# REGULATION OF CHEMICALS: PRODUCT AND PROCESS TECHNOLOGY AS A DETERMINANT OF THE COMPLIANCE RESPONSE

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## ABSTRACT

The relationship between the nature of a technology affected by an environmental or safety regulation and the nature of the responses that emerge as a result of the regulation is explored. A conceptual framework for investigation is developed which may be applicable to many different regulatory situations. In order to make a preliminary application of this framework, the regulations affecting four chemical hazards (vinyl chloride, polychlorinated biphenyls, mercury, and lead) are documented and the affected technologies and the responses that emerged as a result of these regulations are identified via literature research, contacts with regulatory agencies, and interviews with affected firms. This information is examined in terms of the conceptual framework, and preliminary hypotheses about the technology-response relationship are advanced.

It is hoped that this work will facilitate the construction of more cost-effective regulations. There are two ways in which it could do this. (1)It should help to identify the aspects of a particular technology which should be considered in designing a regulation that will affect that technology; and (2)it should improve the ability of the regulator to predict the consequences of regulations and to tailor regulations to achieve particular objectives.

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# CHAPTER ONE

# INTRODUCTION

## 1.Background and Motivation*

In recent years there has been an expanding awareness of the problems of environmental degradation and hazards associated with the workplace and consumer products. Environmental goals and concern about these health risks have been injected into the political process, where they sometmes compete with other social, economic and political goals. The design of public policies involves making difficult trade-offs among these goals. This work will not attempt to address those policy choices.

However, once a policy choice is made it must then be implemented. One major tool for implementing policies relating to environmental and safety problems is regulation. The purpose of this research work is to facilitate the design of cost-effective and technologically appropriate regulations.

Designing a regulation to achieve a particular policy goal is often a difficult task, partly because it is not possible to know in advance what the affected firms will do in response to the regulation. The difficulty is compounded because regulations must not vary too much over

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time. Complying with these regulations frequently requires large sunk capital costs; firms are not likely to make such investments if they are not convinced that the regulation the investment is designed to meet is permanent. If a regulation is changed, firms which complied originally may incur extra costs in complying with the changes, while firms which dragged their feet originally would then have an advantage. Therefore, to achieve compliance and preserve their credibility, regulators have to be prepared to stick with actions once taken. As a result, it would be useful to improve the ability of the regulator to predict the outcome of particular regulatory actions, and to distinguish situations which should be treated differently for the purpose of regulation.

## 2. The Study of Regulation

Before describing the approach taken by this study, it is useful to examine the findings of others who have studied regulation. Environmental and safety regulations on a large scale are fairly recent phenomena; researchers have only recently begun to study them systematically. However, there is an established body of literature on economic regulation, which has a much longer history. (It is generally dated from the Interstate Commerce Act of 1887.) There have been many detailed studies of its effects. There is an accepted methodology for studying its impact on technological change in the regulated industries.[1] However, this methodology is very specifically designed for predicting the effects of traditional modes of economic regulation (rate-of-return constraints, fixed markups, ceiling prices, barriers to entry, etc.). The constraints imposed by regulations of this kind can easily be incorporated into the economic analytical framework, allowing calculation of their effects based on a specification of a production function and a behavioral assumption (such as profit-maximization). The effects of constraints imposed by an environmental or safety regulation cannot be predicted so easily by this economic analytical framework. For this reason, this particular methodology is not useful for the purpose of this study.*

In spite of the short history of environmental and safety regulation, it is possible to identify at least three areas of investigation relative to it:

- the politics of regulation and the process of agenda-setting and decision-making;
- evaluation of the costs and benefits of particular regulations or sets of regulations; and
- discussions of regulatory strategies and alternatives.

The first area is the domain of political scientists and general social commentators. Particular attention has been paid to the problem of air pollution: its transformation from a local problem to a national problem, the passage of the 1970 Clean Air Act Amendments, and the subsequent debate over the auto emission standards.[2,3] This literature is interesting as an insight into the political process and the various public perceptions of these problems, but it is generally descriptive and does not attempt to draw conclusions useful in the design of effective

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*Even if the method were applicable to environmental and safety regulations, it would not yield the kind of answers sought here. The methodology is used to predict general tendencies (such as a preference for capital over labor as an input), not specific technological changes in response to regulation. Additional limitations of economic methods for the purpose at hand will be discussed in Chapter Two, section 3.

regulations.

No particular discipline has a monopoly on the second area of inquiry. Economists, lawyers, political scientists and others have attempted to document the effects of regulation of drugs,[4] chemicals,[5] air pollution,[6] water pollution,[7] product safety,[8] occupational safety,[9] and other forms of regulation. This literature is concerned with the evaluation of specific policy choices, and the determination of the nature of the tradeoffs among those affected. It is not concerned with drawing generalizable conclusions about the *determinants* of regulatory outcomes.

In contrast, the last area is more directly relevant to the problem at hand. There has been much analysis by many different experts of particular regulatory tools,[10,11,12,13,14] and suggestions, mainly by economists, of alternatives to traditional regulation.[15,16,17] The main problem with this literature is that it is primarily speculative, with only anecdotal information on which to base its conclusions. Of course, our experience with regulation is quite limited; as it increases it will be possible to draw conclusions about different regulatory tools.

The regulatory choice does not produce a unique outcome by itself; it does so only through the actions of the people and institutions which are regulated. Obviously, different institutions may respond differently to similar regulations. To design effective regulations, it would be useful to understand what attributes of the regulated entity are important determinants of the outcome of regulation. This understanding could then be combined with the knowledge of different regulatory mechanisms to design the appropriate regulation for different situations.

The regulatory half of the problem has been and is intensively studied. This work will investigate the regulated entity as a determinant of the response. Ideally, to do this one would like to examine the outcomes of similar regulations on a variety of different regulatory objects. Unfortunately, such a "natural experiment" does not exist; the regulations affecting different entities are usually also different. Since one cannot "control" for regulatory differences as determinants of differences in outcomes, it may be difficult to draw definite conclusions about how the attributes of the regulated entity determine the outcome. Both influences must be kept in mind and an attempt must be made to try to sort out cases where one or the other is dominant.

Because of this difficulty, and because there is no previous work in this area upon which to draw, it will not be the goal of this work to produce proven conclusions about the determinants of regulatory outcomes. Rather, an attempt will be made to construct preliminary hypotheses about the process, which can serve as a framework for later research and verification.

## 3.Problem Definition

The outcome of a regulatory action has no precise boundaries; it is a sum of effects which propagate through the economy and society. However, a large term in this sum, and the key to all the others, is likely to be the first one: the direct response of the institutions being regulated. This response will determine most of the environmental, economic and social impacts.

This response will usually have several dimensions; it may involve legal and political action, organizational change, and technological change. Similarly, the attributes of the responding unit which determine these various responses may be organizational, economic, personal, technological, etc. Most likely a combination of such factors will interact with regulation to yield the various kinds of responses.

To make a useful initial contribution to the understanding of such a complex system it is necessary to narrow the focus to the dimensions which are most important and useful in designing regulations. In the long run, the important environmental, health, and economic effects will result from the technological changes that occur; the legal and political responses are primarily important because they may delay or modify the technological response. For this reason, this study will consider the technological response. In addition, it will be limited to the changes which come about as a _direct result_ of regulation. The term _compliance response_ will be used to mean the sum of all changes in the product or processes of the affected unit which are implemented to move the unit towards compliance with the regulation. To speak of a compliance response does not imply that compliance is achieved; the response may only move in that direction. Of course, it is also possible that there will be no compliance response at all.

The technology employed by a regulated unit before a regulation arises obviously constrains the changes that the unit can undertake, and it may deeply affect the way it perceives and approaches the problem posed by regulation. Therefore, existing technology is likely to be an important determinant of the compliance response. Moreover, understanding of the role played by technology in determining the response could be easily incorporated into regulatory design because information about the technology is readily available and regulations frequently are addressed to technologically homogeneous groups. Information about personal or organizational factors is harder to obtain and to use in regulatory design. Economic factors can be and are frequently considered. This very fact of frequent use suggests that they are better understood and are not in as great a need of exploration.

### 4.Research Design

The first task in this research effort is to develop a conceptual framework for addressing the problem of technology as a determinant of the compliance response. This requires a specification of the entities which will be considered to respond to regulation, the development of a way to characterize technologies, the development of a scheme for characterizing compliance responses, and consideration of *a priori* expectations with respect to the technology-response relationship.

The second task is the identification of a sample of regulations and affected technologies for an initial application of the conceptual framework. This involves the selection of some regulations and sufficient documentation of those regulations to understand the responses, and the identification of the affected technologies and the characterization of those technologies according to the approach developed in the first task.

The third task is to document the changes that emerged in response to the regulations, and to characterize those responses according to the approach developed in the first task.

The fourth and final task is the construction of simple hypotheses about the role of technology as a determinant of the compliance response. These hypotheses will be developed from the conceptual framework in conjunction with the observations made in the initial sample application.

A chapter of this report is devoted to the discussion of each of these tasks. Chapter Two is devoted to the development of the conceptual framework. Chapter Three explains the sample selection and describes the regulations and technologies contained in the sample. Chapter Four is devoted to the responses. Chapter Five brings together the *a priori* expectations and the lessons of the observed sample to yield likely hypotheses, speculates on the implications of this work for regulatory design, asesses the overall usefulness of the approach, and makes some suggestions for useful future work.

## REFERENCES FROM CHAPTER ONE

1. Capron, William, ed., *Technological Change in Regulated Industries*, Brookings, 1971

2. Jones, Charles O., *Clean Air*, University of Pittsburgh Press, 1975

3. Ingram, Helen, "The Political Rationality of Innovation: The Clean Air Act Amendments of 1970," *mimeo* (1976)

4. e.g. Pelzman, S., "An Evaluation of Consumer Protection Legislation: The 1962 Drug Amendments," *Journal of Political Economy*, *81*: 5, p. 1049 (1973)

5. e.g. MIT Center for Policy Alternatives, *The Impact of Government Restrictions on the Production and Use of Chemicals*, CPA-76-3 (1976)

6. e.g. National Academy of Sciences-National Academy of Engineering, *Costs and Benefits of Automobile Emission Control*, report to the Committee on Public Works of the U.S. Senate, 93-24 vol. 4

7. e.g. Peskin, H.M., ed., *Cost-benefit Analysis and Water Pollution Policy*, Urban Intstitute, 1975

8. e.g. Kelman, S., "Regulation by the Numbers--the Consumer Product Safety Commission," *The Public Interest*, *36*: 82 (1974)

9. e.g. MIT Center for Policy Alternatives, *Economic and Social Impact of Occupational Noise Exposure Regulations*, EPA 550/9-77-352 (1977)

10. Rosenberg, Nathan, "The Direction of Technolgical Change: Inducement Mechanisms and Focusing Devices," *Economic Development and Cultural Change*," *18*: 1 (1969)

11. Atkinson, Scott E. and Donald H. Lewis, "Cost-effectiveness Analysis of Alternative Air Quality Control Strategies," *Journal of Environmental Economics and Management*, 1: 237 (1974)

12. Greenfield, S.M., "Incentives and Disincentives of EPA Regulations," *Research Management*, *17*: 11 (1974)

13. Schwartz, W.F., "Mandatory Patent Licensing of Pollution Control Technology," *Virginia Law Review*, *57*: 719 (1971)

14. Crocker, T.D., "On Air Pollution Control Instruments," *Loyola University Law Review*, *5*: 280 (1972)

15. ibid

16. Irwin, W.A. and R.A. Liroff, Economic Disincentives for Pollution Control: Legal, Political, and Administrative Dimensions, EPA Office of Research and Development, July, 1974

17. Spence, Michael, and Martin Weitzman, "Regulatory Strategies for Pollution Control," *mimeo* (1976)

# CHAPTER TWO

# CONCEPTUAL FRAMEWORK

## 1. Introduction

The first section of this chapter defines what is meant by "a unit responding to regulation." The second section distills from the sociological literature on technology a way of distinguishing technologies which may be likely to yield different compliance responses. The next section develops a set of attributes of responses which captures the aspects important to regulatory design. The final section brings these together to suggest the likely role of technology in determining the response.

## 2. The Productive Segment and the Productive Unit

The entity or entities which are identified as responding to regulation must employ a single identifiable technology if conclusions about technology as a determinant of the response are to be drawn. In this work, two related concepts--the _productive segment_ and the _productive unit_--will be used for this purpose.

The productive segment is comprised of all economic activities employing a particular technology to produce a line of related products. Obviously, the typical productive segment includes parts of many different firms. Conversely, a large, integrated firm would not be classified within one productive segment.

The _productive unit_ is that member of a particular productive segment which is contained within a single firm. (Alternatively, it could be defined as that portion of a particular firm which employs a distinct technology.) Thus, both the segment and the firm are sets of productive units; the units in the firm have different technologies but the same ownership, while the units in the segment have different ownership but the same technologies.

The decisions about how to respond to a regulation are made within the productive unit and the firm. These decisions will be influenced partly by firm-specific and non-technological factors. Therefore, all of the units in a segment may not respond to a regulation in the same way. However, to the extent that technology is a major determinant of the response, one would expect similarity among the responses in a particular segment. This work will consider the response of a productive segment to regulation, i.e. the set of responses emerging from the units within that segment. In each case the degree of uniformity of such responses within the segment as a whole will be noted.

The units making up productive segments are not fixed over time. If the technology employed by different units within a segment evolves differently over time, then at some point what was considered a distinct segment no longer has a single identifiable technology. The units that were in that segment now comprise two or more distinct segments. Regulation may induce such a change if the responses of the units in a pre-regulation segment are radically different from each other.

The segment or segments which respond to a particular regulation will not in general be limited to those directly regulated. They may be customers of or suppliers to the regulated segments, or any other segment that perceives the regulation as a market opportunity.

## 3. Characterizing Technologies

It is possible to identify at least three contexts in which people have attempted to characterize technologies: economics, organizational sociology, and management science. Economists specify the technology of a firm using a production function.[1] The specification of a production function can generally tell one the following things about a technology:

- the inputs to the process and their relative contribution to the final product,
- the elasticity of substitution among the inputs, and
- the "returns to scale" inherent in the technology.

The main purpose of the production function specification is to calculate the cost-minimizing input combination and from that to derive the cost function for the firm and the supply function for the industry.

Unfortunately, this abstract characterization does not capture the detailed qualitative distinctions among technologies which may be crucial in determining the differential responses to regulation. Further, it is a static model, and the object of our inquiry is the <u>change</u> that may be likely to emerge from a particular technology under regulation. Therefore, the characterization of technologies by production function is not suitable for the purpose at hand.

Sociologists have been interested for some time in the role played by technology in determining the organizational structure of the working group or firm.* In the course of investigating this issue, they have

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*In passing, it should be noted that this question is itself relevant to this research. If technology does affect organizational structure, then developed methods of characterizing technologies. Several of these will be discussed here, in the approximate order in which they were developed.

James Thomson and Frederick Bates suggested "rigidity" as a characterization of technologies. This depends on "the extent to which the appropriate mechanics, knowledge, skills and raw materials can be used for other products."[2]

Joan Woodward has identified eleven catagories of production technologies. As illustrated in Table 2.1, the categories consist of a nine-point scale of "technical complexity" and two "mixed categories" which involve combinations of the others.[3] Woodward also points out that the scale is one of chronological development; "the production of unit articles to customers' individual requirements being the oldest and simplest form of manufacture, and the continuous-flow production of dimensional products, the most advanced and complicated."[4]

Charles Perrow has suggested that technologies be placed along a continuum from "routine" to "nonroutine." Further, he distinguishes two dimensions to the notion of routineness: (1)the number of exceptional cases encountered in the work, and (2)the degree to which logical analytical procedures are employed to deal with exceptions when they do arise. As examples he cites the aerospace industry (nonroutine: many

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what appear to be effects of the technology on responses may be due in part to organizational effects, in which case conclusions about the causal mechanism involved in the technology-response relationship would be difficult to draw. Unfortunately, this issue has not been resolved. Some researchers claim to have found significant correlation between technological factors and organizational structure,[3] but other researchers dispute these findings.[7,9]

## TABLE 2.1

## WOODWARD'S CLASSIFICATION OF TECHNOLOGIES BY "TECHNICAL COMPLEXITY"

1. Production of units to customers' requirements
2. Production of prototypes
3. Fabrication of large equipment in stages
4. Production of small batches to customers orders
5. Production of large batches
6. Production of large batches on assembly lines
7. Mass production
8. Intermittent production of chemicals in multi-purpose plant
9. Continuous flow production of liquids, gases, and crystalline substances
10. Production of standardized components in large batches subsequently assembled diversely
11. Process production of crystalline substances subsequently prepared for sale by standardized methods.

exceptions, no analytical methods), craft industries (intermediate: few exceptions but no analytical methods), heavy machinery (intermediate: many exceptions but analytical methods), and steel mills (routine: few exceptions and analytical methods).[5]

Amber and Amber have developed a ten-fold characterization of the "order of automaticity" of a technology.[6] The factor which determines the order of automaticity is <u>the human attribute which is mechanized</u>. The ten categories correspond to the mechanization of no human attributes, then energy, dexterity, diligence, judgment, evaluation, learning, reasoning, creativeness and dominance. Examples range through shovels, electric hand tools, machine tools, production lines, process control, dynamic positioning, sophisticated dispatching and weather forecasting. (Amber and Amber leave examples of the higher orders of automaticity to the imagination of science fiction writers.)

Perhaps most important among the sociologists, David Hickson and his colleagues at the University of Aston distinguish three facets of technology:[7]

- operations technology,
- materials technology, and
- knowledge technology.

James Taylor uses a similar formulation in his study of technology as a determinant of organizational change.[8]

Hickson, el. al. note that Perrow's "number of exceptions encountered" is an aspect of materials technology, and his "use of analytical methods" is an aspect of knowledge technology. They go on to develop a detailed characterization of operations technology. They call their characterization "workflow integration", and it consists of four subconcepts:

- automaticity,
- continuity,
- workflow rigidity, and
- specificity of evaluation of operations.

For the first subconcept they use Amber and Amber's scale, and for continuity they use a modification of Woodward's "complexity" scale. For workflow rigidity they developed the scale presented in Table 2.2. Essentially, this scale measures the degree of interdependence of the operation steps as well as the rigidity of the process in the Thomson and Bates sense of applicability to a variety of purposes. Finally, they developed the three-point scale presented in Table 2.3 for specificity of evaluation operations.

Peter Blau, et. al. constructed a somewhat similar scale, based solely on automaticity and a modification of Woodward's complexity scale.[9] They suggest that this scale yields results similar to those of Hickson, el. al, and has the virtue of simplicity.

In the management literature, the work of primary importance for the purpose at hand is that of Abernathy and Utterback.[10,11] They are concerned with the management of technological enterprises, improvement of productivity, and technological innovation. They combine the ideas of complexity, rigidity, and integration of operations technology (which they call process technology) with a parallel idea of <u>product</u> techno-

## TABLE 2.2

## HICKSON'S WORKFLOW RIGIDITY SCALE

One point is assigned for a positive answer to any of the following conditions, yielding an eight point scale:

In the event of a breakdown all workflow stops immediately

No waiting time possible

No buffer stocks and no delays possible

Single source input

Single purpose equipment

No rerouting of work possible

In the event of a breakdown, some workflow stops immediately

Production or service line or lines

## TABLE 2.3

## HICKSON'S SPECIFICITY OF EVALUATION OF OPERATIONS SCALE

1. Personal evaluation only
2. Partial measurement (some aspects of outputs)
3. Measurements used over virtually the whole output(s), to compare against precise specification (blueprint or the equivalent)

logy.* They then argue that the rate and direction of technological change in a productive unit depends on the nature of its product and process.

Utterback and Abernathy visualize an evolutionary process whereby product and process technology develop together from an initial stage in which the product is poorly defined and rapidly changing and the process is uncoordinated and based on general purpose equipment, through an intermediate stage in which the product begins to standardize and portions of the process are automated and optimized, to a final stage in which the product is a highly standardized commodity and the process is automated, integrated and large scale. As shown schematically in Figure 2.1, in the initial stage the product changes rapidly while little attention is paid to the process; as the product begins to be standardized this makes possible a rapid increase in process change; finally the rates of both kinds of change level off as product and process become standardized.

The early stage is characterized by the attempt to maximize the performance of the product; price may not be important within some range. As standardization progresses, the emphasis may shift to sales maximization as the enterprise tries to grow and insure a market share for itself when the product market stabilizes. In the final stage, the emphasis shifts once again, this time to cost-minimiztion, and competition is on the basis of price because all the competing products are

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*This notion of the separate but parallel existence of process and product technology is a major contribution of Abernathy and Utterback's work.

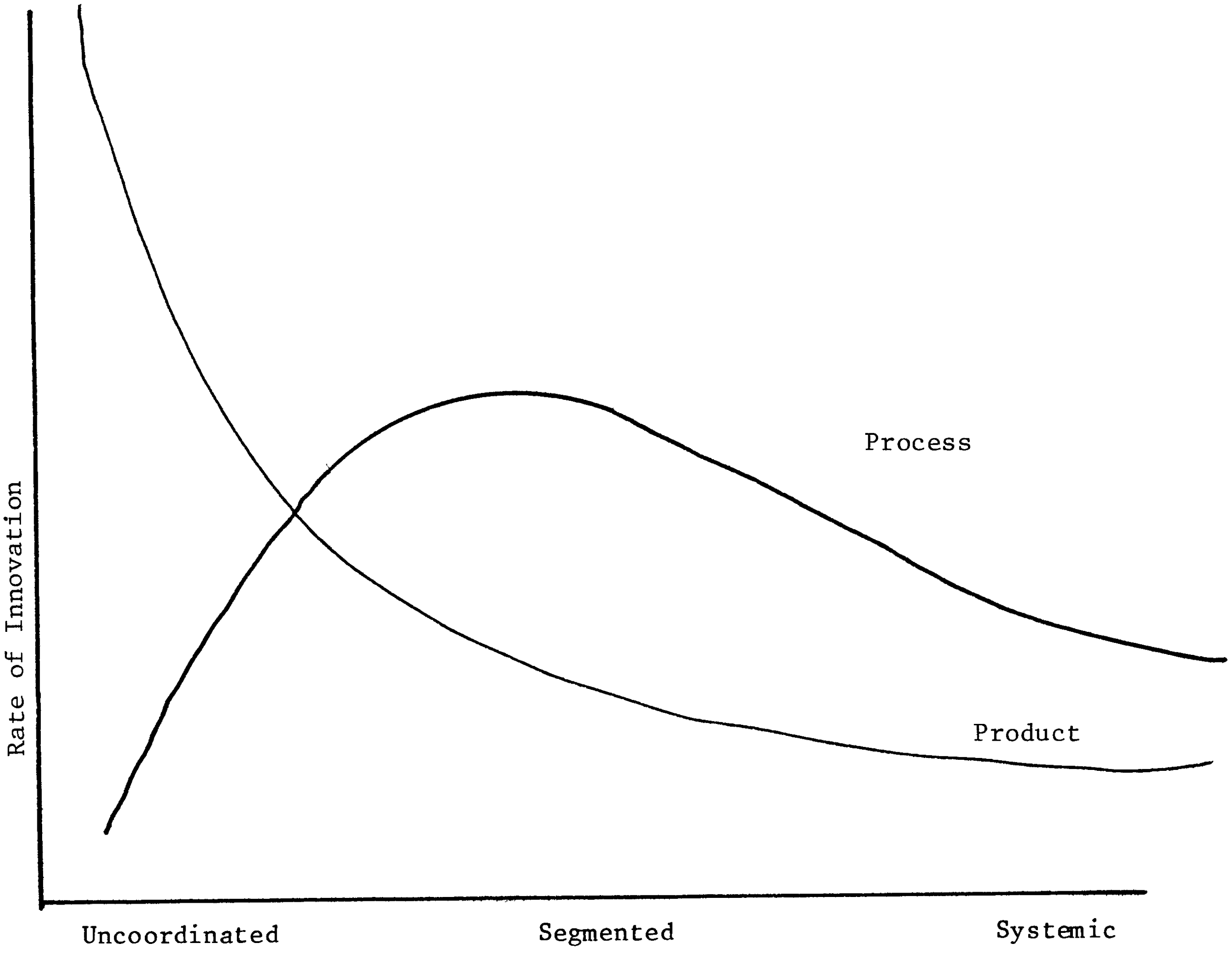

FIGURE 2.1

PRODUCT AND PROCESS INNOVATION IN THE ABERNATHY-UTTERBACK MODEL similar in quality. Abernathy and Utterback call the three stages uncoordinated, segmented, and systemic.

In Abernathy and Utterback's work, rigidity is used simultaneously to mean the inherent physical rigidity of a technology and also the historical change or lack of change in a productive segment. That is, a fluid segment is characterized by <u>both</u> an inherently fluid product and uncoordinated process <u>and</u> by a recent history of frequent product change; a rigid segment is characterized by <u>both</u> a standardized product and highly integrated process <u>and</u> a recent history of little product or process change. Further, Utterback and Abernathy's work suggests that the likely <u>future</u> pattern of change can be predicted based on the recent past, and hence can also be predicted based on the physical rigidity of the technology at a given point in time.

In the present work, segments and units will be characterized as rigid or fluid without reference to historical trends. However, based on the Abernathy-Utterback model, the historical pattern of change will be inferred from the physical rigidity of the technology at the time when a regluation is imposed.

This study is concerned with technological change in response to regulation. If units respond to regulation in exactly the same way that other technological changes are undertaken, then the Utterback-Abernathy model would suggest that the kind of response that is most likely can be predicted by examining the physical* rigidity of the segment. Although

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*Henceforth the word "physical" will be omitted; rigidity will always be used in the sense of inherent physical rigidity of a technology at a specific point in time.

the simultaneous stimulus and constraint imposed by regulation may be a unique situation for the productive unit, generalizations from the "normal" pattern of change may still apply. Since there is no model to be used of the process of responding to regulation, the best approach is to start with a general model, such as that suggested by Abernathy and Utterback's work, and proceed to try to determine what modifications are necessary to account for the unique features of regulation.

An additional reason for using some notion of rigidity for characterizing technologies is the fact that a number of different workers in different areas have arrived at fairly similar (or at least related) characterizations of technology. As the above discussion shows, Thomson and Bates' "rigidity," Woodward's "complexity," Perrow's "routineness," Amber and Amber's "automaticity," Hickson's "integration," and Abernathy and Utterback's "stages of development" all are somewhat different aspects of the same notion. There is a rough overall continuum that runs from less rigid, less complex, less routine, less automated, less integrated and more fluid to more rigid, more complex, more routine, more automated, more integrated and more systemic. Because of the exploratory nature of this study, it is not necessary to choose a particular scale or measure of technology to begin with. Rather, it would seem most useful to use the general notion of rigidity, keeping in mind the aspects of rigidity suggested by different workers, and the notions of materials, operations, product, and knowledge technology. To summarize, in characterizing technology the following aspects of rigidity will be considered:

- narowness of equipment function and interdependence of process steps (Thomson and Bates and Hickson, et. al.),

- degree of automaticity (Amber and Amber),
- continuity of the production process (Woodward and Hickson, et. al.),
- degree of standardization of inputs (Perrow) and outputs (Abernathy and Utterback), and
- price versus quality as the basis of competition (Abernathy and Utterback).

As in Abernathy and Utterback's work, the continuum of rigidity will be abstracted into three stages, recognizing that the lines between them may not be clearly drawn. Since a strictly operational measure of rigidity is lacking, it would be impossible to rank segments absolutely along the continuum; but it is not hard to group them into approximate stages. Since productive units and productive segments both were defined as having a single identifiable technology, either can be characterized at any point in time as fluid, segmented, or rigid. Of course, a unit or segment may become more or less rigid over time. Regulation may, in fact, result in a change in the rigidity of a unit or segment.

### 4. Characterizing the Compliance Response

One characteristic of a response which is useful to identify is simply whether it involves product change, process change, or both. As indicated earlier, the Abernathy-Utterback model predicts that one or the other is more likely in different stages of rigidity. When a given regulation could be met with either product or process change, it would be useful to predict which is more likely.

Beyond the product-process distinction, it is necessary to develop a method of characterizing responses which can assist in forming the basis for the evaluation of responses in the regulatory context. It must capture elements of the response which determine the broadly construed costs and benefits of the outcome.

This study will not, however, attempt to quantify the environmental and health effects which were the explicit goal of the regulations considered. Although it is a crucial task, and one which regulators routinely attempt to perform, it is beyond the purpose of this study. Instead, the consequences of the particular method chosen to meet the regulation (i.e. the compliance response) will be explored. The specific nature of the compliance response will determine both the direct and indirect costs of compliance and the indirect environmental effects beyond those intended by the specific regulation.

A set of attributes important for evaluating the effects of the compliance response has been developed. It includes:

- the degree to which the response is innovative,
- the degree to which the response is comprehensive,
- the degree to which the response results in greater overall isolation of hazards from the environment, or substitution of safer materials for hazardous ones,
- the net cost of the response to the affected unit, and
- any effects on the utility of the unit's product.

An innovative response is one that incorporates a new technological idea, or an existing idea in a context or manner significantly different from that of its previous use. To be innovative, a change need not be a major (i.e. comprehensive) one; a minor modification is innovative if the idea is new. The innovativeness of the response is important because new technologies may provide improved solutions for other problems or for similar problems in another industry. Thus there is a potentially signigicant external benefit in innovation.

The comprehensiveness of the response applies both to the product and the process. It measures the extent to which the response permeates the entire process or product. Just as a change need not be comprehensive to be innovative, a change need not be a new idea (i.e. innovative) to be comprehensive. Both quantitative comprehensiveness (e.g. every valve in the process checked or replaced) and qualitative comprehensiveness (some segment of the product or process completely redesigned) are important.

Sometimes, environmental and safety problems can only be solved by transferring the hazard from one place to another (e.g. from the workplace to the atmosphere or from the atmosphere to the water), or by replacing a hazardous material with which may also cause environmental or safety problems. Ultimately, it would be desirable to permanently isolate the hazards from both people and the environment. Therefore, an indicator of possible indirect health and envrionmental effects is the degree to which the response results in greater overall hazard isolation. This may be achieved by improving the physical integrity of the production process to prevent hazard release or by replacing the hazardous material with one which is known to be safer. Together with comprehensiveness, this will indicate whether the problem is likely to crop up in a new form at a future date.

The net cost of compliance to the firm must take into account money, manpower, and other resources expended, any loss in output that results, and any benefits, such as material savings, which accrue. Transition costs associated with the process of change and continuing costs of compliance must be distinguished, though both are relevant.

Finally, if the utility of the product is improved or lessened by the compliance technology, this is an important element of the response.

These dimensions are not wholly independent; for example, other things being equal, a more comprehensive response will cost more. But each dimension tells something about the response <u>not</u> captured by the others; knowing a response was more comprehensive makes a difference above and beyond the cost difference. Also, these are obviously not the only dimensions that could be considered. However, in thinking about the universe of possible responses, these features have been identified as the <u>most</u> important for evaluating possible compliance technologies in the context of regulatory decision-making.

It should be emphasized that an attempt will not be made to perform actual <u>evaluations</u> of technologies. Whether innovativeness or comprehensiveness is good or bad is not the issue here; indeed, each is almost surely good in some cases and bad in others. The intent here is to improve the ability of the regulator to tune the system to yield technologies with particular attributes, not to try to decide which attributes are in fact desirable.

Part of the purpose of applying this conceptual framework to a sample of observations will be to determine if these attributes are possible to identify and if they seem adequate to capture the crucial differences among responses. It is hoped that this formulation for characterizing responses can be improved upon in the process.

### 5. A Priori Expectations Regarding the Compliance Response

In order to facilitate the process of examining a sample of regulations, technologies and responses, it is desirable to enunciate expectations with respect to the problem being studied. Otherwise, there would be no guideposts for the examination of the data, and it is unlikely that useful hypotheses would emerge.

This is not to say that these expectations are hypotheses to be tested and then either accepted or rejected as they stand. Rather, they will be examined in the light of the sample and educated judgment will be used to modify them if possible and if necessary to arrive at what seem to be likely hypotheses. Such freedom and judgment are crucial at this exploratory stage.

The Abernathy-Utterback model makes direct predictions about the degree and kind of change likely from productive segments in different stages of rigidity operating in a stable political and economic environment. Fluid segments are likely to yield major product change, while the process, being general-purpose and uncoordinated, is unlikely to be ripe for any kind of change. In the intermediate (segmented) stage, the process is ready for major change, while the product has somewhat less flexibility and so is somehat less likely to change. In the final stage there is little room for product change; the process, being highly integrated, is subject to incremental modification but not major change.

To construct a priori expectations about likely responses to regulation, this "normal" model must be examined to try to foresee circumstances in which the response to a regulatory stimulus might diverge from the normal pattern of change. In this section are discussed the implications of the "normal" model for each of the attributes (introduced in the previous section) of product and process change, along with some suggestions of likely deviations from the normal pattern in the case of regulation. *A priori* expectations will be formed using the predictions from the normal model in cases where there is no obvious reason to believe that these are inapplicable, and modifications of the normal model where these appear to be necessary.

### Innovativeness

With respect to the likely innovativeness of the response, it would seem that the normal model would apply to responses emerging from the fluid and segmented stages. That is, in the fluid stage, *product* innovation is expected to be quite likely, because such innovation is easy due to the flexibility of the product, and because the trend in such segments is usualy product innovation. *Process* innovation is not likely, because the primitive nature of the process makes it hard to work with, and because the emphasis in the segment is on product rather than process modification.

Thus, if the *product* of a fluid segment is regulated, an innovative product modification or substitution might be expected to result; the process is unlikely to change. If the *process* is regulated one might still expect the fluid segment to attempt to comply via a product change,* since process change is so difficult and unfamiliar. This product change may very well be innovative.

In the segmented stage, product innovation is still a possibility, but it is somewhat less likely because the product has begun to be standardized and the emphasis has shifted to process change. Process innovation is quite likely because the process has begun to be rationalized and is ripe for change, and because process improvement is the major concern of such segments.

*Product* regulations affecting the segmented stage may lead to product innovation, although it is less likely than in the fluid stage. *Process* regulations can be expected frequently to lead to process innovation.

In the rigid state, deviation from the normal pattern is expected. The normal model would predict little product or process innovation because the product has become highly standardized, the process highly integrated, and the whole product-process system optimized in its present configuration. However, regulation my simply *demand* a change. Since the product is highly standardized and product change has not been pursued for a long time, any change would probably be highly innovative. Since the process is so integrated, major change is not likely to occur without total redesign, which may very well also be innovative.

Thus, one would not expect *product* regulation of the rigid stage to result in innovation, although occasionally a highly innovative product

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*Note that *process* regulation can sometimes be met with a *product* change (e.g. if the process is leaking a hazardous material the product can be redesigned without the material as an ingredient), but a *product* regulation cannot be met *solely* by *process* change.

change may result. Process regulation is likely to lead to minor non-innovative process changes, but occasionally a highly innovative response may result.

Obviously, all of these results depend to some degree on the "severity" of the regulation. A very non-severe regulation is unlikely to elicit any change from the affected segments. However, the effective severity of a regulation is derived from the inherent ability or inability for change of a technology, in addition to the actual magnitude of the change which is mandated. Thus a "severe" regulation (such as requiring a very large reduction in worker exposure to a chemical) may, in fact, not have severe effects, while a "non-severe" regulation (requiring a smaller reduction) may be a very difficult one with which to comply if the technology is difficult to change.

### Comprehensiveness

With respect to comprehensiveness, the expected results parallel those expected for innovativeness. In the fluid stage, product regulation would be expected to lead to major product change and little process change. Process regulation may produce some process change, but it is unlikely to be comprehensive because a certain degree of order in the process is necessary before really comprehensive process change can be undertaken. Again, if a process regulation can be met with a product change, this is quite likely in the fluid stage.

In the segmented stage, product regulation may lead to some product change, but it is not as likely to be comprehensive as in the fluid stage. Process regulation will quite likely to lead to comprehensive process change.

In the rigid stage, _product_ regulation is unlikely to be successful in comprehensively changing the product, although if change is absolutely necessary radical change (such as total substitution) is made quite likely by the fact that _any_ change will require total process redesign, thus eliminating any savings from sticking with minor changes. _Process_ regulations are likely to yield incremental, minor process change, but the difficulty and expense of such changes may occasionally stimulate total process redesign.

### Overall Hazard Isolation

Overall isolation of hazards from the environment is very difficult in the fluid stage. Such isolation requires a certain degree of organization and integration. Further, because of the flexible nature of the product, there is a danger that regulation of one hazardous material will result in a simple switch to another material the effects of which are unknown. Thus, _product_ regulation on the fluid stage is likely to lead to substitution; the substitutes may or may not be safer than the regulated hazard. _Process_ regulation may cause the hazard to be moved around (e.g. ventilation) but it is unlikely to lead to greater overall isolation of the regulated hazard. It may lead to product change, yielding the same possibilities as product regulation.

In the segmented stage, hazard substitution becomes less likely, reducing the chance of eliminating the hazard completely, but also reducing the chance of a more dangerous substitute. As the process becomes more and more organized, there is more opportunity to isolate the production system by integrating separate steps and recycling.

Product regulation can therefore be expected to lead to little overall change in exposure to hazards, although an occasional substitution may occur which could either increase or decrease such exposure. Process regulation has a very good chance of improving the overall isolation through process change.

In the rigid stage, product change is unlikely, but when it does occur its direction is unpredictable, so there is no way of predicting if the substitute will be better or worse. Process regulation may be quite successful in achieving an overall isolation (although this may be costly), since a completely integrated system provides the best chance for such isolation.

### Cost

The cost of the compliance technology may be difficult to predict, since it obviously depends on the severity of the regulation. However, it might be expected that a flexible segment, simply by virtue of having more options available, would be more likely to find a lower cost solution. As one moves toward more and more rigid technologies, the inherent technological constraints become more binding, and costs would be expected to rise.

### Product Utility

Obviously, changes in the utility of the product are dependent on there being a change in the product. Such changes are most likely in the fluid stage, and become less and less likely in more rigid stages. Since fluid segments are generally already trying to maximize the performance of their product, it seems unlikely that regulation would increase the utility, but decreases are certainly possible.*

This section completes the conceptual phase of the overall project. The next chapter describes the selection of regulations for study, and the productive segments affected. The following chapter describes the observed compliance responses. The last chapter attempts to analyze this data and modify the conceptual framework and expectations in light of it.

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*Obviously, the utility of the product is improved in a sense if a hazard is eliminated, but that would be accounted for as a direct environmental or safety effect. Included here are only changes in the utility other than any intended by the regulation.

# REFERENCES FROM CHAPTER TWO

1. see Nicholson, Walter, *Microeconomic Theory: Basic Principles and Extensions,* Dryden Press, pp. 193-218 (1972)

2. Thomson, J.D. and F.L. Bates, "Technology, Organization and Administration," *Administrative Science Quarterly*, *2*: 325 (1957)

3. Woodward, Joan, *Industrial Organization: Theory and Practice*, Oxford University Press, p. 35-49 (1965)

4. ibid, p. 40

5. Perrow, Charles, "A Framework for the Comparative Analysis of Organizations," *American Sociological Review*, *32*: 194 (1967)

6. Amber, G.H. and P.S. Amber, *Anatomy of Automation*, Prentice Hall, p. 2 (1962)

7. Hickson, D.J., D.S. Pugh and D.G. Pheysey, "Operations Technology and Organizational Sructure: an Empirical Reappraisal," *Administrative Science Quarterly*, *14*: 378 (1969)

8. Taylor, J.C., *Technology and Planned Organizational Change*, Center for Research on Utilization of Scientific Knowledge, pp. 25-29 (1971)

9. Blau, P.M., C.M. Falbe, W. McKinley, and P.K. Tracy, "Technology and Organization in Manufacturing," *Administrative Science Quarterly*, *21*; 20 (1976)

10. Abernathy, W.J. and P.L. Townsend, "Technology, Productivity and Process Change," *Technological Forecasting and Social Change*, *7*: 379 (1975)

11. Utterback, J.M. and W.J. Abernathy, "A Dynamic Model of Process and Product Innovation," *Omega*, *3*: 639 (1975)

# CHAPTER THREE

# THE REGULATIONS AND THE PRODUCTIVE SEGMENTS

## 1. Selection of the Sample

Everything said to this point could apply equally well to many different regulations affecting many different industries.* In this work the applicability of this approach to the regulation of the chemical industry will be investigated. Such regulation is among the most important there is both in terms of health and environmental concerns and economic impact. In the concluding chapter the possibility of generalizing these results to other industries will be discussed.

There are several major kinds of regulation pertaining to chemicals, including:

- water pollution (Federal Water Pollution Control Act as amended (FWPCA))
- air pollution (Clean Air Act as amended)
- solid waste disposal (Solid Waste Disposal Act and Resource Conservation and Recovery Act)
- occupational safety and health (Occupational Safety and Health Act (OSHA))
- pesticide registration (Federal Environmental Pesticide Control Act)
- food additive registration (Food, Drug and Cosmetic Act)

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*The Abernathy-Utterback model was developed to apply to integral products (output measured by the number of units) as opposed to dimensional products (output measured by weight or volume). However, the earlier work on characterizing technology was completely general, encompassing integral and dimensional products as well as service industries.

- consumer product safety (Consumer Product Safety Act (CPSA) and Federal Hazardous Substance Control Act (FHSA)), and
- toxic substance control (Toxic Substance Control Act (TSCA)).

The regulation of drugs under the Food, Drug, and Cosmetic Act was omitted from this study because it was felt that it is such a special kind of regulation that its effects are not likely to be predictable on the same basis as the others.

An extensive search of the regulations promulgated in each of these areas yielded a list of approximately 150 chemicals with respect to which some government action had been taken. This list included highly regulated hazards as well as some with repect to which only preliminary action had been taken. This list was reduced to 40 hazards that had been regulated under more than one kind of regulation in a way likely to affect more than one industrial segment. From this list, eleven hazards were selected which had the widest distribution across kinds of regulation and segments within the chemical industry. These three lists of hazards are presented in Appendix One.

It was determined that these eleven hazards represented more responses than could be documented in detail within the limitations of this project. Therefore, four of the eleven were chosen for study. These four have all had significant regulatory action taken with respect to them sufficiently long ago that the responses could be observed.

By choosing regulations known to have had a significant impact, the sample is obviously being biased towards more substantial responses. This was necessary to insure in this initial effort that there would be something to observe. It should not affect the results with respect to the role of technology in determining the nature of the response, except that, as noted earlier, more severe regulations will likely lead to more radical changes.

The four hazards are vinyl chloride, polychlorinated biphenyls (PCB's), mercury and lead. The next section will describe the regulations pertaining to each.

## 2. The Regulations

Government actions with respect to the four hazards were documented in order to understand the technical problems posed by these actions for industry. It should be emphasized that such "actions" cannot be limited to formal regulations in final form. Informal "government scrutiny" may have significant effects and produce observable technological responses.

Because the role of the regulations in determining the response is not the issue here, the following discussions do not go into great detail about the regulations. In addition, some regulations, which were not judged to have had significant technological effects, were excluded from the study and so are not discussed.

### Vinyl Chloride

On April 5, 1974, the Occupational Safety and Health Administration (OSHA) promulgated an emergency temporary standard which lowered permissible levels of worker exposure from 500 parts per million by volume (ppmv) to 50 ppmv. On October 4, 1974, a final standard (to be effective April 1, 1975) was promulgated setting the maximum exposure at 1 ppm time weighted average (TWA) for an eight hour period with a maximum 5 ppmv exposure for any 15 minute period.[1] These two actions will be referred to collectively as the OSHA vinyl chloride regulation.

The EPA has declared vinyl chloride to be a hazardous air pollutant under Section 112 of the Clean Air Act. In October, 1976, EPA promulgated regulations (effective January 1, 1977) limiting stack emissions to 10 ppmv, and requiring control of fugitive emissions and stripping of PVC resins to remove residual vinyl chloride monomer (RVCM).[2] This regulation affected only vinyl chloride monomer and PVC resin plants. (See discussion of the vinyl chloride/PVC industry in section 3.) These requirements will be referred to as the EPA vinyl chloride regulation.*

There have been several other government actions with respect to vinyl chloride taken by EPA, the CPSC, and the FDA. All of these are either not yet final or have had little technological impact on the regulated segments.

PCB's

Concern about the problem of PCB's in the environment goes back to the late 60's. In 1971, Monsanto, the sole U.S. PCB producer, voluntarily restricted PCB sales to "closed" uses (capacitors and transformers). The responses to that action will not be considered. Subsequently, the New York State Department of Environmental Conservation brought action against the General Electric Company for release of PCB's

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*This regulation has been challenged in the D.C. Circuit Court of Appeals by the Environmental Defense Fund. Pursuant to an agreement reached in that case, EPA has proposed amending this standard to make it stricter.[3] The final status of this regulation is uncertain at present, but it is still possible to observe the response to the original standard.

into the Hudson river, EPA proposed national water effluent standards, Congress (in the Toxic Substances Control Act) banned PCB's after October, 1979, Monsanto announced it would cease PCB production in October, 1977, and GE was threatened with private liability suits arising out of PCB misuse. It is somewhat difficult to separate out the effects of these various actions. These actions will be referred to collectively as the PCB regulation.

OSHA has also regulated PCB's and FDA has set PCB tolerances for certain foods, but these actions have not resulted in significant technological change.

### Mercury

In 1970, after a flurry of publicity about fish being contaminated in the Great Lakes region, the Justice Department brought suit (under the Rivers and Harbors Act) against ten chlorine-caustic producers (who use a mercury-cell technology--see section 3) to halt their discharges of mercury into various bodies of water. At about the same time, there were a series of state, local and private civil actions with the same intent. Mercury effluents were eventually limited to about .1 lb/day from chlorine-caustic producers, and these limitations were incorporated into discharge permits under the FWPCA after that act was passed in 1972. These actions will be referred to as the mercury water regulations.[4]

EPA has also designated mercury a hazardous air pollutant, and promulgated regulations under section 112 to limit its emission.[5] Chlorine-caustic makers are supposed to limit their mercury air emissions to 2300 gm./day. However, it is difficult to measure most of the emissions because they escape through leaks and cracks in the walls and through the ventilation system. Therefore, compliance is assumed if a series of housekeeping rules is observed and emissions from the stack are limited to 1000 gm./day. This will be called the mercury air regulation.

Also in 1970, the registration for Panogen, an alkyl mercury seed treatment, was suspended and then cancelled (an action equivalent to its being banned).[6] In addition, tort liability cases were brought against the maker of Panogen and the federal government on behalf of a family poisoned by eating meat from a hog fed alkyl mercury-treated grain.[7] These actions will be referred to as the mercury pesticide regulation.

In 1972, EPA began hearings on banning phenyl mercurial pesticides from use in paint (where they preserve the paint in the can and protect against mildew and fungi on the paint film). In early 1976, the administrator announced that EPA was banning all such uses. The ban was stayed pending appeal, but before the appeal was resolved, EPA reversed itself and reinstated mercury for use in water based paints. The ban on mercury in oil based paints was allowed to go into effect.[8] In addition, concern has been expressed about tort liability with respect to mercury-containing paints.[9] These actions will be called the mercury paint regulation.

Actions by OSHA and FDA with respect to mercury have not had significant technological effects.

## Lead

In 1971, Congress enacted the Lead Based Paint Poison Prevention Act

(LBPPPA) which, among other things, banned the use of lead based paint in all federally subsidized housing. "Lead based paint" was defined as any paint containing more than 1% lead by weight in the dried film. In 1973,Congress lowered this level to .5%, and dictated that it drop to .06% on December 31, 1974, unless the Chairman of the Consumer Product Safety Commission (CPSC) determined prior to that date that a level between .5% and .06% was safe. On December 23, 1974, the Chairman determined, based on the health effects information available at that time, that the .5% level was indeed safe. In June of 1976, Congress again amended the LBPPPA, extending the ban on lead based paint to cooking, eating, and drinking utensils, furniture, and toys. In addition, they required the definition of lead based paint to drop to .06% on June 22, 1977, unless the Chairman of the CPSC could once again determine that a higher level was safe. This time, a more formal procedure for that determination was mandated, and on February 16, 1977, the chairman decided that he could not determine that any level over .06% was safe. Therefore, after June 22, 1977, all paint for use in federally subsidized housing, utensils, toys, and furniture must dry to a film containing less than .06% lead by weight.

In a parallel regulatory process, leaded paint has been regulated under the Federal Hazardous Substances Control Act (FHSA). In March of 1972, the Food and Drug Administration (FDA) issued a regulation declaring that household paints containing more than .5% lead were banned hazardous substances. Further, they ruled that after December 31, 1973 the level would be lowered to .06%. However, the latter part of the regulation was indefinitely stayed. The CPSC, which took over administration of the FHSA from FDA as a result of the Consumer Product Safety Act, has proposed putting the .06% level into effect under a new standard, to be issued under the Consumer Product Safety Act.*[10] These regulations will be referred to as the lead based paint regulations.

The Clean Air Act gave EPA the authority to regulate any motor vehicle fuel additive that interferes with the performance of a certified emission control device.[11] When the catalytic converter (which is rendered inoperative by lead in the fuel) was introduced in 1974, EPA used this authority to require any service station pumping more than 200,000 gallons of gas per year to offer for sale a fuel with less than .05 gm lead/gallon.[12] This requirement will be referred to as the un-leaded gas regulation.

EPA has also been trying since 1973 to promulgate a regulation requiring a general reduction of the lead levels in gasoline, based on the health threat of the lead itself. However, legal challenges delayed the regulation to the point where the growth in the number of cars requiring un-leaded fuel because of the converter has substantially lessened its impact. Still, the possibility of this regulation elicited some interesting technological developments which will be discussed. This regulation will be referred to as the gasoline lead phase-down regulation.

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*The CPSC has a choice whether to regulate under the FHSA or the CPSA. Because the procedural requirements are easier under the latter, they have proposed abandoning the FHSA lead regulations and starting over with CPSA regulations.

TABLE 3.1

REGULATIONS AND AFFECTED PRODUCTIVE SEGMENTS

| Hazard | Regulation | Productive Segment | SIC |
|---|---|---|---|
| Vinyl Chloride | OSHA | PVC resin manufacture | 2821 |
| | | PVC fabrication | 3079 |
| | EPA | Vinyl chloride monomer manufacture | 2869 |
| | | PVC resin manufacture | 2821 |
| PCB's | | PCB's | 2869 |
| | | PCB substitutes | 2869 |
| | | Transformer manufacture | 3612 |
| | | Capacitor manufacture | 3629 |
| Mercury | Water | Chlorine-caustic production | 2812 |
| | Air | ditto | |
| | Pesticide* | Pesticide formulation | 2879 |
| | Paint | Paint formulation | 2851 |
| | | Paint additives | 2869 |
| Lead | Paint | Paint formulation | 2851 |
| | | Paint additives | 2869 |
| | | Pigments | 2816&<br>2865 |
| | Unleaded gas | Petroleum refining | 2911 |
| | | Lead Alkyls | 2869 |
| | Gas lead phase-down | Petroleum refining | 2911 |
| | | Lead alkyls | 2869 |

*Farmers are obviously also affected by pesticide regulation, but since agriculture is qualitatively different from manufacturing, no attempt was made to identify and characterize agricultural productive segments.

Actions by OSHA with respect to lead, and other EPA actions have not resulted in technological change in the chemical industry.

## 3. The Productive Segments and Their Technologies

Table 3.1 lists these regulations, and indicates the productive segments affected by them. Although only regulations on the chemical industry were examined, productive segments outside that industry were included if they were affected indirectly by such regulations. The fourteen segments include at least one from each of the Standard Industrial Classification (SIC) groups within Chemicals and Allied Products (SIC 28), except Drugs (283), Soaps and Detergents (284), and Miscellaneous Chemical Products (289). In addition, there are segments from Electric Transmission and Distribution Equipment (316), Electrical Industrial Apparatus (362), Miscellaneous Plastics Products (307), and Petroleum Refining (291).

### Vinyl Chloride Monomer

Vinyl Chloride Monomer (VCM) is manufactured using a highly integrated continuous process. There are about 15 plants in the U.S. with an average annual capacity of about 500 million pounds each. (The largest plant produces about one billion pounds per year.)[13] The dominant process is based on chlorination of ethylene to yield ethylene dichloride (EDC), which is thermally cracked to yield VCM and hydrogen chloride (HCl) which is then reacted in a separate step (called oxychlorination) with ethylene and air or oxygen to yield additional EDC. Because of this HCl recycle step, this process is called the "balanced" process.[14] An older route, based on direct addition of HCl to acetylene, has essentially been abandoned in the U.S. Because of the very large scale and highly integrated and continuous nature of VCM manufacture, this is a highly rigid segment.

## Polyvinyl Chloride Resin

VCM is polymerized to yield PVC resin using four distinct technologies, each of which produces resin with different properties suitable for different end uses. PVC polymerizers are more numerous than VCM makers, with an average plant capacity of about 150 million pounds per year. Although the four technologies are somewhat different, they are all more labor intensive and segmented than VCM manufacture.[15]

The *suspension* process is used to produce 78% of all PVC in this country. It is a batch process, with polymerization carried out in water, the VCM being suspended with the aid of surface active agents. The average reator capacity is 3000 to 6000 gallons, but the trend has been towards increased size, with 35,000 gallon reactors now in use. After reaction, the slurry of PVC is stripped to remove much of the unreacted VCM, then dried, and bagged or otherwise stored.[16]

The *dispersion* or *emulsion* polymerization process accounts for 13% of PVC production. This process is quite similar to the suspension process, except that larger amounts of dipersants and detergents are added, resulting in a smaller particle size. To preserve this advantage, spray driers are usually used. Some dispersion resins are not dried at all; that is, they are used as a liquid or "latex" in various coatings and paints.[17]

The *bulk* or *mass* polymerization process, accounting for 6% of PVC capacity, is a two stage batch process in which an initiator is added directly to VCM liquid. In a "pre-polymerization" reactor, conversion of VCM to PVC is only 7 to 12 percent. The mixture is then transferred to a second reactor where the reaction is carried to 85-90% completion. Because no water is present, bulk resins do not have to be dried. Bulk resins are characterized by a high chemical purity, since it is not necessary to use any suspending agents. They have superior optical clarity, heat stability, and fusion properties.[18]

The solvent polymerization process, accounting for 3% of capacity, is a continuous process, used primarily to produce copolymers of vinyl chloride (75-90%) and vinyl acetate (10-25%). Solvent (usually n-butane), monomer, and initiator are continuously added to a reactor vessel; a slurry of PVC is continuously drawn off the bottom. Again, no drying step is necessary. Solvent resins are also of a high purity and command a premium price.[19]

PVC resin manufacture is in the segmented stage. This is because there are a few different processes and product lines, and all of these except one are somewhat disjointed batch processes, though some process steps have been automated.

## PVC Fabrication

PVC resin is fabricated into final products at about 8000 plants which vary tremendously in size and the technology they employ. The major processes are extrusion (50%), calendering (22%), dispersions (11%), injection molding (6%), compression molding (6%), and blow molding (3%)[20] Fabrication is a fluid segment because of the great diversity in products and processes, and the relatively small scale of the individual operations.

### PCB Manufacture

Since 1971 U.S. PCB production has been about 40 million pounds per year, all produced at a single Monsanto plant.[21] PCB manufacture is a fairly simple batch process, based on direct chlorination of biphenyl over a ferric chloride catalyst. Various fractions with different chlorine content are separated by distillation. Because it uses a fairly large scale batch process and the products are a line of related mixtures, PCB manufacture is in the segmented stage.

### PCB Substitute Manufacture

The PCB substitute makers are difficult to characterize because the PCB substitutes themselves differ greatly. (This will be discussed in Chapter Four.) In most cases a company realized that materials similar to ones they were already selling for another purpose had properties which made them suitable as a PCB substitute. Because of this lack of uniformity, PCB substitute makers cannot really be characterized as fluid or rigid. (It is not really a distinct productive segment.)

### Capacitor Manufacture

Although obviously not part of the chemical industry, capacitor manufacturers are severly impacted by regulation of PCB's. Since 1971, 65 to 70 percent of the PCB's sold in the U.S. went to the capacitor industry, where they were used as a dielectric in 90-95% of all liquid-impregnated capacitors.

Capacitor manfacture is a segmented process with a series of semi-automated steps. First the cans are fabricated from metal sheets and the capacitor paper or film is wound with aluminum foil. Then the capacitor is assembled and leak tested. After being subjected to vacuum and high temperature to insure thorough drying, the capacitors are flooded with the liquid dielectric, sealed, cleaned and tested.[22]

## Transformer Manufacture

Most transformers (90-95%) are manufactured using mineral oil as the dielectric fluid. Askarels (blends of 60-70% PCB's with trichlorobenzene) are used only in transformers for use in locations where the fire hazard presented by mineral oil is not acceptable.

About 5000 askarel or askerel substitute transformers are manufactured per year, each containing between 500 and 20,000 pounds of liquid.[23] Each tranformer is virtually custom designed and assembled. For this reason, and because of the undeveloped nature of the process, this is a fluid segment.

## Chlorine-Caustic Production

Chlorine and Sodium or Potassium Hydroxide (caustic) are joint products of the electrolysis of brine (water saturated with NaCl or KCl). There are two processes that are used, which differ in the manner in which the anode and cathode electrolysis products are isolated from each other. The older of the two technologies employs an asbestos diaphragm. The other technology employs a flowing mercury electrode, which amalgamates the sodium ions produced. This amalgam is reacted with water in a separate chamber to produce sodium hydroxide and hydrogen. Both are continuous processes.[24] The mercury-cell process requires a larger capital investment but produces a more concentrated and purer caustic. Only the mercury-cell process is affected by mercury regulations. About 10 million tons of chlorine were produced in the U.S. in 1975, with the average output per plant about 300 million pounds per year.[25] Because of this high volume, the continuous nature of the process, and the commodity-like nature of the product, this is a rigid segment.

## Pesticide Formulation

Pesticides are mixtures of various pesticide compounds with a carrier and various inert ingredients. A wide variety of different formulations are produced by a wide variety of companies. Some of the pesticide syntheses may be quite complex, and they are done on a fairly small scale in batch processes. The formulation steps are simple batch processes. Pesticide formulation is a fluid segment because the products are so complex and varied and because formulation is a non-rigid process technology.

## Paint Formulation

Paint formulation is a non-capital-intensive industry where raw material costs dominate the production economics. There are some economies of scale achievable with large batches, but there is a demand for a wide variety of specialty products, and transportation costs are high, so many small companies survive serving special or local customers.

The process technology consists of various measuring, grinding, and mixing operations. The expertise in the industry is devoted to determining the optimum combination of the various ingredients for particular uses. Even the smallest of companies generally produce more than one paint, and it is a highly diversified market.

The basic ingredients common to all paints are:[26]

1. Resins- bind the pigment into a homogeneous film. Polyvinyl acetate (sometimes combined with PVC) is used in water based paints and oil-modified alkyds are used in oil based paints.
2. Pigments- color the paint and increase its protective power. Important pigments include titanium, zinc and iron oxides, lead chromates, and various insoluble organic dye compounds.
3. Solvent- facilitates application of the paint. Either water or organic solvents such as white spirit, xylene, and trichloroethylene are used.
4. Extenders- cheapen paint and improve its physical properties. These include barytes, blanc fixe, whiting and china clay.
5. Additives- include driers which catalyze cross-linking of oil-modified alkyd resins, a polymerization initiator in water based paints, surfactants, anti-settling agents, bactericides and fungicides.

The driers are naphthenates of heavy metals, including lead, and the bactericides and fungicides may be mercury compounds.

Like pesticides, this is a fluid segment because it involves batch formulation of a complex product.

Pigment Manufacture

With the exception of white pigments like titanium dioxide, pigments are manufactured on a fairly small scale. Total production of inorganic colored pigments in 1972 was 119 thousand tons. The lead chromates accounted for about 30 thousand tons.[27] Production of organic pigments of all types was also about 30 thousand tons.[28] Pigment manufacture may be considered a fluid segment because of the large number of different pigments and the relatively small volume of each.

## Paint Additives

All of the paint additives are in the category of specialty chemicals, and are manfactured on a small scale using batch processes. The additive manufacturers seem to have significant technical expertise, and often assist the smaller paint companies with formulation problems. Production of specialty products is always a fluid technology.

## Manufacture of Gasoline Anti-Knock Compounds

Prior to the unleaded-gas regulation, tetraethyl lead (TEL) and tetramethyl lead (TML) were the major anti-knock compounds produced. They are fairly large volume chemicals; U.S. capacity in 1975 was 850 million pounds at six plants.[29] TEL and TML are made by autoclaving of a sodium lead alloy with ethyl or methyl chloride. In addition, TML is made by one small producer via electrolysis of a mixture of methyl magnesium chloride and methyl chloride using a lead anode. Although both of these are batch processes, they are fairly rigid because of the severe reaction conditions and the high volume.

The only commercially available non-lead anti-knock compound is methylcyclopentadienylmanganese tricarbonyl (MMT). This was developed in the late 1950's by Ethyl Corporation (the first and largest anti-knock maker) as a complement to the lead alkyls.[30] By 1976, it accounted for 10-15% of anti-knock sales on a dollar basis.[31] (See Chapter Four.) At the present time MMT is made at only one plant in the U.S. (Production figures are apparently unavailable.) Like the lead alkyls, it requires some fairly complicated chemistry to produce, and so involves a fairly complex production technology. Because of these complexities and the large volume, this would be considered a rigid segment. In spite of the fact that they are produced by the same company, the lead alkyls and MMT are not produced at the same plant.

## Petroleum Refinining and Gasoline Production

Petroleum refining is probably the most capital intensive of all major industrial categories. It consists of continuous distillation of the crude into various fractions, followed by various types of processing steps which convert less desirable products into more valuable ones. In the U.S. this consists mainly of catalytic cracking and reforming to isomerize n-alkanes into isoalkanes and dehydrogenate cycloalkanes to yield aromatics. These two constituents are needed to improve the octane rating of gasoline.[32]

Because of its high capital intensity and the use of continuous processes, this is a fairly rigid productive segment, although there are aspects of petroleum refining which lessen somewhat its inherent rigidity. First of all, the input feedstocks are quite variable, adding a "non-routine" element (in the sense of Perrow; see Chapter Two) to the technology. Also, the product stream has flexibility in the sense that any particular need (such as a gasoline of a specified octane) can be achieved in several different ways.

An important contributor to this flexibility has always been the use of the anti-knock compounds. These additives (TEL, TML and MMT), used in the range of 1-2 grams/gallon, can substantially reduce the need for the cracking and reforming operations mentioned earlier.[33]

The classification of these segments according to rigidity is summarized in Table 3.2. The next chapter describes the responses that emerged from these segments, allowing the technologies and responses to be related in Chapter Five.

## TABLE 3.2

## CLASSIFICATION OF SAMPLE PRODUCTIVE SEGMENTS BY STAGE OF TECHNOLOGICAL RIGIDITY

Fluid Segments:

- PVC Fabrication
- Transformer Manufacture
- Pesticide Formulation
- Paint Formulation
- Pigment Manufacture
- Paint Additive Manufacture

Segmented Segments

- PVC Resin Manufacture
- Capacitor Manufacture
- PCB Manufacture

Rigid Segments

- VCM Manufacture
- Chlorine-Caustic Production
- Lead Alkyl Manufacture
- Petroleum Refining and Gasoline Production

Not Classifiable

- PCB Substitute Manufacture

# REFERENCES FROM CHAPTER THREE

1. 39 Federal Register 35891
2. 40 Code of Federal Regulations 61.60 Subpart F
3. Environment Reporter (Current Developments), 7: 48, p.1824 (4/1/77)
4. 40 CFR 415.60-65
5. 40 CFR 61.50-55
6. MIT Center for Policy Alternatives, The Impact of Government Restrictions on the Production and Use of Chemicals, op cit, Alkyl Mercury Case Study
7. First National Bank of Albequerque v. Nor-Am, 537 F2nd 682 and First National Bank of Albequerque v. U.S. No. 9705 (D.N.M. 1975)
8. Environment Reporter (Current Developments) 7: 18, p.687 (9/3/76)
9. interview with paint additive firm
10. The entire chronology of leaded paint regulation is outlined in: U.S. Consumer Product Safety Commission, Final Environmental Impact Statement on Lead Content in Paint, May, 1977
11. Section 211 of the 1970 Clean Air Act amendments

12 40 CFR 79.32

13. U.S. Environmental Protection Agency, Standard Support and Environmental Impact Statement: Emission Standard for Vinyl Chloride, EPA-450/2-75-009
14. ibid
15. ibid
16. ibid
17. ibid
18. ibid
19. ibid

20. Stanford Research Institute, *Chemical Economics Handbook*, p. 580.1882H (1976)

21. U.S. Environmental Protection Agency, *PCB's in the U.S.: Industrial Use and Environmental Distribution*, EPA-560/6-76-005

22. ibid

23. ibid

24. Reuben, B.G. and M.L. Burstall, *The Chemical Economy*, Longman Group, Ltd, p. 387 (1973)

25. Chlorine Institute, *North American Chlor-alkali Industry Plants and Production Data Book*, Chlorine Institute pamphlet #10 (1977)

26. Reuben and Burstall, op cit, p. 272

27. SRI *Chemical Economics Handbook*, p. 577.5100

28. ibid, p. 577.5500

29. *Chemical Marketing Reporter*, 6/28/76, p.9

30. *Chemical Engineering*, 11/25/74, p.40

31. Ethyl Corporation, *1976 Annual Report*, p.9

32. Reuben and Burstall, op cit, p.159

33. interview with petroleum refining company

# CHAPTER FOUR

# THE OBSERVED RESPONSES

## 1. Introduction

In this chapter the technological changes that occurred in the various productive segments as a result of the regulations will be described. The information used to document these changes came from three sources:

- trade and technical journals,
- documents published by regulatory agencies and conversations with individuals in these agencies, and
- telephone conversations and interviews with affected firms and publications supplied by such firms.

Within the last category, a total of nine interviews, averaging about two hours each, were conducted with eight different firms.* Substantial information was collected from three additional firms by telephone and in writing. As Table 4.1 indicates, the eleven firms represented eleven of the fourteen productive segments, and information about one additional segment (pigments) was obtained indirectly from the paint formulators.

The productive units to be interviewed within each productive segment were chosen on the basis of geographic convenience and the existence of contacts suggested by regulatory agency personel or the MIT Industrial Liason Program. Where several firms were available, those

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*The interviews were conducted under a promise of confidentiality, so no firms will be identified by name and an attempt has been made to omit information which might permit identification.

TABLE 4.1

SOURCES OF INFORMATION ABOUT RESONSES

| | Journals and Other Published Literature | Regulatory Agencies | Interview* | Other Personal Contact* |
|---|---|---|---|---|
| VCM | x | x | 1 (E.A.) | 1 (E.A.) |
| PVC Resin | x | x | 2 (both E.A.) | |
| PVC Fabrication | x | | 1 (E.A.) | |
| PCB's | x | | | |
| PCB substitutes | x | | 1 (T) | |
| Capacitors | x | | | 2 (both T) |
| Transformers | x | | 1 (T) | |
| Chlorine-Caustic | x | x | 1 (E.A. and T) | |
| Pesticide | x | | | |
| Paint | x | x | 1 (E.A. and T) | |
| Pigments** | | x | | |
| Paint Additive | x | x | 1 (M) | |
| Anti-Knock | x | | 1 (T) | |
| Gasoline | x | | 1 (E.A. and T) | |

*E.A.= Spoke with representative of environmental or regulatory affairs group

T = Spoke with technical (i.e. R&D or operations) expert

M = Spoke with general manager of operating unit

**Additional information about pigments was obtained from the interview with the paint unit.

that were known from the technical literature survey to have had a major role in the technological developments arising from the regulation were chosen.

An attempt was made to speak with two individuals in each productive unit: one who was familiar with the regulation and its broad effects on the unit (usually someone from an "environmental" or "regulatory affairs" group), and one who was familiar with the technical details of the response (someone from an R&D or operating group, depending on the firm). Table 4.1 indicates the extent to which this attempt was successful. These people were asked to describe their perception of the important regulatory events and the technical details of the compliance response they developed. In addition, the interviewees were asked how typical for the segment as a whole their response was. Also, part of the interview was devoted to the attempt to identify any unique features of the productive unit being interviewed which might be judged to render it unrepresentative.* In general, the congruence of the responses identified from the literature, the agencies, and the firms was sufficient to understand the response of the entire segment.

## 2.Vinyl Chloride

The OSHA vinyl chloride regulation impacted primarily on the PVC resin manufacturers, with less impact on the fabricators and on the VCM manufacturers. The EPA regulation also had its largest effect on the resin makers and less effect on the VCM producers; the fabricators were

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*In addition, questions were asked for the related NSF study about the organizational process by which the response was developed.

not covered by the EPA regulation. Because the responses to the two regulations are interrelated, the response of each segment to both regulations will be discussed together.

The fabricators' problem resulted from residual, unreacted vinyl chloride monomer (RVCM) which remained in the resins as they came from the polymerizers. Previous to any regulation, polymerizers had stripped (i.e. removed the unreacted monomer from) the resins for two reasons. First, it allowed them to raise their overall efficiency of conversion (which saves materal costs). Second, the RVCM can adversely affect the physcial properties of the resin itself. However, the economics of recovery and the severity of the physical degradation problem were such that resins typically contained 600-1000 ppm by weight (ppmw) of RVCM. Because the fabrication processes generally involve heating, the RVCM was driven off into the atmosphere of the fabricating plant. Of course, with the pre-regulation Threshold Limit Value for VCM of 500 ppmv, this was never considered a problem.

When the regulations were imminent, the fabricators' first action was to try to find out what were the VCM levels in their plants. Some hired outside laboratories to do measurements, but at least one installed gas chromatography equipment in each plant and trained their employees to use it do these measurements.[1]

The fabricators reduced their VCM problem with some combination of three approaches. The simplest, and one which was widely employed, was extra ventilation. Ventilation is a non-innovative, non-comprehensive solution that transfers the hazard outdoors.

The second approach is to attempt to drive off most of the RVCM in a controlled way during the first processing step. The gas can then be vented to the atmosphere, and the need for ventilation around subsequent processing steps is reduced. The first step is usually dry-blending of the PVC resin with the plasticizer and other additives. If extra heat and air are added during this step, RVCM in the dryblend can be reduced to as low as 5-10ppmw, as opposed to 100 ppmw with conventional techniques.[2] This approach is more innovative and somewhat more comprehensive than simple ventilation. It costs more to install, but operating costs are lower. Of course, it still results in venting of the VCM to the atmosphere.

Finally, worker exposures can be minimized by automating materials handling tasks, thus removing the worker from the highest danger areas. There are many different ways this can be done, and probably most were incorporated to some degree.[3]

Of course, the permanent solution to the fabricators' problem is to contain all the unreacted VCM within the resin plant. This was, in fact, the ultimate solution which emerged. PVC resins as they arrive at the fabricators usually now contain about 50 ppmw or less RVCM.[4]

The problem is more complex for the resin manufacturer because VCM is a direct material input. Whereas the fabricators had a fairly constant, low level problem, the resin manufacturers have a highly variable problem including temporary or localized high level situations resulting from reactor openings and leaks or malfunctions. As a result, one aspect of the response has been the installation of continuous monitoring at several locations within the plant; an alarm is automatically triggered if the standard is exceeded. Action can then be taken immediately to locate the source of the leak and correct the situation. In the mean time, local ventilation can be activated to reduce the immediate hazard. This is superior to permanent general ventilation, because it costs less and also because such general ventilation would make it more difficult to find and repair leaks when they do occur.[5] The occurence of leaks has also been reduced through the use of dual seal pumps and dual rupture disks on the reactors.

Another major source of employee exposure is reactor maintenance. In the early days of PVC manufacture, the polymerization reactor was opened after each batch, and employees would manually scrape the insides of the reactor to remove accumulated resin. Eventually, it was found that this led to a disease of the hands called acroosteolysis.[6] As a result, efforts were underway to reduce this particular exposure even before the OSHA action. Two approaches were taken simultaneously: the reactant recipe was modified to reduce resin buildup inside the reactor, and automated reactor cleaning systems (using a solvent such as tetrahydrofuran or jets of high pressure water) were developed which did not require that the reactor be opened.[7,8] These developments were undoubtedly speeded up by the OSHA regulation.[9] One firm indicated that their plant now averaged 45-50 days between reactor openings.[10]

As mentioned earlier, the resin manufacturers improved their VCM stripping to reduce the fabricators' OSHA problem. This obviously reduced their own problems from resin handling as well. B.F. Goodrich

Chemical Co. has developed a new stripping technology which employs steam in a countercurrent tower.* Goodrich has made this technology available for licensce, and some other firms have apparently adopted it. Some other units have simply improved or increased their previous stripping efforts.

Except for ventilation, these changes also helped in complying with the EPA vinyl chloride regulations. Specifically, the EPA regulation requires dual seal pumps, dual rupture disks, and improved stripping. In addition, the EPA regulation requires reduction of the VCM concentration in the process vent-gas stream. This requires some combination of condensation, adsorption or incineration.

Overall, the response of the PVC resin manufacturers to these two regulations was fairly comprehensive, and did involve some innovative development work, even if the basic technology already existed. The net effect was a further isolation of the hazard from the environment. The costs were fairly high, both in terms of capital and operating costs. (B.F. Goodrich, the largest resin manufacturer, has estimated a total capital cost for VCM control of $42 million, spread over six years.[11]) In a sense, the utility of the product was improved by the removal of the RVCM. However, certain resin lines which are difficult to strip were abandoned altogether.[12]

As mentioned earlier, the VCM manufacturers were not significantly

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*It is not completely clear whether this was an OSHA or an EPA response. It was announced before the EPA regulations were final, but knowledge that the air regulations were impending may have contributed to its development. In any event, it helps solve both problems.

impacted by the OSHA regulation. The reason for this last fact is that VCM plants are generally outdoors so that VCM does not build up in the air. In addition, the continuous, integrated process has less potential for escape of VCM, and less direct worker intervention in the process. They were able to comply through the use of a program of tightening valves and fixing leaks. However, the EPA regulation does require new technology. Most have apparently turned to incineration to reduce the vent-gas streams (particularly from the oxychlorination reactor) to 10 ppm.[13,14]

This is an interesting example of technological rigidity limiting the comprehensiveness of the response. The VCM unit which was interviewed indicated that they had considered the possibility of more radical change, analagous to the new stripping column. For example, the air emission problem is less severe if pure oxygen rather than air is used in the oxychlorination step.* Such technology is used, but unfortunately, it is not feasible with an integrated technology to make a change (like switching from air to oxygen) in an existing plant without incurring substantial expense. Thus, it was more economical to simply use incineration.[15]

The vinyl chloride case is interesting because the VCM/PVC industry spans the three stages of technological rigidity. The fabricators, being fluid, were unable to effectively deal with their problems by process

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*The emissions from the oxychlorination step result because the recycled HCl is contaminated with VCM. If air is used, large quantities of nitrogen must be vented from the system, and this venting carries VCM with it.

change. The resin makers, being segmented, were able to institute comprehensive process change, though it was not terribly innovative. The VCM manufacturers, being rigid, were limited to end-of-pipe controls, even though an alternative process (using oxygen instead of air) would have reduced the problem.

### 3. PCB'S

The response to the PCB regulation originally took two directions: the search for substitutes and the attempt to continue the use of PCB's but reduce the hazard associated with their use. The latter of these was ultimately abandoned, but it is interesting none the less.

In the early 1970's Monsanto introduced a new PCB mixture for use in capacitors (Aroclor 1016) which contained a much higher fraction of the lower chlorinated biphenyl isomers, which are much more biodegradable than the higher isomers.[16] In addition, at least one capacitor firm (Westinghouse) reduced the amount of PCB's used in each capacitor by 66% through redesign of the capacitor itself.[17]

Westinghouse also attempted to reduce the release of PCB's resulting from capacitor manufacture. This effort included "housekeeping" steps such as closing drains, separating PCB and non-PCB laden waters, and the use of sawdust on the floors to trap spilled PCB's. In addition, Westinghouse attempted a major process change; they went from flood-filling of the capacitors to individual manifold filling. Unfortunately, this led to greater capacitor failure because of air entrapment, and the effort had to be abandoned.[18]

Eventually, it became clear that PCB's would have to be replaced.

Five substitutes have emerged, four for capacitor use and one for transformer use. Each will be discussed in turn.

The replacement for transformers was polydimethylsiloxane (a "silicone"). Silicones had apparently been considered as transformer fluids many years ago, but had never been pursued because of their high price.[19] When PCB's were called into question, silicones were developed for tranformer use independently by Dow Corning (a major silicone producer) and General Electric (a silicone producer and a transformer manufacturer).

Because the silicones have a higher viscosity (and so are poorer heat exchangers) and lower resistance to electrical "creep," the transformers had to be redesigned to achieve the same performance with silicones. However, the production process is essentially unchanged.[20] The silicones are considerably more expensive than the PCB's.

The substitutes for PCB's in capacitors are isopropyl naphthalene, butylated monochlorodiphenyl oxide, di-isononyl phthalate ester, and a mixture of di-octyl phthalate ester with trichlorobenzene.[21,22] The first and last of these were developed by capacitor firms; the second and third were developed by chemical firms in conjunction with capacitor firms. The monochlorodiphenyl oxide had been considered as a liquid dielectric long ago, but the others are new to this field. The phthalate esters are manufactured in large quantities for use as a PVC plasticizer; the others were not made in significant quantities before their introduction as PCB substitutes.[23]

All of these are more flammable than PCB's. In addition, the phthalate esters may be suspected carcinogens, and highly toxic dioxins may be formed as degradation products of the monochlorodiphenyl oxide.[24] The monochlorodiphenyl oxide* is more expensive than PCB's, but the others are considerably cheaper.[25]

Because these compounds are more flammable than PCB's, the capacitor manufacturers introduced a pressure switch which shorts the capacitor to prevent an explosion if the capacitor begins to break down. However, this technology was established for other uses; it was necessary only to modify the capacitor design to incorporate it.

Thus there were a diversity of responses as a result of PCB regulation. Some were innovative; some were less so. Some aimed at process change (at least initially); some introduced new products. Some came from the users of the PCB's; some came from new entrants; some came from cooperative efforts between a user and a new entrant. Interestingly, none came from Monsanto, the PCB producer. Overall the PCB regulation resulted in fairly comprehensive product change, and little process change. New injection of PCB's into the environment has ceased, although the problem of PCB's in existing units remains and there are some unresolved questions about the safety of the substitutes. The cost of tranformers has increased, and capacitor fluids are no longer non-flammable, but capacitor fluids are much cheaper. It is interesting that the innovative substitutes came from new entrants to the liquid

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*No evidence was found that indicated that any capacitor firms are actually using the monochlorodiphenyl oxide.

dielectric market, working in conjunction with existing capacitor firms.

In order to understand the responses to the PCB regulation, it is important to understand that there were strong insitutional forces acting against the replacement of PCB's. Many local fire codes and insurance regulations specifically mandated PCB's for certain capacitors and transformers. This was certainly a disincentive over the years to perform research into alternative liquid dielectrics. Even when it became clear that PCB's had to go, the makers of the substitutes had an uphill battle to get them accepted.

### 4.Mercury

The mercury water regulation has led to two basic changes in the mercury-cell chloralkali process. First, process water and cooling water streams have been separated. The cooling water (which is by far the larger volume) is now given no opportunity to come into contact with mercury. All of the sewer pipes were dug up, inspected for trapped mercury, and cleaned or replaced.[26]

The process water stream is now treated to remove almost all of the mercury. About 90% of the mercury-cell plants use some variation of a sulfide precipitation process.[27] Generally, mercury-laden waters are treated with $Na_2S$ under controlled pH conditions and then filtered to yield a clean (less than 3 ppb Hg) filtrate, which is discharged, and a mercury sulphide filter cake. This cake is then combined with muds from the brine pretreatment clarifier which contain chlorine, caustic and some mercury. The mercury is dissolved as a complex ion, and this slurry is filtered again; the mercury-laden brine is recycled to the mercury cells, and the filter cake (containing 20-30 ppm Hg) is sent to landfill.[28]

Although the idea of sulfide precipitation is not new, its application in this area is somewhat innovative. The use of such an add-on technology is not a very comprehensive approach, although the rebuilding of the sewer pipes was a fairly comprehensive response in a quantitative sense. The mercury is somewhat better isolated from the environment, although some of the mercury which was in the water is now in landfill. The capital costs are moderate ($500,000-1,000,000 for an average sized plant) and operating costs are also significant.[29] The products are unaffected.

As discussed earlier, the mercury air regulation has two parts. One is the specification of a series of housekeeping rules to be followed. Such rules, while they may impose substantial expense, do not require true technological change.* The other part, limiting end-box emissions to 1000 gm/day, requires some technology to reduce those emissions.

Several different approaches have been taken by various chloralkali producers. The mercury mist and vapor in the gas stream are removed

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*They require things like epoxy floors to prevent mercury buildup in cracks, tight covers for mercury containers, and the like. Although the question of whether the regulators' immediate environmental goal was met by regulation is not a direct concern here, it should be noted that cell room emissions do not appear to have been reduced to anywhere near 1300 gm/day by the observation of these rules. The mercury cell companies consume something like half a pound of mercury per ton of chlorine produced; this amounts to something over 100 pounds of mercury per day for an average plant. Very little of this can be accounted for by water and solid waste discharges. Some may be lost through theft and inventory buildup, but it seems unlikely that these could account for the remaining mercury.[30]

using some combination of mist eliminators, refrigeration, chemical scubbing, "molecular sieves" and carbon adsorption.[31,32] Usually, most of the captured mercury is recycled, although the adsorption techniques require disposal of the spent adsorbant. In any case, it would appear that these technologies are adequate to achieve the 1000 gm/ day level.

The overall costs of air emission controls would appear to be on the same order as the costs of water effluent control.[33] None of these technologies is particularly innovative or comprehensive. They are achieving some overall reduction of environmental mercury contact.

An additional effect of the combined mercury regulations has been a halt to new construction of mercury cell plants, although the mercury cell had been emerging as the dominant technology prior to regulation. Also, a handfull of plants have closed and a few have converted to diaphragm cells.[34]

A final development which is at least partially attributable to these regulations is the development of an alternative to both the mercury cell and the asbestos diaphragm processes. This a membrane cell which employs a perfluorosulfonic acid resin membrane (DuPont tradename "Nafion") to separate the anode and cathode compartments.[35] This membrane allows production of mercury cell-quality caustic without the use of mercury. Although work on the membrane has been in progress for many years, it has almost certainly been speeded by the mercury regulations. Unfortunately, at the moment the membrane technology suffers from poor durability of the membrane itself, which leads to poor electrical efficiency as the membrane ages. Several plants using the membrane cell are in commercial production, both in North America and Japan, and the membrane cell developers (DuPont in conjunction with Hooker Chemicals and Diamond Shamrock, two chloralkali firms) are hard at work to improve its efficiency.

Overall, the mercury air and water regulations resulted primarily in end-of-pipe solutions in this rigid segment. Capital and operating costs were significant. The devlopment of an alternative process was encouraged and new use of the existing process was halted completely.

When alkyl mercury seed treatments were banned in 1970, the manufacturers simply abandoned the product and went into related product lines. Other companies supplied previously developed substitutes such as maneb, pentachloronitrobenzene, hexachlorobenzene and phenyl mercury acetate. Some farmers stopped treating their seeds, some used the substitutes, and some turned to farmer organizations and agricultural extension services to develop new substitutes.[36]

The main response to the mercury paint regulation has been the substitution of organic compounds for the mercurials in some paints. Some of these have been around for many years, but at least one new one has been registered with EPA since the concern over mercury developed.[37] Even where existing compounds were used, substantial work on the actual paint formulation may be necessary to achieve the desired properties.

It appears that the larger companies have switched to the non-mercurials more readily than the smaller ones.[38,39,40] This may be because they are better able to do the research necessary to modify a

TABLE 4.2

MERCURY IN PAINT AS OF 1977
(Based on interview with paint additive firm)

| Paint Type | Pesticide Function | |
|---|---|---|
| | In-can preservative (Bactericide) | Film Preservative (Mildew and Fungicide) |
| Exterior Oil-Based | Not necessary | Hg banned; substitutes available; some at same cost do not remain effective very long; some at higher cost almost as good. |
| Exterior Latex | Hg still permitted; most still use it. Some big companies have switched to organics. | Hg. still permitted; almost two thirds of paints now use organics; organics cost about 50¢ more per gallon of paint and last 2½ to 3 years as opposed to 4 years for Hg. |
| Interior Latex | Hg. still permitted; most still use it. Some big companies have switched to organics. | Not neccesary |

paint formula. It may also be that the smaller firms cater more to specialty needs where it is more difficult to go without the mercurials.

The overall response is summarized in Table 4.1. While the phenyl mercury compounds served both as in-can preservatives and film preservatives, none of the substitutes perform both functions. Of the two, the in-can preservative problem seems to have been the more difficult. Only a few of the largest companies have abandoned mercury for this use. For the mildewicide and fungicide function, substitutes are available for oil-based paints (in which mercury is banned). However, these compounds are susceptible to hydrolysis and so are not as stable in water based paints. Still, some two thirds of the water-based paint fungicides sold by one maker are now non-mercurials.[41]

This response does not seem to have been either very innovative or very comprehensive. The mercury has been partially eliminated, but there are some doubts about the safety of the organic substitutes. The cost of paint has increased slightly, and the utility may have been slightly impaired by reduced mildew and fungus resistance.

The mercury pesticide and paint regulations are a case of fairly easy product modifications and substitution in the fluid stage. However, none of the responses was very innovative.

### 5.Lead

Taken together, the LBPPPA and the FHSA and CPSA lead paint regulations limit the lead content of household paints to .5% by weight in 1973 and .06% in 1977. Also in 1977, the limit is being extended to paints for use on toys furniture and other items to be sold for household use.

The effect of the .5% level is to prohibit the use of lead pigments; the .06% level prohibits the use of the lead driers.

The response to both of these regulations has been simple substitution of existing substances.[42,43] In the pigment case, various organics had already been in use in some paints, and these uses were expanded to include those formerly met with the lead chromates.* As for the driers, various combinations of calcium, zinc, zirconium, and lead had been used; the lead is being removed and replaced with additional quantities of the others.

The organic pigments are somewhat more expensive than the lead chromates. The non-lead driers are no more expensive, but do not work quite as well, so that paint drying is impaired under conditions of low termperature and high humidity.[45]

As in the mercury paint case, these responses demonstrate easy product modification. The changes were not innovative, but they did not need to be; there was a stock of substitutes available. The changes were comprehensive in terms of eliminating the regulated substance, although the safety of the substitutes has not been unequivocably proven. Costs were incurred, but they were easily passed on in a price-insensitive market. Some minor losses in the utility of certain products were accepted.

The major gasoline producers knew in 1970 that the auto companies were going to use the catalytic converter to meet the Clean Air Act's

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*At least one paint company had already voluntarily eliminated the lead chromates because of concern over the carcinogenicity of chromium.[43]

auto emission standards for carbon monoxide (CO) and hydrocabons (HC).[46] Thus they had three or four years to prepare for the requirement to market unleaded fuel.* In spite of this, no particularly innovative responses emerged. Ethyl Corp. began marketing MMT, on which it had been working for years. Most refiners now use MMT** to some degree, in conjunction with additional processing, to achieve the octane requirements of the new cars.[47] (The engines of catalytic converter-equiped cars are designed with a lower compression ratio and so do not need as high an octane fuel as older cars.) At most, technological change in response to the regulation consisted of a somewhat increased rate of introduction of new catalysts for reforming developed in the sixties.[50]

One interesting development indirectly related to this regulation has been a massive effort on the part of both the oil companies and the chemical companies who produce the anti-knocks to develop systems for control of CO and HC that would not require lead-free gasoline. This effort has included work on lead-tolerant catalysts, a non-catalytic "thermal reactor" which would perform the same function, and alternative power plants such as the stratified charge engine.[51,52,53] It is difficult to assess the success of this work from a technical viewpoint,

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*Unleaded fuel was marketed voluntarily by some companies as early as 1970. However, it never sold well (presumably because of its cost) until the catalytic converter-equipped cars were on the roads.[48]

**MMT itself has recently been called into question. The auto companies claim that it increases hydrocarbon emissions and plugs the catalytic converters. Ethyl has lowered the recommended maximum concentration from .125 to .06 gm/gallon, and supended construction of a new MMT plant pending an EPA decision on the additive.[49]

but it has certainly been a commercial failure. The auto companies remain committed to their original approach.

The story of the response to the gasoline lead phase-down regulation is somewhat similar. Again, both the oil companies and chemical firms have been at work on technologies which would allow them to preserve their products intact. In this case, the goal was a "lead trap," a device that would capture the lead in the exhaust and prevent its release to the environment. This work does appear to have been technically successful,[54] but the adoption of the catalytic converter has made it unusable. (The lead-trap would not be efficient enough to prevent the poisoning of the catalyst.)

As mentioned earlier, the anti-knocks gave a crucial element of flexibility to an otherwise rigid industry. This may be one reason why the industry tried so hard to save them.

Thus in response to the gasoline lead regulations two rigid industries failed to achieve an innovative or comprehensive solution when their product was regulated. Yet, they were quite innovative in pursuing technologies which would have protected their existing product line. There is no way of knowing if this contrast is in fact a result of the rigidity of these segments, or if the regulations were simply inherently difficult ones with which to comply.

This concludes the discussion of the responses to the selected regulations. In the next Chapter the lessons of these observations will be discussed.

# REFERENCES FROM CHAPTER FOUR

1. interview with PVC fabricator firm

2. Plastics Technology, December, 1974, p.43

3. ibid

4. interview with fabricator firm

5. Gideon, J.A, K.S. Schoultz and J.H. Bochinski, Engineering Control Assessment of the Plastics and Resin Industry, Case Study: Manufacture of PVC by Bulk Polymerization, NIOSH mimeo (1977)

6. Adams, Georjean L., Toxic Substance Control: Vinyl Chloride, Department of Technology and Human Affairs and Center for Development Technology at Washington University, Report No. THA/CDT-77/1, p. 22 (1977)

7. Chemical Engineering, 11/24/75, p.25

8. interviews with PVC resin firms

9. ibid

10. ibid

11. Oil and Gas Journal, 6/9/75, p.25

12. interview with PVC firm

13. interview with VCM firm

14. U.S. Environmental Protection Agency, Standard support document for Vinyl Chloride, op cit

15. interview with VCM firm

16. Kerns, Bernard, statement representing Westinghouse Electric Corp., in National Conference on PCB's, Nov. 19-21,1975, EPA-560/6-75-004

17. Sawyer, R.B., "Manufacturing," Westinghouse Distribution Apparatus Division mimeo

18. ibid

19. interview with transformer firm

20. interview with capacitor firm

21. U.S. Environmental Protection Agency, PCB's in the U.S...., op cit

22. interview with PCB substitute maker

23. ibid

24. U.S. Environmental Protection Agency, PCB's in the U.S...., op cit, p. 230-232

25. ibid

26. interview with chlorine-caustic producer

27. ibid

28. Chemical Engineering, 2/3/75. p. 36

29. letter, dated 10/23/75 from Edmund J. Laubusch (Chlorine Institute) to Edwin A. Gee (National Commission on Water Quality)

30. U.S.E.P.A. Office of Enforcement and General Counsel, Report of Mercury Source Investigation of Diamond Shamrock (8/75), Penwalt (8/73), and B.F. Goodrich (11/73)

31. Chemical and Engineering News, 2/19/72, p.15

32. interview with chlorine-caustic producer

33. Laubusch letter, op cit

34. ibid

35. Chemical Week, 3/24/76, p. 33

36. MIT Center for Policy Alternatives, The Impacts of Government Restrictions on the Production and Use of Chemicals, Alkyl Mercury Case Study, op cit

37. interview with paint additive maker

38. ibid

39. interview with paint formulator

40. Chemical Marketing Reporter, 3/29/76

41. interview with paint additive firm

42. ibid

43. interview with paint formulator

44. ibid

45. interview with paint additive firm

46. interview with petroleum refiner

47. ibid

48. Wall Street Journal, 2/11/70, p.38, 4/3/70, p.11, and 2/19/74, p.1

49. Environment Reporter (Current Developments), **7**: 45, p.1721 (3/11/77), **8**: 6, p.225 (6/10/77), and **8**: 9, p.343 (7/1/77)

50. interview with petroleum refiner

51. ibid

52. interview with lead alkyl maker

53. Ethyl Corporation 1976 annual report

54. interview with lead alkyl maker

# CHAPTER FIVE

# RESULTS AND TENTATIVE HYPOTHESES

## 1. Introduction

Table 5.1 is a reproduction of Table 3.2, showing the classification of the productive segments affected by the sample regulations into the stages of rigidity. This classification is based on the criteria outlined in Chapter Two and the descriptions of the technologies in Chapter Three. Although there might be some disagreement about a few of the segments, these assignments should be adequate for this exploratory effort.

In Chapter Two, section 5, *a priori* expectations with respect to each response attribute were discussed. This was useful conceptually because it helped to introduce and explain the attributes themselves. However, since regulators will be conscious of the nature of the segments they propose to regulate, it is more useful for regulatory design to express the hypotheses in terms of what is to be expected from productive segments in each stage of rigidity. Of course, the two methods of presentation contain the same information and are interchangeable. In this chapter, some general observations will be presented, followed by tentative hypotheses about the likely outcome of regulations affecting segments in the different stages. Of course, these results can only be expected to be valid if other factors (particularly the nature of the regulations) are constant. The last two sections of this chapter specu-

# TABLE 5.1

# CLASSIFICATION OF SAMPLE PRODUCTIVE SEGMENTS BY STAGE OF TECHNOLOGICAL RIGIDITY

Fluid Segments:

- PVC Fabrication
- Transformer Manufacture
- Paint Formulation
- Paint Additive Manufacture
- Pigment Manufacture
- Pesticide Formulation

Segmented Segments:

- PVC Resin Manufacture
- Capacitor Manufacture
- PCB Manufacture

Rigid Segments

- Petroleum Refining
- Lead Alkyl Manufacture
- VCM Manufacture
- Chlorine-Caustic Production

Not Classifiable

- PCB substitutes

late on the implications and limitations of this work, and suggest future work which might prove to be fruitful.

## 2. General Observations

Although this thesis is not primarily concerned with categorizing and characterizing regulations, one distinction among regulations emerges as being crucial for understanding the interaction with technology. This is whether the particular regulation impinges primarily on the product or the process of each productive segment. It was argued earlier that the distinction between product and process change is important in the response; clearly the emphasis of the regulation on product or process will affect whether the response is likely to be a product or process change. To be sure, product regulations may affect the process and vice versa, but the locus of the immediate impact is important.

One hypothesis, suggested by the PCB case, is that product regulation (particularly a partial or complete ban) is more likely to lead to new entrants offering a solution to the problem. Such entrants can perceive the need to be filled in the absence of the regulated product, and produce a product of their own to meet that need. In fact, the phthalate ester PCB substitute offered by a non-PCB chemical firm was among the most innovative responses seen in this study. On the other hand, when it comes to process regulation (especially attempts to limit exposure to a substance), the existing units are likely to have an edge because of developed expertise and proprietary knowledge.

Another general conclusion is that "cost" is an attribute of the response which has no simple measure. There are many different kinds of costs. For instance, a capital cost and an increased material cost because of sustitution for a banned product each accrue to different groups and over different time periods. Perhaps, the best that can be done is to anticipate the kinds of costs which are likely to be important in different cases. This will be attempted in the subsequent sections.

## 3.Regulation of the Fluid Stage

To recapitulate briefly, the expected results of regulations affecting the fluid stage were:

- easy product change, quite possibly innovative and comprehensive, as a possible response to both product and process regulation,
- little process change, and non-comprehensive change if any,
- little overall isolation of hazards from the environment via process change, and product substitutes which may or may not be safe,
- relatively lower cost solutions, and,
- possible product utility losses.

The observed regulations on transformers (PCB's), paints, paint additives and pigments (lead and mercury), and pesticides (mercury) were all product regulations. These all led to some combination of product modification and product substitution. In the tranformers, the PCB's were replaced with a new substance and the tranformers were redesigned. In the paint cases, substitutes existed; the paints were reformulated. In the pesticide case, substitutes also existed. Thus, change does occur easily as a result of product regulation in these cases. Note that there was little effect on the process in every case.

An interesting result which is counter to expectations is the lack of innovative change; for the most part product substitutes and modifications* which had already been developed were used. The only possible exception is the introduction of the silicone transformer fluids; even that had been considered earlier.

On further reflection, this does not seem so unlikely. If the fluid segment had seen a lot of product innovation in the absence of regulation, that really makes it less likely that an additional innovation will be required to meet the regulation. Precisely because the segment had been innovative and rapidly changing, it has a large store of alternatives ready when the regulation occurs. When one looks at fluid segments for innovation in response to regulation, it is not found, simply because it was made unnecessary by previous developments.

The one case of process regulation on a fluid segment resulted, as expected, in little change. The ultimate solution to the PVC Fabricators' OSHA problem emerged from the PVC resin manufacturers.

There were also examples of the danger (inherent in the fluid segment) of being unable to isolate the production process from the environment and of substituting one hazardous substance for another. The fabricators simply ventilated until the RVCM was removed, and the substitutes for the lead pigments, the mercury paint biocides, and the mercury pesticide are all of questionable safety.

The costs associated with these responses resulted primarily from the increased costs of substitutes. (There was also a small amount of

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*Note that minor modifications which are new are considered to be incremental innovations.

design cost involved in implementing the changes.) None of the units interviewed were terribly concerned over these increased costs; because these are performance maximizing segments, competion is on the basis of quality and demand is not terribly sensitive to price.

Finally, there were examples of decreases in a product's utility as a result of the compliance response. The organic fungicides do not remain effective as long as the mercurials, and the non-lead driers do not function under certain extreme conditions. These do not appear to be major losses, but they are real.

In summary, three major hypotheses can be advanced with respect to regulation of the fluid stage:

1. Product regulation will lead to product modification and substitution, probably along lines that have been previously explored. It is possible that new hazards or product utility losses will result. The process is unlikely to be affected.

2. Process regulation is unlikely to lead to innovative or comprehensive change. The response is unlikely to result in greater overall hazard isolation. Process regulation may lead to product change. If it does, the expected responses are the same as for product regulation.

3. In any case, costs are likely to be reflected in readily imposed price increases because of the price-inelasticity of the markets.

## 4. Regulation of the Segmented Stage

The expected results of regulations affecting the segmented stage were:

- product regulation possibly leading to some product change, with the likelihood of comprehensive or innovative change less than in the fluid stage,

- innovative and comprehensive process change as a result of process regulation,

- increased isolation of hazards from the environment as a result of process regulation and some chance of substitutes as a result of product regulation,
- costs of an intermediate magnitude, and
- few product utility changes.

From the observed cases, the most striking fact that emerges with respect to the segmented stage is the multiplicity and diversity of responses. This was true for process regulation (on PVC resin manufacture and to some degree on capacitors) and for product regulations (capacitors). The PVC resin makers, because of the segmented nature of the technology, were able to attack the problem using a variety of approaches aimed at different segments of the process. In the PCB-capacitor case, three distinct approaches were taken initially: manifold filling, PCB substitutes and capacitors that needed less PCB's. The first of these is a process change, the latter two are product changes. It would seem that the intermediate position of the segmented stage, where the product retains some flexibility while the process begins to be integrated, provides an opportunity for many kinds of responses.

The PVC resin case was an example of comprehensive process change in the segmented stage. An entire new operation (column stripping) was introduced, and major changes in reactor operation were implemented. In addition, overall release of the hazardous material was greatly reduced; the vinyl chloride stripped from the resins and purged from the reactor is almost entirely recycled. It is interesting to note that such recycling requires greater overall integration of the process. Hence, one effect of process regulations affecting the segmented stage may be to increase the tendency towards integration and therefore towards rigidity.

As far as the innovativeness of the responses is concerned, the same situation that occurred with respect to product change in the fluid stage may exist here with respect to process change. All of the process changes observed were based partly upon previous lines of effort, although substantial additional development and engineering may have been required. Again this may not be indicative of a lack of innovativeness, but rather of a wealth of previous innovative work upon which to draw.

The PCB-capacitor case showed that product change in the segmented stage is not impossible, although a preference for process change might be inferred from the fact that that was the direction initially taken. In any event, the capacitor makers were able to replace the PCB's and incorporate a pressure switch in the product to partially make up for lost resistance to fire.

This lost resistance does represent a product utility loss. In addition, in the PVC resin case the number of resin lines was reduced. This represents some loss. Since product line diversity is an indicator of fluidity, it also represents another way in which the regulation moved the segment towards increased rigidity.

It is hard to draw any conclusions from these observations about the cost of compliance in the segmented stage. In the PVC resin case, the costs were fairly substantial in terms of both capital outlay and operating expense. The price of PVC was probably affected, but by how much is not clear. It is also not clear how the price of capacitors was affected; the substitute dielectrics are generally cheaper, but the need for the pressure switch adds to the expense.

To summarize, six major hypotheses can be advanced with respect to regulations affecting the segmented stage:

1. Responses to both product and process regulations are likely to be quite diverse, with a preference for process change where possible.
2. Although *process* change is preferred by such segments, if the *product* is regulated, it may change. Such change is less likely to be comprehensive than in the fluid stage.
3. *Process* regulation is likely to lead to comprehensive process changes following previously established directions.
4. Greater overall hazard isolation is likely to be achieved through increased integration of the process. If product change occurs, substitutes may or may not be safer.
5. Capital and operating costs arising from process changes may be significant; price rises are less likely than in the fluid stage.
5. The utility of the product may be affected, particularly by reducing product line diversity.

### 5.Regulation of the Rigid Stage

The expected results of regulations affecting the rigid stage were:

- little change as a result of *product* regulation, with an occasional innovative and comprehensive response,
- non-comprehensive and non-innovative process change as a result of *process* regulation, with an occasional major process redesign,
- a high degree of overall hazard isolation with little chance of product substitution, and
- relatively high cost solutions.

For the most part, these expectations were realized. The VCM manufacturers, chlorine-caustic producers, and petroleum refiners essentially chose end-of-the-pipe controls or minor process modifications.

The chlorine-caustic and VCM manufacture cases were examples where a completely new process may have received a boost from regulation. Also in these cases, no product change resulted. In the un-leaded gasoline case, a new product (unleaded gasoline) was mandated, and it was produced. MMT was also used, but it was not really new, in the sense that it had already been developed and was conceptually similar to lead alkyls. (Both are in the broad category of organometallic compounds.)

In spite of the non-comprehensive nature of the changes, both the VCM manufacturers and the chlorine-caustic producers did improve the overall isolation of their respective hazards. The gasoline makers did get some of the lead out, but the questions about MMT make it difficult to judge if this response represents an overall hazard reduction.

The costs in the VCM and chlorine-caustic cases included both capital and operating expenses. Again, the effect on the prices is hard to determine but was probably small. The unleaded gasoline is noticeably more expensive, presumably because of processing costs.

An interesting unanticipated result was the extensive, fairly innovative effort by the lead alkyl makers and the refiners to develop technologies which they hoped would prevent the need for any regulation of their products. Apparently, the combination of large resources with a large committment to a particular technology was sufficient to produce this effort, in spite of the low probability of success.

To summarize, four hypotheses can be advanced regarding regulations affecting the rigid stage:

1. Process regulation is likely to lead to process change. Because of the inability to achieve comprehensive change in

existing processes, the development of alternative processes may be encouraged.

2. Product regulation is unlikely to lead to product change unless absolutely necessary; if necessary it may or may not be innovative and/or comprehensive.

3. Costs are least likely in this stage to be passed on as price increases because of the generally price-elastic nature of the markets.

4. Substantial and possibly innovative efforts may be made by some units in rigid segments to obviate the need for regulation that would require product changes.

## 6. Implications for Regulatory Design

Some hypotheses about the kinds of responses to regulation that can be expected from productive segments in the three stages of technological rigidity were advanced in the previous section. In spite of the tentative nature of these hypotheses, their implications for regulatory design should be considered. Specific policy recommendations would require a careful examination of these hypotheses in the context of particular regulatory decisions. Such a detailed examination is beyond the scope of this research, but it is possible to suggest some general considerations.

The most obvious implication of this research is that regulators should attempt to assess the technological rigidity of segments likely to be affected by regulations. Further, they should attempt to go beyond the directly regulated segments in looking for those which may respond, particularly when a regulation of a product is being considered and possible substitutes are being identified. The suppliers and customers of the regulated segments are likely candidates for producing a response, but it is also possible that an unanticipated response will emerge from a new entrant.

### Fluid Stage

In the case of product regulations affecting fluid segments, the alternative substitutes should be identifiable in advance, based on previous developments within the segments. Such substitutes should be scrutinized for unexpected health or environmental consequences and utility losses as well as cost.

If a hazard is associated with the process of a fluid segment (e.g. an occupational hazard) regulators should be skeptical about the likelihood of achieving an ultimate solution in the fluid stage through direct process regulation. Rather, it may be necessary to look for input or product modification to achieve the desired result without creating a new problem.

### Segmented Stage

By contrast, such process-related problems should be solvable in the segmented stage and hence process regulation may be desirable and effective. Such segments can draw on previous development work to deal with those portions of the process that are a problem and integrate the process overall.

In addition, regulators should be cognizant of the multiplicity of responses that may develop in such segments. If the qualitatively different approaches that may develop can be identified in advance, regulators may be able to direct developments towards technologies that are consistent with long range goals. For example, if process change is being attempted, the regulator may perceive that a product change would be a better ultimate solution in this case. Such change may be possible, and yet occur only if an incentive to move in that direction is provided.

In the segmented stage, capital and operating costs resulting from regulation may be significant. In addition, regulators should consider the possibility of increased rigidity resulting from regulation. This may occur because greater process integration is required or because product line diversity is reduced.

Rigid Stage

Regulation of the rigid stage should again take into account the inherent limitations and possibilities of the technology. The difficulty and expense of any change in existing plants must be recognized. In the case of product regulation, no change is likely from a rigid segment. Product innovation may emerge from new entrants. For process regulation, the most likely response is a minor process change. Occasionally there may be major process innovation, because since even minor changes are expensive, more radical changes may be attempted. Here too, process regulation may result in product innovation on the part of new entrants. These complexities need to be considered by regulators.

The resources of these segments and their ability to devote substantial development work* to prevent their product being regulated should be recognized. It seems quite conceivable that such work could result in a new technology which permits a desirable alternative regulatory solu- tion to a problem. Regulators should look for this possibility and make use of this tendency of rigid segments if possible.

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*Because large capital investments are needed, rigid segments tend to be characterized by large firms having established R&D operations.

Finally, great care should be taken in imposing regulations that may increase the rigidity of these already rigid segments. Sometimes there may be no choice, but the possibility of such increased rigidity should be considered in regulatory decisions.

## 7. Assessment of the Approach and Suggestions for Future Work

Much effort was devoted at the beginning of this study to the development of a conceptual framework for studying the technology-response relationship. On the basis of an initial application, a preliminary assessment of that framework is possible. Based on that assessment, some areas of additional study that are likely to prove fruitful can be suggested.

First of all, the concept of technological rigidity seems fairly easy to apply. In addition, although the results contained herein are not conclusive, it would seem that rigidity is useful in predicting the nature of the response.

Of course, it is necessary that this notion be applied to other kinds of industries if its relevance to the technology-response relationship is to be established generally. The basis of the idea is in fact quite general, so there is no reason at this point to believe that it cannot be generalized. Further, in this study the approach seemed equally applicable to the chemical industry and to the non-chemical segments which were included because the regulations impacted on them indirectly.

If the applicability is to be rigorously established, an operational measure of technological rigidity is needed. For this purpose, the five "aspects" of technological rigidity summarized in Chapter Two (narrowness of equipment function, automaticity, continuity, degree of standardization and price vs. quality as the basis of competition) could be condensed to a three dimensional scale. One dimension would be "continuity," and Woodward's scale (Table 2.1) or the modified Woodward scale used by Hickson, et. al. could be used to measure it. The second dimension would be "integration" and an appropriate measure would be Hickson's "workflow rigidity" scale (Table 2.2). Finally, some scale of product standardization and degree of emphasis on performance maximization is needed. This would have to be based on the subjective judgement of an individual in the productive segment. The five-point scale in Table 5.2 is suggested as a measure of this dimension.

Of course, this notion of "physical" rigidity is inherently more limited than a notion which encompasses the historical trends exhibited by a segment. This limitation was accepted in order to make the characterization of segments by rigidity more straightforward. However, a characterization which also included an historical examination would be expected to be an even better predictor of future technological change.

It would also seem to be useful to try to identify important attributes of technologies that are independent of rigidity. Although this thesis has argued that there are important ways in which (for example) transformer manufacture and paint formulation are similar, there are also obvious differences. Some of these are likely to be important for regulation.

With respect to the characterization of the responses, additional

## TABLE 5.2

## SUGGESTED SCALE FOR MEASURING DEGREE OF CUSTOM PRODUCT DESIGN

1. custom designed products made to individual specifications
2. large number of related products which do not compete with each other on the basis of price
3. distinct product lines exist; differentiation among lines is large both in terms of price and quality
4. small number of product lines with smaller degree of price and quality differentiation
5. standardized commodity with virtually no quality differences among competing products

## TABLE 5.3

## SUGGESTED SCALE FOR MEASURING THE INNOVATIVENESS OF THE RESPONSE

1. technology was already in commercial use in similar situation
2. technology was already in commercial use but some adaptation required
3. technology was not previously in commercial use but some development work had been done
4. idea had been considered but no significant development work had been done
5. totally new idea

work is needed to develop workable measures and to investigate the usefulness of the concepts in more case studies involving different regulations and different industries. Though subjective judgments are required, "innovativeness," "comprehensiveness" and "degree of hazard isolation" do seem to be possible to apply to different situations. Suggested five-point scales for evaluating each are presented in Tables 5.3 through 5.5. On the other hand, the attempt to compare costs and product utility losses in different cases is frequently frustrated by apparently incommensurable outcomes. Perhaps these concepts need to be further subdivided to yield attributes that can be compared across different cases.

The tentative conclusions about likely responses from segments in different stages of rigidity will only be established by investigation of different segments and regulations. There is also clearly room for further exploratory work to discover additional relationships between technological features and responses. In addition, regulation does result in indirect and long-run changes in industries, which were not investigated in this study. The interaction of technological factors with those effects needs exploration.

Finally, there is a need to combine this line of investigation with an understanding of attributes of <u>regulations</u> which are determinants of the response. Such an integration would express what is known about this process in the form most useful to regulators.

## TABLE 5.4

## SUGGESTED SCALE FOR MEASURING COMPREHENSIVENESS OF THE RESPONSE

For Product Change

1. no change
2. minor changes not observable by user
3. significant, observable changes
4. major redesign of product
5. completely different product

For Process Change;

1. no change
2. end-of-the-pipe additions with no integration into existing process
3. significant segments of the process affected to some degree
4. virtually every aspect of process affected
5. totally different process

### TABLE 5.5

### SUGGESTED SCALE FOR MEASURING HAZARD ISOLATION AND SUBSTITUTION

For <u>Product</u> Change:

1. substitute for regulated material is even more hazardous than the regulated material itself
2. substitute equally hazardous
3. safety of substitute uncertain
4. substitute is clearly somewhat safer than regulated material
5. substitute is of unquestionable safety

For <u>Process</u> Change:

1. hazardous material is now released to the environment which was previously contained
2. overall release of hazardous material to the environment is unchanged
3. hazardous material which was previously released is now captured and destroyed or sent to scientific landfill
4. hazardous material which was previously released is now recycled
5. hazardous material which was previously released now has no opportunity to escape from process

# APPENDIX ONE

## HAZARD SELECTION

### 1.Hazards Identified as Regulated

asbestos
13 carcinogens
vinyl chloride
ammonia
beryllium
explosive materials
6 ketones
kepone
carbolic acid
lead
sulfur dioxide
toluene
trichloroetheylene
alkylbenzene
cyclohexane
ozone
acetylene
acrylamide
allyl chloride
carbon dioxide
epichlorohydrin
hydrogen cyanide
hydrogen sulfide
methyl parathion
tetrachloroethylene
cadmium
carbon tetrachloride
chlorine
chloroform
mercury
methyl alcohol
methyl chloroform
oxalic acid
nitric acid
nitrogen oxide
phenol
silica
aluminum sulphate
parathion
butanes
formaldehyde
oil of bergamot
sodium hydroxide
potassium hydroxide
cyanide salts
hydrochloric acid
sulfuric acid
silver nitrate
mineral spirit
nickel
octanes
pentanes
petroleum naphtha
phosgene
stoddard solvent
benzidine
ethylene dichloride
hydrogen fluoride
xylene
hypochlorous acid
potassium hydroxide solution
red dye #2
polychlorinated biphenyls
phosphate
mirex
strobane
aldrin/dieldrin
chlorobenzilate
DDT
DDD
DDE
endrin
panogen
nitrosamines
photochemical oxidants
sodium azide
nitrogen dioxide
calcium hydroxide
silver
zinc
solvents
butadiene
cyanoacylate adhesives
acrylic tempolymer sealant
polyurethane foam
tris (2,3 dibromopropyl phosphate)
methylene chloride
acetone
acrylonitrile
ethylene oxide
captan
2,4,5-T
linear alkylbenzene sulfonate (LAS)
carbaryl
dicamba
guthion
lead arsenate
chlorofluorocarbons
amitrole
aluminum chloride
hydrogen peroxide
calcium carbide
potassium dichromate
titanium dioxide
fatty acids
iodine
glycerine
urea
BOD/COD
benzene
flammable fabrics
calcium chloride
hydrocarbons
calcium oxide
potassium sulfate

carbon disulfide
hexanes
4,4'diaminodiphenyl-
   methane
kerosene
turpentine
carbon monoxide
paraphenylenediamine
epoxy resins
copper sulfate
ferrous sulfate
lead monoxide
fluorides
phosphoric acid
particulates
sulfates
toxaphene
barium
nitrate
selenium
cuprous oxide
hydrogen
manganese sulfate
sulfur trioxide
sodium carbonate
sodium dichromate
sodium chloride
sodium silicate
sodium sulphite
ammonium chloride
aluminum fluoride
ammonium hydroxide
acetic acid
chromic acid
nickel sulfate
lithium carbonate

## 2.Hazards Affecting More than One Productive Segment

asbestos
acrylonitrile
carbon tetrachloride
vinyl chloride
hydrogen sulfide
cadmium
PCB's
particulates
fluorides
toluene
phosphates
nitrites
chlorofluorocarbons
ammonia
chromium
trichloroethylene
hydrogen cyanide
sulfuric acid
beryllium
butadiene
BOD
lead
toxaphene
selenium
red dye #2
arsenic
chlorine
chloroform
cyanide salts
benzene
acids/alkalies
reactive hydrocarbons
flammable fabrics
mercury
nitric acid
alkylbenzene sulfonate
ethylene oxide

## 3.Widely Distributed and Highly Regulated Hazards

arsenic
benzene, toluene and
   xylene
toxaphene
carbon tetrachloride
PCB's
lead
phosphates
vinyl chloride
reactive hydrocarbons
mercury
nitrites

## APPENDIX TWO

## GLOSSARY OF ABBREVIATIONS

| | |
|---|---|
| CFR: | Code of Federal Regulations |
| CO: | carbon monoxide |
| CPA: | MIT Center for Policy Alternatives |
| CPSA: | Consumer Product Safety Act |
| CPSC: | Consumer Product Safety Commission |
| EDC: | ethylene dichloride |
| EPA: | U.S. Environmental Protection Agency |
| FDA: | Food and Drug Administration |
| FHSA: | Federal Hazardous Substances Control Act |
| FWPCA: | Federal Water Pollution Control Act |
| HC: | hydrocarbons |
| Hg: | mercury |
| KCl: | potassium chloride |
| LBPPPA: | Lead Based Paint Poison Prevention Act |
| MMT: | methylcyclopentadienyl manganese tricarbonyl |
| NaCl: | sodium chloride |
| NIOSH | National Institutes of Occcupational Safety and Health |
| OSHA: | Occupational Safety and Health Act or Occupational Safety and Health Administration |
| PCB's | polychlorinated biphenyls |
| ppm: | parts per million; ppmv: parts per million by volume; ppmw: parts per million by weight |
| PVC: | polyvinyl chloride |
| RVCM: | residual vinyl chloride monomer |
| SIC: | Standard Industrial Code |
| SRI: | Stanford Research Institute |
| TEL: | tetraethyl lead |
| TML: | tetramethyl lead |
| TSCA: | Toxic Substances Control Act |
| TWA: | Time Weighted Average |
| VCM: | vinyl chloride monomer |