reduce the time between development project inception and completion, and to reduce the risk of technological change compared with a sequential technology development approach. With ongoing kaizen activities and concurrent product design, the pace of technological change is continuous. Furthermore, the technology change resulting daily from the kaizen process may be insignificant in cost and risk. Finally, technology generated from kaizen and concurrent design will be firm-specific, making innovations harder for other firms to copy, and will require greater (rather than less) cost and time to copy than for the CIF to develop.

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[125]An example of this type of depiction of technology leader and follower advantages can be seen in Porter (1985: 181).

Because improvements are incremental and generated specifically for the firm, the CIF reduces the trial and error aspects of introducing new technology. The integrated nature of CIF technological development simultaneously makes emerging technologies of greater advantage to the CIF and less advantageous to other firms than externally developed technology. Because information and concerns particular to the CIF's use of a technology are included in the technology's design, the resulting technology is particularly appropriate to the needs of the CIF and less likely to fit in the operational context of other firms. This is especially true in the case of kaizen. Process improvements like JIT work better, for example, where there are close supplier relations. This difference between the context of original development and possible competitor application is one of degree. The more alike the innovator and copier firms, the more likely innovations are to be useful and the more successful copying can be.

The CIF approach to technological development also raises a question of how readily technological change can be observed and copied. Bartmess and Cerney (1993) reported that strategic moves by firms were most successful when the competitive advantage resulted from internal process improvements. Unlike input cost reductions and product improvements, changes in the production process appeared to be the hardest changes for other firms to copy. Further evidence for this conclusion may be the success with which Japanese firms adopted U.S. product technologies, while U.S. firms are having far greater difficulty understanding and duplicating Japanese process technologies (as well as product improvements that have resulted from improved process technologies). Extrapolating from Bartmess and Cerney's findings, it can be hypothesized that the facility, speed, cost and accuracy with which technology improvements can be duplicated depends on the observability of the source of a technological improvement, and the separability of the change from the original context of its development and use.

CIF innovations have been part of a long stream of improvements, rather than isolated and clearly identifiable changes. Rather than depending on externally developed capital equipment for these improvements, CIF have made adaptations to their operations directly. As many of these changes are small and undocumented, and voluminous in quantity,[126] it would very difficult for a competitor to observe them. Also, the changes are very specific to the contexts to which they are applied. The changes in product quality can be seen in overall standards, but the means for achieving the heightened quality standards are not directly observable or attainable from outside equipment sources.

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[126]Watanabe et al. (1991).

Typically in economic analysis, changes recommended by a capital equipment user for incorporation into future generations of capital equipment can be captured by other firms willing to invest in the improved capital equipment. In fact, the user recommending the change may require more time to capture the gain than new market entrants because new capital equipment is required.[127] This same assessment can be extended to the case of improvements for inputs other than capital equipment.

However, the appropriability of a firm's capital equipment, material input, and product improvements by its competitors depends on the accessibility of these improvements to other firms (both in appropriateness and availability in the market) and the innovator firm's own ability to make capital equipment, material input, and product changes directly within its own operations. The CIF's focus on flexibility in use of labor and capital resources decreases the degree to which its capital equipment "vintage" (or technological capability) is fixed, and reduces the firm's dependence on external feedback loops to make improvements in the use of capital equipment. This point is graphically illustrated by Toyota's famous Kamiga Number 9 engine plant (Schonberger: 302). Toyota started

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[127]See Jovanovic and Lach (1989) for an example of an analysis using this depiction of leader and follower advantages.

with imported secondhand (U.S.) equipment, which was transformed through kaizen into a "state of the arts" manufacturing system. The Nippondenzo approach of producing its own capital equipment in-house using kaizen suggestions also puts the appropriability of innovations in question. Internally generated and implemented process changes would not necessarily be available through the capital equipment market. The CIF's relationships with suppliers (using a smaller circle of firms and developing closer working relationships) further decreases both the appropriateness and the availability of changes in components and materials to other firms. More exclusive supplier relationships also make the sources of technological improvements harder for competitors to observe directly, and, therefore, harder to copy.

On the basis of the characteristics of the CIF kaizen and concurrent design systems for technology development, we would expect the conventional assumptions in the analysis of the technological capability of firms to be inadequate. In particular, assumptions that leaders in a new technology face higher risks and costs than copiers, that innovations are infrequent, and that innovations are generally appropriate and accessible for other firms are in question. On the basis of these considerations, a technological follower strategy is untenable for maintaining competitiveness in a market with firms using continuous improvement methods. This conclusion is consistent with extensive evidence reported by Clark and Fujimoto (1991)[128] that the movement toward the further integration of technology development efforts within the firm is widespread.

TECHNOLOGICAL CHANGE IN A DYNAMIC CONTEXT

A second issue for firm competition in the presence of technological change is the relative positions of firms over time. Important to this consideration are the relationship between generations of technological innovation and the rate of technological change. These concerns have not yet been integrated into economic analysis. In this section, the relative performance of firms will be examined, first in the case of externally developed technology, and second in the case of continuous improvements made within one firm.

For the first case of externally developed technology, both continuous improvement and non-continuous improvement firms are in the same position of adopting new technology. In this case, the conventional depiction of technology originating outside of the firm is useful. Each firm's

[128]See Chapter 3.

experience with employing the new technology, however, will vary. Using the analytic tools of viewing a firm's learning curve as a performance gap and the division of technological mastery into on-line and off-line learning introduced in Chapter 4 allows the ramifications of firm differences to be examined.

While the learning curve is treated as a dynamic concept and is described as occurring over real time, it remains essentially static in its analysis. To date, research on firm learning has failed to consider the interrelationship among past, current, and possible future technologies and firm capabilities, and the importance of the rate of change. Arrow (1962) wrote of a production operation start-up with a prior production (and, hence, productivity) level of zero. Theoretically in this case, the intercept of the learning curve could be anywhere between zero and the full productive capability inherent in the new technology. However, in the case of an existing operation, a crucial question becomes whether the learning curve intercept for new technology matches or exceeds prior productivity levels, or whether productivity falls back toward zero and rebuilds.

It is unclear whether it is reasonable to expect the new learning curve to start at or above the plateau level of the earlier generation of technology, as implied by the literature. Several questions must first be addressed to postulate the new learning curve's position relative to previous firm performance:

- Had firm performance with the prior technology reached the full competence level (in learning curve terms, the plateau),

- To what extent do current skill levels carry over to the new technology, and

- What will the rate of productivity improvement be with the new technology and how does it compare with the rate of improvement with the prior technology?

Another major question concerning the learning curve is the extent to which aspects of performance other than productivity might be affected by the technology change.

The answer to these questions will lie in part in the nature of skill and adaptation required by the new technology. Appropriateness of the new technology to its intended use, the preparedness of the firm, and the completeness of the technology itself for practical use will all determine the firm's initial productive performance in introducing the new technology to its operations. These questions become increasingly important in markets where the speed of technological change is said to be accelerating.

In economic analysis, changes in product and production technology is treated as a relatively infrequent occurrence. With the advent of firms capable of continuous improvement, as well as rapid product development, the pace of technological advance has accelerated. This is not claiming that the magnitude of technological change is greater because of CIFs, although that may well be the case. What we know is that with kaizen, technological improvements are occurring daily with their impact on the market being almost immediate. With concurrent design, the new product development period has been significantly shortened. What remains unanswered is the relative accessibility of those technology advances to rival firms. Mansfield (1988) has noted, for example, that Japanese firms in his survey displayed a greater ability to adopt new externally developed technology than their American counterparts. This he attributed to a greater facility in making production process and design improvements that make the technology feasible in actual production conditions. From a conventional approach, one would expect any gains in production capabilities generated by Japanese firms to be quickly copied by other firms. Indeed, there has been a great flurry of activity to institute JIT, lean manufacturing, and zero-defect manufacturing techniques in non-Japanese firms. These efforts have not always had favorable results, and where favorable, have not always closed the performance gap with the technologies' originators.

Viewing firm learning as variable and as impacted by organizational characteristics and management practices suggests a need to consider the consequences of rapid technology change and intra-firm innovation on firms with variant approaches to technological advancement.

Firms may vary along a spectrum in approach to technology development and performance improvement. At one end of the spectrum is the **learner firm** that embodies the conventional depiction of a firm dependent on external sources for the development of technologies to improve performance. Once such a technology has become generally available, the learner firm can purchase it and embark upon learning to use the new technology as the firm starts production. Once the firm has completed the learning process, performance remains unchanged until which point the firm decides to invest in another generation of technology. The firm's technology is tied to the capital equipment it employs - both are long run decisions and are, therefore, fixed for the firm in the short run. There is an expectation that, after the initial disruption of employing a new technology, production processes will remain stable.

If a firm is dependent on externally developed technology, it must be in a response mode, adapting skills and configuration to the form of the technology it acquires.

How this change in skills and methods is carried out will affect the time and extent of disruption before successful integration of a new technology. This leads to three areas of concern in evaluating potential performance for a firm that pursues a conventional learning strategy: in learning curve terms, the intercept, or initial productivity levels when employing a new technology; the slope, or rapidity of movement to full proficiency with a new method; and the transition (and performance consequences) in moving from one technology to another.

At the other end of the spectrum in approach to technology development and performance improvement is the **innovator firm** that develops its own technology through kaizen and uses concurrent design to draw on externally developed technologies as they fit into the firm's own technology development plans. With concurrent design, the emphasis is on planning and coordination prior to implementation, followed by monitoring and further process improvements after implementation. With both kaizen and concurrent design, the firm pursues technological change in a systematic and broad-based manner in a continuous process of review and innovation. Each "generation" of technology is unlikely to be very different from the generation before, and is likely to follow quickly upon the prior "generation."[129] There is an expectation in the firm of constantly evolving production processes and constantly innovating products.[130]

On-line learning (as the delayed mastery of a newly implemented technology) is minimized or even eliminated from the innovator firm's performance. The idea of eliminating learning curves from firm performance may at first glance appear untenable. When the learning curve is viewed from an individual perspective, it may be assumed that there must be a time span in which an individual is given the opportunity to master a new skill. This analogy is not appropriate when extended to the context of the firm, however. The learning curve of the firm suggests that the "learning" is taking place while learners produce output. This means that output and firm operations will be adversely impacted by the deficiency in workers' ability to carry out the firm's

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[129]Because innovations occur daily, the concept of distinct generations of technology and its implication of lengthy time intervals between changes are less appropriate for describing technology change within the CIF.

[130]In support of this depiction is Clark and Fujimoto's comparison of the product development process of automakers (Ibid.: 1991). Clark and Fujimoto observed that Japanese automakers tended to initiate new product designs more frequently, with each generation of product design encompassing less change than its American and European counterparts. Clark and Fujimoto also alluded to what they believed to be a system for frequent product change within the Japanese firms.

current methods properly. This need not be the case. As discussed in Chapter 4, skill development and organizational adaptation to ensure the "fit" between a new technology and the circumstances of its use can be achieved through what we have termed off-line learning.

From this perspective, the shape and very existence of the learning curve are affected by the readiness of the firm for the new technology and the appropriateness of the new technology to the needs and circumstances of the firm. If technology were employed which was entirely appropriate to the firm and if the firm were fully prepared for its introduction, then, theoretically at least, no curve would occur. Rather, the initial productivity rate would match the full capability of the new technology. This is more likely to be the case if the new technology is emerging incrementally from the production process on the basis of problem solving by production workers. The ability to avoid a performance gap when importing ideas is surely enhanced by organization characteristics that improve the ability to select, prepare and implement technological change. A firm that can do these things well may be able to reduce or eliminate the learning curve for new technology and enjoy full productivity at the instant production begins for the market.

In looking at the differences in learner and innovator approaches to technological advance, we are faced with a combination of factors shaping each firm's performance. In Figure 5.1 we see that Firm B (the innovator) has two advantages over Firm A (the learner). First, Firm B is able to start each new externally developed technology at a higher performance level than Firm A, due to its utilization of off-line learning. Second, Firm B is able to simultaneously make its own technological advances internally. Firm A is handicapped both by a delay in achieving the full performance capability of externally developed technology, and a need to wait on external sources (and even copying Firm B) for any technology advance. When we looked only at on-line learning in a single technology generation in Chapter 4, the performance gap experienced by a firm consisted only of the difference between the full productive capability of a single technology and the firm's beginning performance. However, in a competitive arena where some firms can innovate, the learner firm faces a **competitive performance gap** composed of two parts: a performance gap in implementing externally acquired technology, and the innovation gap between what it and its competitors can internally generate.

When the performance levels of these two end members on the technology development spectrum (the learner firm and

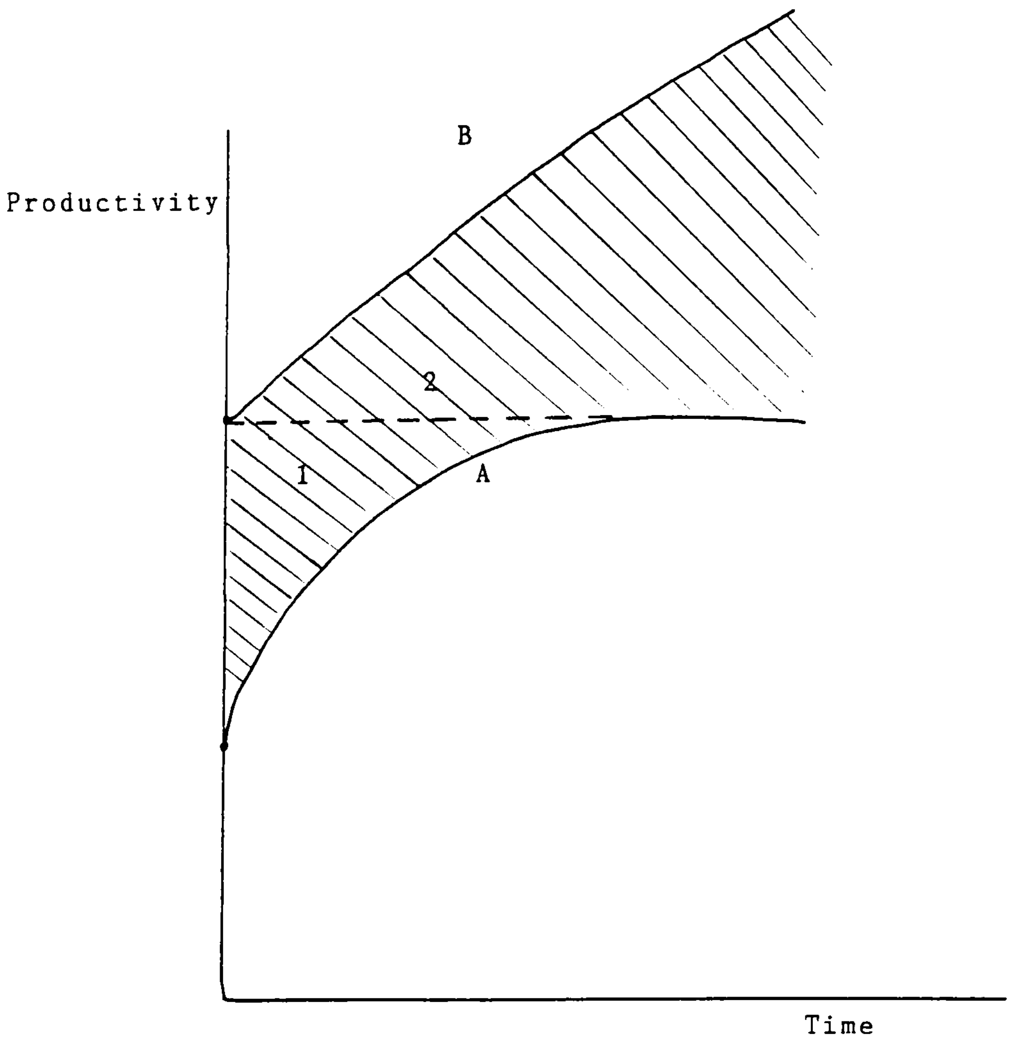

Figure 5.1. The Competitive Performance Gap Between Learner and Innovator Firms

the innovator firm) are compared over time, diverging performance can be anticipated, as demonstrated in Figure 5.1. These divergences can be further explored by breaking down the sources of technology advancement into two categories: technology generated externally to both learner and innovator firms, and internal innovations made routinely within innovator firms. First, the experiences of the two firms in using externally developed technology can be separately considered, as demonstrated in Figure 5.2.[131] In a very optimistic case, the learning curves for subsequent generations of technology in the learner firm each start at the prior performance level of the firm, without any transition period of disrupted production. The learner firm (dependent on external technology and with a "full scale," or undiminished, learning curve) follows the performance history described by Line A. The firm able to remove on-line learning starts each new technology at full productive capability described by Line B.[132]

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[131]This analysis ignores the issue brought up by Mansfield (1988) of divergent abilities among firms to adopt incipient technology and use it effectively in production.

[132]In this case, Firm B's own innovation activities are ignored. Instead, we consider only a case where Firms A and B purchase and implement an externally developed technology for the same initial investment cost at the same time.

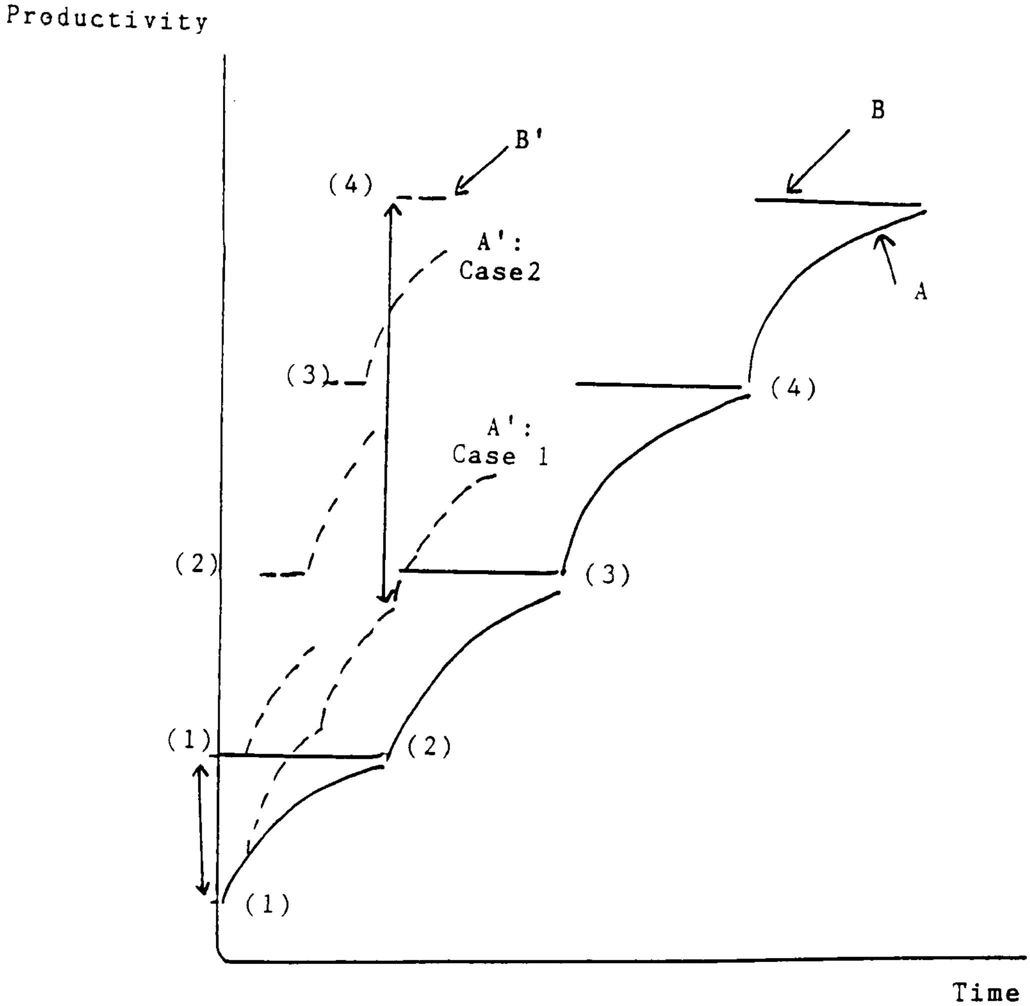

Figure 5.2. Learner and Innovator Firm Performance With Externally Developed Technology

In a market environment of rapidly changing product and production technologies, the pressure on the firm to quickly change technologies and achieve maximum competence can be very great. The more rapid the pace of technological change, the shorter the time span a firm has for learning before it has to move to a new technology. What then becomes relevant to a firm's overall performance is its initial technological competence with any given generation of technology. The firm that takes longer to reach the full productive capability of one technology may be forced to move on to the next generation of technology without having reached the full capability of the prior generation. For the innovator firm that does not require an on-line learning phase, the productivity path moves to the left as the rate of technological change increases, as described by Line B'. However, while the innovator firm is able to make a leap to the next level of performance, the firm requiring on-line learning is not.

It is not possible to say decisively what the learner firm's performance path will be without first examining the basis of the firm's experience and the determinants of its initial performance level with a new technology. The exact path of the learner firm is dependent upon the initial intercept of each successive learning curve, and whether the firm can jump above its current productivity levels immediately when changing to a new technology. Case 1 describes a situation in which the learner firm starts each new learning phase at its prior productivity level.[133] Productive capability for learner and innovator firms diverges further with each successive generation of technology. Because the learner firm lacks sufficient time to complete learning phases with prior generations of technology, it starts each subsequent generation of technology at a lower point than if it had been able to fully learn earlier technologies. Because each subsequent learning curve starts with a lower intercept, the performance potential with each generation of technology diminishes over what it could have been in an environment of slower change.

To assume that learning curves for a technology are the same regardless of the prior capabilities and experience of the firm requires that the firm be able to jump to a higher productivity level immediately upon employing a new technology.[134]

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[133]In other words, the learner firm's learning curve intercept when changing to a new technology is equal to its final productivity level with the prior generation of technology.

[134]Case 2 in Figure 5.2 describes a circumstance in which the learner firm is able to start its learning process at the same initial level of productivity as the innovator of a new technology, regardless of its stage of learning with the prior generation of technology. Economic analysis frequently implicitly assumes this capability by not

The question of the learner firm's initial learning curve intercept when changing technology is not limited to increases over prior levels. While it is assumed in economic models that technological change moves firm performance upward, the necessity of firm learning raises the question of whether initial performance (or learning curve intercept) with a new technology is indeed higher than prior performance levels. The outcome, in learning curve terms, depends on whether the intercept of the firm's learning curve with the new technology is equal to or higher than the firm's location on the learning curve of its prior technology. The new technology may have a greater ultimate capability, but require more time than the prior technology for the firm to ascend to full performance. In this case, if a firm is in an industry experiencing rapid technology change, it may not fully ascend one learning curve before having to embark upon another. When adopting a new technology, the firm may experience a drop in productive capability and need to rebuild. In this case, a firm's average performance could conceivably remain below the

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considering past technological capabilities as a factor. Jovanovic and Lach (1989) provide an example of the possibility of a firm leap-frogging the innovator when entering a market by utilizing innovator insights. Mookherjee and Ray (1993) provide a review of leap-frogging literature in development economics, using varying assumptions of the potential for spillover from innovator to follower. In contrast, Dosi and Lall consider a case where experience with innovation provides a building advantage to firms, creating an escalating asymmetry among past and potential innovators.

capability achievable with even early generation technologies. This outcome results from the movement to suboptimal performance with new technologies.[135]

One may sidestep this issue by assuming that if it is difficult for a firm to change technology, it will avoid doing so, and choose to continue with its existing technologies. Eschewing technological change is not always a choice for a firm in a competitive arena, however. When a product improvement is introduced that has widespread customer appeal, firms in the market must be able to meet customer expectations or lose sales to firms able to do so. An example of this is the rapidly evolving computer industry, where past technologies are no longer in demand. Technological change may also be required by changes in the general economic environment, such as a change in the availability of inputs or in regulatory requirements. In these cases, the firm does not have the choice to maintain the same production processes and remain in operation. One can appreciate that this argument is especially relevant for a Less Developed Country contemplating the promotion of industrial exports.

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[135]The importance of alignments between generations of technology and a firm's capabilities is explored in Appendix C.

The significance of the difference between a learner and innovator firm's performance, therefore, is increased by the rapidity of technology change.[136] Clearly, even in the case of externally developed technology, the ability of a firm to minimize learning curve effects may be pivotal to its ability to compete.[137]

The prospects for the learner firm are more dismal when considering its performance relative to a firm that can develop its own innovations. Figure 5.3 describes the productivity experience of innovator and learner firms in the case of technology advances introduced by the innovator firm. In the best of circumstances, as the innovator firm develops a technology, the learning firm can observe the change and copy it. As Figure 5.3 illustrates, this process requires real time and production before the learner firm can "follow" the innovator's technology change. The learner firm will not be able to observe the new technology until some time after the technology is implemented by the innovator, and can not copy the technology until it has first observed the new technology. Once copied, the learner firm goes through a learning phase to develop full

[136]This is considering only the productivity effects of on-line learning.

[137]This situation is similar on a macro scale for countries seeking to adopt externally developed technology.

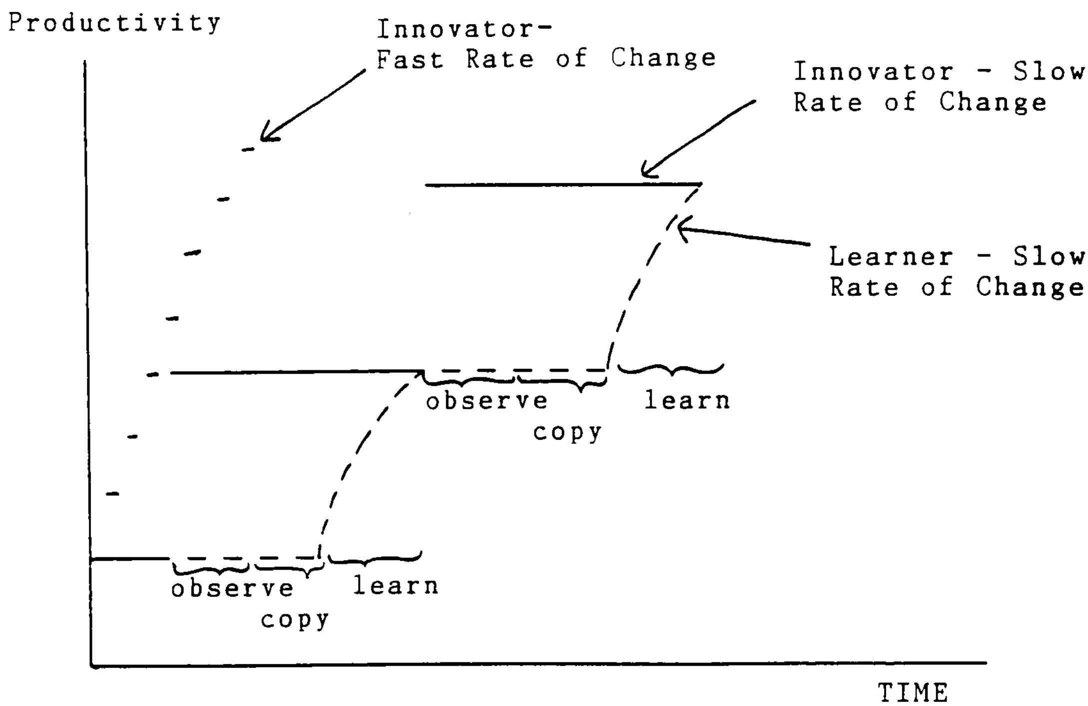

Figure 5.3. A Comparison of Learner and Innovator Firm Performance With Innovator-Generated Improvements

proficiency. In the interim, the innovator firm has had the benefit of nearly full proficiency since its technology change took place. As the speed of technology change increases and the length of each generation of technology is shortened, each firm's performance is limited to its initial capability with a technology. Unlike in the external technology case depicted earlier, however, the learner firm is handicapped by a need to observe and copy a technology before it can initiate learning. Even in the most advantageous circumstances for copying technology, the learner firm can not compress its observe, copy and learn cycles without changing how it approaches the whole process of technology change. As Figure 5.3 shows, the gap in the performance capabilities of innovator and learner firms increases over time. Of course, if performance disruption during technology changeover is included, this scenario worsens for the learner firm.

In the case of technology improvements generated within an innovator firm, some added questions arise that further bleaken the position of the learner firm. Unlike in the case of externally developed technology, the innovator firm's improvements have been generated to fit its own circumstances and needs. In addition, each technology improvement fits into an existing technology base within the firm. Unlike the historic isolation of Arrow's curve, each innovation in an innovator firm is a point on a technology development path the firm is travelling upon.[138] It is unlikely that the innovator's technology will be equally appropriate to the particular circumstances of the learner firm. Copying is also likely to be imperfect in duplicating the innovation and costly to the copying firm (while the innovation may be insignificant in cost to the innovator).[139]

REQUIREMENTS FOR CONTINUOUS IMPROVEMENT WITHIN THE FIRM

For a firm to be able to make continuous changes to its production methods implies that the firm is able to change how things are done without experiencing deficiencies in production performance. Rapid technological change becomes more feasible as the firm is able to eliminate trial-and-

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[138]Some have suggested the term technology trajectory or vector to describe the evolution of technology over time. Dosi (1988) provides a review of the use of the term "technological trajectory" in economics. This terminology is not used here, however, because it suggests a pre-defined course of development as in the physics use of the terms. The firm, however, is not pre-committed to a trajectory or vector. Rather, each technology generation developed by the firm has the potential to alter the course of future development.

[139]The cost of innovating versus copying has been examined in research by Levin et al. (1984, as reported in Dosi, 1988). Hattori (1986) describes the great difficulty even with assisted in-organization technology transfer from Japanese to Korean plants.

error periods in technology implementation and to perform without performance shortfalls in productivity, quality or timing during technology change-overs. This essentially means eliminating the experience of learning curves for the firm, with initial technological capability fully capturing the desired performance levels once production for the market starts.

To achieve such high performance standards in the midst of frequently changing production methods requires a standard of technology research, planning and implementation within the firm that is not so essential in an environment of slower change.[140] The firm that is better able to anticipate its needs and the ramifications of process and product changes on a routine basis will tend to have a competitive advantage, ceteris paribus.

The ability to make continuous changes to products and production processes implies an internal structure that at least allows, if not supports, routine change without undue stress, difficulty, or misstep. This ability implies as well that a firm be able to move in the direction of a goal, rather than be restricted to a pre-defined approach to products and production. Agents operating within the firm

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[140]Avoiding the quality gap may be the most crucial aspect in some markets.

would need an understanding of the nature of change sought by the firm, in order to coordinate individual efforts in the pursuit of a single goal. The firm would need to have a continuous source of good, well-researched ideas for improvements appropriate to the goals and circumstances of the firm.

Utilization of these resources has several benefits. Psychology studies have shown that performance improves when a worker understands the context of the task being performed, feels a member of group effort, and feels an ability to influence the work environment. Beyond the psychological benefits, those actively engaged in carrying out a process have a valuable perspective on how the process is performing, and have the benefit of being present at the site of production. Workers, thus, have an opportunity for insight into how the production process might be improved and how it might currently be failing. This capability is greatly enhanced if workers are trained in how to monitor and evaluate the processes in which they are involved. While Taylor envisioned this type of scientific analysis of production, he conceived of it as an exclusive function of management to establish enduring procedures, rather than a routine approach taken by every worker in the firm to discover opportunities for change.

CHAPTER 6

CONCLUSION

The conclusion of this work is that conventional models of technology development used in the analysis of the firm confine the role of directly productive operations in technology creation and utilization. Technological change by the firm is represented as a long run investment decision with the same assumptions that apply to capital in general. This depiction of how firms acquire technology is based on the concept of technology development as a specialized function. Technology creation in these models is external to directly productive operations and is, therefore, exogenous to models of the firm.

Involvement of those in directly productive activities is limited to the point at which the firm applies technology to its production processes. This process of technological change is conceptualized as starting with a technology choice and investment by the firm. This is followed by a learning period, in which the firm's productivity grows as it learns to use the new technology in its operations. This analysis makes the case that the conceptual model of a linear and segmented sequence in technology development and subsequent phase of firm learning is not universally applicable in that it does not explain emergent forms observed in some industry today. The concept of firm learning limits performance change to a learning curve where diminishing productivity gains are a function of the firm's cumulative output.

The emergent Continuous Improvement Firm provides evidence of technological contributions within directly productive operations beyond that described by the sequential model of technological change and the concept of a diminishing (and capital dependent) function of cumulative output. This work provides evidence of the manner in which technology is generated routinely within directly productive operations through the kaizen or continuous improvement system. A description is also provided of a concurrent design approach to technology development that is used in the CIF. Because of conceptual restrictions on the extent of improvement from directly productive activities of the firm, sequential models of technological change and the concept of firm learning do not encompass the recent emergence of systematic and broad-based innovation activities within the firm. In major R&D projects within CIFs, concurrent cross-functional participation is used, rather than a functionally segmented sequence; making specialist and user contributions inseparable in time and importance. In kaizen innovations, R&D units and capital investment may not be involved.

This evidence is used in this study to establish that CIF internal technological capabilities have not been incorporated in economic models of technology and the firm, and that the CIF approach has resulted in the ability of firms to both better utilize existing technology and to create technology in situ. A conceptual model of concurrent technological change is introduced in this work to represent the CIF approach to technology creation and implementation. This approach is characterized by the joint participation of the full range of functional specialties in technology development, in contrast to the sequential model's linear and segmented progression of an incipient technology from one functional specialty to another. The concurrent model also allows for a directed, broad-based and continuous technological innovation system within the directly productive activities of the firm, as opposed to the externally-determined technological resources available to the firm in the sequential/firm learning model.

Evidence of a variant approach to technology development is used in the current analysis as an impetus for examining the basis of divergent performance trends among firms. The concept of firm learning is used in economics to describe the impact of a wide range of factors on the firm. These factors are all subsumed into an asymptotic function with a single determinant of cumulative output. The conceptual basis for explaining this increasing function in economics is "practice makes perfect."[141] While learning increases have been treated as a gain to the firm, this work proposes an opposite interpretation: the production and time needed to learn a newly infused technology reflects a performance gap between the firm's technological capability and the inherent capability of the new technology. While the learning curve includes only productivity aspects of firm performance, other aspects (such as output quality, delivery, product and production reliability and timeliness) are also likely to be negatively impacted by the firm's technological incompetence. These other aspects are especially relevant to the firm's strategic position in the marketplace. This perspective on the concept of firm learning is used to examine whether a firm's performance in implementing a new technology can vary.

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[141]As previously mentioned, this succinct distillation of the learning concept is owed to Tirole (1988).

In this work, learning is treated conceptually as the aggregation of numerous functions, each of which is subject to its own determinants. Specifically considered is the conventional theoretical premise that improvement within the directly productive activities of the firm are strictly limited to a diminishing function of cumulative output or investment in externally developed technology. Also examined is Arrow's proposition that improvements arising within the directly productive activities of the firm are not technology, and that technology is fully capital embodied.

The framework used to address these questions is one of distinguishing the scope of activities undertaken within the directly productive operations of the firm as belonging to one of two categories: skill mastery of an unchanging technology and adaptation to technology and production processes. Adaptation can be restricted to allow only change up to the point of making the technology perform as intended, or expanded to include improvements beyond what was originally conceived of in the technology's design.

The first of these categories, skill mastery, is linked in this analysis to the concept of rote learning in psychology. As an externally defined finite task, this study points out that skill mastery is ultimately limited to learning 100% of the necessary skills. Therefore, performance improvements attributable to mastery of an unchanging technology are limited to completion of the task. The production experience needed to achieve full technology mastery is dependent, however, on the actions and existing capabilities of the firm, rather than being a set function. It is concluded, therefore, that firms can vary in their ability to learn a new technology.

In the case of adaptation to technology and production processes, the potential for improvement is not limited, unless the scope of improvement itself is definitionally confined. With both skill mastery and adaptation forms of learning, the environment for learning need not be restricted to the technology's initiation into production. The concepts of on-line and off-line learning are introduced to distinguish between developing technological competence on marketed output in real production time (on-line learning) and developing competence without impairing or slowing production (off-line learning). Off-line learning factors; such as the match between an externally developed technology and the circumstances of the firm, generalizable nature of worker skills, the appropriateness of a technology to its intended use, and level of preparation prior to implementing a new technology; impact the initial performance level of a firm using a new technology. Once a technology is in place, the effectiveness of process monitoring, generation of solutions, and rapid response affect the speed of on-line learning. Because on-line learning has negative effects on marketed output, improvement in off-line and on-line learning is a strategic tool available to the firm in improving its market position.

In moving beyond the productive capability of externally developed technology, internal adaptation provides the firm with the opportunity to exceed what is externally available to it. Adaptation in this sense does not comply with Arrow's depiction of a firm learning to use externally developed technology, but is itself knowledge (and technology) creation.

Based on this analysis, the CIF role in technology advance is distinct from firm learning as conventionally depicted. Rather, the CIF concurrent approach to technology development utilizes off-line learning to reduce or eliminate on-line learning and its attendant suboptimal cost and qualitative performance levels. These methods also allow the CIF to extend its performance capabilities by adding to its technology resources.

The last area of analysis undertaken by this work is a comparison of the technological capabilities of firms using the conventional sequential approach to technology development (and, thus, restricting themselves to firm learning), and firms using the concurrent approach to technology development. Specifically, two issues are examined: the appropriability of CIF innovations and the relative performance of firms using each approach in a dynamic and competitive context. It is concluded that, due to the multitudinous and incremental nature of CIF innovation, changes are difficult to perceive and to understand outside of the CIF. Also, innovations are appropriate for the specific (and changing) circumstances for which they were developed. This makes these innovations less likely to be appropriate without modification to other firms. The cost and risk of successfully perceiving, copying and implementing these innovations is likely to be higher for the copier than the innovator.[142] This circumstance of a higher cost and risk for the technological follower versus the leader is contrary to conventional economic depictions of technology leader and follower advantages. The difference between leader and follower technological performance is depicted in this analysis as the competitive performance gap, including both a performance gap between the initial available technology and the follower firm's mastery of the technology, and the

[142]This is particularly true when the copier limits its technological capabilities to a conventional sequential/firm learning approach.

additional technological gains made by the CIF through internal innovations.

In examining technological change in a dynamic context, it is concluded that firm learning is a static concept that does not consider the effect of a firm's prior technological capability in evaluating its performance with new technologies. In introducing time and rate of technology change into the analysis, the divergence of the conventional sequential/firm learning approach and the concurrent approach is apparent, as the follower does not have the opportunity to catch up to the leader and does not enjoy lower risk and cost access to leader innovations. This suggests that a follower strategy is untenable in competing with a firm using a concurrent approach to technology development. Nor is there a theoretical basis for assuming that the CIF's innovation capacity is ultimately limited, as in models assuming a slowing in innovation rates for leaders.

Based on this analysis, we speculate that a possible motivation for developing a concurrent approach to technology development (reflected both in kaizen and concurrent design methods) is to: 1) reduce the risk of innovation by making changes more appropriate, incremental and routine, 2) reduce the development period, 3) generate more innovations by broadening the base of involvement within the firm, and 4) reduce the appropriability of innovations.

IMPLICATIONS

The CIF phenomenon raises many questions about whether the use of distinct stages, capital-embodied technology, and productivity measures adequately illuminate current pressing factors in firm performance and competition. Internal innovation makes the treatment of technology as a function of investment insufficient because firm innovation is not limited to long run or investment decisions. Likewise, R&D laboratory/industry linkages do not address questions of technological capability within directly productive operations of the firm. While a firm's innovations may be copied (at some cost and delay to the copier), internally developed technology will not be equally applicable to other firms.

Difficulties in technological change can be approached from the perspective of misalignments and inefficiencies in the organization of the technological change process. These misalignments are created by treating technological change as a segmented and sequential progression of functions, rather than as a holistic and interactive process in which phases of development are interdependent.

The CIF has dramatically illustrated the potential to incorporate the whole technological process within normal operations of the firm and to consequently capture the benefits of an unending stream of firm-specific (and, therefore, wholly appropriate) technology, without necessitating large scale investment, risk, or disruption. With the ability to generate internal improvements, firm performance gains need not be dependent on imported technology or limited to productivity increases.

To copy a CIF, however, is to pay more for the innovations than the CIF, as a copier to implement the change less effectively than the originator, and to always lag the CIF as it develops new methods. The approach of SM/MP firms to copying past CIF methods such as Just-In-Time, quality circles and statistical process control without developing the ability to generate their own internal improvements is insufficient to compete. Importing technology and methods without internal development is to stay in a learning curve mode; necessitating investment, a learning period, and disconnects as new approaches are brought in from outside sources.

Issues of technological applicability to the resources and circumstances of follower firms, the cost and delay in technological acquisition from innovators, and the pace of change (exceeding the speed at which followers can copy) are all areas for concern in technological competitiveness. This points to the need to give greater consideration to the ability of firms to innovate.

In considering strategies available to firms based on technological capability, it is generally asserted that the roles of technological leader and follower each have advantages and disadvantages. For developing countries, policy prescriptions result from these assumed relationships. Developing countries face an innovation disadvantage due to capital shortages and smaller markets. Attention is focussed instead on means of transferring technology from leaders to followers. The Multi National Corporation (MNC) is often viewed as a catalyst to development, and as the logical source of technology transfer via investment in facilities in developing countries. With investment, these firms will transfer physical capital and, subsequently, technology to the host countries.

Based on the analysis provided in this study, the transfer of physical capital and static production methods without enhancing the capability to utilize imported technology and to generate a continuous stream of improvements within the firm's directly productive activities will not allow less developed country firms (and satellite MNC facilities) to be on equal footing with firms with continuous improvement capabilities. Expanded technological capability is based on a concurrent approach to technological development that speeds up, increases the volume of, and improves the technology creation and implementation process. This contrasts with an assumed dependence on technology created by separate R&D and subsequent phases of firm learning. In markets where a concurrent approach to technology development is used by some firms, technological capability is not simply a matter of capital equipment transfer, but the ability to internally generate technology and to better utilize (externally or internally developed) technology.

The question of the cost of off-line learning is empirical and a candidate for research. In the case of kaizen activities, Aoki (1984) sees a cost to kaizen while Imai (1986) does not. Beyond cost, however, is the matter of structuring technological change in ways that allow technological change itself to be used as a strategic market factor. This is especially true when considering the possibility of creating an environment of rapid technological change.

The question of the appropriability of technological change is especially pertinent to Less Developed Countries (LDCs). If the ability to compete in global markets requires the elimination of the performance gap in adopting a new technology and the ability to routinely generate a multitude of technological innovations, LDCs will have to look for ways to endogenize that capability. One method consistent with the conventional focus in technology and development literature would be to encourage foreign direct investment by CIFs. Research by Bos (1991) and Wilson (1992) indicates, however, that Japanese based CIFs have largely failed to transfer continuous improvement capabilities to their facilities in Mexico and Brazil. In the case of Japanese CIF facilities in South Korea, Hattori (1986) provides documentation of the difficulty in transferring CIF technology and processes even where there is an overt effort to do so by the parent company.[143]

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[143]Brazil furnishes an example of a country that is taking this overall problem into consideration. This can be seen in the Brazilian Quality and Productivity Program, which focuses on building industry organizational development through quality training. We, of course, will not know the impact of this program for some time, but its existence is evidence of a growing recognition of the new set of problems faced by LDCs in the changes taking place in technology development.

This analysis also has implications for social benefit analysis methods widely used in development economics. These methods currently take products and production processes as given. This analysis suggests that the initial performance intercept and learning rate, and off-line learning capabilities should be explicitly considered.

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APPENDICES

APPENDIX A

DEFINITIONS

Competitive Performance Gap: The difference between the productive capability of a firm following a learning curve in adopting new technologies and a firm that both starts with the full productive capability of the technology it utilizes and further develops its own technological advances within its directly productive activities. The gap between learner and innovator capabilities affects not only productivity, but other attributes of product and production.

Firm: The directly productive activities of a firm, the basis of the unit of analysis in the economic theory of the firm.

Off-Line Learning: Developing competence at implementing a new technology and working out problems while not engaged in actual marketed output. This can include training and skill development (both before and during the use of a new technology), preparation for technological change, the product and process design review of new technology and process modification before initiation of marketed production, and "shakedown" production in which the output is not sold.

On-Line Learning: Developing skills, discovering problems and making product and process modifications in implementing a new technology on actual marketed output of the firm.

Performance Gap: The difference between the full (ultimate) productive capability of a technology and the initial performance level of a firm using that technology. The magnitude of the performance gap in terms of productivity is the area between the firm's learning curve and the ultimate performance level achievable with a technology. The performance gap includes productivity levels achieved with a technology, but also quality, timeliness and reliability of production, and other product and production attributes.

Technology Development Path: Product, production and organizational technology employed by a firm over time. Viewing technology used by a firm over time as dynamic, generations of technology as interdependent, and technological capability as dependent on the characteristics of the firm; the concept of a technology development path focusses on the continuity and interrelationship of generations of technology within a firm and the firm's ability to move from one generation to the next.

APPENDIX B

NIPPONDENZO TENNESSEE PLATING DIVISION

SCHEMATIC DIAGRAMS

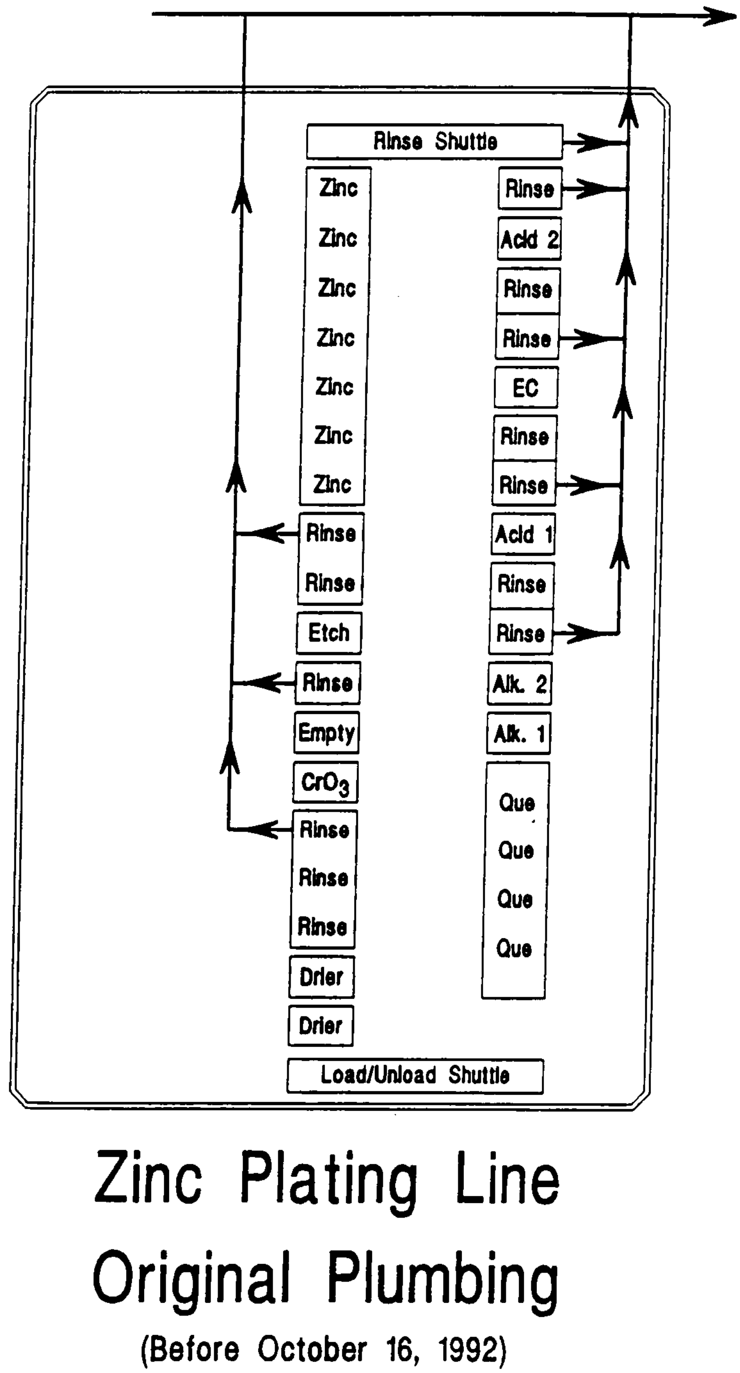
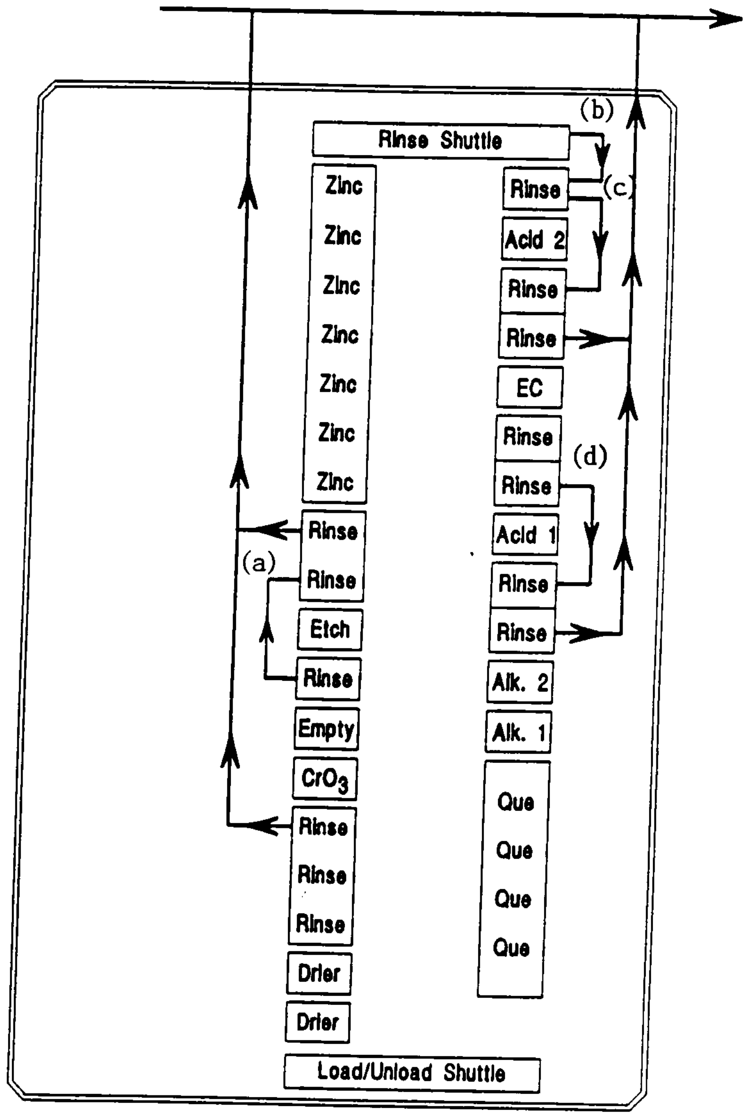


Figure B.1. Diagram of Plumbing Before Modifications

Source: Adapted from Nippondenzo Dream Team unpublished materials. Nippondenzo Tennessee; Maryville, Tennessee, 1992.



Zinc Plating Line

Improved Plumbing

(After October 16, 1992)

Figure B.2. Diagram of Plumbing After Modifications

Source: Adapted from Nippondenzo Dream Team unpublished materials. Nippondenzo Tennessee; Maryville, Tennessee, 1992.

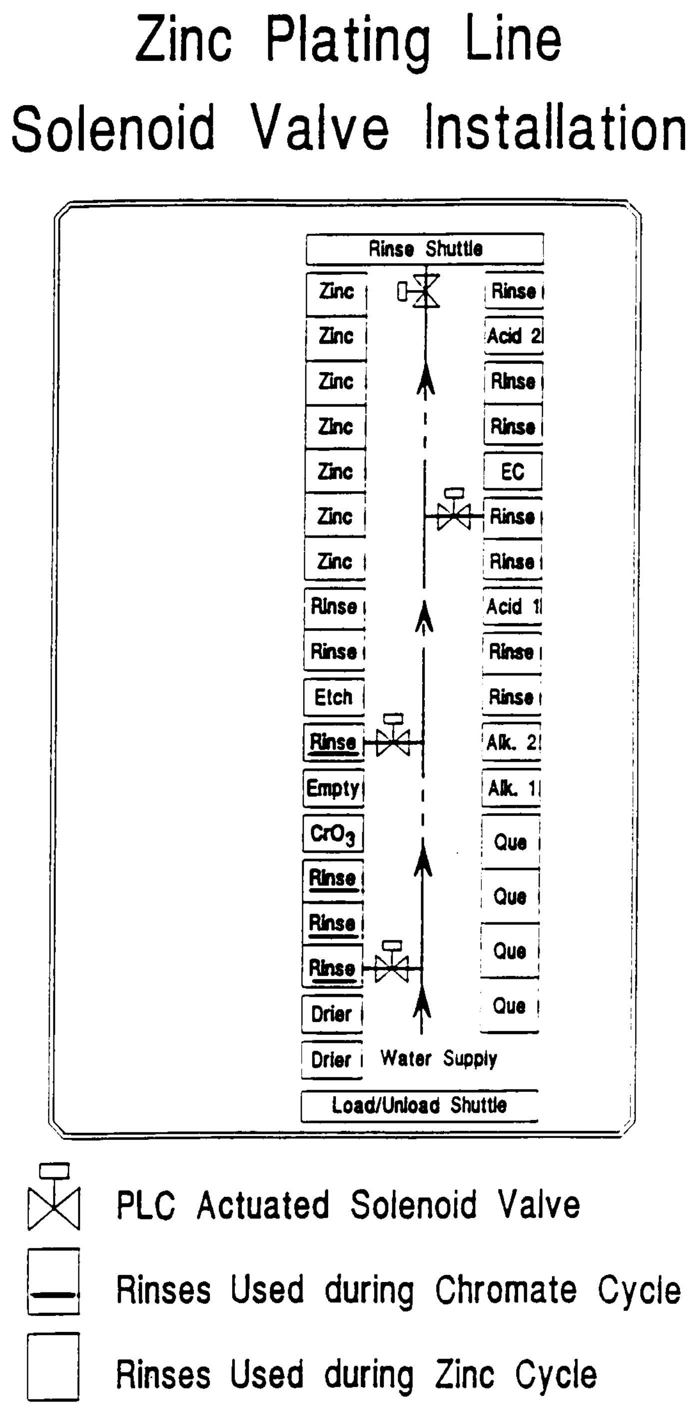


Figure B.3. Plating Line With Solenoid Valve Installations

Source: Adapted from Nippondenzo Dream Team unpublished materials. Nippondenzo Tennessee; Maryville, Tennessee, 1992.

APPENDIX C

AN ANALYSIS OF THE TRANSITIONS BETWEEN GENERATIONS OF TECHNOLOGY IN THE CASE OF FIRM LEARNING

The amount of change required by any given generation of technology when compared with the firm's previous technology will in part determine the amount of learning required of the firm in making a technology change-over. A firm's technology choice is therefore best interpreted not as an isolated choice based solely on the present value of streams of benefits and costs of producing a given product for a given market (as typically described in economic literature), but as a choice of **technology development paths**. At each point along a firm's technology development path, the firm makes choices that determine not only its current capabilities, but its foundation for future technology development and, therefore, its future capabilities. This point will be seen in sharper relief when considering the firm's own contributions to technological advancement, which is addressed elsewhere. At this point, suffice it to say a firm's current technological capability will affect its preparedness for newly introduced technology. The greater the difference between a firm's current capabilities and those required by new technology, the lower its initial performance level with the new technology and, hence, the greater its performance gap. Planning skill development and preparation to complement the firm's expected technology development path will diminish the necessary preparation and skill development needed with each individual technology generation.

The role of technology capability building and overlapping skill development can be seen in examining the connections between successive generations of technology over time. Figure C.1 depicts the possible alignment between a firm's technological capabilities and the requirements of a new technology, and the effects on productivity for the firm. The learning curve for each technology generation depends on the alignment between the firm's capabilities and the requirements for fully utilizing the new technology.[144] This alignment determines the

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[144]In the case of kaizen, the integration of change with production practices is assured by the development and implementation of improvements by those performing the process. In concurrent design, the integration of technology needs and manufacturing needs is improved by including downstream functions in the design process.

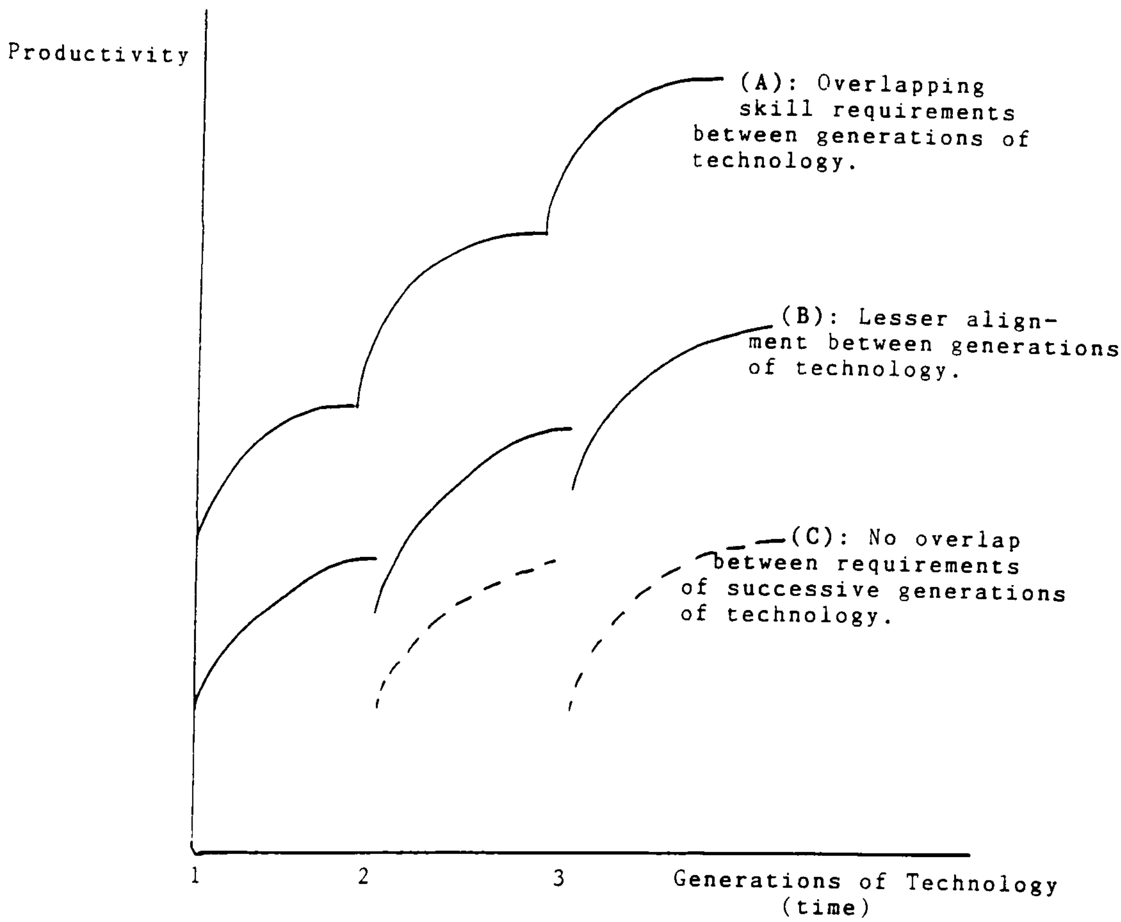

Figure C.1. Technological Continuity: The Effect of Alignment Between Generations of Technology intercept for each technology's productivity level. Without this alignment, one would expect the firm to have a lower initial productivity level and a greater potential disconnect between productivity levels with succeeding generations of technology, as illustrated in Figure C.1. Case A describes a situation of overlapping skill requirements between successive generations of technology. In this case, a firm's productivity is strictly increasing. Case B depicts a circumstance where a firm can partially capitalize on past experience, but still lacks the ability to maintain prior productivity levels when changing to a new technology. Case C describes a circumstance in which there is no overlap between the requirements of successive generations of technology.

The on-line production time and output needed for a firm to gain competence with a new technology determines in part the frequency with which a firm can change technology. Should the learner firm not be able to start each technology generation at prior productivity levels, and skill overlap not be significant between generations of technology, then the learner firm's performance will drop initially when changing technology. Such a fall may have serious consequences to firm viability and may be paralleled by faltering quality and reliability of production.[145] If a firm is forced by competitive pressures or changing external circumstances to adopt new technology more quickly than it is able to reach the potential of each successive generation of technology (i.e., the firm is a "slow learner"), the average productivity rate of the firm may be well below the productive potential of any individual technology. With on-line learning, the shorter the interval between generations of technology, the lower the average productivity and the higher average cost will be for the firm.

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[145]In economic literature, a distinction is made between learning which affects cost, and strategies which affect quality, delivery and flexibility (Pappas and Hirschey, 1987). However, these factors are interrelated, often with actions that affect one affecting other factors as well.

VITA

Stella Sherrouse Schramm is a native of New Orleans, Louisiana. She received a Bachelor of Science degree in Psychology from Louisiana State University, Baton Rouge in 1979, and a Masters of Business Administration degree from the University of New Orleans in 1983. She served on the staff of the Economic Development Council/New Orleans and the River Region from 1979 until 1990. She is married to William Edward Schramm.