THE ROLE OF INDUSTRYWIDE VOLUNTARY PRODUCT STANDARDS IN STIMULATING ECONOMIC EFFICIENCY

by

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B.S., Wharton School, University of Pennsylvania (1971)

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ABSTRACT

The thesis is concerned with understanding the role that industrywide voluntary product standards can play in stimulating economic efficiency, the stages in the evolution of an industry at which various types of product standards can be useful, and the potential inefficient effects which standards may have. In order to address these concerns, a large conceptual foundation is developed. First three types of economic efficiency are identified—firm dynamic efficiency, firm static efficiency, and marketplace efficiency. Second, an empirically-based model of the sequential patterns of product and process innovation over the evolution of an industry is described. Third, nine major sources of economic inefficiency are examined in terms of the types of economic inefficiency each can cause and the stages in the industry evolutionary model in which they tend to appear. Fourth, the basic types of standards, differentiated by technical functions, are identified and discussed.

On the basis of an integration and extension of the conceptual foundation, it was found that industrywide voluntary product standards can positively effect the three types of economic efficiency through direct impacts, indirect impacts, impacts through use as building blocks in the development of other standards, and impacts through the discovery of new technical information as a byproduct of the standards development process. Sources of inefficiency which can be directly affected by standards include producers' market and technological uncertainty, buyer uncertainty, and negative externalities. The types of standards which can create direct impacts are compatibility standards, variety reduction standards, and quality standards. Indirect impacts may be as important as direct ones.

It was found that the introduction of standards may inhibit product innovation by institutionalizing certain product characteristics from the point of view of users and producers. The recommendation is made that only elementary standards be developed in stages of frequent product change.

Thesis Supervisor: Dr. Richard D. Tabors

Title: Lecturer, Department of Urban Studies and Planning
# TABLE OF CONTENTS

Abstract

Table of Contents

Acknowledgements

Chapter I: Introduction

Chapter II: Economic Efficiency

Chapter III: A Model of the Sequential Patterns of Innovation

  The Abernathy-Utterback Model

  Key Themes of the Model

  Criticisms of the Abernathy-Utterback Model

  Chapter II Revisited--The Relationship between Market Structure and Economic Efficiency

  Extension of the Model--A General Pattern of Response to Technological Invasion

  The Application of the Abernathy-Utterback Model to an Industry

Chapter IV: An Examination of Potential Sources of Economic Inefficiency

  Market Uncertainty

  Technological Uncertainty

  The Public Good Nature of Technical Information

  Inefficient Market Structure

  The Nature of the Production Process

  Management Orientation

  Buyer Uncertainty

  Excessive Transaction Costs

  Externalities

  The Relationship between the Sources of Inefficiency and the Stages of the Abernathy-Utterback Model
Sources of Inefficiency and Technological Invasion 58

Chapter V: The Basic Technical Functions of Industrywide Voluntary Product Standards

Terminology 61

Measurement Method Standards 62

Test Method Standards 63

Compatibility Standards 64

Variety Reduction Standards 64

Quality Standards 65

Chapter VI: The Role of Industrywide Voluntary Product Standards in Stimulating Economic Efficiency 70

A Matrix of the Relationship between Types of Standards and Sources of Economic Inefficiency 70

The Direct Impacts of Standards 73

Potential Negative Effects of Standards 76

Standards by Stages of Introduction and Nature of Direct Impact 78

Additional Impacts of Product Standards on Sources of Economic Efficiency 81

The Degree of Impact of Standards 83

Summary and Conclusions 84

Appendix 86

Notes 92

References 97
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CHAPTER I. INTRODUCTION

In order to get the sputtering U.S. economy out of its current state, policy analysts are looking at a number of strategies for stimulating greater economic efficiency. By achieving efficiency gains (through product innovation, on the production line, and in the marketplace), it is hoped that real economic growth will rise and inflationary pressures fall.

The list of potential tools for generating greater efficiency is a long one. Possible (or implemented) public sector initiatives include cuts in the capital gains tax, deregulation, tax credits, increases in Federally-funded research and development, and modifications in Federal patent law. Proposals for the private sector include implementation of quality-of-worklife programs and Scanlon plans, and the creation of incentives for corporate executives to push high-risk, long-range, innovative strategies which have the potential for high returns. However, one tool for increasing economic efficiency which both the public and private sectors can (and do) utilize is not usually mentioned in the conventional litany of possibilities-- industrywide voluntary product standards.

Webster's Dictionary defines a standard as "something established by authority, custom, or general consent as a model or example." Essentially, a standard is a means for institutionalizing a behavior or understanding. The size of this paper, the way we dress, the printed word all reflect certain standards. Standards may be formal (codified) or informal (a tacit understanding between people).

A product standard is a formal standard which institutionalizes a
certain behavior or outcome regarding a specific commercial product or type of product. Product standards can specify terminology regarding a product; methods of measuring, testing, or using a product; or certain characteristics of the product itself, e.g. size, design, quality. A product standard can be mandatory (codified by government to protect the public interest) or voluntary (institutionalized by a producer or a group of producers).

Industrywide voluntary product standards are developed through consensus by members of a particular industry. Standards are generally written by industry trade associations, professional engineering societies, and other national engineering bodies such as the American Society for Testing and Materials. The demand for industrywide standards may originate from the buyers or producers of a particular product. Standards are sought by producers for many reasons, e.g., to reap the benefits of production economies of scale, reduce consumer uncertainties, eliminate substitute goods, increase market share for dominant firms or reduce the possibility of government imposed mandatory standards. Buyers of intermediate products, stimulated by cost or quality considerations or the threat of government intervention, are also a frequent source of demand for industrywide product standards. Final consumers tend to be less organized than intermediate buyers, and therefore are less vocal in calling for and less powerful in inducing industrywide voluntary standards.

The process of standards development varies from organization to organization. Standards-writing committees may be dominated by members of an industry (either the buyers or the sellers of the product
under review) or may have a balanced representation of buyers, sellers, and representatives of the public interest. The voluntary standards developed may be used in a number of ways, as well. Firms in the industry may or may not follow them. They are often used in contract specifications, and may be incorporated into local, state and Federal law as mandatory standards. Testing laboratories, like Underwriters Laboratory, use them. (For the reader unfamiliar with U.S. voluntary standard-setting institutions and processes, see Appendix.)

The companies involved in voluntary standard-setting are generally motivated by their own self-interest. (Even members of engineering society committees see themselves as representing their respective employers.) The synthesis of interests coming out of the consensus-building process may or may not result in standards which encourage efficiency in the production line, in the development of innovations, or in the marketplace. Standards may freeze a technology before its development is complete, may prevent alternative technologies from being pursued, or may facilitate the monopolization of supply by a particular company.

Furthermore, the people who write standards are technical experts for the most part. Given that most standards-writing is done by technical experts pursuing private-sector interests, it is likely that much standard-setting activity takes place without a clear appreciation of the efficiency benefits or costs standards can have for society as a whole.

Unfortunately, economists also have not appreciated the role of industrywide voluntary product standards in stimulating efficiency--the literature on the subject is almost non-existent. The primary work is
David Hemenway's *Industrywide Voluntary Product Standards* (1975), but this book ignores the relationship between innovation and standards, and is not satisfactory in its development of theory.

In light of the large gap in the literature, the purpose of this thesis is to answer the following question: what role can industrywide voluntary product standards play in stimulating economic efficiency, and how should they be implemented to play this role? More specifically,

1) What sources of inefficiency can industrywide voluntary product standards help resolve?

2) What are the appropriate chronological points in product development and diffusion for the promulgation of standards? If developed too early, standards may retard innovation. On the other hand, commercialization of an innovative product may unnecessarily be held back if standards are delayed too long.

3) How can standards be written so that, in attempting to resolve certain market failures, they do not exacerbate others? An example of the problem--if a standard is too design-specific it may prevent the development of other designs yielding superior performance.

It is hoped that the answers to these questions will form a theory of the potential economic role of standards. As theory, the answers will not fully address the institutional issues so important for the implementation of the theory. However, such a theory can be of use to those involved in standard-setting. A better appreciation of societal interests may further private interests. Also, organizations representing the public interest in standards-setting, such as the National Bureau of Standards, may find a theory of use to guide their involvement in the voluntary process.

In order to provide a framework within which to answer the questions, the paper needs to set forth a rather large conceptual foundation. The
next three chapters will set out a model of the industrial environment in which standards function. Chapter II will break down the notion of economic efficiency into three parts—efficiency in developing innovations, in production, and in the marketplace. In Chapter III, a model of the sequential patterns of innovation in industrial products and processes will be developed—this model draws on the work of William Abernathy and James Utterback. An understanding of the likely sequence of and interrelationship between product and production process innovation is important for the discussion of the appropriate timing of the various types of standards. Chapter IV uses the two preceding chapters to describe the significant sources of inefficiency that occur at each major phase in the evolution of a product and an industry. The sources of inefficiency will be characterized according to their effects on the three types of economic efficiency. The last section of the conceptual foundation (Chapter V) will define and describe the types of product standards according to technical function. Once the foundation has been set, the remainder of the paper (Chapter VI) will concern itself with answering the questions posed earlier.

Because the conceptual foundation is long and complex, a summary of the findings of each chapter is provided below to give the reader an overview. An explanation of the findings is left to the main body of the text.

In order to discuss economic efficiency in a world where innovation exists, Chapter II will describe three types of economic efficiency—marketplace efficiency, firm static efficiency, and firm dynamic efficiency. The first two types are derived from neoclassical
economics, which holds product and process technology constant. The third concept, based on the work of Burton Klein, is a measure of the extent to which firms develop product and process innovations.

Drawing on the empirically-derived model of William Abernathy and James Utterback, Chapter III traces the sequential patterns of innovation over the evolution of an abstract industry and its product. Essentially, in the early stages of an industry and product development, major and frequent product innovations take place; competition between firms tends to be over product performance. As time goes on, a dominant product design is adopted by the market; product change becomes less frequent and more incremental. When products share a dominant design, competition tends to be over reducing product cost.

In the early stages, the production process tends to be flexible and labor-intensive because of small market volume and the need to adapt to frequent innovation. Later, as product demand and production volume rise, production process innovations tend to become frequent, yielding significant economies of scale. They are sought because, after dominant design, the competitive emphasis is on cutting costs. Process innovations usually lead to greater capital intensity, which often inhibits further major product innovation because of the costliness of overhauling the production process.

Using the terms of economic efficiency of Chapter II, a high level of dynamic efficiency tends to occur in the early stages of industry and product development--product innovation is frequent due to a large untapped technological potential and flexible production process. Static efficiency is sacrificed somewhat. In the later stages, the focus is on
achieving a high level of static efficiency; dynamic efficiency tends to be inhibited by the rigidity of the production process.

Chapter IV identifies the major sources of inefficiency, their impacts on the three types of efficiency, and their general stages of appearance in the evolution of an industry. Thus, Chapter IV integrates and extends the work of the previous two chapters. The major sources of inefficiency include producers' market uncertainty, technological uncertainty, the public good nature of technical information, inefficient market structure, narrow management focus, buyer uncertainty, excessive transaction costs, and negative externalities. For example, buyer uncertainty about the performance of a product is a marketplace inefficiency in that buyers do not have accurate product information; it tends to be most significant when a product is new to the market.

The basic types of industrywide voluntary product standards will be described in Chapter V. The elements of the typology are differentiated by the type of technical outcome to be induced by the information being communicated, i.e. by technical function. We have identified six basic types of standards, each with a distinct technical function:

1) Terminology--establishes a common language for a product, product components, product characteristics, units of measurement, and patterns of behavior.

2) Measurement method standards--specify methods for quantitatively measuring the physical characteristics or properties of objects. Examples are standards for measuring size, level of radiation, temperature, and viscosity.

3) Test method standards--specify methods for testing the characteristics, properties, or performance of a product pursuant to quality or compatibility standards. Test method standards often rely on measurement method standards.
4) Quality standards--establish criteria which indicate acceptable and unacceptable product performance, design, or materials. Quality standards can be divided into several categories, such as durability standards, efficiency standards (e.g., miles-per-gallon standards for cars), safety/environmental standards, and output/outcome standards.

5) Variety reduction standards--establish a limited and discrete variety of acceptable product characteristics (e.g., physical dimensions, output levels) for the purpose of achieving production economies of scale and/or reducing buyer information costs.

6) Compatibility standards--specify the characteristics or properties a product shall have in order to be compatible with a conjoint product (e.g., standards for light bulbs which make them compatible with light sockets).

Chapter VI provides the final analysis, integrating and extending the work which has come before. Standards are found to have four types of impacts on the sources of inefficiency--direct, indirect, impacts through use as building blocks for direct-impact standards, and impacts through the discovery of new technological knowledge as a byproduct of the standards development process. The sources of inefficiency which can be directly impacted by standards are market, technological, and buyer/excessive transaction costs, and negative externalities. The resolution of these uncertainties can increase all three types of efficiency. Each type of standard has at least one direct impact on a source of inefficiency. Terminology, measurement method standards, and test method standards act as building blocks for the other three types of standards. New technological knowledge can be discovered through the development of any of the standards types--this knowledge can reduce technological uncertainty and the negative effects of the public good nature of technical information.

One danger in standards development is that standards may retard future product innovation by institutionalizing certain product
characteristics. This problem needs to be dealt with by not issuing
detailed standards until the targeted product characteristics seem to have stabilized in a technological sense.

When discussing an industry in the abstract, it is very difficult to say which standards have the greatest impact and which types of impacts are most important. The importance of each impact varies from industry to industry, depending on the industry's product, market structure, technological potential and so on.
CHAPTER II. ECONOMIC EFFICIENCY

The ways in which we allocate our resources have a direct effect on economic growth. Some patterns of allocation can produce more output than others, given the same initial input. The term "economic efficiency" as used here is a relative measure of the productiveness of possible allocations--some allocations are more "efficient" than others.

For the purpose of this paper, we can distinguish among three types of economic efficiency: (1) firm dynamic efficiency, (2) firm static efficiency and (3) marketplace efficiency.

The concepts of firm dynamic efficiency and static efficiency are drawn from Burton Klein's Dynamic Economics (1977). Let us assume a world of imperfect technological knowledge, contrary to the neoclassical formulation. In this world, product and production process innovations are always possible. Such innovations allow society to get more utility for its resources, either through extending society's production-possibility frontier, or changing the composition of the frontier by adding final goods with greater utility per unit input than substitutes which serve an unmet need. (Many new final goods do both.)

A firm's dynamic efficiency is a measure of its contribution to the expansion of or positive change in the composition of the societal production-possibility frontier through its addition to technological knowledge (which it may or may not share with others) and the application of this new knowledge. Applications can take the form of product innovations or innovations in a firm's production process. Dynamic efficiency is a relative (and unquantifiable) concept--there can be no optimal dynamic efficiency because knowledge is incomplete. Klein
asserts that dynamic efficiency is a function of competitive risk; uncertainty regarding profits and market share forces firms to take technological risks.

The notion of firm static efficiency is based on the neoclassical concept of optimal production efficiency, where output is maximized subject to budget constraints. In the neoclassical formulation, technological knowledge is perfect—the product is static, and the production function of all possible combinations of inputs is known. Accepting the assumption that technological knowledge is imperfect, we can think of static efficiency as a measure of the extent to which the firm is able to minimize production costs on the basis of initial conditions, i.e. existing knowledge. Static efficiency is a measure of the distance of the firm from the point of cost minimization for the output produced.

To keep the use of terms clear: the developer of a new cost-saving product, say a word processor, is being dynamically efficient, while the buyer of the new cost-saving product is being statically efficient because the word processor is now, to the buyer, incorporated into a new set of initial conditions.

Marketplace efficiency measures the extent to which the present outcomes of exchange between buyers and sellers approaches the pareto optimal condition, in which no one can be made better off without someone else being worse off. The situation being observed is static -- no innovation is being introduced. The degree of marketplace efficiency is positively related to the degree of effective competition, the extent to which accurate information is available to buyers and sellers, and the
absence of externalities and public goods. These characteristics influence marketplace efficiency through their impact on prices, the mechanism by which resources are allocated in an exchange economy.

These three types of efficiency are not independent of one another. Because a firm has limited resources, there are tradeoffs between a firm's degree of static and degree of dynamic efficiency. For instance, a high dynamic efficiency implies flexibility in the use of resources so as to quickly be able to utilize new product and process ideas; however, flexibility may mean that equipment is less specialized than is possible, and some economies of scale in production are lost. (Costs are not being minimized on the basis of initial conditions). On the other hand, a high degree of static efficiency often involves rigid, capital-intensive production processes which generate large economies of scale but are too specialized, and therefore too costly, to adapt easily to a series of new ideas.

The relationship between marketplace efficiency and dynamic efficiency is a complex one. In theory, optimal marketplace efficiency requires perfect competition (a very large number of small firms) so consumers are gaining the largest consumer surplus possible. The question is: What type of market structure induces significant dynamic efficiency?

Perfect competition may be the desired market structure in a situation where the composition of goods in the production-possibility curve is fixed. However, perfect competition may not induce much dynamic efficiency. Scherer (1979) suggests that with a very large number of firms in a market, the impetus to innovate would be lessened because
imitation would quickly reduce any new profits. "Also, if the number of imitating rivals becomes large, pricing discipline may break down, causing not only the innovator's share of the pie, but the pie itself, to shrink." 4

To Klein, dynamic efficiency is positively related to the degree of profit uncertainty faced by the firms in an industry, not the number of firms per se. Profit uncertainty stimulates firms to invest resources into taking technological risks. A significant degree of competition is needed between firms to provide this uncertainty—and a certain number of firms are needed for effective competition. Klein estimates that, as a rough guess, at least 4 to 8 firms must account for 50 percent of the market. "If the degree of competitive rivalry is high, industries such as the aircraft industry can bring about an impressive rate of progress with fewer than six firms." 5

Scherer posits that firms will make their decisions about investing in technological development of new products in response to two conflicting factors related to market structure. The stimulus factor is a function of the number of firms in an industry:

The more evenly matched rivals there are with a stake in the market, the larger will be the portion (which would otherwise go to rivals) the innovator gets to enjoy during its term of leadership. Moreover, by leading the way the innovator may also be able to gain an image or reputation advantage, enabling it permanently to increase its market share at the expense of rivals. The larger the share of the market rivals would command if they exactly matched its new product introduction date, the more the innovator has to gain by being first and permanently capturing some of that share, ceteris paribus. Or to put the point the other way around, the smaller a company's share of some new product market will be if it fails to lead, the more it has to gain by leading, and hence the more rapidly it will be inclined to proceed in its R & D effort. 6

On the other hand, dominant firms are not likely to be vigorous
innovators, since there is not much it can take away from others, and, in Klein's terms, they face low uncertainty.

The market room factor reflects the profits a firm expects to obtain through product innovation. It says that a larger number of firms, beyond some point, can discourage innovation because expected profits are too low:

Whether or not this happens depends largely upon the interrelationship of five variables: the size of the overall market profit potential, the number of actual or potential rivals vying to share that potential, the speed at which rivals are expected to react and imitate, the degree to which being first confers a permanent product differentiation advantage, and the magnitude of anticipated R&D costs. The smaller the new product market's total profit potential is in relation to any single firm's development costs, ceteris paribus, the more the presence of a significant number of rivals is apt to discourage early innovation.7

In light of these factors and after a review of a number of empirical studies, Scherer feels that the extent of recognized untapped technological opportunities in a field is the primary determinant of whether product innovation best occurs with a large or small number of rivals. In a field of high technological opportunity, the existence of large numbers of firms seems to stimulate innovation because of the great profit potential and belief that success in the marketplace is a result of innovative leadership. On the other hand, in fields of low and medium technological opportunity, a degree of oligopoly seems to stimulate innovation, probably because expected profits and market share need to be large enough to justify R&D expenditures in a situation of modest profit potential.

Scherer's analysis coincides with Klein's notion that uncertainty breeds innovation. Uncertainty is greater the larger the potential for
new profits is.

One also would think that process innovation would be stimulated by uncertainty, where uncertainty is a function of the degree of competition between firms. According to Abernathy and Utterback, major process innovations tend to take place once the dominant design of a product is established. Competition over performance shifts to competition over cost -- economies of scale are sought. (More about this in Chapter III.) It seems clear that process innovation can be stimulated by uncertainty regarding the outcome of price rivalry. However, many major process innovations require a large product volume to be worthwhile. Consequently, process innovations may result in a reduction in the number of firms in an industry, and a lessening of uncertainty. Buyers may receive the benefits of economies of scale on the one hand, but face oligopolistic pricing on the other.

In sum, the relationship between marketplace efficiency and dynamic efficiency is complex. We assume that marketplace efficiency increases with the number of firms competing. In fields of high technological opportunity, a large number of firms is also conducive to dynamic efficiency. However, in fields of less technological opportunity, fewer firms may be more conducive to product innovation, but this may have a negative effect on marketplace efficiency. Further, innovations may result in fewer firms and oligopolistic pricing as the innovations enable production costs to fall as volume gets very large.

What is the market structure that provides the optimal mix of marketplace and dynamic efficiency, the optimal mix of competitive pricing, economies of scale, and product innovation? This is difficult
to determine, because it means ascertaining the present discounted value of future benefits of yet-to-be-invented product and process innovations. However, the general relationship between market structure and marketplace and dynamic efficiency seems clear, and will be referred to as we analyze the role of standards.

Having refined the notion of economic efficiency into three types and having shown the basic interrelationships between them, we now are also able to refine the basic question guiding this thesis: what role can standards play in increasing the three types of economic efficiency? Given that increasing one type of efficiency may reduce or increase another, how can standards maximize overall efficiency?

From a quick review of the typology of standards listed in Chapter 1, we can intuitively see that the implementation of each type of standard can have different implications for each type of economic efficiency. For instance, terminology can increase all three types of efficiency through the facilitation of communication. Quality standards may increase marketplace efficiency (by reducing consumer uncertainty and information costs); subsequent increased demand may increase economies of scale (static efficiency) and generate funds for further research and development (dynamic efficiency). The context and timing of a standard has implications as well. A quality standard could be imposed in such a manner as to lock in an inferior or underdeveloped technology, to the detriment of dynamic efficiency. Also, we can see potential examples of the tradeoff between static and dynamic efficiency. The standardization of a product through variety reduction may allow investment in specialized capital equipment which can reduce production costs (and
hence increase static efficiency); such capital-intensiveness may, however, reduce flexibility to respond to innovation.

We can move from an intuitive to a more systematic discussion of the effect of standards on efficiency after we set out a model of the sequential patterns of product and process change and the sources of inefficiency in the following two chapters.
CHAPTER III. A MODEL OF THE SEQUENTIAL PATTERNS OF INNOVATION

After a new product is introduced, the nature of the product and its manufacturing process usually change over time. The airplane, the automobile, the light bulb, the computer and the record player all have evolved significantly since their invention, as have their associated manufacturing processes. The intent of this chapter is to present and comment on a model of the sequential patterns of such changes, developed by William Abernathy and James Utterback in Abernathy's The Productivity Dilemma (1978), and to extend that model for the purposes of this paper.

The Abernathy-Utterback Model

The unit of analysis in the Abernathy-Utterback model is the "productive unit," which the authors define as "an integral production process that is located in one place under common management to produce a particular product line." Thus the concept of productive unit takes in both the product line and the manufacturing unit. According to Abernathy and Utterback:

A productive unit would typically be an operating unit of a firm that is located in one geographic area under the management of one senior executive. An engine plant and the line of engines it produced is one productive unit. An assembly plant and the particular car it produces is another.

One firm can be composed of one or many productive units. A productive unit can produce final goods, capital goods, or components (material inputs) to be used in manufacture by other units (within or outside the firm). This segmentation does not appear to alter the generality of the model.

The productive unit can be described in terms of a number of
characteristics, and change in the productive unit can be described in terms of changes in these characteristics over time. Production-process characteristics include: types and sources of material inputs, scale of operation, production-process equipment (e.g., general purpose, specialized), production-process configuration (e.g., job shop, assembly line), necessary work force skills, and methods of organization and supervision. Product-line characteristics include: degree of product standardization, frequency of product change, and degree of product-line differentiation.

Abernathy and Utterback developed their model after an extensive study of the automobile industry and review of numerous case studies of technological change in other industries. They discovered great similarities across industries in the evolution of product and process technology. The hypothesis underlying the model is that the type, frequency and locus of innovation change as the productive unit evolves.

In respect to type and frequency, it is expected that major product innovation will be more frequent initially, relative to process innovation, but that process innovations will increase in relative importance as development advances. In respect to the locus of process innovation, . . . the originating source of important process innovations is expected to shift from within to outside the firm.4

The authors perceive that productive units tend to evolve through three distinct stages: 1) the fluid stage - characterized by frequent product innovation and a flexible production process, 2) the transition stage -- in which the frequency of product innovation falls, the frequency of process innovation rises, and the production process becomes more capital-intensive and inflexible, and 3) the specific stage in which the rate of product and process innovation both fall, the product is
almost completely standardized, and the production process is very rigid. Figure 1 depicts the authors' perception of the relation between stages and rates of technological change.

Tables 1A and 1B, show the structure and flow of the Abernathy-Utterback model in detail, in terms of the productive unit characteristics listed before. The model embodies three principal ideas: "...that there is a normal rate and direction in technological progress, that progress in one aspect is dependent on that in others, and that a certain degree of evenness in progression among many different elements is essential to the advance of any one." In the above quote, one may read "aspect" as "characteristic."

According to the authors, "(t)he model applies most directly to a productive unit in which multiple inputs are combined and transformed through a complex production process that yields a highly valued product whose characteristics may be varied." It is not intended to depict the patterns of innovation in industries with a definitionally standardized production, e.g. sulphuric acid, nylon, or copper. In these cases, radical production innovation is by definition limited.

The model begins at the point where a radical product innovation is developed. Radical product change involves identificaton of an emerging need or a new way to meet an existing need. Often, the need and form of the innovation are suggested by potential users. Usually new firms are founded to exploit the innovation. Existing firms producing older, competing products tend to be too oriented to existing markets to understand the opportunities offered by the new product, or tend to be unwilling, because of sunk costs in specialized production processes,
Figure 1: The Rate of Major Innovations by Stage of Productive Unit Development

From Abernathy, The Productivity Dilemma, p. 72.
© William J. Abernathy
## Table 1A: Productive Unit Characteristics

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
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<th>E</th>
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<tbody>
<tr>
<td><strong>Central tendency in development</strong></td>
<td><strong>From: Custom product, specialized for appeal to specialized markets</strong></td>
<td><strong>To: Fluid change</strong></td>
<td><strong>From: Fluid change and independence among included operations</strong></td>
<td><strong>From: High trade craft skill and manual tasks</strong></td>
<td><strong>From: Manufacturing equipment</strong></td>
<td><strong>From: Small scale; assembly with ill-defined output limits</strong></td>
</tr>
<tr>
<td>1.</td>
<td><strong>Produced to customer order and specification.</strong></td>
<td><strong>Frequent major and novel product change.</strong></td>
<td><strong>Job Shop: Adaptable, fluid flow configuration</strong></td>
<td><strong>Craftsman or artisan skills required.</strong></td>
<td><strong>General-purpose equipment predominates.</strong></td>
<td><strong>Capacity limits ill-defined. Scale is small, many components purchased.</strong></td>
</tr>
<tr>
<td>2.</td>
<td><strong>At least one model “sold as produced” in substantial quantities (with or without options).</strong></td>
<td><strong>Incremental change introduced during production, with periodic major model redesign across product line to increase functional product performance.</strong></td>
<td><strong>Line-flow configuration with separate production process for each standard product.</strong></td>
<td><strong>Operative skills and short task duration (minimum skills and training).</strong></td>
<td><strong>Frequent use of machines that perform multiple operations at one station.</strong></td>
<td><strong>General-purpose plant of moderate scale. Capacity increased by parallel similar plants.</strong></td>
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<tr>
<td>3.</td>
<td><strong>Dominant product design (one type design gains major market share, forcing competitive reaction).</strong></td>
<td><strong>Long periods between major model changes. Refinements emphasized. Changes no longer made across all models in line but are introduced selectively by model.</strong></td>
<td><strong>Closedly balanced, commonly paced tasks organized and controlled by component.</strong></td>
<td><strong>Mixed skills and tasks, some operators and others monitoring.</strong></td>
<td><strong>Integration of special machines at some stations to form islands of automation.</strong></td>
<td><strong>Substantially devoted input sources either through backward integration or other forms of close supplier control.</strong></td>
</tr>
<tr>
<td>4.</td>
<td><strong>Highly standardized product. Options for different market segments formed as peripheral variations</strong></td>
<td><strong>Incremental product change implemented through process improvement, emphasizing greater product consistency and standardization.</strong></td>
<td><strong>Technology controlled continuous or near-continuous flow.</strong></td>
<td><strong>Predominant tasks are equipment monitoring and intervention when equipment fails. Predominant skills are process maintenance.</strong></td>
<td><strong>Extensively integrated and direct linked process designed and procured as system.</strong></td>
<td><strong>Capacity organized by process types. Separation of dissimilar or uncommon production processes from segment.</strong></td>
</tr>
</tbody>
</table>

**Specific**

| E | 5. | **Functionally standardized product(s).** | **Predominant tasks are equipment monitoring and intervention when equipment fails. Predominant skills are process maintenance.** | **Extensively integrated and direct linked process designed and procured as system.** | **Extensive integration into raw materials.** | **Large-scale plant specialized to particular process function, capacity well defined, increased only by designing new facilities.** |

From Abernathy, The Productivity Dilemma, p. 148-149 © William J. Abernathy
Table 1B: Productive Unit Characteristics

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Product Line</th>
<th>Production Process</th>
<th>Organizational Control</th>
<th>Kind of Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid Boundary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequent and novel product innovation market stimulated.</td>
<td>High product-line diversity produced to customer order.</td>
<td>Flexible, but inefficient. Uses general-purpose equipment and skilled labor.</td>
<td>Loosely organized. Entrepreneurially based.</td>
<td>Small scale, located near technology source or user. Low level of backward vertical integration.</td>
</tr>
<tr>
<td>Cumulative product innovations usually incorporated in periodic changes to model line. and Increase in process innovations—internally generated.</td>
<td>At least one model sold as produced in substantial volumes.</td>
<td>Increasingly rationalized process configuration with line-flow orientation, relying on short-duration tasks and operative skills of the work force.</td>
<td>Control achieved through creation of vertical information systems, lateral relations, liaison and project groups.</td>
<td>Centralized, general-purpose capacity where scale increases are achieved by breaking bottlenecks.</td>
</tr>
<tr>
<td>Technology-stimulated innovation.</td>
<td>Highly standardized product with few major options.</td>
<td>“Islands” of specialized and automated equipment introduced in some parts of process.</td>
<td>Control achieved by means of goal setting, hierarchy, and rules as the frequency of change decreases.</td>
<td>Facilities located to achieve low factor-input costs, to minimize disruption, and facilitate distribution.</td>
</tr>
<tr>
<td>Cost-stimulated incremental innovation predominates. Novel changes involve simultaneous product and process adaptations and are infrequently introduced.</td>
<td>Commoditylike product specified by technical parameters.</td>
<td>Integrated production process designed as a “system.” Labor tasks predominately those of systems monitoring.</td>
<td>Bureaucratic, vertically integrated, and hierarchically organized with functional emphasis.</td>
<td>Large-scale facilities specialized to particular technologies, capacity increases achieved only by designing new facilities.</td>
</tr>
</tbody>
</table>

From Abernathy, The Productivity Dilemma, p. 82
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to take advantage recognized opportunities

Competition among producers of a new product and between them and producers of older substitutes is generally on the basis of performance rather than lower cost. First of all, it is obvious to all competitors that there is room to improve performance. Secondly, early users of the product often have price-inelastic demand, and the lack of standardization of the new product (i.e., lack of equal performance) makes comparison on cost alone not worthwhile. Thus, the competitive pressures to improve new product performance in order to capture and hold on to desired market share result in a high rate of product innovation and radically different product versions soon after initial product introduction. These major innovations force frequent model changes that quickly make existing versions obsolete.

When a radical product innovation first appears, performance criteria are typically vague and poorly understood. "...(T)here is a proliferation of product-design criteria or performance dimensions. These frequently cannot be stated quantitatively, and the relative importance or ranking of the various dimensions may be quite unstable." Initially, the product line is diverse in the sense that most products are made to customer order and specification. Market needs are ill-defined. Because the product is new, the size of the market is small and often unstable.

Because of low volume, non-standardized products, a high rate of product change, and market instability, the initial production configuration tends to be the job shop.
In the early fluid state, the production process is inchoate, the duration of labor tasks is long, there is reliance on skilled labor often organized along trade-craft lines. Flows of work in process are erratic, inventories are high, and general-purpose equipment is utilized. In general, the organization of the production process is like a job shop: there is slack, and capabilities are flexible even though they are not "efficient" in the same sense as non-production facilities.8

The transition stages are represented by stages 2-4 in Table 1A. In the first step of the transition process, the productive unit develops a product "that has sufficiently broad appeal to be produced in long runs and sold as standard rather than a made-to-order product."9 Major product innovations still occur, but these now tend to be cumulative in nature rather than a radical redesign of the product. The production process configuration changes from one of a job shop to an intermittent line-flow movement. "That is, changes are made so that operations are performed as work moves forward, without retracing, typically in batches that are processed intermittently."10,11 Semi-skilled workers replace craftsmen, and some specialized equipment appears. Plant capacity increases; the firm may build new plants.

The productive unit moves into the stage 3 once a dominant product design for the industry has been established, "one that attracts a significant market share and forces imitative competitive design reaction."12

The superior designs of products like the DC-3 and the Model T Ford seem to mark turning points in the development of their respective productive units. These designs were synthesized from individual technological innovations that had been introduced independently in prior products. The important economic effects of a dominant design afford a degree of enforced product standardization, so that production economies can be sought, and provide a benchmark for functional performance competition, so that effective competition can take place on the basis of cost as well as product performance. Product design milestones are also apparent in other product lines.
where evidence is available on patterns of development over time. Sealed refrigeration units for home refrigerators and freezers, the development of an effective can-sealing technology in the food-canning industry, and, in the locomotive industry and railroads, Charles Kettering's standardized diesel locomotive can be considered dominant product designs.\(^3\)

For the purposes of this paper, it is important to note that the appearance of the dominant design induces a large degree of product standardization throughout the industry, as a competitive reaction.

Once a dominant product design has been accepted, the rate of product innovation falls and changes become incremental. Periodically, entire product lines get redesigned to improve functional performance. The impact of a dominant design decreases product line diversity as well.

In part because the appearance of a dominant design facilitates cost competition as well as performance competition, the frequency of production process innovation (to cut costs) rises as the frequency of product innovation falls. Through increases in product standardization, demand for the product, and market stability, the production process can be further "rationalized". The production process configuration becomes a line-flow (i.e., assembly line) one. Special-purpose machinery is developed to eliminate production bottlenecks. Work is further de-skilled, now only requiring the manual dexterity of an operative. (An automobile assembly line before robotics is a good image of this stage.) As volume increases, the productive unit tends to subdivide into more homogenous units.

With the growth of and standardization in the industry, supplier networks develop to provide specialized material and capital inputs. Competition between suppliers encourages innovation in factor goods as
In large part because of the high frequency of process innovations induced by competitive pressures to reduce costs, the appearance of a dominant design is usually followed by a drastic reduction in production costs. Unit costs of incandescent light bulbs have fallen 80% since their introduction; costs of the Model T fell a similar percentage. Similar dramatic reductions have been observed for semiconductors, computer core memories, and TV picture tubes. In addition to process innovation, the decline in costs can also be attributed to movement along a learning curve for use of existing production technology.

Productive units in stage 3 often build up their product research and development efforts. In the earlier stages, market needs are too undefined to make large R & D expenditures seem worthwhile; users provide much of the input in early product development. However, as a stable market grows for a standardized product, firms set up formal R & D units to exploit technological opportunities. This has occurred in the automobile, bicycle, food, and mining industries, for example. Thus, though the frequency of product innovation falls in stage 3, incremental changes continue.

In the late transition and specific stages, competing products within a particular market become more and more standardized with successive refinements, although product differentiation may be developed to appeal to different market segments. Now, the competitive emphasis is on reducing costs and ensuring product quality. Both goals are pursued through process technological change, for the most part. Increasingly, process innovations come from the supply firms set up to meet the needs
of the productive unit. Through innovation, the production process becomes further rationalized. In stage 4, assembly-line tasks become combined in "islands of automation". In the the specific stage, automation increases to the point where all or almost all manufacturing work is done by machine (what the authors call "continuous or near-continuous flow") -- the predominant tasks are equipment monitoring and the predominant skills are process maintenance and repair. "By linking equipment in this manner, ... it becomes highly specialized to a particular product design. The effect is to link product and process so that both are costly to change, but highly efficient."15

In these later stages, a firm is "composed of tightly balanced homogenous operations and organized in (productive) units synonymous with product components (engine plants, rolling mills for sheet steel, body-building lines and so forth)."16 Other products associated with these stages are light bulbs and refined gasoline.

In order to gain economies of scale and predictability of supply, firms in the later stages often seek control over supply sources through backwards integration. Methods for this are merger, new facility construction, acquisition, and long-term contract.

As a productive unit evolves, the means for organizational control tend to mirror changes in the production process. While organizations in the fluid and early transition stages tend to be flexible, those in later stages tend to be "bureaucratic, vertically integrated, and hierarchically organized."17

After the large investment in a rigid, capital-intensive system geared to one product, the productive unit becomes dependent on a
constant and high-level demand for its current product. Product and process innovations which would significantly disrupt the current process system are not pursued. Because the process is integrated, change is too costly. R & D expenditures fall off. The firm is vulnerable to "changed demand, technical obsolescence, and the need to maintain production volume to cover fixed costs." 18

The authors take pains to point out that they see evolution along the model as neither inevitable nor beneficial. Some industries may never reach the specific stage. Reversal of movement is not ruled out. In Abernathy's study of the automobile industry, he found that reverse transitions in product development sometimes occur. For example, because of a significant product innovation, the Ford auto engine in the 1920's moved from being a stage 4 product (The Model T engine) to a stage 2 product (The Model A engine). However, the product cannot revert to a stage much earlier than the stage of the production process or the product and process will not be compatible. Furthermore, the more capital-intensive the process is, the more costly and difficult process reversal becomes. So, production processes in the middle and late stages limit product reverse transitions. 19

Key Themes of the Model

Looking at the model as a whole, there are a number of major themes running through it which need to be drawn out (some are implicit) and extended for the purposes of this paper. First, the nature of the competitive pressures on the productive unit shifts from competition on product performance to competition on cost as the unit evolves through
the model.

Secondly, in terms of Chapter II, one can see that productive units trade off dynamic efficiency for static efficiency as they progress through the model. In the fluid state, competition is on developing products with higher performance (dynamic efficiency); the flexible production process allows the product innovations to be quickly realized in production. But the production process itself is purposely inefficient in the static sense. As the product is standardized, dynamic efficiency comes from process innovation—but the basic standardization in the process of combining inputs results in higher static efficiency. Finally, as the product is further standardized and the process becomes rigid and capital-intensive, managerial efforts go toward maintaining high static efficiency; the degree of dynamic efficiency is low as innovations come in small increments. In Abernathy and Utterback's words, "The implication is that a given productive unit cannot respond well to all types of demands. It cannot be both highly efficient and support a high rate of innovation."\textsuperscript{20}

Thirdly, once a dominant design is adopted, there is some form of implicit industry-wide standardization. We can assume this may or may not be made explicit by a standards-writing body. Fourthly, the frequency of product innovation is negatively related to the existence of a dominant design, and positively related to production-process fluidity. The determinants of process technological change are the degree of product standardization, the size of the market, and market certainty and stability. As process technological change occurs, the process becomes less fluid, and so more expensive to alter—this impacts
on the unit's ability to afford to implement product innovations.

Finally, though the author never says it directly, the model carries a tendency towards oligopoly as the market expands. There is the implication that in most industries the potential exists for process innovations which generate large economies of scale, and that large production runs are required to generate these economies; the inescapable conclusion one must draw is that the number of firms in the industry in the later stages is smaller rather than larger. There is also the implication that barriers to entry rise as the production process moves to higher stages. This is particularly so for new firms which want to replicate the dominant design; firms which want to challenge the dominant design with an innovative product perhaps can rely less on capital intensity and economies of scale, and be successful with a more fluid production process.

**Criticisms of the Abernathy-Utterback Model**

In order to determine the appropriate chronological points in product development for the promulgation of products standards, we need a model of the sequential patterns of innovation. As such, the Abernathy-Utterback model is clearly very useful for the purposes of this paper. However, there are several criticisms which can be made of it, though few enough to keep it worthwhile for our use.

First of all, the relationship between the productive unit and the firm is not made clear. The model implies that innovation takes place within the productive unit -- this may or may not be true. It would seem that the productive unit is the site of the implementation of policy and
learning that may go on elsewhere. It is both the instrument of and constraint on firm policy. As such, it is still a useful unit of analysis in that it reflects firm policy, innovation and constraints.

Secondly, one wonders somewhat about the generalizability of the job shop-stage of the model for today's new products. Perhaps in most of the case studies the authors reviewed, new products were first produced in job shops. However, it seems that many new products today are first produced at stage 2, e.g., word processors and video cassette recorders. There still are recent new products that were first made in job shops, e.g., solar cells and gene mutations. Perhaps a distinction needs to be made between incrementally new products and radically new products. The distinction between the two is twofold. Incrementally new products are forthright extensions of existing technology and have sizable (though still small) markets with knowledgeable and not particularly resistant customers. These customers can see how the new product is an extension of products they are already familiar with. For example, a videocassette recorder combines the functions of a TV set and a tape deck. Yet it is clearly a new product, not a differentiation of an existing one. Radically new products are not linear extensions of existing technology, and face small, uncertain, unstable markets; most of the potential customers neither understand the possible benefits of the new technology, nor how it operates. Because the incrementally new products face larger and more certain markets, and their technological direction is clear, they can begin production in a higher stage. The radically new products still begin in the job shop.

Having made some criticisms of the model, this chapter will concern
itself with three more topics: 1) the relationship of the discussion in Chapter II on market structure and dynamic efficiency to the Abernathy-Utterback model; 2) James Utterback's findings regarding an established production unit's response to the "technological invasion" of its product market by production units offering innovative products and 3) the application of the Abernathy-Utterback model to an industry, as we are concerned with industry-wide standards.

Chapter II Revisited: the Relationship between Market Structure and Dynamic Efficiency

One can now see that the discussion in Chapter II regarding the relationship between market structure and innovation fits well with the Abernathy-Utterback model. It was suggested that in fields of high technological opportunity, a large number of firms will be most conducive to product innovation because of the large potential for profits stemming from innovation, and the related large profit uncertainty. This situation corresponds to the stages in the Abernathy-Utterback model before the acceptance of a dominant design. With dominant design comes the process innovations which produce the economies of scale, and which in turn induce a reduction in the number of firms which can viably compete in the industry. Scherer suggested that in fields of low technological opportunity, product innovations tend to come from concentrated market structures. Again there is a correspondence with the Abernathy-Utterback model because in the post-dominant design stages, the industry is concentrated and has become one of low technological opportunity -- product innovations are incremental. In a situation where
much of the technology has been exploited and competition is mainly over cost, a large market share is needed to pay off research and development expenditures in the face of the modest per-unit profit potential of innovation.

Extension of the Model -- A General Pattern of Response to Technological Invasion

In Abernathy and Utterback's model, the productive unit is presented in isolation of competing industries in its later stages. One would guess that because the model was presented in a book on the automotive industry, the authors did not think it appropriate to deal with the "technological invasion" of an older industry by a new industry manufacturing a product with a similar purpose, but with a different and innovative technological base. However, consideration of this situation is important for our purposes if we wish to think about standard-setting when an older and a newer industry conflict.

In a paper presented before the American Chemical Society and Industrial Research Institute Symposium on Innovation in Industry, James Utterback claims that the technological invasion of mature industries is more the general rule than the exception. Examples include "electronic calculators replacing electro-mechanical calculators, transistors replacing vacuum tubes, jet engines replacing piston driven engines in aircraft, and diesel electric locomotives replacing steam locomotives..." Other examples: "...the replacement of manual typewriters by electric typewriters, synthetic fibers displacing natural fibers, celluloid roll film replacing gelatin plates in photography...,
(and) gas lamps replaced first by carbon filament incandescent lights, later by tungsten filaments and still later by fluorescent lighting."  

Radically new products tend to be developed not by the established firms, but by users, by small new entrepreneurs, and by larger firms diversifying into new markets:

Usually a radical innovation originates outside the recognized set of competing units in an industry. Small new ventures, or larger firms entering a new business, introduce a disproportionately share of the innovations which create major threats and conversely opportunities. There are many reasons why new entrants as opposed to firms with an existing stake in a business should be expected to be major innovators. The rewards may be greater to the entering firm which views the innovation as opening a new market rather than as a substitute for an existing product. The established firm may view rewards to be obtained from improvement of the existing technology as more attractive, because given the high volume of production of existing lines, return on investment in improvements can be high, rapidly realized, and relatively certain. By entering the new technology, an existing firm may substitute for its own products, thus reducing the benefits to be gained. In markets with relatively stable demand an innovation may even lower total revenues. Established firms are faced with choosing among massive investment in new equipment which will result in stable or declining sales, modifications of current products which can be built with existing equipment, price cutting, or exit from business. But the new firm without an existing stake sees the innovative product as a means for market penetration and rapid expansion.

Established firms are ordinarily highly sophisticated and capable in technical terms. In almost every instance of an invasion studied, existing firms had considered and tried the new technology earlier themselves, or at the same time that invading firms were developing it and rejected it for a number of reasons. While economic arguments may reinforce perceptions and organizational influences, the latter must be governing in most cases. The established business may be growing moderately or strongly. Peoples' careers in the organization have been built on a subtle understanding and long contribution to the development of the established business. Ways to improve the old may be clearly seen while the potentials in the new are much more difficult to comprehend either by the established firms or invading firms. The returns to the old will be quick and sure and spread over a large production volume, while the early gains in the new technology will be slow in coming and difficult. Most importantly, the established firm will tend to view
the new technology simply as a substitute of the old, and it is objectively a poor substitute at first. Its real potential to broaden the base of the technology and market may well be hidden at first and may develop in completely surprising and unexpected ways as users experiment with it in various applications and combinations.24

With regard to economic influences, the Abernathy-Utterback model also points out that the high cost to the established firm of retooling a large, capital-intensive production process is another factor which inhibits major product innovation. Concerning the organization itself, the structure and the managers in the established firms are usually chosen to achieve high static efficiency; they are not intended to successfully handle competitive pressures to be dynamically efficient.

The normal response of the established firms to technological invasion is to push for new levels of performance and quality for their existing product line. Innovations occurred in the gelatin plate industry, the steam locomotive industry, the natural fibers industry, and the icebox industry in reaction to threatening radical innovations. Usually though, such competitive reactions are not enough and the established firms are either forced to exit the business or must accept a greatly reduced market.

In some product lines, the last few firms in the established technology can be highly successful and profitable and even highly innovative. There will probably always be a demand for fine mechanical watches, and perhaps the few firms that survive the present shakeout in the industry will be highly profitable and stable companies. And the few firms which remain manufacturing vacuum tubes, probably supply a higher specialized and profitable market for high performance designs, research and other specialized applications.25

Periodically, the innovative response of the firms relying on the old technology may be so strong as to give the new technology a run for its
money. Aluminum engine blocks appeared likely to capture a major part of the market prior to the introduction of thin-walled cast iron engine blocks in response. The Gar mantle was invented after Edison's incandescent lamp and it was a strong competitor for a time.26

In sum, there is a general tendency for established firms not to be major innovators because of 1) economic considerations -- the availability of certain, substantial short-term profits from selling the established product versus massive retooling of production lines, and less certain and likely smaller profits, and 2) organizational influences -- managers in the established firm have significant personal investment in the existing product, the potential of the new product is unknown, and the established firm tends to be set up for static rather than dynamic efficiency. Thus, the appearance of radical innovations which replace older, established products, tends to start the sequence of the Abernathy-Utterback model over again.

The Application of the Abernathy-Utterback Model to an Industry

The Abernathy-Utterback model was developed to describe the evolution of the characteristics of one productive unit. As was discussed earlier, the productive unit can be seen as a reflection of firm policy and constraints. For the purposes of this paper, however, we need a model of the evolution of an industry over time, because the types of product standards we will be looking at are industry-wide. In Chapter VI, we will use the Abernathy-Utterback model for this purpose. In this section, we provide a definition of an "industry" and highlight how the Abernathy-Utterback model will later be used to look at one. The reader
can keep these in mind as he reads Chapters IV and V.

We will define an "industry" as a group of firms producing products with the same basic function and technological base. The products may vary in quality, cost, and ancillary functions. What constitutes a group of products with a common function and technological base is an arbitrary determination. For our purposes, that determination is made by the firms and professionals who get together to write standards. The standards for gas-powered refrigerators are made by people different from those writing standards for electric refrigerators. Thus, there are two refrigerator industries. Of course, standards-writing groups do not immediately emerge for all radically new products, though perhaps they may for incrementally new products.

Distinctions can be made between industries which produce components/material inputs (used in the manufacture of some final good), those which produce capital inputs (manufacturing equipment), and those which produce final goods (to be used for non-manufacturing purposes). Buyers of final goods may be households or institutions, including other firms. For example, typewriters bought by advertising agencies are considered here to be final goods. The labelling of industries by type of product is somewhat arbitrarily done. One group of firms can make all three types of goods. For the purposes of this paper, if a group of firms manufactures inputs primarily to supply itself for the production of a common final good, the industry is defined by that final good.

For the succeeding analysis in this paper, it will be assumed that the "industry's" good is a final one. Final goods serve a diverse market, whereas material and capital inputs tend to serve narrow ones.
Standards development in the latter markets is generally dictated by the nature of the users' products -- innovation of inputs is technologically constrained by the nature of the final good. This situation is not particularly interesting. On the other hand, the development of final goods is less technologically constrained by users' needs, since they are not embodied in specific products. This characteristic, plus the existence of diverse users, makes the analysis of standards development more interesting. Choosing one type of good simplifies the analysis -- the points to be made about standards for final products are relevant for inputs as well.

Further, the "industry's" product is assumed not to be definitionally standardized, but one for "which multiple inputs are combined and transferred through a complex production process that yields a highly valued product whose characteristics may be varied." 27

With regard to the extension of the Abernathy-Utterback model to an industry in Chapter VI, a number of clarifying assumptions will be made in order to keep the analysis manageable. It will be assumed that all firms' products are concurrently moving through the same stages of the Abernathy-Utterback model, and there are no major technological differences between them. It also will be assumed that most firms move through the process stages concurrently as well -- firms supplying a similar product made in a different process stage are either pursuing product differentiation (and are assumed to be out of the industry) or are non-competitive and will soon be out of business. Reverse transitions for a product may take place, but are constrained by the degree to which process reversal may occur -- in the middle and late
stages, the production process essentially cannot revert. The industry may compete with a more established industry in its infancy and a younger industry in its maturity.
CHAPTER IV. AN EXAMINATION OF POTENTIAL SOURCES OF ECONOMIC INEFFICIENCY

In Chapter II, we identified three types of economic efficiency:

1) **firm dynamic efficiency**—a measure of the extent to which the firm, through product and process innovation, is extending the societal production-possibility curve and/or changing the composition of the curve so as to increase utility.

2) **firm static efficiency**—a measure of the extent to which the firm is able to minimize production costs based on initial conditions, i.e. existing knowledge.

3) **marketplace efficiency**—a static measure of the efficiency of interaction between buyers and sellers, i.e. the extent to which prices represent the outcome of perfect competition, externalities are internalized in prices, all information regarding the product and substitutes is available, and public goods are absent from the marketplace.

The concept of economic efficiency brings with it the concept of economic inefficiency, a situation where the potential for efficiency is not being met. If we can understand the nature of the inefficiency, we can label it, in light of the above definitions, as a dynamic inefficiency (e.g., unmet potential for innovation), a static inefficiency (e.g., non-cost-minimizing choice of production process), or a marketplace inefficiency (e.g., poor information). These three labels will be called types of inefficiency. If significant static and dynamic inefficiency exists over time, it is only because marketplace inefficiencies exist. If the marketplace were efficient, inefficient firms would be driven out of business.

Inefficiencies, however labelled, come from one or several sources, e.g., one source of inefficient prices may be lack of accurate product information. The purpose of this section is to identify potential sources of economic inefficiency as productive units in an industry move through the Abernathy-Utterback model, and label these sources by type of
inefficiency. This will provide the framework for the discussion in Chapter VI of the economic role of industrywide voluntary product standards.

As was said in Chapter III, we will assume that the productive unit's product is a final good, and is not definitionally standardized. To facilitate the discussion of economic inefficiencies, we will define four types of actors which interact with the productive unit. On the supply side are the suppliers of financial capital to the productive unit (investors/lenders), technology developers (product and process), and factor producers. Investors/lenders, technology developers and factor producers may or may not belong to the same firm as the productive unit. Product buyers are the demand-side actors. Their demand may be intermediate or final. It will be assumed that the product is not "sold" to another unit of the firm, but has to compete in the marketplace. Because decision-making authority regarding product and process in a multi-unit firm may be divided between the productive unit and the firm, for the purposes of simplicity it will be assumed decisions are made by the firm and reflected in the productive unit.

To simplify matters, the main body of the discussion below will assume that the industry, in its later stages, is not invaded by a younger industry making a product with an innovative technological base. This assumption will be relaxed at the end of the chapter.
Market Uncertainty

Market uncertainty is a firm's uncertainty regarding its answer to the question: "In order to maximize profits in this industry, what type of product should we produce and how much?" Market uncertainty is always in existence to some degree, but particularly in the pre-dominant design stages when the product is quickly evolving and the market for the product is unsettled. In the early stages, the firm needs to make choices regarding both product development goals and size of production process investment. Uncertainty is acute regarding the future nature of the product (i.e., the dominant design-to-be), current and future demand for and production costs of the product, and the future demand for and nature, supply and prices of substitutes. In addition, market uncertainty exists because consumers do not yet possess "full information about prices and quality differentials of all available alternatives, and therefore their adjustments are gradual and not instantaneous." 2

As a result, the firm and associated technology developers, investors/lenders, and factor producers will slow down their rate of investment in product and process development and manufacturing capacity as they attempt to gather information.

When uncertainties are significant, acquisition of information is called for before decision-making takes place. Firms utilize market studies and engineering cost estimates to reduce uncertainty. Rules of thumb which have worked previously, such as "learning curves" and "product life cycle," will be utilized in some instances. But given bounded rationality, acquisition of full information is not possible. And since costs of making a "wrong" (ex post) decision are substantial, firms will tend to utilize an adaptive, sequential decision-making process.
This is of particular importance with respect to firms' investment decisions on plant and equipment designed to attain the long-run minimum costs of production. Given production uncertainties, the optimal scale of plant will not be attempted at once. Since the market is the final arbiter of whether an investment decision is profitable, actual market tests will be utilized. Pilot plants and initial attempts at market penetration are needed. Firms, if risk-averse, will not seek rapid attainment of scale economies, but rather will respond gradually to market signals.3

The result of market uncertainty in the early stages is a loss both in dynamic and static efficiency. Product development and capacity building which would generate scale economies are slowed. Static inefficiency may also result if guesses about approximate volume and capacity are incorrect, and so resources are inefficiently utilized. In the later stages, when the product is fairly homogenized and "mature", market uncertainty revolves more around the single question of "how much?". Uncertainty regarding present and future demand can result in static efficiency losses if production runs and capacity investment are inappropriate to actual demand.

Market uncertainty can also be a source of marketplace inefficiency. Even though technological knowledge is assumed to be static when marketplace inefficiency is considered, a lack of understanding by firms in an industry regarding what current possible product variations buyers desire can result in a less-than-optimal exchange. This lack of information by producers needs to be widespread to affect marketplace efficiency -- if some producers have accurate knowledge and some do not, marketplace efficiency will be maintained if buyers flock to the producers where products better meet their needs. Situations of widespread lack of understanding of consumer desires tend to occur when
buyers' and sellers' experience with a particular type of product is new, i.e. in the early stages of the Abernathy-Utterback model.

**Technological Uncertainty**

--- Product

For any desired, but undeveloped, product, there exists several alternative technological paths/designs which a firm could pursue. Product technological uncertainty is uncertainty regarding the list of the possible technological options, the feasibility of the various options, their respective development costs and time, and the ultimate relative performance of each option. Uncertainty about relative performance relates to market uncertainty—a firm cannot be sure that it will choose one path and successfully develop a product only to find that a competition has produced a better one.

In the pre-dominant design stages, product technology is unsettled and experience with the technology is minimal, so technological uncertainty is high. Coupled with the high degree of market uncertainty in this period, the effect is to raise investment risk, and slow down investment in product development. Adaptive sequential decision-making is adopted. In nascent, high-risk industries where large amounts of investment capital are needed (e.g., photovoltaics), the two types of uncertainty may result in the majority of investment being undertaken in subsidiaries of large, well-financed firms successful in other older industries (e.g., oil companies). Such restrictions could have
anti-competitive results (marketplace inefficiency).

After a dominant design is accepted, the basic form of the product is stable for a longer period of time; in the short-run only incremental innovations are pursued. The product technology itself is better understood. Product technological uncertainty will likely be lessened as a result of these two factors. Further, with greatly increased market certainty better estimates can be made of the investment risk in pursuing product technological change, and so research and development is more likely to be pursued.

--Process

Process technological uncertainties exist as well. In the early stages, producers seek flexible process arrangements so any process uncertainties are unimportant. However, once a firm begins planning for mass production, particularly if a dominant design has not yet been accepted, it faces significant process technological uncertainties, i.e. uncertainty regarding the feasibility of various process options, their respective development costs and time, and the relative performance of each option. While process technological uncertainties peak in the stage 2-3 period, they exist afterwards to significant degree, as long as frequent process changes are taking place. Abernathy and Utterback make the point that in the later stages, process innovations tend to be developed outside the firm producing the good. External developers of process technologies will also have product technological uncertainty, as their product is process innovations.
Public Good Nature of Technical Information

Technical information which is embodied within a product may be called a public good if competing technology developers and producers can gain the information through examination of the product. Such information is called a public good because 1) one person may utilize the information without diminishing its intrinsic usefulness to another person, and 2) preventing people from obtaining and using the information is difficult. Because of the public good nature of technical information, a technology development firm or producer firm may find that information on which it spent significant resources developing is being utilized by other firms at little cost to them and with no financial remuneration to the originator. As an example, semiconductor manufacturers often strip down rival manufacturers' new products to copy the newly developed technology.4

Because of the public good nature of technical information, technology developers may decide to restrict the use of new information through patents and licensing. Such restriction could result in one or a few firms dominating an industry—a potential marketplace inefficiency. On the other hand, patents and licensing can spur competition to further innovation.

Further, if technology developers and producers believe that competing firms cannot be prevented from utilizing new information despite patents, they may decide to decrease their investment in research and development, a reduction in dynamic efficiency.
Inefficient Market Structure

In Chapter II, it was noted that market structure has an effect on both marketplace and dynamic efficiency. Specifically, it was posited that less concentration increases marketplace efficiency and stimulates product innovation in fields of high technological opportunities, and some concentration stimulates product innovation in fields of medium and low technological opportunity. In Chapter III, it was suggested that the degree of technological opportunity in a field tends to decrease as an industry's productive units move through the stages of the Abernathy-Utterback model. Process innovations were said to be generated by profit uncertainty, a function of the degree of effective competition, in turn in part a function of number of competing firms. However, a greater concentration of firms may be needed to exploit the process innovations, to reap the economies of scale.

A desired market structure is one which maximizes the net benefits of competitive pricing, economies of scale, and product innovations. Present market structure has an impact on present pricing and economies of scale, and on future benefits of all three kinds. Different market structures will result in different levels of present and future benefits. Society has some time preference regarding benefits, generally valuing certain positive impacts in the present somewhat more than equal impacts in the future. Taking into account society's time preference of benefits, certain market structures will have higher overall net benefits than others. A market structure is considered inefficient if a change in
the market structure will bring greater net benefits.

While a large number of rivals may mean greater marketplace efficiency at any stage, it seems the number of rivals conducive to dynamic efficiency falls as the industry evolves through the stages. In the early stages, low concentration tends to be conducive both to marketplace and dynamic efficiency; high concentration tends to be inefficient. In the later stages, there appears to be some tradeoff between dynamic and marketplace efficiency as some concentration is helpful to the former but harmful to the later. Because society may be willing to trade off some present competitive pricing benefits for future dynamic efficiency benefits, there may be several efficient market structures in the later stages. Market structures which do not offer maximum net benefits also may occur. With too little concentration, the dynamic efficiency losses (relative to an efficient structure) outweigh the consumer surplus gains; with too much concentration, the consumer surplus losses (relative to an efficient structure) are greater than any additional economies of scale and product innovation benefits.

The Nature of the Production Process

To the extent that the production process is kept flexible to accommodate product innovation, static efficiency is lost. Conversely, to the extent that the production process is made rigid to generate product volume and economies of scale, and potential product innovations are not pursued because of the costliness of overhauling the process
configuration, dynamic efficiency is lost. In the Abernathy-Utterback model, the static efficiency losses occur in the early stages, and the dynamic efficiency losses in the later ones.

Management Orientation

The management skills needed to operate a firm when competition requires a high degree of dynamic efficiency are quite different than those in a competitive situation calling for a high degree of static efficiency. The former emphasizes flexibility, adaptiveness, and an ability to work in the face of the unknown; the latter emphasizes a predilection for detail, ability to work in a hierarchy, and a technocratic orientation. Burton Klein basically sees the difference in another way:

If it is granted that the pursuit of dynamic efficiency requires dealing with more uncertainty than does the pursuit of static efficiency, and that people differ in their capacity to deal with uncertainty, then we should expect to observe a division of labor between firms engaged in dealing with more or less uncertainty.6

If firms (or rather the individuals within firms) specialize in one orientation or the other, there will be instances that managers in firms in the early stages of the Abernathy-Utterback model will miss opportunities to increase static efficiency without sacrificing dynamic efficiency. Similarly, managers in firms in the later stages may miss opportunities to increase dynamic efficiency through product innovation that would provide greater benefit to the firm, despite possible losses in static efficiency, then would sticking with the existing product. This latter point relates to the discussion in Chapter III of James
Utterback's ideas that established firms tend not to develop major product innovations primarily because of the strong orientation of the managers and organizational structure to producing and selling the established product.

Klein paints a picture of the effects of a static orientation (in the days before a 20% Japanese share of the U.S. auto market):

There are Ford and Chrysler engineers who complain bitterly that while they are permitted to undertake some research-and-development projects to prevent General Motors from obtaining a lead, they are seldom permitted to undertake projects that would enable their companies to obtain a significant lead. Why are engineers from these companies so highly constrained? The reason is that what is rational behavior from a creative engineer's point of view is not necessarily rational behavior from the point of view of the Ford and Chrysler top management. Because the firms in question are optimized to deal with a low degree of uncertainty, they dare not impose risks upon their competition to which they cannot respond.

Buyer Uncertainties

In the stages before dominant design, with rapid product evolution and existing products which are not standardized across the industry, buyers are often faced with incomplete product-related information in a number of categories. Often, the information exists but is not easily accessible because of product diversity and constant change, and lack of mass market experience; other times, the information concerns the future and cannot be known until then. In any case, buyer uncertainties are a source of marketplace inefficiency.

There are three major categories of buyer uncertainties. Performance uncertainties are uncertainties about the level of product quality, and
compatibility with the product's technological environment. Product quality characteristics are output/outcome, efficiency, reliability, durability, and health/environmental effects. (These characteristics will be defined in Chapter V.) When a new product appears on the market, potential buyers have a relatively high uncertainty regarding product performance until they begin to hear feedback from reliable sources (e.g., other firms, Consumer Reports, friends), but it takes time and market growth for reliable feedback to become available.

Support uncertainties are uncertainties regarding the availability and reliability of a support infrastructure for helping the buyer with product installation, operation, maintenance and repair. For instance, foreign cars initially did not sell as well as they could have in the U.S. in the 1950's and 60's because many potential buyers were unsure if they could easily obtain reliable support services.

Cost uncertainties take several forms. Buyers are often not sure of the money and time and effort costs the product will require in terms of installation, operation, maintenance, and repairs. These cost uncertainties are in part related to performance uncertainties--the buyer lacks complete information regarding the frequency and intensity of quality problems. In addition, he lacks complete information regarding the costs of fixing any particular quality problem.

Opportunity cost uncertainties are another form of cost uncertainties. The lack of performance certainty regarding the diverse product choices in the early stages makes it difficult for buyers to compare products on the basis of quality-adjusted price. Further, because the product is rapidly evolving, buyers cannot be certain of the
performance characteristics of future product offerings, and thus whether it is better to buy now or later.

Though they always exist to some degree, uncertainties held by buyers tend to diminish as the product evolves through the Abernathy-Utterback model. Once a dominant design is accepted, product offerings of different firms are more easily compared. Product stabilization and the development of an experienced mass market facilitates the development and institutionalization of easily accessible sources of information on production performance.

**Excessive Transaction Costs**

Transaction costs are considered here to be the time, money and effort spent by buyers in searching and arranging the transportation for a product. Costs of finding out information regarding the product itself are discussed in the section on buyer uncertainty. While a large degree of product differentiation in terms of quality, dimension of size or output, and compatibility with other products may offer buyers the benefits of a wide choice, it also may involve higher transaction costs. Because sellers may not carry all the varieties of a product, a specific variation of a product may be harder to find, and may need to be transported over a larger distance than with more product standardization.

Product differentiation is considered optimal if the transaction costs of greater differentiation exceed the benefits of greater choice. If, in these terms, too much product differentiation exists, the
transaction costs are considered excessive and are a source of marketplace inefficiency.

**Externalities**

Negative externalities are costs, resulting from the manufacture and use of a good, which are incurred by persons other than the buyer and seller and not internalized in the market price of the good. They are marketplace inefficiencies. Examples of negative externalities are air, water, and noise pollution, and injuries to third parties resulting from product use. Potentially, negative externalities can occur anywhere along the Abernathy-Utterback model.

Positive externalities are benefits to third parties which are not included in the market price. If one firm trains a worker who then leaves for another firm, the benefit of his training is a positive externality for the second firm. The public good nature of technical information is one type of positive externality.

**The Relationship between the Sources of Economic Inefficiency and the Stages of the Abernathy-Utterback Model**

The discussion above has identified nine major sources of inefficiency, described each in terms of the types of inefficiency (dynamic, static, marketplace) it encourages, and the stages in the Abernathy-Utterback model where it tends to be prominent. Table 2 presents one way of looking at the relationship between stages, types of
### TABLE 2. Significant Sources of Each Type of Economic Inefficiency by Stage of the Abernathy-Utterback Model--for Firms in A Single Industry

<table>
<thead>
<tr>
<th>Stages of Abernathy-Utterback Model</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tr>
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<tr>
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<td></td>
<td></td>
<td>X</td>
<td>X</td>
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<tr>
<td>Narrow Management Focus</td>
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<td>X</td>
<td>X</td>
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<td><strong>Sources of Firm Static Inefficiency:</strong></td>
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<tr>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Nature of Production Process Required</td>
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<td><strong>Sources of Marketplace Inefficiency:</strong></td>
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<td>Excessive Transaction Costs</td>
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</tbody>
</table>

**KEY:**

- **X** A stage when a source of inefficiency will *most likely* appear, as is inherent to the model.
- **0** A stage where a source of inefficiency *may* appear, depending on the nature of the industry's product, structure and management.
inefficiency, and sources of inefficiency. (Remember it is assumed firms in an industry move together through the stages of the model.) In the table, X's are used for sources of inefficiency whose appearance at the designated stages is inherent in the Abernathy-Utterback model, that is, in some sense the sources are a function of technological considerations that occur across almost all industries. The "0's" in the table are used for sources of inefficiency which may appear at certain stages to exacerbate a certain type of inefficiency because of the specific nature of an industry's structure, product, or management.

The placement of X's and O's is somewhat arbitrary. While some degree of each source of inefficiency appears in all stages, we are interested in the stages where the sources are a significant problem. In an abstract model, where significance ends or begins is a judgment call. The earlier discussion in this chapter attempted to point out in what stages the sources tend to appear as significant problems.

Of the sources of inefficiency inherent in the Abernathy-Utterback model (the X's), the table shows all but two appearing primarily in the early stages (1-3). Market uncertainty is a source of all three types of inefficiency in the early stages. It slows investment in innovation and inhibits the use of efficient, high-volume production and equipment; that producers are not clear what consumers want results in marketplace inefficiency as well. Technological uncertainty also slows the development of innovations (product and process) in the early stages. Buyer uncertainty is clearly a source of marketplace inefficiency in the early stages - consumers lack information regarding product performance and ownership costs with which to compare existing and future product
variations. Finally, a flexible productive process required in the early stages by competitive pressures means producers are consciously choosing to reduce static efficiency to gain the fluidity to be dynamically efficient.

The two sources of inefficiency in the later stages of the model reflect established firms' tendency to seek static efficiency at the expense of dynamic efficiency. First, because competition in the later stages is over cost, firms need a capital-intensive production process which yields high economies of scale. However, capital-intensive processes often make process and product innovation, in the short-run, not economically worthwhile. Second, a management narrowly focused on static efficiency and short-term profits will reject, not comprehend, or not have the skills to fully exploit possibilities for major product innovation. As Utterback points out, "(w)hile economic arguments may reinforce perceptions and organizational influences, the latter must be governing in most cases." ⁸

Of the four sources of inefficiency just discussed, three are forms of informational uncertainty while the fourth is a result of conscious management decisions to emphasize one form of efficiency over another. The three forms of uncertainty are related to the same origins - rapid product evolution, lack of experience with the technology and the market, and the inability to predict the future (i.e., what new and better forms of the product will appear). Market uncertainty is also a function of buyer uncertainty -- if buyers hold back purchases because of lack of information, producers lose feedback by which they can learn about the nature of the market.
The other sources of inefficiency do not inherently occur in the Abernathy-Utterback model, but may because of the nature of a particular industry under study. Inefficient market structure may occur at any point in the model, and constrain both dynamic and marketplace efficiency. The public good nature of technical information may serve as a restraint on companies' investment in product innovations (a dynamic inefficiency) -- this restraint may occur at any stage. The appearance of negative externalities depends upon the nature of the product, e.g., if it can cause harm to third parties uninvolved in the market transaction. Negative externalities also may occur at any stage.

Excessive transaction costs due to product differentiation tends to occur in the first three stages -- there is little product differentiation in stages 4 and 5. Narrow management focus on dynamic efficiency in the early stages may result in static inefficiencies beyond those needed to maintain dynamic efficiency; the reverse is the case in the later stages, where opportunities for dynamic efficiency can be lost because of too narrow a focus on static efficiency. Finally, consumers may face high information costs in determining product quality in later stages if there are no minimum quality standards in force.

Sources of Inefficiency and Technological Invasion

Firms in an established industry (i.e. in the middle and late stages of the Abernathy-Utterback model) faced with invasion by a younger industry making a technologically innovative product have several choices. They can either stick with the established product and not
venture into the new industry, abandon the established product and begin making the new one, or hedge their bets by developing a foothold in the new industry while continuing to manufacture the established product (as oil companies have done with photovoltaics). It seems likely that established firms would not enter a new industry and abandon the old unless the new industry was advanced enough in terms of market size and short-run profits to make up for the opportunity costs of leaving the old industry.

It will be assumed that any productive units created by established firms to manufacture the new product are in the new industry, i.e. not on the Table 2 matrix for the established firms. For firms which keep productive units in the established industry, the sources of inefficiency which tend to appear in a situation of technological invasion are the same as those appearing in a situation of no invasion. Dynamic efficiency is held back by narrow management focus and the nature of the production process required. If market uncertainty appears because of technological invasion, it is likely to be a spur to product innovation, as Utterback points out.
V. THE BASIC TECHNICAL FUNCTIONS OF INDUSTRYWIDE VOLUNTARY PRODUCT STANDARDS

Having discussed the major sources of economic inefficiency, our next step is to outline the basic technical functions of industrywide voluntary product standards. In Chapter VI, we will integrate the analyses of Chapters IV and V to determine the role standards can play in increasing economic efficiency.

Industrywide voluntary product standards transmit technical information regarding product development, manufacture and/or use, and prescribe behavior regarding the use of that information. For instance, the Paper Stationery and Tablet Manufacturers Association recommends that typewriter tablets should be 8-1/2 x 11 inches or 8-1/2 x 13. The technical information transmitted is that of the dimension; the behavior prescribed is that tablet manufacturers should produce typewriter tablets in accordance with the technical information.¹

Standards vary by the nature of the information contained in them. For instance, some standards define the meaning of words; others specify the strength of certain materials, and others indicate the appropriate dimensions of one product so it will fit with another product of standardized dimensions. The nature of the information in a standard implies a certain technical outcome, if the information is used as presented. By technical outcome we mean a result which can be described in physical terms. For example, definitions indicate the vehicles (words) by which people will communicate, materials specifications lead to a built product of a certain strength, and compatibility standards insure certain goods will fit together.
After reviewing existing institutional and academic literature on standards and looking at specific standards themselves, we have identified six basic types of technical outcomes which standards induce. One standard may be intended to bring about one or several technical outcomes. A standard may be described in terms of its technical function(s), i.e. the type of technical outcome(s) it is supposed to bring about. Six basic types of standards, each representing one technical function, are identified and described below -- terminology, measurement method standards, test method standards, variety reduction standards, compatibility standards, and quality standards. Actual standards may be a combination of two or more of these types.

It should be noted that the categorization of standards by form (what they look like) rather than by function (what they do) has been the normal practice heretofore. For instance, ASTM suggests there are five types of standards -- definitions, recommended practices, test methods, classifications, and specifications. Although there is some overlap between the two systems, categorization by form is not particularly useful for purposes of determining the economic role standards can play. We seek to understand what economic functions the technical functions of standards can play.

Terminology

The technical function of terminology is to establish a common language for products, components, product characteristics, units of measurement, and patterns of behavior. An example of standard
terminology is the definition issued by ASTM for the term "vacuum cleaner":

A system or device that removes material, usually loose, from surfaces by means of the air flow caused by subatmospheric pressure, having an intake intended to be moved in proximity to the surface, a means of separating the material from the air, and a receptacle for collecting the separated material. The inlet may be fixed or attached to other equipment and provision is made for removing collected material.3

Another example is the definition of the "curb weight" of an automobile, according to the Society of Automotive Engineers (SAE): "The total weight of the vehicle including batteries, lubricants, and other expendable supplies but excluding the driver, passengers, and other payloads."4

A classification system is a systematically related set of definitions which divide materials, products, or services into discrete groupings according to certain characteristics, e.g., origin, material composition, physical properties, or use. One example of a classification system:

ASTM Committee D-13 on Textiles has devised standard tables for classifying man-made and natural fibers. Man-made fibers are listed according to commercial and biological name, use or staple length, and geographical source.5

Measurement Method Standards

The technical function of measurement method standards is to encourage the quantitative measurement of the physical characteristics or properties of objects in a specified manner. (That the object is measured in the specified way is the technical outcome.) Measurement method standards provide a common language for the communication of the
results of measuring. They may be used in technology development, production, or in conjunction with other types of standards.

Examples of measurement method standards are "Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies" (developed through the Institute of Electrical and Electronics Engineers), "Methods of Measurement of Mercury Lamp Ballasts and Transformers" (developed through ANSI), "Diesel Smoke Measurement Procedure" (developed by the Society of Automotive Engineers), and "Instrumentation and Techniques for Exhaust Gas Emission Measurement" (developed by SAE).

Test Method Standards

A test method standard specifies the procedure for evaluating the characteristics, properties or performance of a product. (The use of this procedure is the desired technical outcome.) The standard generally includes directions regarding apparatus, test conditions, procedures, observations and calculations. A test method specified by a standard is often used to determine whether a product meets a particular quality standard i.e. it will be used in making a judgment of some sort. If the prescribed procedure includes making certain calculations, it will often refer to a measurement method standard.

Examples of test method standards are "Wheels-Recreational and Utility Trailer Test Procedures" (SAE), "Brake Lining Quality Control Test Procedures" (SAE), "Test for Rubber Property--Resilience Using a Rebound Pendulum" (ASTM), and "Testing Urethane Foam Isocyanate Raw
Materials (ASTM).

Compatibility Standards

A compatibility standard specifies the characteristics or properties that a product shall have in order to be compatible with a conjoint product. (Compatibility is the desired technical outcome.) An industrywide compatibility standard allows a product made by one manufacturer to work with a conjoint product made by another, and the replacement of either product by similar products of other manufacturers.

Compatibility standards are numerous and their effects are quite visible in everyday surroundings. Examples of conjoint products which are compatible industrywide through standardization include "tires and rims, pipe flanges and fittings, nuts and bolts, shafting pins and washers, guns and ammunition, records and record players, cameras and film, flashlights and batteries, bulbs and lamp sockets, even beds and sheets." A product can be standardized to be compatible with itself. The size of bricks and the gauge of railroad tracks are standardized for this purpose.

Variety Reduction Standards

A variety reduction standard prescribes a limited and discrete variety of product characteristics (e.g., physical dimensions, output levels) in order to achieve lower per-unit production costs (economies of scale) and/or ease consumer transaction costs in comparison shopping.
A good example of a variety reduction standard is that for beds, which have four standard sizes—twin, full, queen, king. Many variety reduction standards were written by industry associations in the 1920's in response to the urgings of Herbert Hoover, in his role as president of the Federated American Engineering Societies and as U.S. Secretary of Commerce. As examples, product varieties were reduced for clothing, shotgun shells, paint brushes, bricks, nails, files, lumber, paper, and business forms during this period.7

A standard may have a variety reduction function and a compatibility function at the same time. For example, standard file folder sizes have a variety reduction function and are compatible with standard sizes of letters, typing paper and legal pads.

Quality Standards

A quality standard attempts to ensure an acceptable level of product performance along one or several dimensions. Possible dimensions of product performance include output/outcome, reliability, durability, efficiency, and safety/environmental impact. (These terms are defined below.) Quality standards come in a number of forms—performance criteria, design criteria, materials specification, recommended practices. Acceptability is often determined through the use of measurement and test methods.

We can identify five basic categories of quality standards, one for each of the possible dimensions of product performance. A standard is placed in a category according to its specific technical function (which
may or may not be clear to the layman). Several of these dimensions are useful labels only for standards of certain kinds of products. While the dimensions are arbitrary, they do provide a useful way of thinking about types of quality standards. Often, one standard can be seen fitting in more than one category.

--Output/outcome standards

Products which are intended to somehow provide a particular type of output (e.g., electricity) or outcome (e.g., a clean windshield) are often manufactured to conform to a quality standard which specifies a desired level of output or outcome. By "outcome" we mean the product's impact on or relationship to its environment.

As an example of a standard which specifies a particular level of output, SAE Recommended Practice J903c (concerning passenger car windshield wiper systems) states:

The windshield wiper system shall be designed to provide two or more frequencies. One of the frequencies shall be a minimum of 45 cycles/min. The highest and one lower frequency shall differ by at least 15 cycles/min. Such lower frequency shall be at least 20 cycles/min.

The minimum speeds are the required outputs, designed to provide the driver with a particular outcome (visibility).

In a long and complex paragraph, the SAE standard describes the "minimum windshield wiped area"--this is the identification of a certain desired outcome. The desired potency of pesticides when sprayed on certain insects, and the required "time-to-dry" for latex paint are other examples of outcome standards.
Sometimes, a standard for output/outcome is stated in terms of design criteria. This is an example from the standard for gas-fueled refrigerators: "Nonautomatic ice making systems shall have a minimum ice storage capacity of 0.4 pound per cubic foot of total refrigerator storage volume, but not less than 0.5 pound of ice." 9

--Reliability standards

Reliability is a measure of a product's ability to repeatedly perform its function in a satisfactory manner, even under adverse conditions. We use the term "reliability" in connection with products, usually with working/interacting parts, which are called on to perform their functions over and over again. Reliability is one measure of how well the product's components work together.

As an example of a reliability standard, the SAE standard on windshield wipers states that the two operating frequencies "must be obtainable under normal vehicle operating conditions regardless of engine speed and engine load..." 10 The American National Standard for gas-fueled refrigerators says, "Burners shall ignite, operate and extinguish without objectionable noise under all conditions of test specified herein." 11

--Durability standards

Durability is a measure of the ability of the component of a product to physically stand up to time and adverse conditions. Thus, durability
refers to single-component products and individual components of multi-component products. Reliability is a measure of the ability of a multi-component product to perform its function. So, an unreliable product (a clock) could have a nondurable part (a gear).

Example: The American National Standard for steel valves has a number of standards aimed at increasing durability. Valves must have a minimum wall thickness, be able to withstand certain temperatures, be composed of specified materials, and be repaired by welding in a certain manner. To ensure that rubber surgical gloves will not rip during operations, they must have a certain tensile strength. The durability of auto windshield wiper systems must be tested through operation for 1,500,000 cycles (a cycle is one sweep and the return): "Any component failure, except windshield wiper blade element, during this test denotes system failure."

--- Efficiency standards

Efficiency is a measure of a product's consumption rate of inputs required for its operation. Obviously, the term applies only to products which require inputs.

Examples: The American National Standard for gas-fueled refrigerator states:

A refrigerator for storage of frozen foods and making ice shall not require an average input rating of more than 300 Btu per hour for each cubic foot of total storage volume to maintain a temperature of 15 F. in the compartment when operating in room temperature of 90 F.
The American National Standard for gas-fired duct furnaces requires: "Duct furnaces shall have a thermal efficiency of at least 75 percent based on the total heating value of the gas." 16

--Safety/environmental impact standards

The technical function of safety/environmental impact standards is to safeguard human life and health, and the physical and natural environment during product use. Safety/environmental impact standards abound in the literature. In addition to the trade and professional associations, entire organizations such as the National Fire Protection Association and Underwriters Laboratory exist to publish and encourage enforcement of safety/environmental standards. A perusal of standards volumes reveals safety standards regarding the construction of electric dry bath heaters, blower and exhaust systems, household electric ranges, vending machines; and recommended practices regarding the guarding of mechanical power transmission apparatus, the care and use of grinding machines and lathes, and the storage of rubber tires. Other examples include standards for the sterility of rubber gloves, the release of noxious gases from refrigeration, and the fire-resistance of power transformers.
CHAPTER VI: THE ROLE OF INDUSTRYWIDE VOLUNTARY PRODUCT STANDARDS IN STIMULATING ECONOMIC EFFICIENCY

Chapter IV set forth the major sources of inefficiency and their likely stages of appearance; Chapter V described the six basic types of industrywide voluntary product standards according to technical function. The purpose of the chapter is to discuss, by integrating what has come before, the role that standards can play in alleviating sources of economic inefficiency.

To reiterate the simplifying assumptions made in Chapter III regarding the evolution of firms in an industry through the stages of the Abernathy-Utterback model: It is assumed that all firms in an industry are concurrently moving through the product stages of the model, and there are no major technological differences between their products. It is also assumed that most firms concurrently move through the process stages as well, though these stages may be different from the product stages at times. Thus, reverse transition may take place, but is constrained by the degree to which process reversal may occur. For stages 3-5, it is assumed that the production process essentially cannot revert.

A Matrix of the Relationship between Types of Standards and Sources of Economic Inefficiency

Product standards transmit technical information and prescribe behavior regarding the information's use. Each type of standard
transmits information for a different technical function. By their information-transmitting nature, standards in general are useful in diminishing certain types of standards but not others. Each type of standard can also have a unique role, and can affect different sources of inefficiency in different ways.

On the basis of the discussion presented in Chapters IV and V, a number of observations can be made concerning the role of the various types of standards in alleviating each source of inefficiency. Table 3 presents these observations in matrix form. The "A's" indicate the sources of inefficiency on which certain standard types can have a direct impact. For some sources of inefficiency, certain standard types do not have a direct impact themselves, but are used as building blocks for standard types which do have a direct impact -- these building block standards/source relationships are designated "B". The "C's" indicate sources of inefficiency which can be alleviated through a standard type's direct impact on another source of inefficiency. Here, the standard types have an indirect impact. In certain instances of standards development, new technological knowledge may be discovered which can reduce inefficiency. The "D's" designate standard/source relationships where this may occur.


TABLE 3
THE POTENTIAL EFFECT OF THE TYPES OF STANDARDS ON SOURCES OF ECONOMIC INEFFICIENCY

Types of Standards

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Measurement Method Stds.</th>
<th>Test Method Standards</th>
<th>Compatibility Standards</th>
<th>Variety Reduction Standards</th>
<th>Quality Standards</th>
</tr>
</thead>
</table>

Sources of Firm Dynamic Inefficiency

<table>
<thead>
<tr>
<th>Market Uncertainty</th>
<th>B</th>
<th>B</th>
<th>C</th>
<th>A</th>
<th>C</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological Uncertainty</td>
<td>A, B, D</td>
<td>A, B, D</td>
<td>A</td>
<td>D</td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>Public Good Nature of Technical Information</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Inefficient Market Structure</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Nature of Production Process Required</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Narrow Management Focus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources of Firm Static Inefficiency

<table>
<thead>
<tr>
<th>Market Uncertainty</th>
<th>B</th>
<th>B</th>
<th>C</th>
<th>A</th>
<th>C</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of Production Process Required</td>
<td>A</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

Sources of Marketplace Inefficiency

<table>
<thead>
<tr>
<th>Market Uncertainty</th>
<th>B</th>
<th>B</th>
<th>C</th>
<th>A</th>
<th>C</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buyer Uncertainty</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Inefficient Market Structure</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Negative Externalities</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Excessive Transaction Costs</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

Key:

A Standard type has a **direct** impact on diminishing the source of inefficiency.
B For the designated source of inefficiency, the standard type is used as a building block for other standard types which have a direct impact on diminishing the source of inefficiency.
C Standard type has an indirect impact on diminishing the source of inefficiency through its direct impact on another source.
D In the development of the standard type, new technological knowledge may, as a byproduct, be discovered which has a **direct** impact on diminishing the source of inefficiency.
As will be seen, the economic efficiency functions of each type of standard which do not have a direct ("A") impact on a source of inefficiency either build toward ("B") or derive from ("C","D") a direct impact. (The "A's" are circled because of their importance.) Thus, the stages in which certain standards are introduced in order to have an "A" impact affect when the "B" relationship standards are introduced and "C" and "D" impacts occur. One primary, and obvious, consideration in the introduction of "A" relationship standards is that the stages of introduction should correspond to the stages in which the target sources of inefficiency (direct and indirect) are most significant. These stage/source relationships are depicted in Table 2 in Chapter IV.

The following section explores the potential direct impacts which standards can have on sources and types of inefficiencies. The next section looks at the potential negative impacts of standards. Based on the first two, the third section discusses the appropriate stages for the introduction of standards.

The Direct Impacts of Standards

As the "A's" in Table 3 show, product standards can have a direct impact on uncertainties, negative externalities, and excessive transaction costs. Table 2 indicates that the uncertainties tend to be across most industries in the early stages (1-3) of the Abernathy-Utterback model; uncertainties in the later stages and externalities and excessive transaction costs may or may not be significant in an industry. The direct impacts of standards have four
aspects. First, terminology, measurement method and test method standards can help decrease technological uncertainty in all stages. The common use of terms, measures, and evaluative methods can facilitate the sharing of information among researchers, which in turn can facilitate problem-solving and spark new technological insights. These new insights may be the basis for development of products with innovative technological bases (i.e. products around which new industries form) as well as for improvements in existing products.

Second, variety reduction standards can be used to reduce process technological uncertainty, buyer uncertainty, market uncertainty, and excessive transaction costs. Variety reduction standards can reduce process technological uncertainty by reducing the number of varieties technology developers need to concern themselves with. For instance, after the standardization of the size of silicon wafers for photovoltaic cells, engineers were quickly able to develop a new automated semiconductor manufacturing process. Variety reduction standards are likely to have the most impact on process innovations in stages 3-4, when the frequency of major process innovations tends to be highest. (See Figure 1 in Chapter III.)

Variety reduction standards also can reduce market uncertainty, which tends to be significant in stages 1-3. Producers in an industry may manufacture too many varieties of a good because they do not know to which set of reduced offerings consumers would react without there being a falloff in demand and profits. If members of an industry pool their information and develop variety reduction standards which meet consumer needs (and which do not violate antitrust laws), they can reap better production economies of scale. The reduction in variety for market
certainty reasons would also enable process innovations to be developed which take advantage of the less differentiated product line.

Though the impact may be trivial, variety reduction standards can decrease buyer uncertainty as buyers will be more familiar with a reduced variety of product (more certain information). They can also reduce excessive transaction costs by cutting down on search time and effort for a desired form of the product, as sellers will be more likely to carry that form.

Third, compatibility standards can be used to reduce buyer uncertainty and excessive transaction costs, basically in the same manner as variety reduction standards do. Compatibility standards enable buyers to reduce cost uncertainties more quickly by learning that various manufacturers' goods are interchangeable. Reduction in cost uncertainties will lead to greater usage, and less performance uncertainties. The standards also enable more knowledgeable and better-trained support personnel (reduce support uncertainties) as there are fewer idiosyncrasies regarding the technical relationship between various manufacturers' products. By reducing the need to search for uniquely compatible parts, these standards also can reduce excessive transaction costs.

Finally, quality standards can ameliorate buyer uncertainty and negative externalities. These standards can assure buyers (either through use or product reputation) that they are getting products with reasonable output, durability, reliability or other quality attributes. Negative externalities can be reduced through the use of safety/environmental impact standards.
The product standards which have a "B" impact on sources of inefficiency are "building block" standards on which certain direct impact standards (variety reduction, compatibility, quality) are built. The "building block" standards are terminology, measurement method and test method standards. Variety reduction standards often depend on the first two; compatibility standards often and quality standards usually rely on all three. Note that in Table 3, "B's" appear in the same row where compatibility, variety reduction, or quality standards have "A" impacts.

The Potential Negative Effects of Standards

Before describing the "C" and "D" impacts of standards, it is important to discuss the potential negative effects which standards can have, i.e. the types and sources of inefficiency which standards may aggravate. First of all, a too concentrated market structure can be created or enhanced if one or several firms' quality or compatibility standards are inappropriately (i.e. not in the buyers' interest) made the industry-wide standard. The capital required by other firms to meet the new standards may be too high to allow them to effectively compete on price. Secondly, variety reduction standards could excessively cut product offerings, i.e. buyers lose more benefits (choice) than they gain (reduced search costs and uncertainty). An excessive reduction could also lead to greater concentration if larger firms can gain greater economies of scale from variety reduction than do small firms.

Third, product standards can have a stultifying effect on the development and diffusion of innovation, i.e. on dynamic efficiency.
Compatibility standards have the potential for institutionalizing certain aspects of a product so that switching to a better product becomes costly for users. For example, television screens in the United States project images of 525 lines, while those in Europe project images of up to 800 lines and so provide a much sharper picture. The U.S. screens have poorer resolution because this country standardized its TV system earlier than did European countries. Because all U.S. television broadcasting systems are compatible with the 525-line screen, changeover at this point would be very expensive.

Further, quality standards may reduce dynamic efficiency by inhibiting technology developers from pursuing innovative ideas counter to the thrust of the standards, particularly if the standards are in the form of design criteria or materials specifications rather than performance criteria. Variety reduction standards also may lower dynamic efficiency by reducing the variation of product characteristics technology developers can work with.

Thus, the introduction of a standard can involve a potential tradeoff between reduction in current inefficiency and an increase in future dynamic efficiency. The stages in which this problem is the greatest are stages 1 and 2, when major and frequent product innovations tend to occur and dominant design has not been accepted, and also when significant uncertainties could be resolved through the use of standards. This problem can be minimized by seeking not to standardize certain product characteristics before they are generally accepted by the market, and/or it is fairly clear that the medium-term potential for significant technological change is low. Thus only elementary standards would be
adopted prior to dominant design. After dominant design, standards can become more refined and detailed as the general characteristics of the product stabilize. In essence, standards should be adopted when the gap between the expected benefits and the expected opportunity costs of adoption are the greatest. This gap is, of course, difficult to measure due to a variety of uncertainties, but standards developers can make educated guesses.

Standards by Stage of Introduction and Nature of Direct Impact

Based on the discussions of the last two sections, Table 4 depicts the sources of inefficiency on which each type of standard can have a direct impact, and the complexity of standards which are appropriate for each stage in the Abernathy-Utterback model. Compatibility, variety reduction, and quality standards are not given any role in Stage 1. Standardization for these functions is difficult and not appropriate in a stage in which there are diverse and custom-made products, and there is a high degree of product innovation occurring.
TABLE 4

The Direct Impacts of Standard Types on Sources of Economic Inefficiency by Stage and Complexity of Standards - for a Single Industry

Stages of Product Development

<table>
<thead>
<tr>
<th>Stages</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>- technological uncertainty</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Measurement Method Standards</td>
<td>- technological uncertainty</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Test Method Standards</td>
<td>- technological uncertainty</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Compatibility Standards</td>
<td>- buyer uncertainty</td>
<td>- excessive transaction costs</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Variety Reduction Standards</td>
<td>- technological uncertainty</td>
<td>- market uncertainty</td>
<td>- buyer uncertainty</td>
<td>- excessive transaction costs</td>
<td>- buyer uncertainty</td>
</tr>
<tr>
<td>Quality Standards</td>
<td>- buyer uncertainty</td>
<td>- negative externalities</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complexity of Standards</th>
<th>Very Elementary</th>
<th>Elementary</th>
<th>More Refined as Characteristics</th>
<th>Stabilize</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Note that Table 4 is concerned with the stage of product development (i.e. Column A of Table 1A), not the stage of the productive unit as a whole. The focus of standardization is on product characteristics, not other elements of the productive unit. The complexity of standards should be a function of the stage of product development. If major innovation and reverse transition occur, more complex standards may need to be discarded and newer, more elementary ones adopted.

On the basis of the last two sections, we can surmise that much of the standards development activity will take place soon after the adoption of a dominant design, i.e. in stage 3. Prior to that, detailed standards could interfere with dynamic efficiency. Subsequent to stage 3, much of buyer and technological uncertainty will have been reduced through buyer and producer familiarity with the product technology. (This familiarity may be facilitated by standards developed in earlier stages). Most of market uncertainty and excessive transaction costs due to too much product variation tend to disappear by stage 4. By definition (Table 1A) most significant product variety is gone by then. This may be due to either implicit or explicit (stage 3) variety reduction. Stage 2 and 3 quality standards resolving negative externalities should significantly reduce the need for further standards for this purpose in later stages.

Table 4 is intended to describe the role and nature of standards over the evolution of a single industry. If several industries are competing, the standards development activity of each is a function of the stage of the development of its product. This goes for instances of technological invasion as well. The table reflects a desire to achieve efficiency benefits for society as a whole, not any particular industry. Misuse of standards could result in an industry being better off, but not society.
Additional Impacts of Product Standards on Sources of Economic Inefficiency

As Table 3 relates, product standards can have two types of indirect impacts ("C's") on sources of inefficiency through their direct impact on other sources. First, compatibility, variety reduction, and quality standards, by decreasing buyer uncertainty and transaction costs, can also decrease producers' market uncertainty. If these standards help buyers become more aggressive and confident in buying the product, producers will receive better feedback regarding the desirability of various product attributes. The resulting drop in market uncertainty can generate an increase in marketplace efficiency -- producers can know consumer wants better and respond accordingly. More market certainty can increase the static efficiency of plant utilization and size -- this is particularly important in stages 2 and 3, when more uncertainty exists relative to later stages. Producers may move forward in seeking process innovation (to respond to more certain demand), and product innovation (in response to a clearer understanding of consumer wants).

The second type of indirect impact which standards may have is to facilitate a more efficient market structure. In an industry with large and small producers, increased certainty for small producers may help make more them more competitive with large producers. If small firms are at a disadvantage in gaining access to capital, an increase in their dynamic and static efficiency could induce an infusion of capital, which would widen the competition. In an industry with too little concentration, greater buyer, technological and market certainty and a
reduction in transaction costs could induce the process innovations which require a greater volume of production, and less efficient firms would be weeded out. Of course, there is a danger in any industry that process innovations induced by greater certainty would cause too much concentration and marketplace inefficiency.

As mentioned earlier, the timing of indirect impacts of standards are a function of the stages in which the standards are developed. Impacts may occur during or after the stage of standards introduction. Because the indirect impacts are tied to compatibility, variety reduction, and quality standards, the indirect impacts will tend to occur in and after stages 2 and 3.

In the process of developing all types of standards, new technological knowledge may be discovered as a byproduct. This knowledge may result in a reduction in two sources of inefficiency (a "D" impact of standards). First, the new knowledge can reduce technological uncertainty. Second, it can diminish the negative impact of the public good nature of technical information. Firms in an industry may be somewhat reluctant to invest in product innovation if rival firms can obtain and use the new technical information at little cost. The discovery of information through standards development is one way of overcoming effects of this reluctance on dynamic efficiency.

As the reader will notice, Table 3 shows that product standards have no impact on narrow management focus or the nature of the production process required to be competitive. Narrow management focus is a function of management skills, an organizational problem that cannot be relieved by a reduction in uncertainty. In fact, if a firm is too oriented towards dealing with static problems, greater certainty could
exacerbate a narrow management focus. In early stages, competition in product performance requires the nature of the production process to be flexible, at the expense of some static efficiency; in later stages, competition over cost requires a rigid, capital-intensive production process, at the expense of dynamic efficiency. Standards cannot significantly affect the existence of these tradeoffs between static and dynamic efficiency -- the tradeoffs are a function of process technology options and the focus of competition (cost/performance).1

The Degree of Impact of Standards

When talking about an industry in the abstract, it is very difficult to say which standards have the greatest impact, which type of impacts ("A", "B", "C", "D") are most important, and which sources and types of inefficiency diminish to yield the greatest impact. In particular, one should be aware that direct impacts need not be more important than other types of impacts. The importance of each impact (each cell of Table 3) varies from industry to industry, and is a function of the industry's product, degree of untapped technological potential, types of product users, market structure, and so on. Thus, the discussion in this chapter has been mostly one of direction and dynamics behind an impact, not degree of impact. It does seem possible that impacts which open up dynamic efficiency may have the highest payoff because the potential for increases in dynamic efficiency is open-ended, while those for static and marketplace efficiency are limited by definition.

One also should not equate the degree and stage of impact with the level and stage of standards development activity. While it is likely
much activity goes on in stage 3, the greatest impacts could be due to the elementary standards developed in stage 2, again depending on the industry. Further, standards produced in one stage also may reap benefits in future stages.

Summary and Conclusions

As mentioned at the outset, the purpose of this paper was to be a theoretical thinkpiece regarding the role that industrywide voluntary product standards can play in stimulating economic efficiency. Specifically, three questions were posed:

1) What sources of economic inefficiency can industrywide voluntary product standards help mitigate?

2) What are the appropriate chronological points in product development and diffusion for the promulgation of standards?

3) What are the dangers that standards can exacerbate certain certain sources of inefficiency while resolving others, and what are some ways these dangers can be avoided?

The answers to the questions were arrived at through the use of several building blocks. First, using a mixture of neoclassical microeconomics and ideas based on the work of F.M. Scherer and Burton Klein, three types of economic efficiencies were defined. Second, a model of sequential patterns of product and process innovations in an industry was developed, drawing on the work of William Abernathy and James Utterback. Third, these first two building blocks were integrated in a discussion of the sources of inefficiency which tend to appear during evolution of an industry. Fourth, the basic types of industrywide voluntary product standards, differentiated by technical functions, were identified.
These four building blocks provided the conceptual foundation for generating answers to the initial questions. Essentially, standards were found to have four means of positively affecting sources of inefficiency -- direct impacts, indirect impacts, impacts through use as a building block for other standards, and impacts through the discovery of new technological knowledge. In particular, standards were found to have a potential direct impact on uncertainties, negative externalities, and excessive transaction costs.

The discussion of the major potential negative effect of standards -- stultifying dynamic efficiency -- led to a recommendation that only elementary standards be developed for a product if further frequent product innovations seem likely, and that standards be refined only as product characteristics seem to stabilize. Several other possible negative effects of standards on dynamic and marketplace efficiency were mentioned.

It is hoped that this paper has offered significant and constructive elements of a theory of the role industrywide voluntary product standards can play in increasing economic efficiency. Clearly, many of the details of the theory need to be proved or disproved by empirical studies. In any case, the paper should provide a framework, a theoretical jumping-off point, from which further exploration of the economic role of standards can take place.
APPENDIX 1

The industrywide voluntary standards setting system in the United States is a complex one, with the Federal government having a relatively minor role. Primarily, industrywide voluntary product standards are developed by three types of organizations—trade associations, professional societies, and national standards organizations.

Trade Associations

Typically, trade associations are non-profit organizations comprised of independent businesses in a single industry and established to improve the financial position of their respective members. The associations usually provide members with informational services and technical assistance; coordinate joint membership efforts concerning research, advertising, and standards development; and represent members before government and the public.

While the nature of standards development activities varies from trade association to association, there are a few similarities. Standards for an industry's products are usually produced through the development of consensus among trade association members. Sometimes an association will invite consumers or public representatives to sit on standards-writing committees. However, consumer representation is not usually provided on any systematic basis, and the representatives are rarely given voting power. Trade associations often send representatives to the committees of the national standards organizations.
Professional Societies

Professional societies are organized along the same lines as trade associations, except that members are individuals rather than firms. Membership policies of professional societies are typically more restrictive than those of trade associations. Membership is often stratified according to years of education and practice, and professional accomplishments.

Professional societies carry out many of the same functions as trade associations. They represent the profession before government and the public, provide information and support services to members, and provide a forum for discussion of profession-related issues. The typical professional society also takes an active role in research and educational matter.

The extent to which professional associations are involved in product standards-writing activities varies according to their concern with technical matters. Even so, some technical professional societies are more active in standards-writing than others. Professional societies active in standards writing include the Association for Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the Association of Official Analytical Chemists, and the Institute of Electrical and Electronic Engineers (IEEE). Typically, professional societies develop test method standards, and leave minimum quality standards to trade associations. Two major exceptions to this pattern are the Society of Automotive Engineers (SAE) and the American Society of Mechanical Engineers (ASME), which do develop product quality standards. Most
technically-oriented professional societies, whether active in writing their own standards or not, send representatives to national standards writing organizations.

**National Standards Organizations**

The most active standards-writing organization in the United States is the American Society for Testing and Materials (ASTM). ASTM is a national non-profit scientific, technical and educational society. It was established in 1898 for the purpose of promoting knowledge of engineering and standardizing specifications and test methods. Presently, ASTM's primary work concerns standardization and research in material inputs, particularly regarding quality and test methods, and with less emphasis on dimensional standards and design.

ASTM membership includes both individuals and organizations. It develops standards upon request from trade associations, governmental agencies, professional societies, manufacturers, universities, consumer groups, and individuals. After making sure that there is no other ongoing standards activity related to a request, all interested parties are invited to a planning and organizational meeting, usually at ASTM headquarters in Philadelphia.

Standards development in ASTM is carried out through standing main committees. A standards document is first drafted by a task force, which sends the results to its parent subcommittee, which in turn sends the results to its parent main committee. In the main committee, 90% of those returning ballots must approve the document (at least a 60% return is required). The document then goes to a Society ballot, which means
that each of ASTM's 26,000 members can comment on the proposed standard. Again, 90% of the ballots must be affirmative (a minimum of 50 ballots is required). Finally, a committee of ASTM's Board of Directors must see that all procedural requirements for approval have been met.

Standards developed by ASTM are known as "full consensus standards" because their development must follow rigorous due process considerations, something which often is not so in trade associations. The principles of due process include: adequate notice of the proposed standards development process to all persons, companies and organizations likely to be affected, opportunity for all affected interests to participate in the standards development, maintenance of adequate records, adequate notice of proposed action, and careful attention and consideration of minority opinions throughout the process.

Two other important national standards organizations are the National Fire Protection Association (NFPA) and Underwriters Laboratory (UL). The NFPA develops fire protection standards for a variety of products. It often collaborates with other standards organizations, e.g., it developed a series of standards with the American Gas Association concerning gas appliances and gas piping. The Underwriters Laboratory is a non-profit corporation sponsored by American Insurance Association. It is primarily a testing laboratory which rates products and materials in regard to fire and other safety hazards. UL also develops product standards -- material specifications, design criteria, test methods, and recommended practices regarding product use.

The last national standards organization to be considered is the American National Standards Institute (ANSI), a voluntary federation of
more than 400 standards-writing bodies in the United States. ANSI has
three principal functions. It serves as the national coordinator for
voluntary standardization in the U.S. It helps to identify specific
needs for standards and arranges for organizations to develop them. In
the event that a standards-writing organization does not exist in a
particular area of need, ANSI organizes technical committees to draft the
standards. It has organized over 170 technical committees. By its
constitution, ANSI may not write standards, so each technical committee
is formally located within a member standards-writing institution. As
coordinator ANSI also attempts to prevent the duplication of
standards-writing activity.

ANSI's second function is to approve American National (consensus)
Standards. These are submitted to ANSI for approval by other
standards-writing organizations. To be accepted as an American National
Standard, a standard must have been developed by the sponsoring
organization via a rigorous procedure in compliance with due process.

The third major function of ANSI is to represent the standards
position of the United States in international non-treaty organization
with which it is affiliated. Examples of these international
organizations are the International Organization for Standards and the
International Electrotechnical Commission.

The National Bureau of Standards

For the most part, the Federal government becomes involved in the
voluntary standards process through the National Bureau of Standards
(NBS), an arm of U.S. Department of Commerce. NBS was established in 1901 to meet the national demand for a unified measurement system. It has several functions. It is responsible for the custody, maintenance and development of national measurement standards, and provision of means and methods for making measurements consistent with those standards. It also does research in the properties of materials, advises the government on scientific matters, and generates innovations. Finally, it develops test methods for materials, mechanisms, and structures, and cooperates with private standards-writing organizations in the development of voluntary standards.

NBS does not establish mandatory standards; rather, it develops voluntary measurement and test method standards for others to use. It has a long history of cooperation with the voluntary standards sector. NBS is represented on the boards of ANSI and ASTM. About 250 NBS staff members serve on ASTM technical committees, and the agency is represented by others on additional standards-writing groups.
Notes

Chapter 1


2. According to David Hemenway, there are over 400 standards-writing organizations in the U.S. However, in 1964, 3 organizations accounted for 50% of the standards written, and another 15 accounted for 20%. Source: Industrywide Voluntary Product Standards (Cambridge, MA: Ballinger Publishing Co., 1975).

3. Hemenway, op. cit.

Chapter 2

1. It is best said that the formulation of the notion of dynamic efficiency in this paper is only inspired by Klein, because he never provides a good operational definition of the term. That had to be developed by this author.

2. In Dynamic Economics, Klein says that dynamic efficiency is "the result of extending the (production-possibilities) frontier by exploiting as fully as possible a technological potential (p.35)." This idea is incomplete. Not all innovations extend the frontier; some change its composition.

Generally, extension of the frontier is thought of as being due to process innovations. What about product innovations? Many product innovations are bought by businesses for use in the process of producing goods and services and in that sense they extend the production-possibility curve. For example, word processors presumably make the operation in the headquarters of a publishing company more cost-efficient -- more books can be produced with the same resources.

What about household product innovations? If refrigerators replace iceboxes on the production-possibility curve, the curve is not necessarily extended. What changes is the composition of the curve. As a refrigerator presumably has more utility per dollar than an icebox, society is getting greater utility out of its resources.

3. Klein believes that U.S. government economic policy needs to stimulate a higher degree of dynamic efficiency in order to make the U.S. more competitive in the world market. He sees the rise and decline of British and U.S. economic fortunes as a function of national dynamic efficiency, and attributes current Japanese and West German success to their relatively high frequency of product and process innovation.


7. Ibid., p. 429.

Chapter 3


2. Ibid., p. 48.

3. Ibid., p. 68.

4. Ibid., pp. 156-160.

5. Ibid., p. 80. It is not entirely clear what the authors mean by "a normal rate ... of technological progress." We know and they say elsewhere that different industries take different lengths of time to evolve. Perhaps they mean there is a normal frequency (i.e. rate) of innovation over time.

6. Ibid., p. 83.

7. Ibid., p. 70.

8. Ibid., p. 77.

9. Ibid.

10. Ibid., p. 150.

11. Ibid.

12. Michael Piore, in his book (co-authored with Suzanne Berger) entitled *Dualism and Discontinuity in Industrial Societies* (Cambridge Univ. Press, 1980), describes four determinants of process technological innovation: 1) size of the market, 2) degree of product standardization, 3) degree of market stability, and 4) degree of producer certainty regarding market demand patterns. The greater these factors, the more impetus for process innovations, resulting in specialized equipment, rigid production process, and de-skilled jobs. Piore makes explicit what is somewhat hidden in Abernathy and Utterback's model; the two theories are quite consistent.


15. Ibid, pp. 151-152.


17. Ibid, p. 82.

18. Ibid, p. 70.


20. Ibid., p. 168.


22. Ibid.

23. Ibid.

24. Ibid.

25. Ibid.

26. A mantle: "a lacey hood or sheath of some refractory material that gives light by incandescence when placed over a flame." Webster's New Collegiate Dictionary, p. 700.

27. Abernathy, op.cit., p. 83.

Chapter 4

1. Abernathy and Utterback never say whether or not in-house technology developers reside within the productive unit. For the purposes of the analysis, we will assume they do not.


3. Ibid., pp. 72-73.


6. Ibid.


8. Utterback, op.cit.

Chapter 5


3. Ibid.


5. ASTM, op. cit., p. 9.

5. Hemenway, op. cit., p. 60.

6. Ibid., p. 37.

7. Ibid., pp. 22-23.

8. Society of Automotive Engineers, op. cit., p. 34.06.


10. Society of Automotive Engineers, op. cit., p. 34.06.


Chapter 6.

1. However, product standards for the production process equipment may directly or indirectly reduce the cost/benefit ratio in a tradeoff, allowing more flexibility for given economies of scale, or vice versa.

APPENDIX

1. The information in the Appendix is drawn from two sources:


   American Society for Testing and Materials, "Standardization Basics."
REFERENCES


. "Principles and Practices of Standardization."


